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CHARACTERISTICS OF MILKING FLOW AMONG DAIRY COWS

by

John Albert Sims

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of The Requirements for the Degree of DOCTOR OF PHILOSOPHY

Major Subject: Animal Breeding

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1962
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I. INTRODUCTION

The changes that have taken place in dairying over the past 15 years have been little short of revolutionary. Production per unit, whether defined as the cow, the operator, or the farm unit, has increased at a much accelerated pace as compared to the previous 30 years. Some of the factors that have brought this about include improved agronomic practices with increasing emphasis on forage harvesting and storage techniques; increases in the genetic merit of our national dairy herd, made possible to a substantial degree by vastly expanded use of superior sires through artificial breeding; increasing specialization and concentration of dairy production in the hands of the more capable operators, partially as a result of pressures for improved sanitation and milk handling methods; and higher efficiencies resulting from labor saving equipment and management methods.

These same changes, together with such concurrent forces as the mounting cost of labor, have focused increasing attention upon areas of breeding, feeding and management that hitherto have occasioned somewhat less concern. For example, the impact of particular sires as a result of their concentrated use in artificial service brings with it the responsibility for continuing refinement of evaluation techniques to take into account traits that may exert larger effects on the profitability of cows as production levels advance and management methods change.
Already, some sires in even the less populous of the five major dairy breeds are estimated to have sired upwards of 50,000 progeny, and over 100,000 is not an unusual estimate of conceptions to the service of individual Holstein sires. Likewise, hand milking has vanished from the dairy farm scene except in the case of a few purebred fanciers. In its place are the milking machines of various brands and designs, none of which is presently capable of the same individual adjustments for particular cow peculiarities as were possible with hand milking. Increasing adoption of bulk handling of milk, with attendant increases in milking parlor milking, has posed problems of synchronizing the time in the parlor for cows with differing yields and milking flow characteristics. The labor requirement necessary to make the most efficient use of this rather uniform mechanized handling system makes paramount the task of selecting and breeding the kind of cow that best fits into the scheme. The role of feeding in its various aspects affecting adaptation to these new management schemes is likewise undergoing increasing scrutiny.

That we have achieved greater success in getting the milk into the udder than in getting it out of the udder, while maintaining udder soundness, is attested, among other things, by the fact that mastitis is our number one health problem in dairy herds today. Hence, our knowledge of milking flow characteristics assumes increasing importance in the economic neces-
sity of achieving efficient long term output from our input of labor and equipment costs. Recognition of the importance of proper removal of milk at milking time is not new. In 1615, Markham (as quoted by Dodd and Foot, 1948) in "The English Housewife" observes that "When she (the dairymaid) seeth all things answerable to her desire she shall then milk the cow boldly and not leave stretching and straining of her teats till not one drop of milk more will come from them, for the worst point of housewifery that can be is to leave a cow half milked, for besides the loss of milk, it is the only way to make a cow dry and utterly unprofitable for the dairy."

Of current concern is the response of the cow to rather standardized machine milking techniques, and it is to this problem that the research studies reported herein have been directed.
II. REVIEW OF LITERATURE

A. Normal Variations in Milking Flow Characteristics

Differences in milking flow characteristics and the various factors affecting them have been studied by a number of workers in recent years. Measures commonly used to describe these characteristics include peak flow, defined as the highest yield during any one minute of the milking process; rate of flow, defined as the average yield per minute during milking; and total milking time, which in some trials has encompassed the time from attachment to removal of the machine from the cow and in others has excluded the time spent in machine stripping.

The measures of ultimate economic importance to the dairyman, which are influenced or effected by the above, are 1) the time required for the complete milking out of each cow and 2) the amount of milk produced per hour of machine time. These are closely related but not completely analogous problems.

A number of the earlier studies give some notion as to milking characteristics. Some of these involve small numbers of animals, and are thus less informative with respect to differences among cows than are several more recent studies. Smith and Petersen (1948) at the Minnesota station studied six Holstein cows in first lactations and found that rate of flow ranged from 3.36 to 4.44 pounds per minute when cows were stimulated by washing and massaging the udder with warm water prior to
milking. When not so stimulated the same cows showed mean flow rates ranging from 3.06 to 3.84 pounds per minute. Whittleston (1946) at the Ruakura station in New Zealand used a milk-flow recording apparatus to record milk-ejection curves of 12 cows throughout a single lactation and found that the average rate of flow tended to decline toward the end of lactation, so that the milking time did not decrease appreciably as yield declined. The milk let-down response tended to become delayed and erratic toward the end of lactation. Phillips (1960) found that 30-second stimulation by washing and massaging the udder prior to milking on one of each set of 13 identical twin pairs resulted in a 32 percent advantage in lactational performance over the twins not so stimulated. He suggests that the response to this treatment was negatively associated with the duration of let-down. At the same station Whittleston and Verrall (1947) found a mean milking rate in different trials under standard milking conditions of from 1.88 to 3.25 pounds per minute. No significant differences in milking rate were found with different pulsator speeds and vacuum levels ranging from 21 to 84 per minute and from 10 to 19 inches, respectively. Dodd and Henriques (1949) obtained data on six cows during a six-day experimental period. They found that, under standard milking conditions using a machine having a teat cup assembly weight of seven pounds and operated at 14 in. vacuum level and 42 pulsa-
tions per minute, the cows produced an average of 32.6 pounds of milk per day with average machine time of 5.45 minutes per milking. Peak flow rates averaged 5.5 pounds per minute, and average rate of flow was about 3 pounds per minute. The effect of reducing the teat cup assembly weight or of adding up to 4 pounds additional weight was found to be significant only on the yield of machine strippings.

Beck et al. (1951) used a continuous-feed kymograph to measure rate of milk flow over a three-year period for cows in the Kansas State College herd from 1946 to 1949. Average milking time for the 102 cows of the Ayrshire, Guernsey, Holstein and Jersey breeds in the second to third months of lactation was 3.5 minutes with a range from 2 to 7 minutes. Differences among breeds in both peak flow and rate of flow were highly significant. The breeds ranked on both measures from most rapid to least as follows: Holstein, Jersey, Ayrshire and Guernsey. Holsteins and Jerseys were similar in machine time, both milking out in significantly less time than the Ayrshires and Guernseys. Data on 306 milkings of the 102 cows at 1 to 3 months of lactation showed the following:

<table>
<thead>
<tr>
<th>Breed</th>
<th>Av. yield/milking</th>
<th>Peak flow (lb/min.)</th>
<th>Av. rate of flow (lb/min.)</th>
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<tbody>
<tr>
<td>Holstein</td>
<td>20.1 lb.</td>
<td>9.3</td>
<td>6.1</td>
</tr>
<tr>
<td>Jersey</td>
<td>14.8 &quot;</td>
<td>7.5</td>
<td>4.8</td>
</tr>
<tr>
<td>Ayrshire</td>
<td>16.9 &quot;</td>
<td>6.7</td>
<td>4.5</td>
</tr>
<tr>
<td>Guernsey</td>
<td>15.3 &quot;</td>
<td>5.7</td>
<td>3.7</td>
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</table>
Johansson and Malven (1960) reported studies of milking flow characteristics of 115 cows made in the Swedish progeny testing station at Trolleberg from 1955 to 1957 and 91 cows at the Illinois Agricultural Experiment Station in the spring of 1959. Data were collected at Trolleberg four times during the lactation at two-month intervals, starting about one month after calving. Machines were operated at a vacuum of 33 cm. Hg and pulsation rate of 40 per minute. At an average of 70 days after calving, average yield per milking was 17.3 pounds, peak flow was 5.2 pounds per minute, average rate of flow was 3.8 pounds per minute and average milking time, including machine stripping, was 5.1 minutes. At an average of 249 days after calving the corresponding values were 11.6 pounds, 4.9 lb./min., 3.4 lb./min. and 3.7 minutes, respectively. These two stages of lactation represented the extremes in all the values listed. The size of the teat orifice was the most important cause of variations in rate of milking between cows in the first part of lactation and on the same level of yield. Using data from 68 of the 115 progeny-testing station cows, highly significant correlations were found between peak flow and yield per milking and between peak flow and 250-day yield. In studies at both stations on yield, udder pressure, size of teats and of teat orifice, significant partial correlations were found between peak flow and each of the other measurements except length and diameter of teats, which in general showed insignificant and negative cor-
relations. First lactation results on the 115 Friesian cows at the progeny testing station showed from the regression of lactation yield on peak flow that an increase of 683 pounds of milk was obtained for each one pound per minute increase in peak flow.

At the Cornell station Stewart et al. (1957) studied rate of milking on 286 cows of the Brown Swiss, Guernsey, Holstein and Jersey breeds over a four-year period. A DeLaval pail-type standard milking machine, operated at 12.5 inches of vacuum and 48 pulsations per minute, was used. Observations were made at afternoon milkings only, following an 11-hour interval. Average total milking time over all observations on the 286 cows of varying ages, averaging 154 days in milk, was 3 minutes and 33 seconds. Observations made at three different stages of lactation on 98 cows showed that both rate of milking and total milking time declined as lactation advanced. Studies made in early lactation showed significant differences among breeds, with Jerseys having the shortest milking times and Holsteins the highest average and peak flow rates. Peak flow rates ranged from 1.3 to 14.0 pounds per minute and total milking time from 1:15 to 11:40.

Gregoire et al. (1954) found an increase in rate of flow and a significant decrease in milking time when vacuum levels were increased from 10 to 13 or 17 inches. Their results on first-calf Holstein and Jersey heifers also showed a tendency
for rate of flow to increase as lactation progressed from the 6th through the 45th week of the experimental period. Bratlie et al. (1961) also found an increase in rate of flow and a decrease in milking time resulting from increasing the vacuum level from 35 to 50 cm. In similar studies to assess the effects of pulsation rate, Bratlie et al. (1959) noted in short-time trials that pulsation rates of 60 or 75 per minute resulted in lower rate of flow, but similar peak flow, as compared to a control group milked at a pulsation rate of 40 per minute. These same workers (1961) at the Veterinary College at Oslo, Norway, tested the effect of changing the pulsation ratio from 1:1 to 1:4 and found the unequal ratio resulted in higher peak flow and rate of flow, and shorter milking time. Kaveshnikova (1960) and Petit and Nicolaus (1961) experimented with different vacuum levels and different pulsation rates and ratios and obtained improved milk ejection by increasing the suction phase. Raising the suction phase to 60 percent with a three-phase milking unit improved the milking rate and reduced the amount of strippings as compared to the conventional milking unit tested by Kaveshnikova. With a constant vacuum level of 40 cm., along with different pulsation rates and ratios, Petit and Nicolaus obtained optimum results with a pulsation rate of 70 per minute and a ratio of 1:2.

Breitenstein (1961) reported results of trials on 107 Thuringian Fleckvieh cows at 6 to 20 weeks after calving. He
obtained an average yield of 14.52 pounds per milking with an average rate of flow of 2.6 pounds per minute. The German studies of Burgkart-Schnepf and Burgkart (1960) with similar mountain breeds showed an average rate of flow of 1.31 liters per minute. Seven cows studied through the first two lactations showed higher peak flow and rate of flow, and slightly shorter milking time, in second lactations than in first.

In a series of trials with Black and White Lowland (Friesian) cows, Comberg and Zschommler (1960, 1961) found, using individual quarter milking machines, that milk flow rate was not affected by pregnancy or length of lactation. Peak flow and rate of flow showed a correlation of 0.974 ± 0.01. While recommending selection for evenness of quarter yields, the high correlations found between milking rates of individual quarters and that for the whole udder lead these workers to conclude that milking rates can be assessed satisfactorily without taking individual quarter measurements. They further suggest that, for practical farm recording purposes, rate of flow may be used satisfactorily instead of the more accurate peak flow measurement and, if limited to a single observation, the optimum time is between the 60th and 120th days of the first lactation.

Dodd (1953), in one of many studies carried out at the National Institute for Research in Dairying in England on milk secretion, udder health and milking flow characteristics (Dodd...
and Foot, 1947, 1948, 1949, 1953; Dodd et al., 1949; Dodd et al., 1950; Dodd and Neave, 1951; Dodd et al., 1957; Ciough et al., 1953; Crossman et al., 1950; Dodd and Henriques, 1949; Baxter et al., 1950; Bailey et al., 1954, 1955; Bailey et al., 1953; Neave et al., 1950; Oliver et al., 1956) presents data on milking rate of 141 cows recorded in 326 lactations. He found coefficients of variation among cows in the various measures of machine milking rate to fall usually within the range of 30 to 40 percent and within-cow variations to be of the order of 8 to 11 percent. Total milking time, including machine stripping, ranged from 4.42 to 21.50 minutes, and peak flow ranged from 1.00 to 10.40 pounds per minute. Peak flow declined as lactation advanced, the decline being larger for fast milking cows. The decline in milking rate as lactation advanced was related independently to change in milk yield and to interval since calving. Thirty-four cows recorded in their first three lactations showed that, while increase in age independent of change in yield had no effect on peak flow, total duration of milking increased with age. He also concluded that total duration of milking within a lactation is influenced more by change in peak flow than by changes in milk yield or in yield of strippings. Calculations from 86 first lactation records showed a correlation of 0.889 between machine time and peak flow.

Using the regression of lactation yield on peak flow Dodd and Foot (1953) found an increase in lactation yield of 419
pounds of milk for each increase of one pound per minute in peak flow. The means, with standard deviations of individual records, were 6768 ± 1633 pounds of milk, 3.94 ± 0.37 percent butterfat test, and 4.04 ± 1.42 pounds per minute peak flow for the lactations. A significant negative regression of lactation solids-not-fat yield on peak flow was found. They reported that sires exhibited a striking influence on peak flow rates of their daughters.

Clough et al. (1961) reported average herd machine milking times varying from 2.5 to 5.4 minutes per cow from observations of 750 cows in 20 herds recorded at morning and evening milkings. In an experiment to investigate the effect of differing pulsation rates in conjunction with a uniform vacuum level of 15.3 inches Clough et al. (1953) obtained significantly higher peak flow and rate of flow, as well as shorter total milking time, when pulsation rate was increased from 20 to 80 cycles per minute. Dodd et al. (1949) found no significant differences in milking flow characteristics resulting from temporary changes in the interval between washing and milking of from zero delay up to six minutes delay.

Dohy et al. (1960) in Hungary used the proportion of milk obtained in the first 4 minutes of milking with an Elfa milking machine as a criterion of milking rate in studying 349 experimental milkings of 109 cows. The average 4-minute yields made up 76 percent of the total yields of cows milked twice daily,
as compared to 74 percent for those milked three times daily. These results would tend to indicate that milking time is not closely correlated with the amount of milk in the udder at milking time. A similar observation was made by Harshbarger (1950) in studying cows at different levels of production throughout lactation. He found that the rate of milk removal increased with higher milk production and that the total time required to milk high producing cows was not proportionally higher than that of low producing cows. He further noted that rate of removal for individual cows declined with advancing lactation along the same trend as the decrease in daily yield.

Johansson (1961) presents figures on 15 cows tested at one-month intervals throughout lactation, showing yield per milking ranging from 9.2 kg. to 3.0 kg. Peak flow was 2.34 kg. per minute at 15-60 days after calving, 2.60 kg. per minute at 61-120 days, and declined to 1.30 kg. per minute at 241-300 days after calving. Average rate of flow followed about the same rate of decline. He also states that high yielding cows tend to decline more in rate of flow during the course of lactation than do low yielding cows.

Groenewold (1961) studied 310 cows of the German Black-and-White breed (Friesians) with respect to maximum and average milking flow rates and found both measures to show a curvilinear regression with total amount of milk. A highly significant correlation of $r = 0.91$ was found between peak flow and rate of
flow, this relationship tending to be lower in first than in subsequent lactations. A similar close correlation between milk yield and milking rate was found by Guba (1959) in Hungary, using a three-phase milking machine. No increase in the rate of flow was found in second lactations as compared to first lactations of 42 cows studied by Holthoff (1956). Using data from 304 observed milkings, he found a correlation of \( r = 0.746 \pm 0.025 \) between rate of flow and total yield.

Murray (1961) tested vacuum levels of 10, 12, 14 and 16 inches with 13 Australian Illawarra Shorthorn cows. Peak flow rates ranged from 3.5 to 6.5 pounds per minute at the 16-inch vacuum level and from 2.0 to 5.2 pounds per minute at the 10-inch level. Both peak flow and rate of flow increased at each vacuum level increase, with the faster milking cows showing a larger response in peak flow than the slower milking ones. Milking rates varied more widely between cows than between vacuum levels. Teat cup vacuum was lowest at maximum milking rate and approached that of the unit only towards the end of milking.

Politiek (1961) analyzed results from 1058 milkings obtained with a Westfalia quarter milking machine from cows at the Schoonoort station and at three farms in The Netherlands. The machine was operated at 44 pulsations per minute and 36 cm Hg. vacuum level. At an average milk yield of about 15 pounds, milking time averaged 4.16 minutes, peak flow averaged 4.5 pounds per minute, and rate of flow averaged 3.6 pounds per
minute. Coefficients of variation were 30 and 33 percent, respectively, for peak flow and rate of flow. Correlation coefficients of $r = 0.33$ and $r = 0.34$ were found between milk yield and peak flow and between milk yield and rate of flow, respectively.

In Italy, Quadri (1959) obtained recordings of milking flow at different stages of lactation for 173 Italian Friesian and 65 Brown Alpine cows. The Friesians had higher yields and shorter milking times than the Brown Alpines. Average milking time was 3 minutes and 52 seconds with average yield of 14.8 pounds, and rate of flow was 4.35 pounds per minute. All these values declined as lactation advanced. Haring et al. (1956) studied milking flow characteristics of two Friesian bull progeny groups started on test at a progeny testing station in the fall of 1954. Wide individual cow differences were observed, and one progeny group was somewhat superior to the other in rate of flow, ranging from 0.81 to 1.26 kg. per minute for one bull progeny as compared to 0.68 to 1.18 kg. per minute for the other. Highest values occurred at mid-lactation at the beginning of the pasture season rather than earlier in lactation when daily milk yield was the highest.

Extensive investigations on milking characteristics have been carried out by Sandvik (1957a,b,c) on cows of the Norwegian Red Poll and Norwegian Red and White breeds at the Hafslund Progeny Testing Station and at farms in the area. Significant
correlations were obtained between lactation yield and mean observed peak flow over the lactation, but peak flow, observed when the yield per milking was 6.1 to 7.0 kg., was not closely correlated with lactation yield. On the basis of the latter observation he concludes that slow-milking cows are not necessarily low producers. Venge (1961) reported on a study of milking rate on Swedish Red-and-White heifers from 1954 to 1959 with readings obtained every four weeks during lactation. The most reliable measurement for assessing milking characteristics was found to be rate of flow taken at between 3.5 and 5.5 months after calving.

Wilke (1960) collected data with a quarter milking machine on 700 test milkings of 310 cows in Germany and found a highly significant coefficient of correlation of about 0.5 between daily milk yield and peak flow. Peak flow did not differ between a.m. and p.m. milking. Peak flow increased as lactation progressed and also from the 1st to the 2nd or 3rd lactations. When ranked in yield groups, with group averages ranging from 1.2 kg. to 15.97 kg. per milking, observed peak flow values for corresponding yield groups ranged from 0.40 to 3.57 kg. per minute.

Milking flow characteristics are routinely recorded on heifers at Danish bull progeny testing stations. Larsen et al. (1960) summarized the results of production tests on 844 such progeny groups tested during 15 years of testing station opera-
tion. The levels of lactation yield (304 days) and milking flow characteristics for progeny groups of the three major breeds for the 1959-60 testing year were as follows:

<table>
<thead>
<tr>
<th></th>
<th>No.</th>
<th>No.</th>
<th>304-day yield</th>
<th>Rate of flow</th>
<th>Av. milking time</th>
</tr>
</thead>
<tbody>
<tr>
<td>groups</td>
<td>groups</td>
<td>heifers</td>
<td>Lbs.milk</td>
<td>Lbs.fat</td>
<td>(lbs/min)</td>
</tr>
<tr>
<td>R.D.M.</td>
<td>59</td>
<td>1056</td>
<td>11,113</td>
<td>499</td>
<td>3.48</td>
</tr>
<tr>
<td>S.D.M.</td>
<td>22</td>
<td>399</td>
<td>10,904</td>
<td>471</td>
<td>3.79</td>
</tr>
<tr>
<td>Jersey</td>
<td>18</td>
<td>326</td>
<td>7,888</td>
<td>496</td>
<td>3.04</td>
</tr>
</tbody>
</table>

Large differences among progeny groups within breeds existed with respect to ease and speed of milking.

B. Maintenance of Udder Health

Several investigators have studied possible relationships of the milking flow characteristics of cows and milking procedures and equipment with the maintenance of udder health. Obviously it is of practical importance to consider maintenance of udder health in any steps designed to achieve milking speed.

Espe and Cannon (1941) utilized X-ray pictures in concluding that no vacuum develops at the end of the teat when the pressure exerted in milking is released. This would suggest that the entrance of bacteria into the udder is not facilitated by any tendency to suck them in via the teat canal during the milking process.

Bratlie (1958) and Bratlie et al. (1959, 1961) made observations on udder health as affected by vacuum level, pulsation rate and pulsation ratio. Increasing the vacuum level from 35
to 50 cm. Hg. resulted in higher incidence of apparent teat injury and mastitis infections. Increasing the pulsation rate from 40 per minute to either 60 or 75 pulsations per minute gave indications of adverse effects on udder health as evidenced by more frequent high leucocyte counts in the milk of cows milked at the higher pulsation rates. On the other hand, clinical and bacteriological tests indicated no adverse effects from milking with a 4:1 pulsation ratio as compared to the more conventional 1:1 ratio.

Dodd and Foot (1947) found that different methods of washing and preparation of the cow, including variations of from zero up to one hour in the time lapse between preparation of the cow and attachment of the machine, produced no udder abnormality as measured by Whiteside mastitis tests. In another experiment, they also found no clear-cut effect on either yield or mastitis incidence from gradually restricting the milking time from 100 to 60 percent of the previous normal flow period for cows in mid-lactation.

In an experiment with 38 first-calf heifers of five different breeds divided into two equal groups, Dodd et al. (1950) subjected the groups to rigid machine times of 4 minutes and 8 minutes, respectively, throughout lactation. No significant 305-day lactation yield differences were noted, even though under-milking was observed in the 4-minute group and frequent over-milking was observed in the 8-minute group. The 8-minute
cows had more clinical and subclinical mastitis. Bailey et al. (1953) observed reductions in both milk and fat yields resulting from incomplete milking of cows, using the "half udder" technique during a 15-day experimental period. Dodd and Neave (1951) used peak flow rate as the sole measure of ease of milking in studying incidence of mastitis in 94 first-calf heifers of the Shorthorn, Friesian and Guernsey breeds. When grouped into five groups on the basis of ease of milking, the faster milking groups showed a higher incidence of mastitis infections than the slower milking groups. The authors conclude that a strong correlation exists between ease of milking and incidence of mastitis. Total machine time was not recorded in this study, thus leaving open the question of whether milking procedure created any bias in favor of any of the groups.

Schmahlstieg (1960) studied the udders of 100 cows showing clinical symptoms of mastitis and abnormal milk secretion. He found a higher incidence of mastitis in the rear quarters than in the front quarters. No single feature of external or internal teat structure appeared to be commonly associated with susceptibility to mastitis.

Seelemann and Obiger (1959) observed no effect on milk or on udder tissue resulting from milking at increased vacuum level up to 50 cm. Hg or from increased pulsation rates. This is an opposite result to that reported by Bratlie and his co-workers, as noted above.
Mochrie et al. (1955) at the Connecticut station studied 48 animals consisting of equal numbers of Guernseys and Holsteins. In each breed group, 12 animals were first-calf heifers and 12 had one or more previous lactations. These groups were further subdivided on the basis of "clean" or "infected" mastitis tests. These were subjected to vacuum levels of 10, 13.5 or 17 inches and to "normal" or "twice normal" milking duration from the 5th to the 44th week of lactation. Animals milked at 13.5 inches of vacuum had larger weekly increases in chloride content than those milked at the other two levels. Vacuum level showed no effect on other criteria. Animals milked for twice the normal milking duration had larger weekly changes in leucocyte number and chloride content of milk than did those milked normally. The Holsteins had a higher chloride content in their milk on the average than did the Guernseys. The first-calf heifers showed less change in any of the criteria of udder health or milk quality than did animals with previous infections or with previous lactations. In another phase of the same experiment, Caruolo et al. (1955) studied milk yield, milking time and rate of flow. It was noted that mastitis infected animals gave higher milk yields and had slower rates of milk flow than did the mastitis clean animals.

In a series of experiments concerning udder infections, research workers at the National Institute for Research in Dairy-
ing in England (Neave et al., 1950 and Oliver et al., 1956a) found that about half of the new udder infections incurred during the cow's dry period persisted into the succeeding lactation. Crossman et al. (1950), at the same station, found that treating infected quarters with penicillin brought little recovery in proportionate yield in the current lactation but that recovery in the following lactation was frequently complete. This would suggest that any correlations between udder infection and either total yield or milking flow characteristics would not necessarily be carried over from one lactation to the next.

Sych (1961b) conducted an interesting experiment on the characteristics of natural suckling of the calf. He found that at eight days of age the calf's suckling rhythm was 150 per minute and that suction was equivalent to 100 to 130 mm. Hg. The ratio of time divided between suckling and swallowing phases was 3:1.

C. Udder Morphology and Physiology

The influence of the shape of udder, size and shape of teats and other characteristics of external mammary system morphology have been studied in relation to their possible effects on both yield and milking flow characteristics. It has been established by many early observations as well as by more recent investigations on evenness of quarter yields (Breitenstein, 1961; Burgkart-Schnepf and Burgkart, 1960; Larsen et al., 1960; Oger,
that the proportion of total yield from front quarters of the udder averages within the range of 40 to 45 percent, with rather wide individual variations. Comparable extensive data on flow rate differences between front and rear quarters of the udder are not available at the present time. However, Burgkart-Schnepf and Burgkart (1960) have presented individual quarter flow rate curves for individual cows which show a higher rate of flow for rear quarters than for front quarters, corresponding closely with their respective yields. This limited amount of evidence would suggest that whatever difference exists in total milking time between front and rear quarters is less than would be expected on the basis of their proportionate total yields. Some breed differences have been observed in distribution of yield between front and rear quarters. The extensive data routinely collected at the Danish bull progeny testing stations, as reported by Larsen et al. (1960), show a value of 46.2 percent of total yield from the front quarters in the Jersey breed as compared to 44.8 and 43.4 for the Red Danish and Black and White Danish breeds, respectively. Horn et al. (1961) found that Jersey X Hungarian Spotted crosses yielded 48.9 percent of their total milk from the front quarters as compared to 42.9 percent for Hungarian Spotted heifers. The crossbreds were also faster milkers and heavier producers than the Hungarian Spotted heifers. Timko
and Gabriš (1960) also found in a study of 112 animals that evenness of quarter yields was significantly better for Pinzgau than for Simmental cows, but these differences could not be reliably assessed from the appearance of the udder. A similar lack of correlation between external udder measurements and either evenness of quarter yields or total yield was found by Wilke (1960). Szajko (1959), however, observed both higher rate of flow and more even distribution of yield between front and rear quarters from the better shaped udders produced in the offspring of Hungarian Spotted cows when crossed with Kostroma bulls.

Dachs (1958) studied the udders of 44 cows of various breeds from photographs taken at varying intervals throughout lactation. Several udder measurements were also taken on part of the cows. The photographs showed that in general there was little variation in udder shape and size associated with stage of lactation except during the first and last few weeks of lactation. Correlations of the order of 0.75 to 0.85 were obtained between 300-day milk yield and udder length, using two different methods of measurement.

In a study of 59 Norwegian Red Poll and 184 Norwegian Red and White heifers in first lactations, Sandvik (1957b) found significant correlations between 300-day milk yield and scores for udder size and udder shape. Peak flow at milking showed no relationship with udder scores or shape of teats. Schwenger
(1958) found from a 6-month study of 36 cows that no relationship existed between udder measurements and milking rate. In agreement with the findings of Sandvik (1957b), Bartsch and Fiedler (1960) found a correlation of 0.66 between udder volume at 30 days after calving and daily milk yield, and 0.61 between udder volume at 30 days and lactation yield. Andreae (1959) calculated udder volume of 100 Black and White cows during their first three lactations from measurements of udder length, breadth, depth and distance from the ground. The ratio of milk yield at a single milking to the calculated udder volume ranged from 1:1.4 to 1:5.1, but was usually within the range of 1:2.0 to 1:2.9 in the first lactation. Wider ratios were associated with smaller total lactation yields, indicating a correlation with meatiness of the udder. Arzumanyan (1960) found that cows with "goat"-type udders gave 20-30 percent less milk than cows with well shaped udders. He also found that glandular tissue accounted for about 75 percent of the udder volume at the beginning of lactation, declining to about 50 percent towards the end of lactation.

Various aspects of the possible correlation between udder shape and function have also been reported by Krippl (1961), Führer (1961), Albat (1958), Suzuki et al. (1959), Wilke (1960), Legates et al. (1960) and Nielsen (1960). Krippl (1961) found relatively large variations in shape of udder and teats, and also observed a higher proportion of sloping udders in the German
Fleckvieh breed than in the German Brown breed. Wilke's (1960) investigations involving 310 cows registered in the Osnabruck Herd Book showed little correlation between udder measurements and milking ability. Suzuki et al. (1959) measured udder and teat size before and after milking in cows of the Holstein-Friesian, Jersey and Brown Swiss breeds and found the greatest change (19.6%) occurred in the distance between the rear teats. No significant correlation was found between udder contraction and milk production at that milking.

Legates et al. (1960) and Nielsen (1960) report correlations of the order of 0.20 to 0.30 between udder measurements taken on heifers at about four to six months of age and their subsequent first lactation yields. These would indicate a prediction value for production about equivalent to a single record on their dams.

Internal udder structure, capacity and pressure have been studied in relation to milk yield, rate of flow and the mechanisms of the milk "let-down" response. Bleeker (1958) microscopically examined udder tissue from each quarter of 20 cows, and found considerable variation in udder characteristics. A relatively low proportion of connective tissue and a larger number of mostly large alveoli tended to be associated with high milk yield. Swanson (1960) also found udder structure differences between members of identical twin pairs which had been
raised on two different nutritional levels. The excessively fattened members of these pairs had averaged only 34.3 percent as much fat-corrected-milk (FCM) in first lactations as their twins grown on a more normal feeding regimen.

Suchanek (1961) shifted groups of cows from three times daily to twice daily milkings at three different stages of lactation and found that udder capacity played an important role in the moderate decline in production which resulted from the mid-lactation shift in milking frequency. Theoretical udder capacity was estimated by Tucker et al. (1961) in experiments with four groups of Jersey and one group of Brown Swiss cows milked at intervals of 8, 12, 14, 16, and 20 hours. Udder capacities estimated for the four Jersey groups ranged from 42.4 to 51.3 pounds, while that for the Brown Swiss was 63.2 pounds. Intramammary pressure increased with increases in total milk. The correlation between udder pressure and milk removal or the milk ejection reflex has also been investigated by Johansson and Malven (1960), Buhr (1958), Whittleston (1955), Janovsky and Bilek (1961), Zaks (1955), Andreae (1961), Kaveshnikova (1960a), Bailey et al. (1953) and Baxter et al. (1950). Johansson and Malven (1960) obtained significant correlations between peak flow and udder pressure, although somewhat lower than the correlations between peak flow and either yield or size of teat orifice. Buhr (1958) also found a significant correlation between milk pressure and maximum flow rate.
Using an electrical pressure recording system, Whittleston (1955) simultaneously recorded intramammary pressure in milked quarters and unmilked quarters. The unmilked quarters showed a very slow fall in pressure, while the milked quarters showed a steady and more rapid fall in pressure. When re-stimulated some time after the experiment, a rise and fall was noted in the milked quarters, but no change occurred in the unmilked quarters. Janovsky and Bilek (1961) found from radiographic studies that each squeeze during hand milking caused milk to penetrate back into the large ducts, resulting in a rise in intra-cisternal pressure. By withdrawing cisternal milk with catheters they further established that stimulation of teats of quarters so evacuated failed to produce milk ejection. They suggest that a certain minimal intra-cisternal pressure is necessary to produce milk ejection, and offer this as a possible explanation for the difficulty in producing ejection in low-yielding animals milked at frequent intervals. Kaveshnikova (1960a) postulated that more efficient evacuation of milk from the udder cistern rather than an improvement in the milk ejection reflex accounted for the improved milk removal which he obtained with an improved three-phase milking unit. Zaks (1955) presents some interesting results and hypotheses with respect to the secretion and storage of milk in the udder, and its evacuation at milking time. He observed only a negligible quantity of milk in the cisterns during the first 3 - 4 hours after milking while the alveoli
were filling up. From about the 5th to the 8th hour, the cisternal milk increased rapidly and then declined in rate of increase. He postulated that as alveolar pressure increases, rhythmical discharges of milk into the cisternal region are at first facilitated by a relaxation of the sphincter mechanisms in the ducts with a steady rise in pressure, and later by loss of tonus and relaxation of the cistern walls with little change in pressure until about 1500 ml. of milk has accumulated. Thereafter, the pressure again rises progressively. He found some evidence from these results that this mechanism that allows the udder to accommodate the greatest possible amount of milk under the lowest pressure becomes more efficient with successive lactations. At milking time it was noted that cistern pressure rises steadily at first, but later rises in a series of steps, probably as a result of a relaxation of the large ducts as alveolar pressure increases. The possibility is suggested that increases in the tonus of the cisternal walls as milk is removed may actually increase pressure there even though volume of its contents has decreased. Rhythmical changes in milk secretion and pressures were also noted in goats by Tverskoi (1955) and Tverskoi and Dyusembin (1955). Shvabe and Kulikov (1961) studied the distribution and composition of milk in the cisternal, alveolar and residual portions obtained. They found larger and more numerous butterfat globules in the residual portion. The difference in butterfat globule size was more pronounced in the
first than in the second half of lactation. No substantial differences were noted between solids-not-fat and protein contents in the three portions of the milk. It was further observed by Kulikov (1959) that milk ejection was most complete when the milking interval was 12 to 15 hours, due to the decline in residual milk with time. An interesting observation concerning maintenance of secretory ability is made by Heidrich and Gehring (1958) from experiments with nine cows in which one quarter was left unmilked for a period of 10 days. The stimulus obtained from milking the other three quarters appeared to be sufficient to prevent involution of the unmilked quarter except in cases of very advanced lactation. Studies of the reabsorption phenomenon by Azimov et al. (1961) using $^{32}P$ indicate that some reabsorption is necessary for the maintenance of milk secretion, since removal of residual milk, by repeated injections of posterior pituitary extract and milking, temporarily interfered with milk synthesis.

The effects of various stimuli on the process of milk removal have been studied for many years, including recent investigations by Peeters et al. (1960), Blau (1959), Gofman (1955), Debackere and Peeters (1960), Bilek and Janovsky (1959), Lauener (1959), Manunta and Marongiu (1961), Pavlov (1955), Tsakhaev (1955), and Chaudhury and Dikshit (1960). Earlier studies had already established the striking effects of the pituitary and adrenal hormones on the milk "let-down" response. Ely and
Petersen (1941) observed no effect on milk ejection from denervating half of the udder. Fright and intrajugular injections of adrenalin resulted in cessation of milk ejection. Intravenous injection of 4 cc. of either Pitocin or Pitressin (oxytocin or vasopressin) caused more complete udder drainage under normal conditions as well as when injected after fright or adrenalin injections, a result essentially confirmed by Bilek and Janovsky (1959). Miller and Petersen (1941) also found that pituitrin injection produced complete expulsion of milk from quarters which were milked after a delay between stimulation and milking. In this latter connection, Blau (1959) found that a warm water wash was superior to dry stimulation in producing the milk ejection response, and attributed this superiority to an increase in the intensity of the hormone secretion. Various natural stimuli were studied by Peeters et al. (1960). They found that milk ejection was best induced by suckling, followed in order of effectiveness by warm water washing of the udder plus sight of the calf, udder washing alone, and sight of the calf alone. Gofman (1955) found differences between the goat and the cow in the milk ejection response. Categorizing the milk ejection reflex in two stages, he observed that in the goat both stages were associated with an increase in cistern pressure, whereas in the cow the first stage was associated with a fall in pressure. Pavlov (1955) observed in goats a segmental reflex, believed to aid in evacuation of milk from the larger ducts,
which occurred immediately after applying stimulation and before the neuro-hormonal milk ejection response. Hed differentiated the two by cooling the dorsal part of the spinal cord at the level of the last thoracic vertebra, thus blocking the ordinary milk ejection reflex but not affecting the segmental reflex. Debackere and Peeters (1960) distended the vaginae of six lactating cows by means of inflated rubber balloons and obtained a milk ejection response after a three to four minute lag period. This response appeared even when the udder was denervated. In experiments with rats, Chaudhury and Dikshit (1960) found intraperitoneal injections of ergotamine and ergometrine, 30 minutes prior to adrenalin administration, effectively reversed the adrenalin-induced block of milk ejection. These drugs are suggested as additional substances possessing a specific milk ejecting property.

It is apparent from a number of studies that the structure of the teats may impose some limitations upon the speed of withdrawal of milk during machine milking. The findings of some investigators assign major importance to size of teat orifice as a determinant of milking flow characteristics (Johansson and Malven, 1960; Andreae, 1961; and Baxter et al., 1950). Other features of teat morphology such as length, diameter, shape and end structure have likewise been observed for possible effects on milking flow characteristics. The lack of agreement in findings with respect to these latter measurements may be at
least partially accounted for by the rather standardized size and design of milking machine teat cups and liners and the relationship of this fact to the possible degrees of variation in teat structure present in the different groups of cows studied. Johansson and Malven (1960) obtained highly significant correlations of up to 0.67 between peak flow and diameter of teat orifice, and a significant negative correlation between peak flow and length of teat. Wilke (1960) found no correlation between peak flow and length or circumference of teats. Loppnow (1959) observed from a study of 30 cows that the teats of cows with a low speed of milk flow are usually shorter, thicker walled, have longer teat canals, and the volume of tissue surrounding the teat canal is twice as great as in those cows with a high speed of milk flow. Renk (1960) concluded from a study of similar measurements that these should not be taken as definite criteria for assessing ease of milking. Venge (1961) reported a highly significant negative correlation between teat length and daily yield in his extensive study of Swedish Red-and-White cows. Characteristic breed differences may be involved in correlations of teat measurements with either yield or speed of milking. This is suggested by the significant negative correlation found by Johansson and Malven (1960) between peak flow and length of teat in the Swedish Red-and-White progeny station heifers, as compared to insignificant correlations between these measures for other breeds studied. Since only first lactation
data were used in these comparisons, age differences can essentially be ruled out in this case as contributory causes. The work of Krippel (1961) with German Fleckvieh and German Brown cows shows an increase in teat length with age in both breeds, along with about 1 cm. greater length in fore teats than hind teats. Donald (1960) found in studies with twin and single-born cows that cows with teat length of less than 4 cm. milked faster and had higher yields than those with longer teats. This finding essentially agrees with that reported by Sandvik (1957a), who found a significant negative correlation between length of teat and peak flow.

D. Repeatability and Heritability of Milking Flow Characteristics

The repeatability of measurements of both peak flow and rate of flow is high, with the former being the more precise due to its lesser dependence on milking techniques. Several investigators (Ace et al., 1959; Dodd, 1953; Donald, 1960; and Brumby, 1961) show the coefficient of repeatability for peak flow determinations to be of the order of 90 percent.

Heritability of peak flow also appears to be relatively high (Beigel, 1955; Brumby, 1961; Burgkart-Schnepf and Burgkart, 1960; Dodd, 1953; Dodd and Foot, 1953; Donald, 1960; Jannermann, 1960; Larsen et al., 1960; Pfeifer, 1957; Politiek, 1961; Szajko, 1959; Venge, 1961; and Wilke, 1960). In general, nutritional levels and other environmental influences which, ac-
According to Horny and Hertrampf (1960), exert large effects on peak flow, have not been evaluated specifically in most investigations reported to date. As a result, considerable variation exists in the estimates of heritability that appear in the literature. Considerable evidence indicates that this value may lie somewhere within the range of 0.6 to 0.8. Brumby (1961) gives a value of around 0.6 as the heritability of peak flow, which closely agrees with the 0.6 to 0.7 value indicated by Dodd (1953). Politiek (1961) ascribes most of the variation in milking flow rates to hereditary factors and gives values for two large groups of animals in The Netherlands of 0.54 and 0.74 as the heritability of peak flow. In his studies with twin and single-born cows, Donald (1960) calculated heritability of peak flow as 0.85.

All the above investigators agree that high repeatability makes it feasible to study milking flow rates on practical farms on a large scale with infrequent observations, and that substantial improvement in milking flow characteristics through breeding seems possible.
III. INVESTIGATIONS

A. Ankeny Twin Herd

In December 1955 an identical twin project was started at the Iowa State University field station at Ankeny, Iowa, which is located about 20 miles south of Ames. This herd is referred to as the Ankeny Twin Herd. In assembling identical twin females for this herd the only requirement is that they be three-quarter or more Holstein in breeding. To date 88 sets of twin heifers have been purchased for the project, all from dairymen in Iowa or bordering states. These represent both registered and non-registered or grade Holstein herds, so they can be assumed to constitute a random sample of the Holstein cattle population of this area. The twins are purchased as soon as possible after birth and brought to Ankeny, where they are assigned to feeding levels and undergo further observation and blood typing to establish monozygosity. Those that the blood tests indicate to be fraternal twins are also retained in the project, and have constituted something over one-fourth of the total sets purchased.

Assignment to feeding levels is directed toward answering the question of whether or not a genetic makeup that excels at one nutritional level also exhibits similar superiority under a different level of nutrition. The assigned nutritional levels are employed throughout growth and production, and are identi-
fied as High and Low. The feeding regimes followed for the two groups are outlined below.

For the first 8 weeks of age — Both groups are started in the same manner, employing a conventional calf feeding system of limited whole milk or milk replacer along with hay and a calf starter concentrate mixture.

Ninth through 16th week — Ad libitum hay feeding is continued for both groups. The Highs are allowed up to 6 pounds of calf starter per day, and the Lows up to 2 pounds per day.

Seventeenth week through 8th month — Ad libitum hay feeding is continued. A simple grain mixture replaces the calf starter, with daily allowances for animals in each group remaining the same as those used previously for the calf starter.

Ninth month of age to first calving — Hay crop silage is fed along with hay during the winter feeding period, and green chopped forage is fed along with hay during the summer growing season, in a continuance of the ad libitum forage feeding program for both the High and Low groups. Up to 6 pounds per day of the grain mixture is allowed for the Highs, while the Lows receive no grain during this period.

During lactation — Animals in the High group receive 1 pound of a 12.0 percent crude protein grain mixture for each 2 pounds of milk produced in excess of 10 pounds daily.
The animals in the Low group receive the same grain mixture at the rate of 1 pound for each 6 pounds of milk produced in excess of 10 pounds daily. Good quality roughage, consisting of a combination of hay and either silage or green chopped forage according to season, is fed ad libitum to all animals.

The cows are grouped by ration levels and kept in dry lots the year around with loose housing sheds. All animals in both ration level groups are bred to calve for the first time at as near 24 months of age as possible.

Assignments of twin sets to ration levels have been made in rotation as follows: The first set is placed in the High group; the second and third sets are split, with one member of each set going to the High and the other member to the Low group; and the fourth set is assigned to the Low group.

Starting in September 1958 flow rate readings have been taken on all cows at a successive evening and morning milking at four-week intervals. The interval between evening and morning milkings has been 14 hours and that between morning and evening milkings 10 hours. The cows are fed grain and milked in a 20-stanchion milking barn equipped with Surge pipeline milkers operated at 15 inches of vacuum and 52 pulsations per minute. Long hoses between the teat cup assembly and the milker pail
permit the pail to be suspended on a scale which can be moved on an overhead track along the rear of each row of cows. The flow rate readings are taken every 15 seconds during the milking of each cow. The time from the start of washing the udder to the attachment of the teat cups is recorded, and the total milking time is recorded as the time from attachment of the teat cups until their removal after machine stripping.

The data from the Ankeny herd included in this study consist of all complete lactations started after July 1, 1958 and completed before June 30, 1962. These include 166 lactations on 82 different cows, consisting of 73 first lactations, 59 second lactations, 31 third lactations, and 3 fourth lactations. Lactation milk yields have been calculated from daily milk weights. Analyses of fat and solids-not-fat have also been made routinely. A total of 3270 experimental milkings are included.

B. University Main Herd

In March and April of 1962, flow rate readings were taken at successive evening and morning milkings five weeks apart on all animals in the main dairy herd unit located at the University Dairy Farm at Ames. This herd consists of registered animals of the Ayrshire, Brown Swiss, Guernsey, Holstein, Jersey and Milking Shorthorn breeds. The total number milking varies between 120 and 130 head. The Dairy Herd Improvement Association production averages for each breed group in the herd for
The 12 months including the May 1962 test period were as follows:

<table>
<thead>
<tr>
<th>Breed</th>
<th>Cow years</th>
<th>Lbs. milk</th>
<th>Lbs. fat</th>
<th>Feeding index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ayrshire and Milking Shorthorn</td>
<td>7.1</td>
<td>10,352</td>
<td>439</td>
<td>140</td>
</tr>
<tr>
<td>Brown Swiss</td>
<td>21.3</td>
<td>11,944</td>
<td>522</td>
<td>129</td>
</tr>
<tr>
<td>Guernsey</td>
<td>12.4</td>
<td>9,177</td>
<td>469</td>
<td>132</td>
</tr>
<tr>
<td>Holstein</td>
<td>68.2</td>
<td>15,290</td>
<td>541</td>
<td>125</td>
</tr>
<tr>
<td>Jersey</td>
<td>18.2</td>
<td>8,626</td>
<td>512</td>
<td>134</td>
</tr>
</tbody>
</table>

The feeding index given for each breed is a figure routinely computed in the electronic data processing of Dairy Herd Improvement Association records from feed consumption estimates. This index indicates the percentage of maintenance and production requirements being provided by the ration. The figures for the University Herd represents a liberal feeding program designed to provide adequate nutrient intake to allow for the requirements of gestation and also the growth of immature animals, in addition to maintenance and production needs. Thus, the feeding level in this herd would closely approximate the level of the High Ration group in the Ankeny Twin Herd data.

The University Herd is housed in a tie-stall barn, and is milked at 12-hour intervals in a four-tandem elevated-stall milking parlor with side opening gates. No grain is fed in the milking parlor. Two men do the milking, operating two units each. The equipment used is a DeLaval pipeline milker.
operated at 15 inches of vacuum and a pulsation rate of 52 per minute. Each stall in the milking parlor is equipped with a glass jar suspended on a scale, so that milk yields for each cow can be recorded at each milking. Recordings of milking flow rates were taken from these same scales by four men stationed in the observation room adjacent to the milking parlor. The readings were taken at 15-second intervals throughout the milking of each cow, from the time of attachment of the teat cups until their removal after machine stripping, in the same manner as the readings for the Ankeny Twin Herd.

These data include milking flow rate observations on 67 Holstein, 18 Brown Swiss, 16 Jersey, 10 Guernsey, 7 Ayrshire, and 2 Milking Shorthorn cows. In total, 441 experimental milkings were involved.

In tabulating the data from both herds, the following measures of milking flow characteristics, with definitions, have been employed:

* Peak Flow -- The largest amount of milk in pounds, obtained during any one minute during milking.

* Rate of Flow -- The average number of pounds of milk per minute obtained during the complete milking of the cow. This figure is obtained by dividing the total milking yield by the total machine time.

* Machine time -- The time from attaching the teat cups until their removal from the cow after machine stripping. In tabulating this figure, any 15-second intervals, at the end
of the milking process, in which no milk flow was recorded were deducted so as not to charge time against the cow which should more properly be charged against the machine operator.

**Time to Reach Peak** — The number of seconds after attachment of the teat cups until the beginning of the minute in which peak flow occurred.
IV. FINDINGS

A first concern in this investigation was to determine how precisely the peak flow, expressed as an average of the observations taken during 24-hour periods at 4-week intervals throughout lactation, measures the milking flow characteristics of individual cows. Thus, the amount of variability introduced by the unequal interval between evening and morning milkings, by any changes in peak flow with stage of lactation, and by the interactions of these with cows on two different levels of nutrition during growth and lactation have been calculated by analysis of variance. Table 1 shows the results of such an analysis for all of the first lactation animals on the High ration level in the Ankeny Herd, without segregation as to genetic background. Table 2 shows a similar analysis for all first lactation animals on the Low ration level. In these analyses, Times (p.m. or a.m. milkings) and Months (1st, 2nd, 10th 24-hour observation at 4-week intervals during lactation) were considered as fixed variables in the model, with cows as the random variable. The assumptions made in setting up the analysis in this way were that an established milking routine and some reasonable sampling interval in keeping with usual herd procedures should be established in advance. Differences among cows can be detected once the effect of fixed variables is known and can be adjusted for in any sampling procedure. In these tables the differences among cows make up the greatest portion of the total variance, accounting for
Table 1. Analysis of variance of peak flow of 35 high ration first lactation animals in the Ankeny Twin Herd

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Sum of squares</th>
<th>Mean squares</th>
<th>Expected mean squares</th>
<th>Variance components</th>
<th>Percent of total variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cows ((c-1)) ((t-1))</td>
<td>34</td>
<td>2146.56</td>
<td>63.13**</td>
<td>(V_{ctm}+20V_c)</td>
<td>3.14</td>
<td>71.5</td>
</tr>
<tr>
<td>Times ((t-1)) ((m-1)) ((c-1))</td>
<td>9</td>
<td>55.45</td>
<td>55.45**</td>
<td>(V_{ctm}+10V_{ct}+350V_t)</td>
<td>0.16</td>
<td>3.6</td>
</tr>
<tr>
<td>Months of lactation ((m-1))</td>
<td>9</td>
<td>94.40</td>
<td>10.49**</td>
<td>(V_{ctm}+2V_{cm}+70V_m)</td>
<td>0.13</td>
<td>3.0</td>
</tr>
<tr>
<td>Cows x times ((c-1)) ((t-1)) ((m-1))</td>
<td>306</td>
<td>433.20</td>
<td>1.42**</td>
<td>(V_{ctm}+2V_{cm})</td>
<td>0.57</td>
<td>13.0</td>
</tr>
<tr>
<td>Cows x months ((c-1)) ((t-1)) ((m-1))</td>
<td>306</td>
<td>87.54</td>
<td>0.29</td>
<td>(V_{ctm})</td>
<td>0.29</td>
<td>6.6</td>
</tr>
<tr>
<td>Times x months ((t-1)) ((m-1)) ((c-1)) ((t-1)) ((m-1))</td>
<td>9</td>
<td>15.31</td>
<td>1.70**</td>
<td>(V_{ctm}+35V_{tm})</td>
<td>0.04</td>
<td>0.9</td>
</tr>
<tr>
<td>Total ((n-1))</td>
<td>699</td>
<td>2862.34</td>
<td>4.09</td>
<td></td>
<td>4.39</td>
<td>100.0</td>
</tr>
</tbody>
</table>

**Significant at 1 per cent level**
Table 2. Analysis of variance of peak flow of 38 Low ration first lactation animals in the Ankeny Twin Herd

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Sum of squares</th>
<th>Mean squares</th>
<th>Expected mean squares</th>
<th>Variance components</th>
<th>Percent of total variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cows (c-1)</td>
<td>37</td>
<td>1653.29</td>
<td>44.68**</td>
<td>V&lt;sub&gt;ctm&lt;/sub&gt;+20V&lt;sub&gt;c&lt;/sub&gt;</td>
<td>2.22</td>
<td>67.3</td>
</tr>
<tr>
<td>Times (p.m., a.m.)</td>
<td>1</td>
<td>70.03</td>
<td>70.03**</td>
<td>V&lt;sub&gt;ctm&lt;/sub&gt;+10V&lt;sub&gt;ct&lt;/sub&gt;+380V&lt;sub&gt;t&lt;/sub&gt;</td>
<td>0.18</td>
<td>5.5</td>
</tr>
<tr>
<td>Months (m-1)</td>
<td>9</td>
<td>100.95</td>
<td>11.22**</td>
<td>V&lt;sub&gt;ctm&lt;/sub&gt;+2V&lt;sub&gt;cm&lt;/sub&gt;+76V&lt;sub&gt;m&lt;/sub&gt;</td>
<td>0.13</td>
<td>3.9</td>
</tr>
<tr>
<td>Cows x times (c-1)(t-1)</td>
<td>37</td>
<td>38.07</td>
<td>1.03**</td>
<td>V&lt;sub&gt;ctm&lt;/sub&gt;+10V&lt;sub&gt;ct&lt;/sub&gt;</td>
<td>0.07</td>
<td>2.1</td>
</tr>
<tr>
<td>Cows x months (c-1)(m-1)</td>
<td>333</td>
<td>359.46</td>
<td>1.08**</td>
<td>V&lt;sub&gt;ctm&lt;/sub&gt;+2V&lt;sub&gt;cm&lt;/sub&gt;</td>
<td>0.40</td>
<td>12.1</td>
</tr>
<tr>
<td>Times x months (t-1)(m-1)</td>
<td>9</td>
<td>6.26</td>
<td>0.70*</td>
<td>V&lt;sub&gt;ctm&lt;/sub&gt;+38V&lt;sub&gt;tm&lt;/sub&gt;</td>
<td>0.01</td>
<td>0.3</td>
</tr>
<tr>
<td>Cows x times x months (c-1)(t-1)(m-1)</td>
<td>333</td>
<td>95.79</td>
<td>0.29</td>
<td>V&lt;sub&gt;ctm&lt;/sub&gt;</td>
<td>0.29</td>
<td>8.8</td>
</tr>
<tr>
<td>Total (n-1)</td>
<td>759</td>
<td>2323.85</td>
<td>3.06</td>
<td></td>
<td>3.30</td>
<td>100.0</td>
</tr>
</tbody>
</table>

*Significant at 5 per cent level

**Significant at 1 per cent level
about 67 percent of the observed variation in the Low group, and about 72 percent in the High group. As shown by the variance components, the Highs show a higher total variance in peak flow than the Lows (4.39 vs. 3.30). Most of this difference is accounted for by the variance among cows, 3.14 for the Highs as compared to 2.22 for the Lows. The Cows x Months interaction contributes the second largest percentage of the total variance, amounting to about 12 and 13 percent in the Low and High groups, respectively. The percent of total variance accounted for by Times, 5.5 percent for the Lows and 3.6 percent for the Highs, is perhaps smaller than expected in view of the unequal milking interval and the correlations between peak flow and yield observed by other workers and in part confirmed by the present study. On a lactation average within-cow basis, the observed peak flow was higher at the morning milkings which followed the 14-hour interval. The 35 Highs in first lactations averaged 6.8 pounds per minute peak flow at p.m. milkings as compared to 7.4 pounds at a.m. milkings. Comparable figures for the 38 Lows in first lactations were 5.8 pounds and 6.4 pounds for p.m. and a.m. milkings, respectively.

The relationship between daily yield and peak flow, which probably explains much of the month to month variation through lactation, is shown in Table 3 for the first three lactations of all animals in both the High and Low groups. Significant
Table 3. Correlation between peak flow and daily yield for individual cows within ration levels at different stages of the first three lactations

<table>
<thead>
<tr>
<th>Lactation no. and ration level</th>
<th>Successive 24-hour observations at 4-week intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1 35 Highs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.21</td>
</tr>
<tr>
<td>1 38 Lows</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.52**</td>
</tr>
<tr>
<td>2 28 Highs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.14</td>
</tr>
<tr>
<td>2 31 Lows</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.46**</td>
</tr>
<tr>
<td>3 13 Highs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.41</td>
</tr>
<tr>
<td>3 18 Lows</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.33</td>
</tr>
</tbody>
</table>

*Significant at 5 percent level

**Significant at 1 percent level
correlations between peak flow and daily yield exist for ani-
mais on the Low ration level throughout lactation, whereas
such significance is not shown in the High ration animals at
the beginning of lactation, and begins to become apparent for
them at a later stage in first lactations than in second lacta-
tions. Correlations for the smaller numbers of animals with
third lactations are more variable, in both ration groups,
than for first and second lactations. These comparisons make
it appear that in general the levels of daily yield and con-
comitant peak flow observations at each stage of lactation are
closely tied together. However, the way peak flow was defined
and measured in this study may have made it somewhat more depend­
ent on daily yield at the low levels than at higher levels of
daily yield. This situation could occur especially in the case
of fast milking cows where the level of yield per milking had
declined to such a point that their potential maximum flow rate
would be maintained for less than a full minute during the milk­
ing process.

The indication that peak flow is, however, essentially in-
dependent of the amount of milk produced, and that it does not
vary with stage of lactation to the same extent as does milk
yield, is notably supported by the following comparisons. The
correlation between average peak flow and average daily yield
through the first lactation was calculated for 10 Split-Ration
identical pairs. For the High members of these pairs a non-
significant correlation of 0.47 was obtained. For the Low members the correlation was 0.64, significant at the 5 percent level of probability. These identical twin mates on different ration levels differed more in yield than in peak flow. The intraclass correlation between average daily yields of members of these pairs was 0.71, significant at the 5 percent level; while that between their peak flow rates was 0.90, significant at the 1 percent level.

Figure 1 indicates that maintenance of maximum yield throughout the lactation, as effected by the High ration level, is also conducive to achieving maximum peak flow throughout the lactation. However, it should be noted that the peak flow attained in early lactation, on either ration level, was maintained throughout lactation to a higher degree than was milk yield. This comparison brought up the question as to whether or not persistency of yield, exclusive of level of yield, is correlated with lactation peak flow rate. To investigate this all of the first lactations, without segregation as to genetic background, were used. The ratio, yield during the last 3 months of lactation divided by yield during the first 3 months of lactation, was used to express the persistency of yield for each cow. The 35 Highs had an average persistency of 0.70 and the 38 Lows as average of 0.68. Correlations were calculated between lactation peak flow and persistency for cows within each ration group. The Highs showed a non-significant correla-
Figure 1. Yield and flow rate curves for 10 first lactation split-ration identical twin pairs
tion of 0.27, and the Lows a negative correlation of -0.37, significant at the 5 percent level. This offers further proof that pressing the cow to her highest yield capability, rather than persistency of yield per se, enhances the expression of her maximum peak flow capability.

These relationships are perhaps better demonstrated by the curves in Figure 1, which show peak flow, rate of flow and daily yield during first lactations for members of identical twin pairs in which one member was on the High and the other on the Low ration level. This graph for 10 such Split-Ration identical twin pairs shows that daily yield, peak flow, and rate of flow were nearly the same for the Highs and Lows at the first month of lactation. The differences occurring as lactation progressed, however, gave an average lactation advantage to the Highs over the Lows of about 12 percent in average daily milk yield, 13 percent in peak flow, and 8 percent in rate of flow. Similar comparisons for seven sets of Split-Ration identical twin pairs that have completed one or two subsequent lactations show a margin of advantage to the Highs in second and third lactations of 8 percent in average daily milk yield, 5 percent in peak flow, and 8 percent in rate of flow over their identical twin mates on the Low ration. This observed maintenance from one lactation to the next, of superiority in rate of flow resulting from the higher ration energy level,
has important practical implications. While peak flow theoretically measures the milking flow characteristics of cows more accurately and precisely without the confounding effect of the machine operating procedure, rate of flow is more important to the dairyman, since it measures the amount of milk obtained per unit of total machine time. High peak flow possesses no apparent economic advantage, except as it may affect or be closely correlated with rate of flow. Furthermore, aside from the problem of establishing satisfactorily the termination point of milking flow among machine operators, who might vary in their alertness to removal of teat cups when milk-out is complete, measurement of rate of flow would lend itself to large-scale field collection of data much better than would peak flow. With this in mind, the relationship between these two measures has been investigated.

The correlations between peak flow and rate of flow based on both Ankeny Twin Herd data and data from all breeds in the University main herd are presented in Table 4. A graphic presentation of peak flow, rate of flow, and yield for all first lactation Ankeny cows is also given in Figure 2. These comparisons show a very high correlation between the two measures used for expressing the milking flow characteristics of the cow. These high correlations between peak flow and rate of flow for animals in both ration level groups at Ankeny, as well as for each of the breeds in the Iowa State University main herd, lead
Table 4. Correlations between peak flow and rate of flow, using the average of all observations on each cow for comparison

<table>
<thead>
<tr>
<th>Herd</th>
<th>Correlations</th>
<th>Peak flow (lbs/min)</th>
<th>Rate of flow (lbs/min)</th>
<th>Av. daily yield</th>
<th>Av. age at calving (mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Means</td>
<td>Ind. std. deviation</td>
<td>Means</td>
<td>Ind. std. deviation</td>
</tr>
<tr>
<td>Ankeny Twin Herd</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35 Highs, 1st lact.</td>
<td>0.94</td>
<td>7.1±0.94</td>
<td>1.7</td>
<td>4.7±0.55</td>
<td>1.0</td>
</tr>
<tr>
<td>38 Lows, 1st lact.</td>
<td>0.92</td>
<td>6.1±0.77</td>
<td>1.5</td>
<td>4.1±0.43</td>
<td>0.8</td>
</tr>
<tr>
<td>University Main Herd</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>67 Holsteins</td>
<td>0.92</td>
<td>7.3±0.70</td>
<td>1.8</td>
<td>5.4±0.46</td>
<td>1.2</td>
</tr>
<tr>
<td>18 Brown Swiss</td>
<td>0.98</td>
<td>4.8±0.41</td>
<td>1.7</td>
<td>3.5±0.82</td>
<td>1.1</td>
</tr>
<tr>
<td>16 Jerseys</td>
<td>0.96</td>
<td>5.6±0.91</td>
<td>1.1</td>
<td>4.0±0.21</td>
<td>0.8</td>
</tr>
<tr>
<td>19 Others</td>
<td>0.96</td>
<td>4.5±0.93</td>
<td>1.2</td>
<td>3.3±0.75</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Figure 2. Yield and flow rate curves for all first lactation Ankeny cows (35 on High and 38 on Low grain ration)
one to conclude that rate of flow is a satisfactory measure to use in assessing the milking rate of cows. This agrees with the conclusion reached by Comberg and Zschommler (1960, 1961).

Another point of interest in this connection is the matter of estimating rate of flow in terms of peak flow. This would tell one how well the cow maintains her maximum flow rate throughout the milking process and take into account the evenness of yield and flow rate between the quarters of the udder. From the machine operator's standpoint, rate of flow also focuses attention on how well he is taking advantage of the cow's milking flow characteristics. The Ankeny Herd data have been analyzed from this standpoint by using the ratio, rate of flow / peak flow, for groups of both High and Low animals that have completed their first three lactations. These consist of 10 Highs and 15 Lows, without regard for twin pairings, since we were interested here primarily in seeing how the milking flow values change from one lactation to another on the same cows. Table 5 presents this information. The average peak flow values over the lactation were lower in both groups in the third lactation than in either the first or second. This table shows that the ratio, rate of flow / peak flow, remains quite constant from one lactation to the next and that it is quite persistent from month to month during each lactation. In all three lactations, for both ration level groups, the average ratio for the last 3 months of lactation declined less than 10 percent from that for
Table 5. The ratio, rate of flow division peak flow, by months for the first three lactations of animals in the Ankeny Twin Herd

<table>
<thead>
<tr>
<th>Ration level and lactation no.1</th>
<th>Successive observations at 4-week intervals</th>
<th>Average ratios</th>
<th>Peak Daily flow yield (lbs/(lbs))</th>
<th>Age at calving (mos.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 3 4 5 6 7 8 9 10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Highs (10)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>0.67 0.69 0.62 0.60 0.61 0.64 0.61 0.62 0.63</td>
<td>0.58 0.63</td>
<td>8.2 42.0</td>
<td>27.0</td>
</tr>
<tr>
<td>2nd</td>
<td>0.65 0.70 0.64 0.61 0.58 0.55 0.60 0.56 0.57</td>
<td>0.59 0.61</td>
<td>8.4 43.7</td>
<td>39.8</td>
</tr>
<tr>
<td>3rd</td>
<td>0.70 0.72 0.75 0.71 0.69 0.66 0.67 0.70 0.70</td>
<td>0.51 0.69</td>
<td>7.8 43.8</td>
<td>52.8</td>
</tr>
<tr>
<td><strong>Lows (15)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>0.64 0.67 0.68 0.64 0.64 0.64 0.66 0.60 0.57</td>
<td>0.64</td>
<td>6.0 30.6</td>
<td>26.5</td>
</tr>
<tr>
<td>2nd</td>
<td>0.63 0.68 0.68 0.65 0.62 0.62 0.64 0.64 0.64</td>
<td>0.60 0.64</td>
<td>6.3 37.6</td>
<td>39.2</td>
</tr>
<tr>
<td>3rd</td>
<td>0.72 0.69 0.67 0.68 0.70 0.69 0.68 0.68 0.67</td>
<td>0.69</td>
<td>5.4 37.9</td>
<td>51.2</td>
</tr>
</tbody>
</table>
the first 3 months of lactation. The comparisons also show that both peak flow and the ratio, rate of flow divided by peak flow, changed little from the first lactation to the second within each ration group, even though the Lows increased 22 percent in daily yield in the second lactations over the first.

Milking flow rates differed significantly among the breeds in the Iowa State University main herd. This agrees with the findings reported in similar studies by Beck et al. (1951), at Kansas and by Stewart et al. (1957) at Cornell University. Figure 3 shows the composite average milking flow curve for the 441 milkings observed during two 24-hour periods 5 weeks apart for all breeds in the Iowa State University herd. The average rate of flow of 3.66 pounds per minute represented by this curve can be contrasted with the average rates of flow for each breed recorded in Table 4. Analysis of variance for peak flow among and within breeds based on these data is presented in Table 6, excluding the small number of Ayrshire and Milking Shorthorn cows from this analysis.

Table 6. Analysis of variance for peak flow among and within breeds in the Iowa State University Herd (67 Holsteins, 18 Brown Swiss, 16 Jerseys, and 10 Guernseys)

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Sum of squares</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Among breeds</td>
<td>3</td>
<td>156.3</td>
<td>52.11**</td>
</tr>
<tr>
<td>Among cows within</td>
<td>107</td>
<td>294.5</td>
<td>2.75</td>
</tr>
<tr>
<td>breeds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>110</td>
<td>450.8</td>
<td>4.10</td>
</tr>
</tbody>
</table>

**Significant at 1 percent level
Figure 3. Composite average milking flow rate curve for 441 milkings of 6 dairy breeds in the Iowa State University Herd during two 24-hour periods 5 weeks apart.
ELAPSED MACHINE TIME (MINUTES)

2
3
4
5
6
7
8

PER CENT OF MILKINGS COMPLETED

0
8
32
58
80
92
97

AVERAGE RATE OF FLOW... 3.66 LBS/COW/MIN

POUNDS OF MILK PER 15 SECONDS

0
0.5
1.0
1.5
2.0

MINUTES FROM BEGINNING OF MILKING
The Brown Swiss cows showed a higher correlation between peak flow and rate of flow than the other breed groups in Table 4, milked out more slowly on the average than either the Holsteins or Jerseys, and showed larger differences among cows in both peak flow and rate of flow than any of the other groups except the Holsteins.

Dodd and Foot (1953) reported a significant negative regression of lactation solids-not-fat yield on peak flow in their studies of the Shorthorn, Guernsey, and Friesian breeds in the herd at the National Institute for Research in Dairying in England. These cows were highly variable in both lactation yield and peak flow and showed low average values for both. Since milk composition analyses were available on each of the Ankeny cows from another phase of the research, it seemed of interest to check the results here against those of Dodd and Foot, where breed differences were not taken into account. This has been done by calculating the correlation between average lactation peak flow and lactation total solids yield for first lactation cows in the High and Low ration groups, respectively. For this analysis, the totals of the 10 observations on peak flow were coded to the nearest 1 pound, and lactation yields of total solids were coded to the nearest 10 pounds for simplicity in computing. Nearly identical positive correlations of 0.47 for the 35 Highs and 0.48 for the 38 Lows were found between peak flow and lactation total solids yields, both
correlations significant at the 1 percent level. In this analysis, the yields of total solids averaged 1368 ± 50.1 pounds for the Highs and 1111 ± 33.4 pounds for the Lows. The figures here following the plus or minus signs are standard errors, a procedure which will be followed in similar presentations throughout the findings of this investigation. However, the differences in peak flow among breeds, as noted in the present study as well as in previous ones, would tend to produce a result similar to that of Dodd and Foot on an all-breed basis, particularly if percentage of total solids or solids-not-fat were used rather than total pounds.

The promptness with which a cow reaches her maximum milking flow rate after attachment of the machine has apparently not been scrutinized widely except as depicted in flow rate curves presented by various investigators. Advance preparation of the cow is a practice routinely recommended to stimulate the milk let-down response. Although, as noted in the review of literature, a number of types of stimuli have been studied, the usual stimulus is the washing and perhaps some massaging of the udder shortly before attaching the teat cups. Dodd et al. (1949) found no significant difference in milking characteristics resulting from attaching the teat cups immedi-
ately after washing the udder, as compared to delays up to 6 minutes after washing. The recorded times from udder washing to attachment of the teat cups in the Ankeny Twin Herd almost without exception are within such a 6-minute interval. The differences do not appear to exert any clear cut influence on the normal milking flow pattern of the cow. The author is of the opinion that rigid control of the time between stimulating the cow and attaching the machine needs to be imposed if one is to eliminate the biases introduced by circumstances of the milking routine and by the knowledge of a cow's milk let-down pattern which the machine operator gains within a short time after the cow enters the milking herd. It can be logically theorized, on the basis of current knowledge of the milk let-down pattern of cows, that discernible effects would result only from either no advance preparation of the cow or delays of such magnitude after preparation of the cow that would not permit the complete milk-out of high producing, slow milking cows before the hormonal effect on milk let-down had subsided. Since cows on the High ration level represent the highest yields in the Ankeny data, the extremes in times from washing the udder to attaching the machine, which occurred fortuitously, during the first lactations have been analyzed. The extreme values have arbitrarily been taken as those of less than 1 minute or more than 4 minutes. The average peak flow rates attained at milkings following each of these extreme "wash to
milk" times were compared to the average peak flow rates attained by the cows at all other observed milkings during lactation. Peak flow values so compared gave t-tests falling far short of significance. The value for t was 0.3 (11 d.f.) for differences between preparation time of less than 1 minute and time within a range of 1 to 4 minutes. The similar value for differences between preparation time of more than 4 minutes and time within the 1-4 minute range was 0.4 (25 d.f.). Thus, it seems clear that peak flow rate is insensitive to differences in "wash to milk" time of the magnitude studied here. Other characteristics of the cows milking flow pattern might exhibit differences detectable by more elegant experimental design or analysis.

The time required to reach peak flow after milking begins is a facet of the cow's milk-out pattern that seems to deserve attention. The average pattern is shown in Figure 3 for all breeds in the Iowa State University herd. The peak flow was reached at about 1 minute and 15 seconds after attaching the machine. The Ankeny milking procedure involves more massaging of the udder at the time it is washed and prepared for milking. The Ankeny cows are also fed grain when they enter the milking barn, whereas no grain is fed in the milking parlor in the University main herd milking routine. These differences in procedure may account for the shorter lag between machine attachment and the start of peak flow at Ankeny than was observed
in the University main herd. These comparisons are presented in Table 7. Large differences among cows were observed in this trait. This is shown by the large differences in average time among breeds as well as by the large standard deviations among cows within breeds. Table 7 shows that ration level exerted little effect on the average time required to reach peak flow for unpaired first lactation animals in the Ankeny Twin Herd. Figure 4 presents comparisons between the Split-Ration identical pairs, showing both the time to reach peak flow and the total machine time for the members in each ration group for each observation throughout lactation. The time required to reach peak flow is an important factor in achieving a high average rate of flow during the milking process and is not subject to the alertness of the machine operator as is the end point of the milking procedure. Table 7 shows that it required somewhat longer at Ankeny to reach peak flow at the morning milkings, following the 14-hour interval, than at the evening milkings, but the peaks at the morning milkings were higher. The Ankeny cows uniformly reached peak flow more quickly during the later months of lactation than during the earlier months. This is substantiated by Table 8, which compares by ration levels and lactation numbers the time required to reach peak flow in the second month of lactation as compared to that in the ninth month.

The high repeatability of peak flow from month to month
Table 7. The amount of time required to reach peak flow after milking machine is attached

<table>
<thead>
<tr>
<th>Herd</th>
<th>P.M. Means</th>
<th>P.M. Ind. std. deviations</th>
<th>A.M. Means</th>
<th>A.M. Ind. std. deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankeny Twin Herd</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35 Highs, 1st lact.</td>
<td>32.5 ± 4</td>
<td>22.9</td>
<td>55.6 ± 6</td>
<td>35.3</td>
</tr>
<tr>
<td>38 Lows, 1st lact.</td>
<td>33.7 ± 4</td>
<td>22.5</td>
<td>55.0 ± 5</td>
<td>28.3</td>
</tr>
<tr>
<td>28 Highs, 2nd lact.</td>
<td>30.0 ± 5</td>
<td>24.1</td>
<td>50.1 ± 5</td>
<td>26.1</td>
</tr>
<tr>
<td>31 Lows, 2nd lact.</td>
<td>34.5 ± 4</td>
<td>19.3</td>
<td>55.5 ± 7</td>
<td>37.5</td>
</tr>
<tr>
<td>13 Highs, 3rd lact.</td>
<td>29.9 ± 7</td>
<td>24.7</td>
<td>48.2 ± 8</td>
<td>29.3</td>
</tr>
<tr>
<td>18 Lows, 3rd lact.</td>
<td>47.4 ± 7</td>
<td>30.4</td>
<td>66.7 ± 8</td>
<td>34.4</td>
</tr>
<tr>
<td>University Main Herd</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>67 Holsteins</td>
<td></td>
<td></td>
<td>92.9 ± 7</td>
<td>57.8</td>
</tr>
<tr>
<td>18 Brown Swiss</td>
<td></td>
<td></td>
<td>133.3 ± 19</td>
<td>80.3</td>
</tr>
<tr>
<td>16 Jerseys</td>
<td></td>
<td></td>
<td>65.9 ± 7</td>
<td>28.1</td>
</tr>
</tbody>
</table>

during lactation and between morning and evening observations within 24-hour periods has been demonstrated by the analyses already presented. Repeatability from one lactation to another is also of interest. Table 9 presents this for the Ankeny cows that have completed their first three lactations. The intraclass correlations are 0.77 for the Highs and 0.86 for the Lows. Comparable correlations, eliminating general monthly differences, for repeatability among months are 0.81 for the Highs and 0.80 for the Lows, computed from all Ankeny first lactations.
Figure 4. Comparison of machine time and time to reach peak flow for 10 split-ration identical twin pairs in first lactations
SUCCESSIVE OBSERVATIONS AT 4-WEEK INTERVALS
Table 8. Times required to reach peak flow at milkings in the 2nd vs. 9th month of lactation in the Ankeny Twin Herd

<table>
<thead>
<tr>
<th>Lactation no. and ration level</th>
<th>Time to reach peak flow (seconds)</th>
<th>2nd month</th>
<th>9th month</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Ind.Std.Dev. Mean Ind.Std.Dev.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2nd month</td>
<td>9th month</td>
<td>2nd month</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35 Highs</td>
<td>68.8 ± 8</td>
<td>48.8</td>
<td>27.0 ± 4</td>
</tr>
<tr>
<td>38 Lows</td>
<td>65.3 ± 6</td>
<td>22.6</td>
<td>31.8 ± 5</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28 Highs</td>
<td>81.7 ± 12</td>
<td>61.0</td>
<td>11.0 ± 2</td>
</tr>
<tr>
<td>31 Lows</td>
<td>86.3 ± 11</td>
<td>60.2</td>
<td>26.9 ± 5</td>
</tr>
<tr>
<td>3 + 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 Highs</td>
<td>56.8 ± 13</td>
<td>47.4</td>
<td>24.6 ± 7</td>
</tr>
<tr>
<td>20 Lows</td>
<td>72.0 ± 17</td>
<td>74.3</td>
<td>30.0 ± 7</td>
</tr>
</tbody>
</table>

Table 9. Intraclass correlations for average peak flow of Ankeny cows over the first three lactations

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Sum of squares</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis of variance for 10 Highs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Among cows</td>
<td>9</td>
<td>69.9</td>
<td>7.77</td>
</tr>
<tr>
<td>Among lactations</td>
<td>2</td>
<td>2.7</td>
<td>1.35</td>
</tr>
<tr>
<td>Cows x lactations</td>
<td>18</td>
<td>12.4</td>
<td>0.69</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>85.0</td>
<td>2.93</td>
</tr>
<tr>
<td>$r_I(h) = 0.77$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Analysis of variance for 15 Lows |
| Among cows         | 14  | 73.0 | 5.21 |
| Among lactations   | 2   | 6.9  | 3.45 |
| Cows x lactations  | 28  | 7.2  | 0.26 |
| Total              | 44  | 87.1 | 1.98 |
| $r_{I(1)} = 0.86$  |      |      |      |
Finally, some estimates of the heritability of peak flow seem desirable. The present data, as well as the findings of other investigators cited in the review of literature, indicate conclusively that selection for peak flow could achieve a high rate of flow per unit of machine time. Previous estimates of the heritability of peak flow range from $h^2 = 0.54$ on one group of animals studied by Politiek (1961) to $h^2 = 0.85$ obtained by Donald (1960) from paired twin and single-born cattle. Since the number of first lactation fraternal pairs included in the Ankeny data was small, particularly in the High group, estimates have been made from the intraclass correlations on the identical pairs only. Analysis of variance among and within pairs for each of these estimates is presented for High pairs in Table 10, for Low pairs in Table 11, and for Split-Ration pairs in Table 12. These estimates range from $h^2 = 0.58$ based on Low pairs to $h^2 = 0.978$ based on High pairs. The within-pair variance is least for the Highs and most for the Lows. The 10 Split-Ration pairs give an intermediate value of $h^2 = 0.89$, and the within-pair variance in peak flow is also intermediate to the High and Low uniform ration sets.

In all of the computations made in this study where milk yields were involved, those yields were the ones obtained at the particular times that milking flow rate observations were made. Since 305-day lactation yields for all the Ankeny animals are routinely calculated from daily milk weights, it may better
Table 10. Intraclass correlation for peak flow of identical twin pairs in first lactation on high ration

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Sum of squares</th>
<th>Mean squares</th>
<th>Expected mean squares</th>
<th>Variance components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Among pairs</td>
<td>4</td>
<td>122.9</td>
<td>30.72</td>
<td>$V_B + 2V_A$</td>
<td>15.02</td>
</tr>
<tr>
<td>Within pairs</td>
<td>5</td>
<td>3.4</td>
<td>0.68</td>
<td>$V_B$</td>
<td>0.68</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>126.3</td>
<td>14.04</td>
<td></td>
<td>15.70</td>
</tr>
</tbody>
</table>

Intraclass correlation $r_I(h) = \frac{30.72 - 0.68}{30.72 + 0.68} = 0.978$

Table 11. Intraclass correlation for peak flow of identical twin pairs in first lactation on low ration

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Sum of squares</th>
<th>Mean squares</th>
<th>Expected mean squares</th>
<th>Variance components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Among pairs</td>
<td>4</td>
<td>59.7</td>
<td>14.94</td>
<td>$V_B + 2V_A$</td>
<td>5.46</td>
</tr>
<tr>
<td>Within pairs</td>
<td>5</td>
<td>20.1</td>
<td>4.01</td>
<td>$V_B$</td>
<td>4.01</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>79.8</td>
<td>8.87</td>
<td></td>
<td>9.47</td>
</tr>
</tbody>
</table>

Intraclass correlation $r_I(1) = \frac{14.94 - 4.01}{14.94 + 4.01} = 0.58$
Table 12. Intraclass correlation for peak flow of identical twin pairs in first lactation on split rations

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Sum of squares</th>
<th>Mean squares</th>
<th>Expected mean squares</th>
<th>Variance components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Among pairs</td>
<td>9</td>
<td>47.7</td>
<td>5.30</td>
<td>$V_E + V_{PR} + 2V_A$</td>
<td>2.49</td>
</tr>
<tr>
<td>Between rations</td>
<td>1</td>
<td>2.9</td>
<td>2.90</td>
<td>$V_E + V_{PR} + 10V_R$</td>
<td>0.16</td>
</tr>
<tr>
<td>Pairs x rations</td>
<td>9</td>
<td>2.9</td>
<td>0.32</td>
<td>$V_E + V_{PR}$</td>
<td>0.32</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>53.5</td>
<td>2.82</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Intraclass correlation $r_I(S) = \frac{5.30 - 0.32}{5.30 + 0.32} = 0.89$
orient the reader as to the levels of production with which this research has been concerned to supply the summary in Table 13.

Table 13. Production means in the Ankeny Twin Herd

<table>
<thead>
<tr>
<th>Lactation no. and ration level</th>
<th>Age at calving (mos.)</th>
<th>Actual 305-day milk yield (lbs)</th>
<th>Actual 305-day total solids yield (lbs)</th>
<th>Peak flow (lbs/min)</th>
<th>Rate of flow (lbs/min)</th>
<th>Milking time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35 Highs</td>
<td>26.3</td>
<td>11,041</td>
<td>1,368</td>
<td>7.14</td>
<td>4.73</td>
</tr>
<tr>
<td></td>
<td>38 Lows</td>
<td>26.8</td>
<td>9,067</td>
<td>1,111</td>
<td>6.12</td>
<td>4.09</td>
</tr>
<tr>
<td>2</td>
<td>28 Highs</td>
<td>39.3</td>
<td>11,304</td>
<td>1,391</td>
<td>7.35</td>
<td>4.62</td>
</tr>
<tr>
<td></td>
<td>31 Lows</td>
<td>39.2</td>
<td>10,002</td>
<td>1,220</td>
<td>6.26</td>
<td>4.04</td>
</tr>
<tr>
<td>3</td>
<td>13 Highs</td>
<td>52.8</td>
<td>12,758</td>
<td>1,542</td>
<td>7.85</td>
<td>5.24</td>
</tr>
<tr>
<td></td>
<td>18 Lows</td>
<td>51.3</td>
<td>11,149</td>
<td>1,346</td>
<td>5.70</td>
<td>3.66</td>
</tr>
</tbody>
</table>
V. DISCUSSION

Much of the investigation of milking flow characteristics in recent years has been carried out by European research workers, particularly in the Netherlands, the Scandinavian countries and Germany. None of the previous studies have dealt with animals having as high production levels as either the Ankeny High group or the Iowa State University herd of cows. Likewise, no previous study reviewed by the author has specifically defined feeding levels or attempted to segregate the animals on this basis as has been done in this study with the Ankeny Twins. Both peak flow and rate of flow values obtained in the present study have been markedly higher than those found in previous studies, except for those of Beck et al. (1951) at Kansas and Stewart et al. (1957) at Cornell University. Observations of both evening and morning milkings and greater frequency of observations throughout lactation have likewise characterized the greater detail of the present study as compared to most other work on similar numbers of animals.

The peak flow rate of liberally fed first lactation animals, as represented by the Highs at Ankeny, shows a tendency to increase as lactation progresses, whereas that of the Lows appears to follow more closely the decline in production, but not so rapidly, percentagewise. The Highs thus exhibit a pattern similar to that observed by Gregoire et al. (1954) at the
Connecticut station. Our data on total milking time generally agree with the observation of Harshbarger (1950) at Illinois in that the higher producing cows do not require a proportionally longer milking time than the lower producing ones. On the basis of extensive studies, Johansson (1961) states that high yielding cows tend to decline more in rate of flow during the course of lactation than do low yielding ones. Dodd (1953) reached the same conclusion. The present study does not lend support to this view. Both the characteristic milking flow pattern of the cow in early lactation and the feeding level employed to maintain maximum yield through lactation would strongly affect the validity of any observations in the above regard. Whittleston's (1946) observation that milking time did not decrease appreciably with the decline in production during lactation is not generally supported by the present study. His observation that the milk let-down response tends to become delayed and erratic toward the end of lactation is likewise not substantiated in our data. Except for individual variations, the Ankeny cows uniformly reach their peak flow sooner after machine attachment in the last half of lactation than in the first half. This trend is shown in Table 8. The data here support the view that peak flow capability is an individual cow characteristic, but that whatever factors affect maintenance of yield through lactation also affect peak flow, but less strongly, percentagewise. The ration effect on the Split-Ration
identical twin pairs provides good evidence for this viewpoint, since peak flow at the beginning of lactation was the same for pair mates on each ration, but for the Lows tended to follow more closely the decline in yield as lactation advanced. It can further be observed from Figure 1 that the High ration members have a higher peak flow at a given production level in advanced lactation than their Low ration mates had when at the same production level at an earlier stage of lactation. Hence, the use of adjustment factors for peak flow values according to level of yield, as suggested by Sandvik (1957) for yields per milking outside the range of 6.1 to 7.0 kg., seems unjustified on the basis of the present study.

The close correlation between peak flow and rate of flow found in this study agrees with the findings of previous investigators. Rate of flow appears to make up a quite constant percentage of peak flow, regardless of stage of lactation or ration level, under the conditions of the present study. Table 5 shows that, with few exceptions, this percentage falls within the range of 60 to 70 during all stages of the first three lactations for both High and Low ration animals.

Evenness of yield between quarters of the udder has not been investigated in this study. Larsen et al. (1960) and Horn et al. (1961) noted that the Jersey breed exhibits superiority over other breeds in this respect. Without specific measurements, uneven yields or milking rates among quarters of the
udder would be reflected under the measurement procedures of the present study by wider differences between peak flow and rate of flow. On the basis of this criterion, the cows in the University main herd appear to be somewhat superior to those in the Ankeny Twin herd, but no marked breed differences are apparent. Differences in milking technique between the two herds cannot, however, be ruled out as the major cause of the difference between the two herds.

Venge (1961) and Comberg and Zschommler (1960, 1961) suggest early mid-lactation as about the optimum time to measure milking flow characteristics of cows, if such measurement needs to be limited to a single observation. The present data indicate that choice of a single stage of lactation is not very critical in detecting such differences among cows. One way of deriving an answer to this question is to compute the correlation between single observations and the average of all observations made over the lactation to ascertain which single observation is most closely correlated with the cow's lactation average peak flow. It is assumed that one wishes to measure the cow's genetic capability for peak flow, but is cognizant of some inhibition of the expression of the trait by environmental factors. While the 1:1 balance of environments provided for genetically identical animals, as represented in the Split-Ration identical pairs in this study, would not likely be realized under random field studies, these pairs seem to provide data for a useful approximation. Correlations were computed
between the average peak flow values of the High and Low member of a set for each month and the lactation peak flow average of the High member. These correlations for the first through the tenth month, respectively, were as follows: 0.86, 0.91, 0.92, 0.95, 0.93, 0.97, 0.93, 0.91, 0.89, and 0.92. These figures do not conflict with the suggestion of Venge and of Comberg and Zschommler, but at the same time do not give a very clear cut advantage to one stage of lactation over another for measuring the cow's peak flow. Except for perhaps the first month, any single month in lactation would appear to give a reasonably reliable estimate of lactation peak flow capability.

Large scale field studies on rate of flow and evenness of quarter yields, as currently being carried out by Politiek (1961) and others in The Netherlands and in Germany would seem to be a useful extension of the present study. The heritability and repeatability estimates obtained in this study are essentially in agreement with those reported by other workers. Since these estimates are high, and since high milking flow rate is important to the commercial dairyman, effective screening of daughters of bulls to be heavily used in artificial breeding units could be done with limited numbers of observations per cow to improve milking flow characteristics in the general cow population.
VI. SUMMARY

Milking flow characteristics were studied at 3270 experimental milkings throughout 166 lactations of 82 different Holstein cows in the Ankeny Twin Herd maintained by Iowa State University. These included first, second, third, and fourth lactations. Similar characteristics were studied at 441 experimental milkings taken at two 24-hour periods 5 weeks apart on cows of all breeds in different stages of lactation in the Iowa State University main herd.

The measures primarily investigated were peak flow, rate of flow, total machine time, and time required to reach peak flow. The relationships of these with yield, time of milking, stage of lactation, lactation number, and environment were studied.

Two different ration energy levels, designated as High and Low, were employed in the Ankeny Twin Herd to represent environmental differences. The High ration improved average rate of flow during the lactation by about 8 percent over the Low ration.

Large differences existed among cows in all the milking flow characteristics. Both peak flow and rate of flow were much more constant through lactation than was yield. Peak flow and rate of flow were closely correlated, 0.92 or higher for all groups of cows studied. Rate of flow made up a rather constant percentage of peak flow from month to month and from one
lactation to another, falling generally within a range of 60 to 70 percent. Maintenance of the cow's maximum yield capability through lactation appeared to be conducive to maximum lactation peak flow, but persistency of yield as generally defined showed an insignificant or a negative correlation with peak flow.

Highly significant differences among breeds were found for peak flow. Holsteins showed the highest peak flow values, with Jerseys ranking second.

The milking flow pattern, as measured by the time required to reach peak flow during milking, was highly variable among cows. Peak flow was reached more quickly during the last half of the lactation than during the first half. In the later stages of lactation, the peak flow frequently began immediately after attachment of the machine, whereas in early lactation several minutes frequently elapsed before peak flow was reached, particularly in the case of individual cows.

No evidence was found of antagonism between high total solids yields and maximum milking flow rate.

Differences in the elapsed time between preparation of the cow for milking and the attaching of the machine showed no significant effect on peak flow.

The repeatability of peak flow from one lactation to another was high, 0.77 for the Highs and 0.86 for the Lows in
the Ankeny data. On the basis of limited numbers of identical twin pairs, heritability of peak flow was high, especially for the High ration pairs.

All the data support the conclusion that the characteristics of milking flow among cows can be satisfactorily assessed from either peak flow or rate of flow measurements, taken at one or more milkings any time after the cow first becomes accustomed to the milking routine.
VII. LITERATURE CITED


Oliver, J., F. H. Dodd, and F. K. Neave. 1956b. Udder infections in the "dry period". IV. The relationship between new infection rate in the early dry period and the daily milk yield at drying-off when lactation was ended by either intermittent or abrupt cessation of milking. Journal of Dairy Research 23: 204-211.


VIII. ACKNOWLEDGMENTS

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