PELVIC DIMENSIONS AND GROWTH TRAITS OF YEARLING BEEF BULLS AS PREDICTORS OF DYSTOCIA IN PROGENY.

A Thesis

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PELVIC DIMENSIONS AND GROWTH TRAITS OF YEARLING BEEF BULLS AS PREDICTORS OF DYSTOCIA IN PROGENY

BY

DOUGLAS INDETIE

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

ABSTRACT

Internal pelvic area measurements and other growth attributes were obtained from 3291 yearling bulls from three bull test stations in the province of Manitoba for the years beginning test 1988 to 1991. The data comprised of 12 breeds, namely, Angus, Blonde d'Aquitaine, Charolais, Gelbvieh, Hereford, Limousin, Maine Anjou, Pinzgauer, Salers, Simmental, Shorthorn and Tarantaise. For analysis purposes these were grouped into three breed groups according to measured growth. Data were analyzed using general linear models which included the fixed effects of station, year of test, breed group and their two way interactions using age at end of test as the covariate. Bull pelvic areas were positively associated with birth weight (0.04, $P < 0.05$), start of test weight (0.26, $P < 0.01$), gain on test (0.18, $P < 0.01$) and end of test weight (0.31, $P < 0.01$). Backfat thickness was negatively associated with pelvic area (-0.05, $P < 0.05$). Only 934 of these bulls had a recording of their own calving ease, of which 13% were born with assistance. Of these animals 907 had a recording of expected progeny differences (EPD's) for calving ease and maternal calving ease. Pelvic measures were not significantly ($P > 0.05$) associated with EPD's for direct and maternal calving ease. A further subset of data was extracted from those bulls which had progeny records. Thirty seven bulls had 520 progeny which had a record of their calving ease and there was a significant ($P < 0.001$) relationship between bulls and progeny calving ease. Bulls that were born unassisted had 89% of their progeny born without assistance. Bulls born with an easy pull had 74% of their calves born unassisted and those born with hard pulls had 50% of their calves requiring assistance during parturition. Pelvic measures of bulls did

not show any significant relationship with the calving ease of their progeny. These results indicate that bull pelvic measures are not good predictors of ease of calving. However, the ease of calving of a bull could give an indication of the calving difficulty to be expected among his progeny.

DEDICATION

I would like to dedicate this thesis to my Parents, brothers, sisters and my wife Ann whose prayers and support have been inspiring during this study.

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LIST OF ABBREVIATIONS.

ACCCE = Accuracy of EPDCE (%).

ACCMCE = Accuracy of EPDMCE (%).

ACCWG = Accuracy of EPDWG (%).

ACCMWG = Accuracy of EPDMWG (%).

ACCYG = Accuracy of EPDYG (%).

Agedel = Age of bull at time of delivery (d).

Ageeot = Age of bull at the end of test (d).

Agepe = Age at time of pelvic area measurement (d).

Agesot = Age of bull at the Start of test (d).

BF = Backfat thickness (cm^2).

BG = Breed groups.

Bwt = birth weight (kg).

Breeds:

AN=Angus CH=Charolais HE=Hereford SM=Simmental MA=Maine Anjou LM=Limousin SS=Shorthorn GV=Gelbvieh BD=Blonde d'Acquitaine SA=Salers TA=Tarantaise PZ=Pinzgauer

Delwt = Delivery weight (kg).

EPDCE = Expected progeny differences for calving ease (score points).

EPDMCE = Expected progeny differences for maternal calving ease (score points).

EPDWG = Expected progeny differences for weaning gain (kg).

EPDMWG = Expected progeny differences for maternal weaning gain (kg).

EPDYG = Expected progeny differences for yearling gain (kg).

Ewt = Weight at end of test (kg).

Pelhgt = Pelvic height (cm).

Pelwdt = Pelvic width (cm).

Parea = Pelvic area (cm^2).

RCE = Ease of calving.

Swt = Start of test weight (kg).

Tgain = Gain on test (kg d^{-1}).

TDN = Total digestible nutrients (%)

INTRODUCTION

Dystocia, which may be described as delayed and/or difficult parturition, is of great concern to beef cattle producers because it results in calf and/or cow losses, increased labour and veterinary costs, reduced reproductive potential of cows and reduced growth rate of calves (Laster et al. 1973; Wolverton et al. 1990b).

Calving ease is a very complex trait involving a number of factors. A major factor is the relative sizes of dam and calf at birth (Monteiro 1969). This is referred to as feto-maternal disproportion. One aspect of the size of dam is the size of the birth canal as measured by internal pelvic measurements. This is considered by some researchers an important factor in determining the ease with which calves are born, but other studies have not confirmed this finding.

Pelvic area measurements have a heritability of 0.68 (Morisson et al. 1986), indicating that pelvic area is a highly heritable trait and should respond to selection. Bull pelvic area has a positive genetic correlation of 0.60 with female pelvic measurements (Deutscher 1988b) and because male selection has a major influence on the herd, the identification and selection of bulls with large pelvic size should alter daughters' pelvic dimensions, and, according to some researchers (e.g. Duetscher 1988b) should reduce the incidence of dystocia.

Beef sires in Canada are presently evaluated for calving ease. Sires with a high expected progeny difference (EPD) for direct calving ease are expected to produce progeny that are born easily while sires with a high EPD for maternal calving ease are expected to have daughters that calve easily. If sire EPD's for maternal calving ease have a favourable association with pelvic dimensions of bulls then measurements of these dimensions of yearling bulls in test stations may identify bulls that have a reduced incidence of calving problems in their daughters.

Genetic evaluation of beef sires has been done for a number of years in Canada with information published in sire summary lists containing EPD's for many characteristics. This allows selection of individual sires based on EPD's for dystocia-related characteristics, such as calf birth weight, calving ease (direct and maternal) and gestation length. The understanding of how these EPD's are associated with pelvic dimension and growth traits is important in selection of bulls when designing breeding programmes that would minimise dystocia.

The objective of this study was therefore to determine if any association exists between growth traits and pelvic dimensions with direct and maternal calving ease EPD's. If pelvic area plays a role in determining ease of calving then we should expect sires with high EPD's for maternal calving ease to have larger pelvic measurements. A second objective was to determine whether the bull's own ease of calving and measures of body size could be useful predictors of calving ease of their progeny.

REVIEW OF LITERATURE

The process of parturition

Parturition or labour may be defined as the physiological process by which the pregnant uterus delivers the fetus and placenta from the maternal organism. It is normally triggered by the fetus and is completed by a complex interaction of endocrine, neural and mechanical factors (Hafez 1987).

Successful parturition depends upon two mechanical processes: The ability of the uterus to contract and the capacity of the cervix to dilate sufficiently to enable the passage of the fetus. This process may be divided into three stages, referred to as the stages of labour. Stage one: At this stage, preparation of the birth canal and the fetus occurs in readiness for expulsion. It involves dilation of the cervix and onset of myometrial contraction which is regulated by uterine volume through the alteration of myo-electrical activity (Gluckman and Liggins 1984). The fetus assumes the disposition for expulsion by extension of extremities and rotation about its' longitudinal axis (Csapo et al. 1963). For a normal birth in cattle, this stage should last 2-6 h. Stage two: This involves the expulsion of the fetus. It begins with abdominal contractions, then the fetal shoulders and later the hips engage the pelvis causing distension of the maternal birth canal resulting in the release of oxytocin from the posterior pituitary which in turn accentuates myometrial contraction. This consists of combined uterine and abdominal expulsive efforts which results in the delivery of the fetus. This is a very crucial stage and lasts for 0.5-1 h in cattle and any delays may cause suffocation or irreversible damage to the neonate. Stage three: Abdominal contractions cease but myometrial contraction continue with decreased amplitude causing rupture and expulsion of the fetal membranes. This stage may last for up to six hours in cattle.

If for any reason any of these stages lasts longer than normal or is not carried out to completion therefore necessitating the need for assistance then a problem of calving ease is said to occur.

Incidence of dystocia.

Dystocia, which may be defined as delayed and/or difficult calving has been of great concern to beef cattle producers. Calving difficulty took a new dimension in the 1960's in North America following the introduction of the exotic large European breeds. Because of their genetic potential for rapid growth, these breeds produced progeny with birth weights exceeding those of the British breeds to which the beef industry was accustomed (Fredeen et al. 1982; Rahnefeld et al. 1990).

Calf deaths at or shortly after calving result in the loss of over 3.5 million calves annually in the United States of America. Approximately 45% of these losses are caused by dystocia, accounting for an estimated $ 380 million shortfall due to this single factor (Bellows 1989). In addition to these direct losses there are indirect losses due to reduced vitality and depressed breeding potential if the incident of dystocia is not fatal to both the cow and/or its calf.

This problem has further been aggravated in the beef cattle industry by the increased emphasis on rapid growth rates, increased yearling weights and improved production efficiency. As producers select for improved growth rates, larger calves can be expected at birth due to correlated response thus resulting in more calving difficulty (Deutscher 1989; Bellows 1989).

Poor performing or debilitated calves, reduced numbers of calves at weaning, labour costs, cow deaths and impaired reproductive potential are the major economic losses in herds with a high incidence of dystocia (Laster et al. 1973; Brinks et al. 1973; Berg 1979). Heifers calving without difficulty weaned 70% of their calves as compared with 59% for those experiencing difficulty. In addition, during subsequent pregnancies heifers that had experienced dystocia weaned 14% less calves which were 21 kgs lighter than their contemporaries. Of the calves that died at or near birth, 57% of them were due to delayed or difficult parturition (Price and Wiltbank 1978b; Bellows 1968; Deutscher 1989). Studies in Nebraska showed that average calf losses of 4% were observed in unassisted cows within 24 hours of birth as compared to 16% for those animals experiencing dystocia (Laster et al. 1973).

Factors influencing dystocia

Dystocia may arise from a number of causes (Figure 1). Many interrelated factors are associated with calving difficulty, thus making research and methods of reducing this problem complicated. These factors may broadly be divided into two: Those of fetal origin and those of maternal origin. Further, the factors may be categorised as being caused either by genetics or the environment. Some of the most important factors include size and weight of calf (an indication of calf genotype), pelvic

- Dystocia
  - Maternal
    - Forces
      - Uterine inertia
      - Myometrial defect
      - (Intrinsic weakness)
      - Hormone deficiency
    - Birth canal
      - Inadequate pelvis
        - Immaturity
        - Breed
        - Development
      - Insufficient dilation
        - Uterus torsion
        - Cervical fibrosis
        - Vaginal stenosis
  - Fetal
    - Fetus
    - Heredity
    - Prolonged gestation
    - Disposition

Figure 1. Factors causing dystocia in beef cattle
Adapted from Geoffery et al. (1982).

size of dam, age and parity of dam, sex of calf, gestation length, abnormal fetal presentation, body condition of dam and sire of calf amongst others.

The obstruction of calf expulsion due to the relative or absolute size of the calf in relation to the pelvic dimensions of the dam is regarded as one of the most important causes of dystocia particularly in heifers calving at two years of age (Sloss and Johnston 1967; Price and Wiltbank 1978a; Meijering 1984). This obstruction, regularly referred to as fetomaternal disproportion (or incompatibility) shall form the main basis of this thesis. In the case of dystocia due to disproportion, the important variables are fetal dimensions and the capacity of the maternal pelvis. No single fetal body measurement is as useful a criterion of estimating fetal size as body weight (Monteiro 1969). Pelvic size is obtained by measuring the internal height and width of the pelvis and their product is known as the pelvic area. The combination of calf birth weight and pre-calving (three weeks before parturition) pelvic area has been shown to account for up to 45% of the variation in calving difficulty (Johnson et al. 1988). Calf birth weight accounted for 33% of the variation while the maternal precalving pelvic area accounted for 12%. This would therefore suggest that internal pelvic area may play a potentially valuable role in selecting animals with a reduced susceptibility to dystocia. Deutscher (1989) suggested that traits known before calving accounted for 26% of the variation in dystocia and traits known after calving increased this percentage to 39% only. As calf birth weight increases, the percentage of dystocia also increases (Burfening et al. 1978a; Dufour et al., 1981; Nelson and Beavers 1982) and conversely as pelvic area increases there is a corresponding decrease in the incidence of dystocia. Thus a three-dimensional relationship exists between calf birth weight, pelvic area of dam and dystocia (Thompson and Wiltbank 1983).

If frequency of dystocia is connected to the relative dimensions of the dam and calf, then for purebred animals, the increase (or decrease) in the size of the dam should be accompanied by a proportional increase (or decrease) in the size of the fetus, which would result in similar frequencies of dystocia in breeds of different body size (Monteiro 1969). However, this does not seem to be the situation and the incompatibility may therefore be explained by either a breed difference in the physiology of delivery or a disproportionate increase in the size of the fetus as compared to that of the dam.

Monteiro (1969) postulated that for each breed of dam there is a clear relationship between the size of the calf and the frequency of dystocia as would be demonstrated by calves of the same size having different frequencies of dystocia. This would then lead to the hypothesis that the relative size of both the dam and calf are important in determining the frequencies of dystocia rather than the absolute size of the calf alone. Bellows et al. (1971) reported that large animals give birth to larger calves due to some component of maternal environment, but can also experience more dystocia. Therefore large animals with below optimum pelvic size should be culled due to the increased likelihood of having dystocia (Deutscher 1988a).

Posterior or abnormal presentation of the calf, though accounting for only 2-6% of all calvings (Price and Wiltbank 1978b; Philipsson 1976a) are responsible for 20-40% of the dystocia cases recorded. This form of dystocia is more prevalent in older cows as compared to feto-maternal incompatibility which is more frequent in heifers (Phillipson

1976a).

Weak labour can be the cause as well as the consequence of difficult calving. Primary weak labour is reported to be most frequent in older cows and is often associated with milk fever (Sloss 1970). This could be due to inadequate myometrial or abdominal contraction due to insufficient hormone levels (Erb et al. 1981). This could likewise lead to insufficient dilation of the cervix and uterine torsion during parturition resulting in severe dystocia (Osinga 1978; Musah et al. 1986). Low levels of circulating estrogens have been associated with fetal genotypes experiencing dystocia (Osinga 1978), and intracervical administration of relaxin during late pregnancy induced marked increase in cervical dilation and expansion of the pelvic area in all frame sizes of beef cattle (Musah et al. 1986). This increase in pelvic area resulted from linear increases in both pelvic height and pelvic width.

Phenotypic effects of size and shape of the calf

The two main types of fetal dystocia are fetal oversize and faulty disposition (Geoffery et al. 1982). Inadequacies in maternal pelvis will be considered with fetal oversize and this will be termed as fetomaternal disproportion. The delivery process of a dam with an unusually small pelvis and a normal size calf (relative fetal oversize) is no different from that of a normal cow with an excessively large calf (absolute fetal oversize). If the incidence of dystocia is associated with the size of the calf relative to the dam, then in purebred animals it would be expected that an increase in the size of the dam should be accompanied by a proportional increase in the size of the fetus, which would result in similar frequencies of calving difficulty in breeds with different body sizes. However, this is not the case, and the incompatibility must be explained by a breed difference in the physiology of delivery or a disproportionate increase in the size of the fetus relative to that of the dam (Monteiro 1969).

The phenomenon of incompatibility has been shown to be more prevalent in heifers calving at two years of age, but it is also an important cause of dystocia in older cows. Calf size is commonly recorded as birth weight and whenever it is examined in relation to dystocia, it appears to be significant both in cows and heifers (Laster and Gregory 1973; Notter et al. 1978). The effects of birth weight has to be evaluated within parity groups, as parity affects birth weights and dystocia levels inversely i.e. heifers often give birth to calves with lower birth weights than older cows but exhibit higher levels of dystocia and stillbirths (Phillipson 1976b; Burfening et al. 1978b).

The relationship between birth weight and the incidence of dystocia was found to be non-linear (Phillipson 1976c), the frequency of dystocia rising sharply when birth weight exceeds a certain threshold value (Notter et al. 1978; Short et al. 1979). However, Deutscher (1988a) observed that yearling heifers with below average pelvic area (less than 140 cm^2) had twice as much dystocia as compared to animals with larger pelvic areas (49% vs 24% respectively). The factors determining the position of the threshold were breed and parity or age of the animal. This contrasts with Monteiro (1969) who found a linear relationship when birth weight was considered alone, but he indicated that this was only true when these values were considered over a limited range. Other studies by Notter et al. (1978) showed that there was an increase in stillbirth incidence when birth weight dropped below a certain minimum value, which indicates that an optimum birth weight range is necessary for calf viability.

There is a relationship between birth weight and mature size of a breed, and between birth weight of calf and the frequency of dystocia as reported in several studies. The calf weight at birth represents on average, 7.2% of the dam's weight (Geoffery et al. 1982) but there are differences between breeds. The Jersey has a proportion which is distinctly lower (5.6%) while for the Charolais it is 8.9% (Hansen 1966). In light of this finding, Monteiro (1969) noted that calf birth weight in relation to dam weight should not exceed 7% if levels of dystocia are to be kept constant or reduced. In such cases then the use of small sires for heifers would be a reasonable consideration. If birth weight is proportional to dam's weight, this does not follow for pelvic dimensions and that is why probably there is increased incidence of dystocia with increased size of cows (Laster 1974). Also a low phenotypic relationship of $r=0.07$ has been found between a heifer's pelvic area and the birth weight of her calf (Johnson and Deutscher 1986), thus selecting heifers with a large pelvic size should not lead to increased birth weight resulting in increased risk of dystocia. However pelvic area is positively associated to body weight and therefore selection for pelvic area results in higher post-natal weights through correlated response (Benyshek and Little 1982).

The use of birth weight as an indicator for size appears to be most practical, but when we consider fetopelvic disproportion then other factors such as calf dimensions due to skeletal size and muscularity are important. Arthur et al. (1988) reported that there was a higher incidence of dystocia in cows with muscular hypertrophy (a heritable muscle disorder) as compared to normal cows due to a constricted birth canal, 19% verses 6% respectively.

Brown et al. (1982) and Johnson et al. (1988) found no significant relationship between external body measurement of dam (width of hooks, length of rump etc.) and the birth weight of the calf to be born, nor was there any relationship with pelvic area of the dam. They were therefore considered poor predictors of calf birth weight or pelvic dimensions and could therefore not give any indication of the calving difficulty to be expected.

Phenotypic observation of dystocia and stillbirth implies discontinuous variation while quantitative inheritance is assumed due to an unobservable underlying continuous variable (known as the liability) which is normally distributed and has a threshold which imposes a discontinuity in the phenotypic expression (Auran 1972; Falconer 1989). Both the consideration of dystocia as a categorical trait and the non-linear relationship with calving traits may contribute to the underestimation of the true phenotypic correlations of dystocia and stillbirth with birth weight, and heritabilities of these traits (Meijering 1984). Therefore transformation of the observable categories is necessary to determine the true genetic parameters. However, studies by Vinson et al. (1976) and Gianola (1982) suggest that genetic correlation coefficients involving categorical traits are unbiased and do not need any transformation.

Correlation estimates of birth weight with dystocia score are commonly found in the range of r=0.3-0.4 (Rice and Wiltbank 1970; Burfening et al. 1978b) and corresponding estimates for stillbirth occurrence are between r=0.06-0.23 (Phillipson

1976d). When these correlations are corrected for the discontinuity then the associations indicate that birth weight accounts for about 50% of phenotypic variance in dystocia and 20% of the variance in stillbirth liabilities (Meijering 1984).

When birth weight is kept constant, correlations involving calf dimensions are severely reduced and are generally non-significant with regards to dystocia and stillbirth (Laster, 1974). This would indicate that most of the variance in the incidence of dystocia associated with calf dimensions is accounted for by birth weight alone.

Considering the importance of calf birth weight and its effects on dystocia, it is possible that calving ease problems can be drastically reduced if genotype of calf can be determined with some degree of accuracy before breeding heifers. One way this can be achieved is by choosing sires with high EPD's for calving ease for mating to heifers.

Phenotypic effects of size and shape of dam.

It would be desirable to measure the dimensions of the birth canal at the time of fetal expulsion. However, this is not practical and therefore measurements are normally taken prebreeding (13 months of age in both heifers and yearling bulls), when selection of replacement animals is taking place, or precalving (three weeks before parturition) in pregnant heifers. These two (prebreeding and precalving pelvic areas) have been shown to have a high correlations of 0.70 to 0.75 and therefore prebreeding pelvic area could be used as an indicator of precalving pelvic dimension and therefore used to identify potential difficult calvers to be bred to low risk bulls or culled altogether (Johnson et al. 1988; Deutscher 1988a).

Internal pelvic width and height are measured by inserting in the rectum of a live animal, either the Rice (Lane manufacturing™) or the Krautmann (Ed Krautmann™) pelvimeter. The pelvic width is the widest horizontal distance between the shafts of the ilia, while the height is the narrowest point between the pubic symphysis and the sacral vertebrae (Figure 2). The pelvic area is obtained by multiplying width and height values. These measurements have been shown to have a high accuracy and repeatability ranging from 0.87 to 0.95 among experienced technicians (Short et al. 1979; Deutscher 1989; Wolverton et al. 1990a). To reduce variation between instrument or between technician, the same instrument should be used by the same technician when measuring the same group of animals (Siemens et al. 1991).

In general heifer weight and age have a linear positive relationship to pelvic area and are often used as adjustment coefficients for environmental effects whenever animals of different weights and ages are being compared (Deutscher 1988b; Wolverton et al. 1990b; Siemens et al. 1991). Other studies show that pelvic area growth is linear from 9 to 24 months of age in heifers and bulls, the average rate of growth being 0.25 cm^2 per day. It then continues at a slower rate until the animal reaches maturity (Deutscher 1988a; Rahnefeld et al. 1990). Similarly, pelvic area growth has been shown to be related to increase in body weight, the rate being about 0.15 cm^2 kg^{-1} (Siemens et al. 1991) and may be used as an adjustment factor for pelvic area when considering animals of different weights. However these two important environmental factors influencing pelvic area growth should not be used simultaneously for adjustment otherwise this would lead to overcorrection (Wolverton et al. 1990b; Siemens et al. 1991).

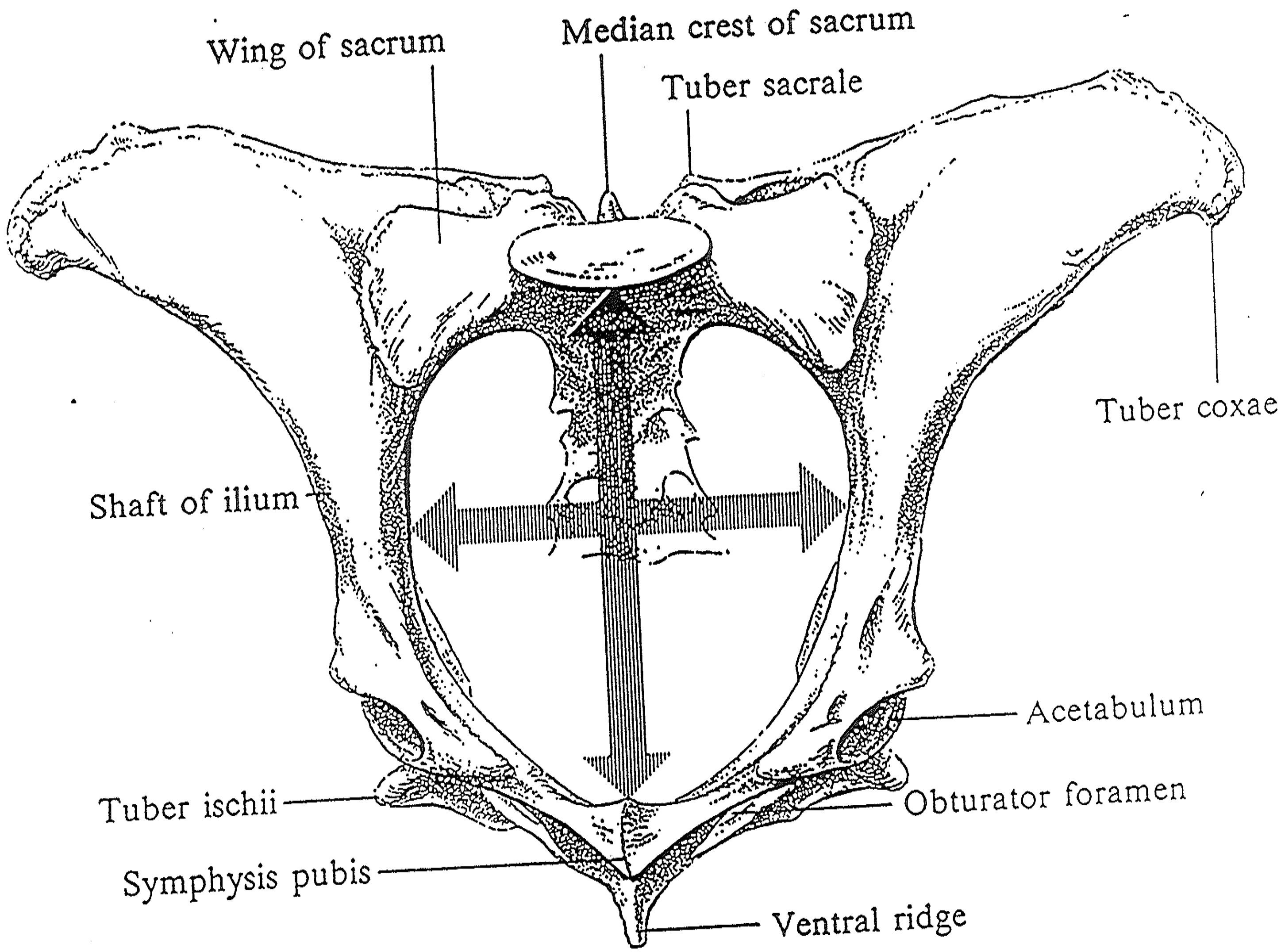

Figure 2. A representation of the pelvis of cattle (Geoffery et al. 1982)

These measurements may be slightly inaccurate due to the effect of hormones which cause expansion of pelvic dimensions during the process of parturition (Erb et al. 1981; Musah et al. 1986). This expansion at parturition is a result of relaxation of the sacroiliac ligaments (Rice and Wiltbank 1972), formation of interpubic ligaments (Leitch et al. 1959), and modification of the pubic symphysis by the transformation of symphysial cartilage and bone. The ratio of the birth weight of calf to that of the dam (Fetal/Maternal ratio (F/M)) seems to be a major factor in determining whether or not an animal experiences relaxation of the pelvic ligaments with the formation of interpubic ligaments (Leitch et al. 1959).

It has been reported that species with an F/M ratio greater than 5%, such as the guinea pig, show marked prepartum separation of the pubic symphysis. Musah et al.(1986) found an F/M ratio of 11% in all frame sizes of beef heifers indicating that beef cattle also undergo considerable separation of the pubic symphysis. These facts would show that fetomaternal disproportion is not only a physical phenomenon but is also mediated by physiological and endocrine mechanisms. Nevertheless pelvic dimensions taken prebreeding or precalving have still been shown to be related to dystocia by several authors (Phillipson 1976d; Wolverton et al. 1990b).

Correlation between dystocia score and pelvic dimensions in heifers have been shown to be negative, ranging from $r=-0.1$ to $r=-0.45$ (Rice and Wiltbank 1972; Price and Wiltbank 1978a). These associations would indicate that about 10% of the phenotypic variance in dystocia score would be associated with variation in pelvic size. However, these associations may be underestimated considering that this trait is categorical in nature as noted earlier.

Most studies on external body measurements have shown little relationship with dystocia. Width of hooks and length of rump are easily measurable but are not good indicators of pelvic size and therefore not good predictors of dystocia (Deutscher 1989; Johnson et al. 1988). They also found that pelvic structure and slope of the rump did not also have any effect on dystocia outcomes.

Johnson et al.(1988) further showed that prebreeding and precalving heifer weights were positively correlated with calf birth weights (both at 0.34), but were not correlated significantly to calving difficulty score. There was, however, a significant positive correlation of precalving pelvic area with precalving weight of $r=0.5$, indicating that larger heifers have larger pelvic areas but we should recall that they also give birth to larger calves. Thus selection for large heifers without knowing their pelvic areas may have no effect in reducing the incidence of calving difficulty. This is because heifer weight is not a good indicator of pelvic size with heifers of similar weights having considerably different pelvic sizes.

Double muscling or muscular hypertrophy, an inherited condition in cattle has been reported to result in a reduced pelvic opening leading to higher than normal levels of dystocia as compared to normal animals of the same size and breed (Arthur et al. 1988).

Thus we may conclude that pelvic dimensions and birth weight of calf are important traits determining ease of calving (Menissier 1975b; Price and Wiltbank 1978a). Several authors have recorded that these traits, between them explain 17-39%

of the variation of calving difficulty scores. The low level of variation accounted for has been said to be due to the discontinuous nature of calving ease scores and the probable non-linearity of the relationship between these scores, pelvic dimensions and/or birth weight (Meijering 1984). Similarly a large part of observed dystocia may not only be due to fetopelvic disproportion but could be due to other causes.

Effects associated with gestation length

Gestation length has a moderate to high heritability and it is correlated with birth weight. Similarly it has been documented that a gestation length can be associated with large breed differences in birth weight i.e. large breeds that give birth to larger calves, also have longer gestation periods (Hanset 1981). Gestation length has been shown to be phenotypically associated with calving ease, with more difficulty observed for longer gestation periods than normal (Philipsson 1976c). He also reported that the relationship between gestation length and dystocia or stillbirth exhibited threshold properties similar to those observed with birth weight. Correlation estimates of about 0.20 have been reported in heifers and older cows for birth weight and gestation length (Menissier 1976; Smith et al. 1976; Philipsson 1976c). This association may be an underestimation if the threshold effect is considered. A non-linear relationship has also been observed between stillbirths and gestation length in heifers, especially when the gestation length is greater than 278 or less than 260 days (Philipsson 1976c). However, conflicting findings from studies on two breeds (Hanset 1981) have shown that easy calving is associated with longer gestation periods and larger birth weights in the Limousin and Blonde d'Aquitaine respectively. The explanation for this observation was that there exists biological differences of gestation length and birth weight due to the maturity of the calf at birth. He therefore suggested that selection should be done directly for ease of calving rather than the use of correlated traits like birth weights and gestation periods.

Anderson et al.(1976) reported that fetus weight in cattle increases by 300-400 g day^{-1} during the last month of pregnancy, thus the association of gestation length and dystocia could be mediated through birth weight. This fact is further supported by Burfening (1978a) who showed that this association was no longer significant when birth weight is included in the model as a covariate. It was also observed that male calves seem to have longer gestation periods than their female counterparts (an average of 1.7 days longer) and as a result they were about 3.0 kg heavier at birth and required 12.7% more assistance during delivery (Burfening et al. 1978a; Smith et al. 1976). Thus the relationship between gestation length and dystocia may largely be explained by birth weight as stated earlier.

Non-Genetic factors influencing dystocia.

Several factors not of genetic origin have been examined for their impact on calving performance and rate of stillbirths. It was found that the most important are age of dam or parity, sex of calf, body condition of the dam and the season of calving (Meijering 1984). While estimating genetic parameters or breeding values it is important to estimate and adjust for these effects.

Age and parity of dam: Age and parity of dam are used synonymously here since they usually represent the same thing. There is adequate documentation that both the incidence of dystocia and stillbirth are much higher in first parities than later parities and frequencies reported range from 3 to 4 times for dystocia and 2 to 4 times higher for stillbirths (Pollack 1975). There is a decreasing tendency in the occurrence of dystocia from the second up to the fifth parity, but the differences between the second and later parities are relatively small (Brinks et al. 1973; Burfening et al. 1978b). This could be an indication that different mechanisms are involved in cow and heifer calvings. Several authors found that age at first calving had no effect on the incidence of calving or stillbirth in heifers calving between two and three years of age in some breeds (Bar-Anan et al. 1976; Philipsson 1976b). However, several authors have given conflicting information that implies an increase in the incidence of dystocia with increasing age at first calving. The reasons advanced for this is that there is reduced elasticity of the pelvis and an accumulation of fat in the pelvic region thus constricting the genital tract (Philipsson, 1976b).

There is however, general agreement that more calving problems are encountered when heifers calve at much earlier or older age than the normal range (Philipsson 1976b; Pointer et al. 1975). Given the higher incidence of calving difficulty in heifers and the major influence of fetopelvic disproportion on dystocia, it is reasonable to assume the ratio between calf size and effective pelvic dimensions is more critical in heifers than in later parity cows. And calf size alone cannot be the main cause because birth weight increases with parity up to the fourth or sixth calving (Burfening et al. 1978b). It has been observed that between the ages of two and five years the pelvic area of the dam may increase relatively more than the average birth weight of the calf, which renders a more favourable pelvic area to birth weight ratio in subsequent parturitions (Menissier 1975a). It is important to note that the effect of age at first calving has to be considered against the maturity of the breed at that particular age due to varied rates of maturity for the different breeds of cattle (Fitzhugh and Taylor 1971).

Sex of calf effects: There is considerable agreement that the sex of calf is a major source of variation in the levels of dystocia and stillbirths, frequencies for males being relatively higher than those of females. McKay et al. (1990) and Cue (1990) reported that twice as much assistance in calving was observed for male calves as compared to their female counterparts (11.31% vs 5.11% respectively). This difference was partly manifest through the size of the calf, with bull calves being larger than heifer calves. However, Thompson and Wiltbank (1983) showed that there was an apparent difference in dystocia even between male and female calves of the same heart girth size. In agreement with other studies, sex of calf had an effect on the size of calf, bull calves were larger and experienced more dystocia than heifer calves (Burfening et al. 1978b; Smith et al. 1976; Thompson and Wiltbank 1983). However, this difference in incidence of dystocia due to sexes diminished in the second and older parities (Burfening et al. 1978b). Laster and Gregory (1973) reported that there was a non-significant sex difference in stillbirths when calving was unassisted, but when dystocia occurred there was a high occurrence of stillbirth in male calves from heifers. Several authors have suggested that the difference in weight of calves of different sexes could be due to the difference in morphology, male calves being relatively broader at the shoulders and thurls for a given weight and also having a heavier skeleton (Philipsson 1976d).

Levels of nutrition during gestation: Effects of both high or low planes of nutrition during the last trimester of gestation has an influence on calving performance of the cow and the vitality of the calf born (Meijering 1984; Lederman and Rosso 1980). Nutritional effects on heifers, apart from the effects on puberty also show some effects in yearling, 18 month and precalving pelvic measurements (Bellows 1989). Feed levels that allow maximum growth and development of the pelvic opening result in pelvic dimensions 2-8% greater and a decreased incidence of dystocia of up to 10% when compared to heifers on low planes of nutrition (Bellows 1989; Philipsson 1976d).

Price and Wiltbank (1978b) concluded that a constant level of dystocia can be maintained only if pelvic area increases at the same rate as calf size. They also concluded that gestation feed level of dam can affect calf birth weight and its eventual vitality if it is severely restricted, but its effect on dystocia is not consistent and can therefore not be considered predictable. Conversely higher levels of nutrition resulting in fat deposition in the birth canal which effectively reduces the size of the pelvic opening causing increased dystocia (Bellows 1989).

Severe feed restriction of heifers during the last 3 months of gestation resulting in negative or zero change in body weight significantly reduces calf birth weight, thus affecting its future survival (Laster 1974; Bellows and Short 1978). However, birth weight of calves from older cows seem to be less affected by similar short term feed restriction, possibly due to reduced competition between energy demands for pregnancy and growth (Meijering 1984).

Season of calving: Variation in dystocia in some regions has been reported to be associated with season. In Northwestern Europe it has been reported that the incidence of dystocia was higher, particularly in the fall and early winter than in spring and summer (Meijering 1984). Cue (1990) also found a similar trend in a study involving Ayrshire cattle in North America. This increased incidence was found to be associated with higher average birth weights (Philipsson 1976b). Some of the reasons advanced for this observation were that changes in daylength influences the amount of circulating levels of hormones, more exercise and increased feeding time during the long days favouring fetal development (Philipsson 1976b).

Of the non-genetic factors discussed above, parity of dam and sex of calf seem to have the most impact on dystocia and stillbirth. However adjustment for most of the environmental factors causing variation is important in genetic analysis.

Genetic effects

Several studies have revealed considerable differences in dystocia and stillbirth incidences between progeny groups of bulls, both as sires (Hanset 1981; Cue 1990) and maternal grand sires of new born calves (Balcerzak et al. 1989; Ron et al. 1986). The genetic factors influencing calving ease are represented in Figure 3.

Traits such as birth weight, gestation length and dystocia measured at time of birth, are a result of interaction between the dam and its fetus. They are not only influenced by the genes the fetus receives directly from its sire and dam but also by the maternal ability of the dam in preparation for parturition. This maternal ability

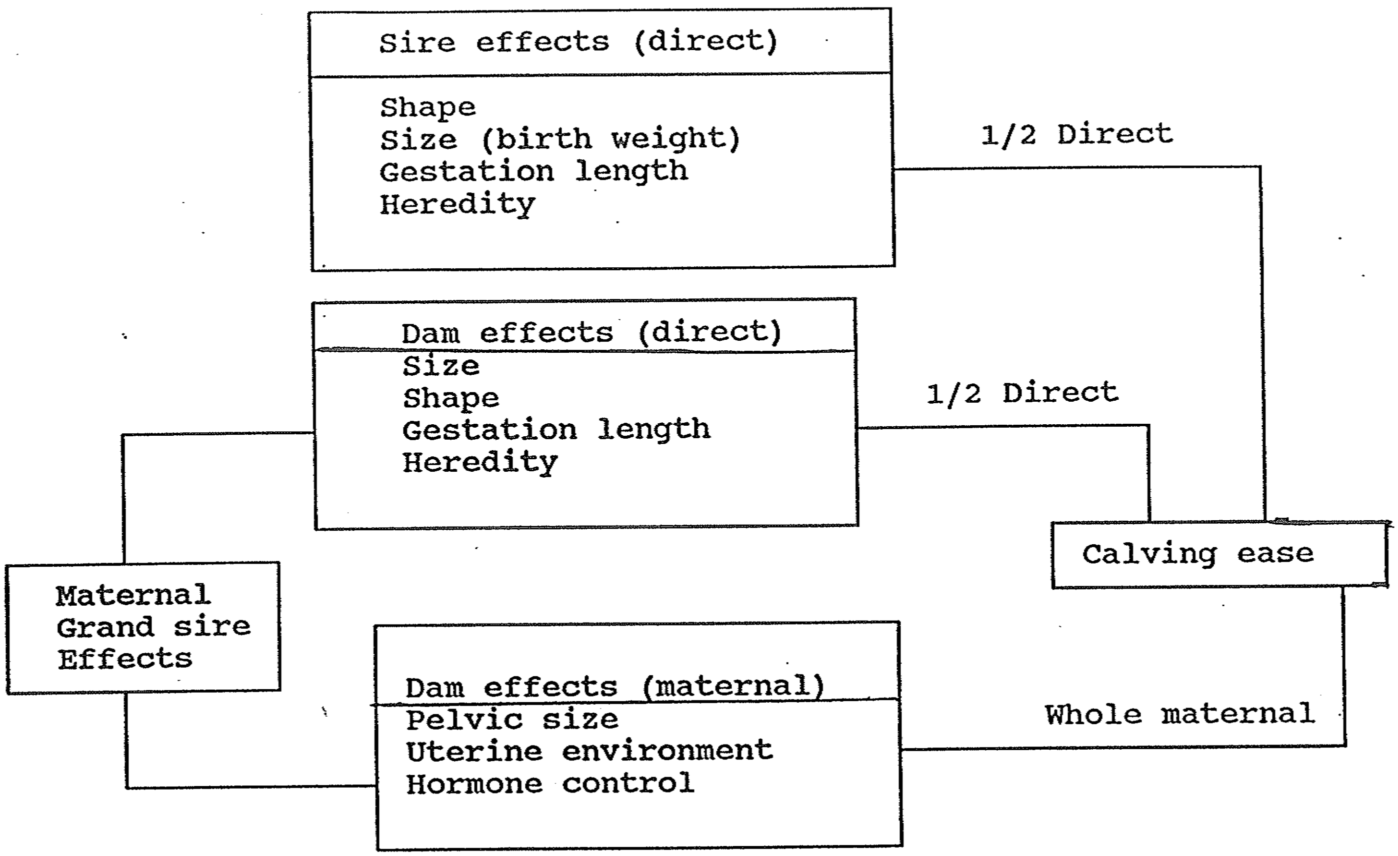

Figure 3. Genetic factors affecting Calving Ease

encompasses genetic and non-genetic factors other than the genes transmitted to the fetus (Hanset 1981).

The phenotype of the offspring P_o may be partitioned according to the following model: $P_o = D_o + E_o + M_m + E_m$, where D_o is the direct effect of the calf's genotype, M_m is the maternal effect on the offspring determined by the genotype of the dam, and E represents environmental effects (Willham 1963).

The genotype of the offspring can be considered as consisting of two parts, one which is expressed when it is born and the other expressed by females during parturition (Hanset 1981). These two effects, direct and maternal can be affected considerably by selection for size and conformation and should be considered as distinctly different traits which have genetic and environmental components (Philipsson et al. 1979). Lapostolle (1983) noted that bulls rank differently when calving difficulty is considered a maternal trait compared to when it is considered as a direct trait. Bulls as sires of the calf (direct effect) and as sires of the dam (whole maternal and half the direct effect), exert an appreciable effect on the incidence of dystocia and stillbirth (Philipsson et al. 1979). Therefore from a genetic point of view, dystocia must be analyzed in relation to both the dam and calf sources of genotypic variance.

Direct genetic effects.

Direct genetic effects can also be referred to as calf effects and correspond to the influence of calf genotype through parentally transmitted genes on calving performance and calf viability (Philipsson et al. 1979). Genetic parameters (heritabilities and correlations) are generally computed from sire variance and covariance components, from half-sib analysis in field data. Several studies concerning genetic variability of dystocia, stillbirth and other related traits (exempli gratia birth weight, gestation length and pelvic opening) have been reported by a number of authors and there is general agreement about the estimates of genetic parameters and the conclusions drawn from these estimates.

It has been observed that heritability estimates for dystocia and stillbirths are quite low in general, but those for heifers are reported to be relatively higher than those of mature cows (h^2 = 0.03-0.20 and h^2 =0.00-0.08 respectively) (Philipsson et al. 1979; Burfening et al. 1981; Cue 1990). Cue (1990) reported that the estimates for variance components for calving ease in adult cows were only 2/3 of those in heifers. The heritability of these traits should therefore be handled separately for these two parity groups. Cue and Hayes, (1985) also found that the heritability for calving ease was 4.2% and 1.2% for heifers and older cows, respectively, and that variances for these parities were also different. They suggested that a two-trait mixed model to include all records could be used for analysis because it would account for the different variances. Genetic correlations between dystocia and calf mortality have also been shown to be higher in primiparous calvings than for later parity cows. This would suggest that the genetic component responsible for calving traits is more important in heifers as compared to its effect in multiparous cows. Ron et al. (1986) suggested that sire evaluations for calving difficulty of multiparous cows be used as preliminary prediction of heifer calving difficulty and that separate calving trait evaluations be combined into an overall calving selection index.

Evaluation of calving ease is made on the assumption that the effect of parity can be considered as an environmental effect and that calvings from heifers and ȧdult cows with subsequent parities are expressions of the same trait. However, some studies suggest that calving ease in heifers and adult cows could be expressions of different but correlated traits. Weller at al. (1988) found genetic correlations of less than 0.5 for calving ease for first and later parities, indicating that these could be different traits. On the contrary findings by Cue and Hayes (1985) and Thompson et al. (1981) reported correlations close to unity suggesting that the same genes are responsible for dystocia in cow and heifer calvings. However, the variances between these two parity groups were quite different in agreement with what other authors found. The estimates of the variance components for calving ease in adult cows were only about 2/3 of those of heifers (Cue 1990). There have been estimates of between 0.06 and 0.10 for the heritability of calving ease in Holsteins (Cady and Burnside 1982) when combining all parities. Weller et al. (1988) compared estimates obtained using a linear model and a threshold model. Their estimates of the heritabilities were 2-5 times larger using the threshold model; however the correlation between solutions under the two models was above 0.9. The difference in heifer and cow calvings has been explained by Philipsson et al. (1979) and Weller et al. (1988) as being due to the different biological phenomenon involved in the physiology of delivery between these parities.

Despite the low heritability values obtained for dystocia in most studies, there is large genetic variability that can be utilised in selection for both calf and dam effects (Bar-Anan et al. 1976). It has also been reported that the heritability of dam-genotype effects (maternal genetic effects) for calving ease characters are generally smaller than calf genotype effects (direct genetic effects), and these two seem to have a negative genetic correlation between them (Ron et al. 1986; Bar-Anan et al. 1976; Thompson et al. 1981; Cue and Hayes 1985). Thompson et al. (1981) reported correlations of -0.38 and -0.25 for heifers and older cows respectively. They therefore postulated that the negative direct-maternal correlation results from small calves being born with ease (Thompson and Rege 1984),but later these small cows have increased dystocia. This hypothesis was in agreement with the findings of Thompson et al. (1983) who reported that cow size does affect calving difficulty at first and second parturition.

Therefore bull evaluation for calf-effects may not be of much use in predicting daughter group outcomes for calving performance and consequently the evaluation and subsequent selection are necessary for both calf (direct) and dam (maternal) effects. Lapostolle (1983) noted that sires rank differently when calving difficulty is considered a direct or maternal trait. There are high genetic correlations between direct effects of birth weight and dystocia, and between heifer and cow performance for birth weight, of 0.6 and 0.9 respectively (Philipsson et al. 1979). Thus there is very little room for selection against dystocia without altering birth weight in both heifers and mature cows.

Several studies indicate the effect of sire of calf is greater than that of sire of cow and there is a negative correlation between these two effects (Thompson and Rege 1984; Ron et al. 1986), and that the incidence of dystocia and calf mortality is higher for male calves as compared to female calves (Meijering 1984; Cue 1990), because male calves tend to be larger at birth. This is mainly determined by the direct genetic effect. As for the female calves, calf size may not be as important as pelvic dimensions of the dam. It could therefore be argued that male and female calvings are under different physiological control, especially when we consider that the incidence of dystocia decreases with calving in subsequent parities for males but not for females (Weller and Gianola 1989). They also reported that h^2 estimates for male calvings were higher than those of females and suggested that male and female calvings should be analyzed separately or possibly through a multi-trait analysis.

Genetic variation in direct effects on the rate of dystocia would successfully allow selection against dystocia and stillbirth. The evaluation of bulls for these traits can be done according to either their influence on calf effects of their progeny (sire effects), or the influence on dam effects through data collected on their daughter groups (maternal grandsire effects) (Philipsson et al. 1979; Bar-Anan 1979). These two effects act along a range of continuous variation with some interaction occurring between them (Menissier 1975b).

The success of such an evaluation depends on the quality of evaluation and the problems that are normally encountered including, the type of recording system in place, adjustments made for the fixed effects and the computational methods that are used (Philipsson et al. 1979). Meijering (1984) suggested that without considering pedigree information, indications about direct genetic merit of a young bull for ease of calving may be derived from his own gestation period and birth weight. Correlation estimates of $r=0.15$ (Meijering and Van Eldik 1981) and $r=0.41$ (Remmen 1976) for gestation length of a bull and the frequency of stillbirth in his progeny were reported. The correlation of gestation length and the incidence of dystocia was found to be r=0.40-0.48 (Meijering and Van Eldik 1981).

Several body measurements of bulls have been taken to find out how closely they correlate to pelvic dimensions or dystocia so that they may be used as an estimate of direct genetic merit of bulls for calving ease. But as reported earlier, these have been found to have low association with dystocia (Johnson et al. 1988).

Maternal effects

Maternal effects are the effects of a dam on calving difficulty. It is an effect contributed to the phenotypic value of an offspring by its dam. This effect is genetic with respect to the mother but acts as an environmental effect with respect to the offspring. Part of the maternal effect may be genetic and part may be environmental (Balcerzak et al. 1989).

Traits such as birth weight, gestation length and dystocia measured at time of birth are the outcomes of an interaction between the dam and its fetus. They are not only influenced by the genes the fetus receives from it's sire and dam, but also by the maternal ability of the dam (Hanset 1981). These calving traits expressed as maternal effects are due to pelvic dimensions, preparation for calving and maternal genetic effect on the calf size (Meijering 1984).

The maternal (or dam) effects are quite complex unlike the direct (or calf) effects, because they not only include the direct effects of a dams genes on the size of her calf but also what is known as 'pure maternal effects', i.e. the uterine influence of the dam on her calf's birth weight, the influence of her own genotype on the pelvic opening and preparation for calving (Philipsson et al. 1979). Consequently, the evaluation of bulls for dystocia and still birth can be made according to either their influence on the calf effects of their progeny (sire effects) or their influence on the dam effect through data collected on their half-sib daughter group analysis regarding calving traits as traits of the dam (or maternal grand sire effects)(Meijering 1984).

Heritability estimates for pelvic area indicate that it is moderately to highly heritable with several estimates showing a range of 0.36-0.61 with mature cows (> 5 years) having higher values than younger cows, and should therefore respond favourably to selection (Morrison et al. 1986). The genetic correlation between pelvic width and height has been found to be lower in young compared to older cows. This would indicate that the growth of these dimensions in young cows occurs independently, but in mature cows where maximum pelvic size had been attained pelvic width and height were more highly correlated (Morrison et al. 1986; Benyshek and Little 1982; Holzer and Schlote 1984). Pelvic dimensions were positively associated genetically with cow weight, $r=0.65$ (Benyshek and Little 1982), indicating that direct selection for increased pelvic size may result in correlated increases in cow weight and presumably cow size. Laster (1974) stated that differences in pelvic size among breeds was due to differences in body weight but also pelvic size independent of cow weight still had a significant influence on dystocia.

For any maternally-influenced trait it is necessary to consider the heritability of the direct effects, the maternal effects and the genetic correlation between them. The heritability of maternal effects for calving traits have been reported to be lower than those of the direct effects and the correlation between them are either negative or equal to zero (Hanset 1981; Balcerzak et al. 1989). Thompson et al. (1981) estimated the genetic correlations between direct and maternal effects to be -0.38 in first parities and -0.25 in later parities. The implication of this association is that bulls producing small calves (with low incidence of dystocia) also produce daughters that are smaller and subject to increased dystocia and vice versa (Meijering and Postma 1985; Thompson et al. 1981). Thompson et al. (1983) also reported that cow size does affect calving difficulty at first and second parturition.

The confounding of the two (direct and maternal) contributions from the dam coupled with the possibility of a negative genetic correlation between the direct and maternal effect constitute the basis of the problems encountered in estimating maternal effects (Willham 1980; Bar Anan et al. 1976). Bull evaluations for direct effects only may not be very useful in predicting daughter group results, as earlier indicated. This is because of the antagonistic nature of the two traits, consequently selection for both traits is important if both characters are to be improved (Hanset 1981; Balcerzak et al. 1989).

The maternal effects are normally realised a generation behind the direct effect in its expression and therefore evaluation of maternal effects normally would lag behind the direct effects. Willham (1972) reported that maternal effects are also influenced by previous maternal effects and are sex limited. Manfredi et al. (1991) indicated that maternal effects are important especially if non-random mating is practised and should be included in dystocia analysis even if selection of bulls is based mainly on direct effects because the direct effects could become counter-productive if the maternal effects, which have a negative association with the direct effects are not considered.

Considerations in evaluation of calving ease.

Several researchers have stated that many physical measurements of a cow particularly pelvic size are associated with dystocia, but these associations appear too low to be able to predict dystocia accurately. It has been shown that even when as many as 49 cow variables are measured, they only account for 33-45% of the variability in dystocia scores (Johnson et al. 1988; Laster 1974).

Price and Wiltbank (1978b) suggested that the low amount of variability in calving ease accounted for by these measures could be an indication that either the factors most related to dystocia are not being measured or the analysis applied to this data may not be appropriate to accurately show the effects of these variables to dystocia. Morrison et al. (1985), Weller et al. (1988) and Johnson et al.(1988) were of the opinion that the use of threshold models rather than linear models and the use of discriminant analysis rather than regression analysis would be more appropriate in the evaluation of dystocia.

Most dystocia experiments use numerically categorised scores for degree of dystocia (basically 1 to 5, with 5 being the most difficult), resulting in discrete categories while considering this trait as a continuous character in the analysis. This therefore results in the violation of some assumptions, namely, a normal distribution, additivity of effects and homogeneity of variances in the observed scales due to the arbitrariness in scoring categories (Gianola 1980a; Tong et al. 1977). Thus the categorical data has to be transformed to provide scores with homogeneous residual variances over sub-classes and with residual deviations that are approximately normally distributed. This is a requirement for the estimation of variance components (Tong et al. 1977).

Although the categorical nature of dystocia and stillbirth implies a discontinuous variation, quantitative inheritance is assumed. A non-observable underlying normal distribution of environmental and genetically-influenced liability values is assumed, which corresponds to the observable scale by one or more thresholds (Falconer 1989). Estimation of genetic parameters (heritability and phenotypic correlations) are grossly underestimated when the raw observations are used rather than when they are transformed to reflect the underlying continuous liability (Gianola 1982). Gianola (1980b) reviewed problems associated with genetic evaluation of categorical traits such as calving ease using linear models and proposed a method for evaluating categorical traits using a log-linear model which is based on the logistic distribution. This is because linear models used in the analysis of categorical traits tends to violate some assumptions as mentioned earlier. In this model the multivariate normal distribution is replaced by a logistic function. In this form, the data are brought back to a linear continuous reference scale in which the usual assumptions made with continuous data hold true.

Sire evaluation for calving ease

As sires of the calves (direct effect) as well as sires of dams (whole maternal and half of the direct effect), bulls exert an appreciable effect on the incidence of dystocia and consequently, breeding values should be estimated for both types of effect. Bar Anan (1979) indicated that the differences between sires are large relative to the mean incidence of calving-character traits, so that given sufficient offspring it is possible to identify sires characterised by a high or low incidence of calving difficulty or perinatal mortality among their mates or daughters.

Calf sex and the genetic potential to grow in utero are genetically determined and are well established at time of conception. Also the relative size of the birth canal at calving cannot distend by very much, therefore little can be done in preventing the incidence of dystocia at time of parturition and therefore the need to be able to prevent it before breeding (Bellows 1989). Because of this scenario, proper sire evaluation and selection and the use of a proper breeding strategy (mating low risk bulls to heifers) is important in reducing the problem of dystocia. This may entail sire selection for larger pelvic size and optimal feeding of replacement heifers during the early stages so that the full genetic potential for skeletal growth is realised (Bellows 1989).

Methods of sire evaluation mainly involve the use of the Best Linear Unbiased Prediction (BLUP). If the records and the genetic merit to be predicted follow a joint normal distribution, then this would be a most suitable method of sire evaluation (Henderson 1973). This is because it gives the maximum likelihood estimation of the predictor which maximises the probability of correct pairwise ranking of sires under such conditions (Ronningen and Van Vleck, 1985).

The use of BLUP procedures for categorical traits has been challenged. Gianola

(1982) indicated that a linear model approach for sire evaluation with categorical data has a number of limitations some of which are that the best linear predictors may not maximise the probability of correct ranking because the data are not normally distributed (Portnoy 1982), the other is that sire and error variances are neither independent nor constant and a possible failure of linear relationships outside the range of the data (Gianola 1980b). Gianola (1980b) suggested the use of a multivariate log-linear method based on the logistic distribution for genetic evaluation of categorical traits. In order to avoid scoring problems, Quaas and Van Vleck (1980) proposed a multitrait BLUP procedure in which each category is considered as a different trait, but this approach is limited to models with only one random effect.

The most valuable information on the direct genetic merit of a young bull is obtained from the birth records of his progeny. In the Canadian beef sire evaluation programme (BSEP) seven traits are considered in a multiple trait individual animal model evaluation procedure (de Rose 1992). The traits considered include both the direct and maternal effects on calving ease, birth weight, weaning gain and the direct effects on post weaning gain.

The breeding value of an individual is a random effect representing the animals genetic worth. The estimated breeding value (EBV) produced when the mixed model equations are solved provides the EPD's as follows: EPD=EBV/2 (de Rose 1992). The maternal breeding value of a dam is an estimate the dam's genetic ability to provide an advantageous maternal environment during gestation, calving and pre-weaning growth. The expected progeny differences for calving ease (EPDCE) is an indicator of the ease with which the progeny of bulls are born. This is a measure of the direct effect of a sire on how easily his progeny are born. The EPD for maternal calving ease is a measure of how easily the daughters of a given animal give birth. Positive EPD's for calving traits represent easy calving while negative EPD's indicate difficult calving.

Many producers utilise EPD's for calving ease to select bulls that are significantly better than breed average. It is also important to know the reliability of prediction for those bulls selected to mate in their herds. An accuracy value is computed for each EPD as an approximation of the square of the correlation between the true genetic value of the animal and the estimate based on a single trait approximation. Accuracy or reliability is based on the relationship and number of observations used to calculate the EPD's (Berger 1991). A good measure of reliability is especially critical considering that we may evaluate animals with tens or even thousands of progeny. The magnitude of EPD's may be the same but their accuracies could be different.

Philipsson et al. (1979) indicated that more calvings of older cows have to be recorded to obtain an accuracy as would be obtained by testing heifers. This is because of the lower heritability of cows for calving performance as reported earlier. Correlations between sire proof's in heifer and cow calvings were reported to be rather low for stillbirths, ranging from r=0.2-0.4 (Lindstrom and Vilva 1977; Meijering 1980), while for dystocia the correlation ranged from r=0.2-0.6 (Burfening et al. 1979; Meijering 1980).

Expected progeny differences (EPD) for a given trait for an average animal in a current evaluation base (calves of the breed born in the last three years) population will average zero. The EPD's are printed in the Canadian Beef Sire Evaluation programme sire summary, normally done twice a year, in the spring and the fall.

Use of pelvic area in predicting dystocia

Deutscher (1989) reported a pre-breeding pelvic area to birth weight ratio of 4.7 $cm^2\ kg^{-1}$ to be a threshold point between assistance needed and normal calving. Pelvic measurements are taken pre-breeding and the area divided by this factor to estimate the calf birth weight the heifer can deliver as a two year old without severe difficulty. These factors depend on the age and weight of the animal (Table 1) . This method has been used to successfully select replacement heifers and the prediction of dystocia with an accuracy of up to 80% as reported by Deutscher (1988a).

Deutscher (1988a) postulated that pelvic area to birth weight ratio and birth weight had a linear relationship to calving difficulty score. However, pelvic area alone did not show such a relationship due to the observation that heifers with large pelvic areas had a similar proportion of calving difficulty due to the proportionate increase of the size of calf (Van Donkersgoed et al. 1991). Deutscher (1988a) proposed that for an animal of given weight and age these ratios could be used to identify potential difficult calvers thus allowing culling decisions for heifers before breeding. Dufour et al. (1981) reported that cows with difficult births at first or second calving had smaller pelvic size to birth weight ratios and suggested that this was due to lack of adequate development of the pelvis and therefore this could be a useful tool for the prediction of calving difficulty. Schwabe and Hall (1989) and Van Donkersgoed et al. (1990), however, did

Table 1. Birth weight and Pelvic area ratios used to predict dystocia. Adapted from Deutsher (1988b).

Age (months)	Weight (kg)	Parea (cm^2).	Parea:Bwt (cm^2/kg)	Deliverable Weight (Kg)
12-14	249-317	120-160	4.7	27-33
18-19	317-385	160-200	5.8	29-34
23-24	363-431	200-240	7.2	29-37

not concur with this opinion, and based on their findings they concluded that there was no relationship between this ratio and the degree of difficult calving nor was there an increased incidence due to large calves. The only explanation offered was that they were perhaps dealing with animals that had been selectively mated for dystocia.

Recent studies have indicated that pelvic size is moderately to highly heritable, averaging about 61% while that of calf birth weight is about 45% (Deutscher, 1989). Thus pelvic size can readily be transmitted from sire and dam to progeny and its effect would be larger than that of birth weight which has been said to be important in causing dystocia. This has prompted the question of the use of pelvic size as an additional selection criterion for bulls used to produce replacement heifers considering the fact that a bull used in artificial insemination may contribute as many as 10,000 daughters to the cow population in a single year or an equivalent of about 50,000 over his lifetime (Kennedy 1981). Boltze (1985) from a study of 164 Simmental heifers from 12 sires which had a pelvic area heritability of 0.37 ± 0.21 reported that daughters had an increased pelvic area of 0.19 cm^2 for each cm^2 increase in sire's pelvic area. Green et al. (1986) and Deutscher (1988b) established that the genetic correlation between male and female pelvic areas was 0.60 and therefore concluded that selection for increased male pelvic areas should result in increased pelvic area of female progeny. Johnson and Deutsher (1986) reported that the best way to compare pelvic areas for bulls to be used as sires for replacement heifers would be to adjust these measurements to a common weight or age, then compare each bull to the average of his breed contemporaries. This would eliminate differences due to environment and allow for a more valid comparison of bulls.

Other methods of predicting dystocia have been suggested by Ko and Ruble (1990) who pointed out that fetal coronary band circumference of hoof and maternal pelvic area may be used to accurately calculate calving difficulty scores since they have been found to have a significant correlation ($P < 0.01$). Further, hoof circumference measurements have been found to have a correlation of 0.94 with birth weight (Kindson, 1978). The hoof measurement is done during the second stage of parturition and would be only useful in determining what type of delivery the cow may have and is only important as an aid to obstetric decision making.

MATERIALS AND METHODS.

Station Management:

The major focus for central performance testing for beef cattle is postweaning growth and entails the evaluation of performance traits of prospective sires from different herds under uniform environmental and management conditions. Amal and Crow (1987), however, indicated that pre-test environmental influences, better known as herd of origin effects account for about 40% of the total variation in performance of bulls at the start of test. These effects reduce progressively and by end of test account for about 16% of the variation in gain. This variation has been attributed to temporary environment and does not have a genetic component since it varies progressively as the animals adapt to their new environment. These effects are larger, the older the animal at the beginning of test, therefore to reduce some of these herd of origin effects, it is recommended that bulls should be put to test as early in age as is possible.

Bull test stations provide for uniform testing procedures and reporting of test results for the individual bulls tested in the various test station within the province of Manitoba. In so doing, they are intended to identify genetically superior bulls for traits of economic importance and thus provide a useful tool for the selection of beef cattle.

A consignment of bulls of various breeds from across the province are normally received at the test stations during the months of October and November, shortly after weaning. Only those bulls meeting a minimum weight requirement of 181 kg or a minimum weight per day of age of 0.95 kg are accepted for test. They should also be within an age range of between 160-250 days on arrival at the test station, though an age span of 60 days is recommended for a given consignment of animals on the same test. This is to ensure that the bulls are at a similar stage of growth during the test period. The bulls must also have a clean medical certificate in as far as vaccination, ectoparasitic and endoparasitic treatment is concerned. Each consignment is divided into contemporary groups, which consists of bulls of the same breed. Each contemporary group is required to have a minimum of 12 bulls to be granted test station status and publication of performance indices. This also allows for sufficient genetic variability which enables meaningful within-breed comparisons.

The bulls are allowed a minimum of 28 days adjustment period to minimise herd of origin effects and also acclimatise the animals to their new nutritional environment. After the adaptation period the animals are put on 140$\pm$5 days on test as recommended by BIF (1986). Bull weights at 28 day intervals, with interim weighings on days 56, 84 112 and finally 140 days on test are recorded and average daily gain on test determined.

The weight of ruminants is inherently variable because the rumen contents make up 15% of the liveweight, therefore weighings are repeated on two consecutive days, at the start and end of test, and are done in random pen order to reduce the effects of short term variability in gut fill on live weight.

Bulls in these test stations were fed, *ad libitum,* a ration of at least 60% TDN. A complete mixed ration is preferred to realise maximum performance response. The common diet in the stations is a grower ration consisting of 81% oats (steam rolled), 10% beet pulp (pelleted), 2% liquid molasses and 7% protein supplement, minerals and vitamins (percentages on an as-fed weight basis). Bulls are also fed hay free choice. Growth stimulants or other feed additives are prohibited during the test period.

At the end of test bulls are ranked within breed according to an index based on average daily gain on test and weight per day of age (end of test weight devided by age). To qualify for sale as breeding stock bulls should have an index of 95 or greater for both average daily gain and weight per day of age.

The bulls which were from herds enrolled on a breed association or Agriculture Canada home test program were genetically evaluated and have EPD's for maternal and direct effects on calving ease and weaning gain, and direct effects on yearling gain. EPD's represent the genetic potential of a particular animal for a given trait of interest and are an indication of the performance expected from the progeny of a bull compared to the average of all progeny within a breed for a given trait.

Description of Data from the test stations.

The stations from which data were collected for this study are operated by various organizations. The Douglas test station is managed by the Manitoba Beef Cattle Performance Association Inc., Gunton bull test station is managed by the Interlake Livestock and Forage Improvement Association, while the Roblin test station is managed by Northwest Manitoba Bull Test Station Co-op. The test stations operate with guidelines recommended by the provincial beef record of performance (ROP) advisory committee.

Data set I comprised a total of 3291 records of bulls from three test stations over the years of 1988 to 1991 from various herds within the province of Manitoba. These records were comprised of twelve different breeds of cattle as indicated in the summary Table 2. Each bull was uniquely identified by a tattoo composed of breed letters (two), herd letters (up to four) a bull number (up to four numerals) and one year letter. This identifies the animal, its breed, herd of origin and the year of birth. These animals that managed to complete the test successfully had their pelvic measurements taken at the end of the test period by qualified veterinarians using either the Krautmann™ or the Rice (Lane manufacturing™) bovine pelvimeters. Pelvic height was the shortest vertical distance between the pubic symphysis and the sacral vertebrae while the pelvic width was the widest horizontal distance between the shafts of the ilia. These measurements were taken by inserting the pelvimeter in the rectum of the animal. The product of the pelvic height and width is considered an estimate of the pelvic area. To reduce measurement error the same technician used the same instrument to measure each contemporary group.

These records were then used for analysis of pelvic areas of the bulls to determine environmental factors causing variation in their measurements. These records were further used to obtain correlations for various adjusted measures of test station records to determine phenotypic association of the various traits of test station bulls.

Data set II was compiled by matching the 3291 records of test station bulls with the record of performance (ROP) data base using individual animal tattoos to uniquely identify each animal's record from the ROP data base. These records were supplied by Manitoba Agriculture and Agriculture Canada. These home test records enabled us to get information on bulls from birth up to the time they were delivered to the test station. Among important records obtained from the ROP data base were birth weights, expected

Table 2. Summary of herds, Years and Stations of Test station Bulls

Breed	Years	Herds	Stations	# of Bulls
Angus	X,Y,Z,A	29	1,6,7	120
Blonde d'Aquitaine	X,Y	11	6,7	27
Charolais	X,Y,Z,A	165	1,6,7	1333
Gelbvieh	X,Y,Z,A	14	7,1	113
Hereford	X,Y,Z,A	92	1,6,7	498
Limousin	X,Y,Z,A	37	1,6,7	178
Maine Anjou	X,Y,Z,A	24	1	110
Pinzgauer	X,Y,Z	3	6	12
Salers	X,Y,Z,A	31	1,6,7	168
Simmental	X,Y,Z,A	23	1,6,7	627
Shorthorn	X,Y,Z,A	14	1	92
Tarantaise	A	3	7	13

Legend:

Years	Stations
X 1988	1 Douglas
Y 1989	6 Roblin
Z 1990	7 Gunton
A 1991	

progeny differences (EPD's) for calving ease and growth traits, accuracies of these EPD's and the observed ease of calving for each bull.

Of these animals only 934 bulls were found to have a record of calving ease. For consistency, only three categories of calving ease were considered, these were 1) Unassisted births (U). 2) Easy calving (E), which included animals requiring minor assistance. 3) Hard calving (H), which consisted of animals requiring major assistance, possibly the use of a calf puller. This categorization was chosen because other categories of difficult births could have been due to factors other than fetopelvic disproportion which is the main interest of this thesis. Animals that didn't have full records, particularly for calving ease and EPD's for calving ease and growth traits were deleted from the data set leaving us with 907 bulls for statistical analysis to determine the relationship of pelvic dimensions with growth traits and EPD's for both growth and calving ease traits.

Data set III was comprised of records of test station bulls that had offspring records on the ROP data base. A total of 37 bulls representing 6 breeds from 23 herds had a total of 520 offspring as indicated in Table 3. These were the records that were used in the analysis of the progeny data to determine the relationship of sire calving ease, pelvic dimensions and birth weight with the calving ease of their progeny. The analyses on data set III would be less reliable than the other two data sets previously described because of the small representation of bulls but it should give an indication of factors affecting calving ease in progeny of test station bulls.

Table 3. Summary of calves sired by test station bulls.

Breed	# of bulls	# of herds	# of progeny
Charolais	14	7	172
Hereford	6	7	114
Maine Anjou	5	2	98
Salers	1	1	1
Shorthorn	4	2	50
Simmental	7	4	85
Total	37	23	520

<u>Statistical Analysis.</u>

Several statistical models were constructed to analyze the data for pelvic dimensions and growth traits. The basic model included station, year and breed groups as the main effects and their interactions (all assumed to be fixed). Age and weight at time of measuring pelvic dimensions were included separately in the models as covariates. Due to the small sample size for some breeds, the animals were reallocated into three breed groups for the analysis. This was to reduce heterogeneity of regression coefficients of pelvic area on age and weight among breeds. The criterion of our grouping was based on the relative size (as measured by growth performance) of the animals, and was as follows: Breed group 1 consisted of Charolais, Maine Anjou and Simmental - these are the large exotic European beef cattle breeds with a total of 2070 bulls; Breed group 2 consisted of Angus, Shorthorn and Hereford the traditional beef cattle breeds of North America and comprised a total of 710 bulls; Breed group 3 was composed of the remaining less popular exotic breeds, the Tarantaise, Blonde d'Aquitaine, Salers, Pinzgauer, Limousin and Gelbveih breeds and consisted of 511 bulls.

Analysis of variance was done by the general linear models procedure for unbalanced data of the statistical analysis systems (SAS, 1988). The model was as follows:

$$Y_{ijkl} = \mu + S_i + Yr_j + BG_k + \text{all two way and three way interactions} + b_1X_{ijkl}$$
$$+ b_2X_{ijkl}^2 + \text{interaction of age or weight of bull with all main effects} + \varepsilon_{ijkl}$$

Y_{ijkl} = is the dependent variable, i.e. pelvic dimensions, birth weight, start of test weight, test gain, end of test weight and back fat thickness.

μ = overall mean

S_i = effect of the i^{th} station on pelvic area i= 1,2,3;

Yr_j = effect of the j^{th} year on pelvic area j=1,2,3,4;

BG_k = effect of the k^{th} breed group on pelvic area k=1,2,3;

b_1 = linear regression of the dependent variable on age or weight;

b_2 = quadratic regression of the dependent variable on age or weight;

X_{ijkl} = age or weight of the l^{th} bull.

ε_{ijkl} = residual effect of the l^{th} bull.

The model using weight as a covariate was used to study the association of bull size and pelvic dimensions but it was not used in further analysis because weight has a genetic component correlated to pelvic area (Bourdon and Brinks 1986). Since we wanted to adjust for variation due to environmental factors, age was used as the covariate for subsequent analyses. The quadratic effect of age at time of measuring pelvic dimensions and its interaction with the main effects was found to be non-significant ($P > 0.05$) and was therefore removed from the model. The three way interaction of year by station by breed group was found to be non-significant ($P > 0.05$) and therefore removed from the model. Calving ease of bulls was also tested in this model as an independent variable to find out if pelvic area of a bull was related to it's own calving ease.

Because of the unbalanced nature of our data set as shown in Table 4, the above

Table 4. Data structure of pelvic area measurements of test station bulls.

Breed group	Station	Year			
		1988	1989	1990	1991
1	1	382	455	363	348
	6	58	76	77	
	7		136		175
2	1	188	115	104	117
	6	6	33	8	
	7		81		58
3	1	18	74	77	79
	6	31	67	34	
	7		70		61
Total		683	1107	663	838

model was further modified to allow estimation of least square means of pelvic dimensions and performance traits. The modification involved combining the individual effects of station and year into a single effect denoted as station-year effect.

$$Y_{ijk} = \mu + Styr_i + BG_j + StyrBG_{(ij)} + bX_{ijkl} + c_jX_{ijkl} + \varepsilon_{ijk}$$

The residuals from the above model represent bull records adjusted for environmental effects (of station, year and age) and brought to a common average for all breed groups. These adjusted records were matched with their home test records (907 bulls as mentioned previously).

Correlations were then calculated for adjusted pelvic dimensions and growth traits with the expected progeny differences (EPD's) of the bulls for ease of calving, maternal calving ease and EPD's for growth traits to see if there was an association of pelvic measurements and growth traits of bulls with growth and calving ease EPD's.

Further analyses were carried out to determine the value of a bull's calving ease record and its adjusted pelvic dimensions, birth weight or end of test weight in predicting calving ease of it's progeny. These analyses were done using data shown in Table 3. Each trait of interest of the bulls were divided into three categories of small, medium and large. Animals with small measurements were those whose measurements were one standard deviation less than the mean, while medium were those animals with measurements between -1 and +1 standard deviations of the mean and large measurements denoted animals larger than +1 standard deviation above the mean. The distribution of calving ease categories of a bull's progeny given his own category for each trait of interest was evaluated. A logistic regression procedure (Hosmer and

Lemeshow, 1989) was used to find out if calving ease, pelvic dimensions, birth weight or end of test weight category of bull's significantly affected the calving ease outcomes of their progeny. The procedure was used because it best describes the relationship between our response variable, which is the calving ease of progeny of bulls, and the observed performance of bulls as the predictor.

RESULTS AND DISCUSSION

Means and standard deviations of various factors measured on test station bulls averaged across breeds are presented in Table 5. The average gain on test across breeds was found to be 236 kg which translates to about 1.68 kg day^{-1} as the average daily gain (ADG). This is in agreement with findings of Brown et al. (1990) who reported a mean ADG range of 1.03 to 1.70 kg day^{-1} in a study consisting of thirteen breeds of beef cattle.

Johnson and Deutscher (1985) reported a mean pelvic area of 172 cm^2 for bulls weighing between 400 and 500 kg, while Siemens et al. (1991) found a mean pelvic area of 166 cm^2 for yearling bulls. These findings are lower than our findings of 182 cm^2. The possible reason for this difference could be attributed to the fact that the bulls studied here averaged nearly 600 kg at the end of test. Test stattion bulls are a selected group of animals for growth and this advantage for growth could have been also reflected in pelvic size unlike the above mentioned studies which concerned experiment station herds not specifically selected for growth.

Pelvic heights and widths of the bulls analyzed here also averaged less than those found by Morrison et al. (1986) for heifers. However in a study by Benyshek and Little (1982) that involved both bulls and heifers, the average pelvic dimensions were found to be 13.9 cm and 12.3 cm for height and widths respectively, which closely agrees with our findings.

Means of expected progeny differences (EPD's) for calving ease and growth traits and their accuracies are shown in table 6. These show that most of the bulls tested on the

Table 5. Means of variables measured on test station bulls.

Variable	N	Mean	Std. Dev.
Parea (cm^2)	3291	182.26	22.50
Pelhgt (cm)	3291	14.12	1.05
Pelwdt (cm)	3291	12.88	0.96
Swt (kg)	3291	358.04	48.79
Bwt (kg)	3291	44.46	4.31
Ewt (kg)	3285	594.29	63.26
Tgain (kg)	3285	236.29	30.35
BF (mm)	3285	3.94	2.17
Agedel (days)	3291	219.28	22.29
Agesot (days)	3291	252.27	22.58
Ageeot (days)	3291	392.18	22.62
Agepe (days)	3291	382.42	22.53

Table 6. Means of Expected Progeny Differences of bulls and their accuracies

Variable	N	Mean	Std. deviation
EPDCE	1009	0.04	0.97
EPDMCE	1009	-0.01	0.73
EPDWG	1009	4.63	7.06
EPDMWG	1009	0.55	4.39
EPDYG	1009	8.22	12.32
ACCCE	1009	15.10	14.09
ACCMCE	1009	10.04	10.83
ACCWG	1009	27.05	22.71
ACCMWG	1009	15.26	14.48
ACCYG	1009	22.91	20.22

test stations were near the national average of zero for calving ease EPD's. The mean EPD's for weaning gain and yearling gain of the bulls were 4.63 and 8.22 kgs, an indication that these animals represented a group selected for growth and therefore had growth capacities higher than their contemporaries in the national herd.

Accuracies for the various EPD's was relatively low, the highest being for weaning gain with an accuracy of 27%. The reason for this could be that most bulls in our study were relatively young and could not have had a large number of progeny for EPD assessment, therefore resulting in low accuracies.

Incidence of dystocia in station tested bulls

According to a study reported by Laster et al. (1973) the proportion of births classified as difficult, that is those requiring surgical intervention or the use of a mechanical puller, ranged from 12% for Jersey sired calves to about 74% for those sired by Limousin. This was so even though calves from Limousin sires were lighter than those from Charolais and Simmental indicating that factors other than birth weight could be responsible for the varied incidence of calving ease observed among the different breeds.

In our study involving twelve breeds of cattle only ten of the breeds exhibited some degree of dystocia (Table 7). Two of the breeds that did not have calving ease records were the Tarantaise and the Pinzgauer. These two breeds were represented by twelve and thirteen animals respectively. The average incidence of dystocia across breeds was about 13% which was slightly below other findings in the

Table 7. Incidence of dystocia for the different breeds among station tested bulls.

BREED	HE	CH	SM	MA	LM	SS	AN	GV	BD	SA	TOTAL	%
N	271	368	101	54	42	51	15	3	6	23	934	
Unassisted	226	335	74	48	42	45	14	3	6	22	815	87.26
Easy Pull	30	21	24	6	0	3	0	0	0	0	84	8.99
Hard Pull	1	5	1	0	0	1	1	0	0	0	9	0.96
Surgical	4	4	1	0	0	0	0	0	0	0	9	0.96
Malpresented	10	3	1	0	0	2	0	0	0	1	17	1.82
TOTAL DYSTOCIA	45	33	27	6	0	6	1	0	0	1	119	12.74

literature. Van Donkersgoed (1990) reported an incidence of dystocia ranging from 15-34%, while Morrison et al. (1985) and Cue (1990) found rates of about 23%. The reason for the low incidence recorded in our study could have been due to the fact that only about 30% of the animals had any recording of their degree of calving ease, and it is possible that some difficult calvings were unreported. This could have led to the low incidence of dystocia that was reported in our study.

On an individual breed basis the Simmental, Hereford and Charolais had an average incidence of dystocia of 27%, 17%, and 9% respectively. These differences among breeds would include true breed differences as well as effects of low levels of reporting. This is in agreement with what Laster et al. (1973) and Monteiro (1969) who reported that there are breed differences in the occurrence of dystocia because of physiological differences between breeds during the process of parturition.

When test station bulls were grouped into three breed groups as mentioned in the Materials and Methods, the incidence of dystocia did not differ much between breed groups 1 and 2 but breed group 3 had substantially fewer recordings of calving ease possibly because this group consisted of the less popular breeds of cattle (Table 8). Hard pull and surgical assistance accounted for about 1% each of the total incidence of dystocia, while malpresentation and easy pull accounted for about 2% and 9%, respectively, and the rest of the births were unassisted.

Table 8. Incidence of dystocia in test station bulls for the different breed groups.

BREED	BG 1	BG 2	BG 3	TOTAL	%
N	523	337	74	934	
Unassisted	457	285	73	815	87.26
Easy pull	51	33	0	84	8.99
Hard pull	6	3	0	9	0.96
Surgical	5	4	0	9	0.96
Malpresented	4	12	1	17	1.82
Total dystocia	66	52	1	119	12.74
% Dystocia in BG	12.6	15.4	1.3	12.74	

<u>Sources of variation.</u>

Station and year were significant factors affecting pelvic area ($P < 0.01$) and accounted for about 7% and 10% of the variation in pelvic areas of bulls respectively (Table 9). This is an indication that pelvic areas of bulls were different between stations and between years. This difference could have been due to differences in management of bulls between stations and the environmental differences from year to year. This is in agreement with the findings of Neville et al. (1978) who reported that pelvic dimensions are affected by differences in management during the growth period. Breed group effect was not significant ($P > 0.05$) as a main effect but its interaction with station and year were significant ($P < 0.05$) an indication that pelvic areas of different breed groups were not similar between stations or between years. This outcome could have been due to breeds not responding the same to management at various stations and environments across years.

Age also had a significant effect on pelvic areas of bulls ($P < 0.01$), an indication that animals of different ages had different pelvic areas. This is an expected outcome because animals of different ages are at various stages of skeletal development and growth and should therefore exhibit differences in pelvic sizes. This is in agreement with the findings of Siemens et al. (1991) and Wolverton et al. (1990b). Age by breed group interaction was also found to be significant ($P < 0.05$) an indication that there were differences in growth rates of pelvic areas of bulls in different breed groups.

Random error accounted for more than 75% of the variation in pelvic areas, an indication that there were large differences in pelvic areas between test station bulls that

Table 9. Analysis of variance for pelvic areas of test station bulls using age as the covariate.

Source	DF	% Sums of squares	F value
Station	2	7.0	148.60**
Year	3	10.2	143.69**
BG[1]	2	0.1	2.22
Station*Year	3	0.3	4.03**
Year*BG	6	0.4	2.53*
Station*BG	4	0.4	3.70**
Agepe	1	4.3	180.13**
Agepe*BG	2	0.2	3.73*
Error	3267	77.2	
Total	3290		

** $P < 0.01$ * $P < 0.05$

[a] Sums of squares of each factor expressed as a percentage of the total.
[1] Breed group.

could not be accounted for by the effects included in our model. When ease of calving was included in the model, it did not have an effect on pelvic area, an indication that pelvic areas of bulls was not related to the ease with which they were born (Table 10).

Results for pelvic height and width are shown in Tables 11 and 12, respectively. Many of the same factors and their interactions affected both of these measurements, but there were important differences as well. Station effects for example, were a very significant source of variation for pelvic height but less so for pelvic width. Year was a significant factor for both measurements as was its interaction with station and breed group. Regressions on age were affected by breed group for pelvic width, but not for pelvic height.

The analysis for birth weight is shown in Table 13. The same model used to analyse other traits was used for birth weight even though few of the effects responsible for variation in the test station traits could have been acting at time of birth. Station effects were important and may indicate an effect of the region from which the bulls were drawn in the province. The interaction of station and breed group was also significant and indicate that breeds may have behaved differently from region to region for birth weight. Age of bull exerted an effect as well as an interaction with breed group. This is not a true age effect but may be due to the effect of date of birth during calving season on birth weight.

As for growth parameters measured at the test station, start of test weight (Table 14), test gain (Table 15), end of test weight (Table 16) and back fat thickness (Table 17), most of the effects that were significant for pelvic area were also significant for

Table 10. Analysis of variance of pelvic area of bulls with calving ease included in the model.

Source	DF	% Sum of squares[a]	F Value
Rce[1]	2	0	0.20
Station	2	7.9	48.05**
Year	3	7.8	31.43**
BG	2	1	6.30**
Rce*BG	2	0	0.29
Station*Year	3	0.4	1.77
BG*Station	4	1.2	3.78**
BG*Year	6	1.2	2.47*
Agepe	1	7.6	91.59**
Error	881	72.7	
Total	906		

[a] Sums of squares of each factor expressed as a percentage of the total.

** $P < 0.01$ * $P < 0.05$

[1] Ease of calving

Table 11. Analysis of variance for pelvic heights of test station bulls.

Source	DF	% Sums of squares[a]	F value
Station	2	14.9	317.58**
Year	3	3.5	49.68**
BG[1]	2	0	1.11
Station*Year	3	1.4	19.72**
Year*BG	6	0.5	3.41**
Station*BG	4	0.4	4.42**
Agepe	1	2.4	102.68**
Agepe*BG	2	0	0.79
Error	3267	76.8	
Total	3290		

** $P < 0.01$ * $P < 0.05$

[a] Sums of squares of each factor expressed as a percentage of the total.
[1] Breed group.

Table 12. Analysis of variance for pelvic width of test station bulls.

Source	DF	% Sums of squares[a]	F value
Station	2	0.3	6.2**
Year	3	11.6	156.83**
BG[1]	2	0.1	2.87*
Station*Year	3	3.1	42.47**
Year*BG	6	0.3	2.34*
Station*BG	4	0.3	2.90**
Agepe	1	3.4	138.66**
Agepe*BG	2	0.3	5.55**
Error	3267	80.5	
Total	3290		

** $P < 0.01$ * $P < 0.05$

[a] Sums of squares of each factor expressed as a percentage of the total.
[1] Breed group.

Table 13. Analysis of variance for birth weight of test station bulls.

Source	DF	% Sums of squares[a]	F value
Station	2	1.3	20.81**
Year	3	0.1	0.84
BG	2	0.1	1.36
Station*Year	3	0	0.21
Year*BG	6	0.2	1.53
Station*BG	4	1.1	8.95**
Agepe	1	0	0.96
Agepe*BG	2	0.3	4.47*
Error	3267	96.7	
Total	3290		

** $P < 0.01$ * $P < 0.05$

[a] Sums of squares of each factor expressed as a percentage of the total.

Table 14. Analysis of variance for start of test weight of test station bulls.

Source	DF	% Sums of squares[a]	F value
Station	2	3.6	86.02**
Year	3	0.1	1.85
BG[1]	2	0.4	8.71**
Station*Year	3	0.7	11.29**
Year*BG	6	0.3	2.6*
Station*BG	4	0.9	10.47**
Agepe	1	23.9	1127.73**
Agepe*BG	2	0.7	15.87**
Error	3267	69.3	
Total	3290		

** $P < 0.01$ * $P < 0.05$

[1] Breed group.

[a] Sums of squares of each factor expressed as a percentage of the total.

Table 15. Analysis of variance for test gain of test station bulls.

Source	DF	% Sums of squares[a]	F value
Station	2	1.0	18.16**
Year	3	6.1	72.61**
BG[1]	2	0.1	2.22
Station*Year	3	0.6	7.64**
Year*BG	6	0.2	1.31
Station*BG	4	0.3	2.88*
Agepe	1	0	0.32
Agepe*BG	2	0.2	3.62*
Error	3267	91.3	
Total	3290		

** $P < 0.01$ * $P < 0.05$

[a] Sums of squares of each factor expressed as a percentage of the total.
[1] Breed group.

Table 16. Analysis of variance for end of test weight of test station bulls.

Source	DF	% Sums of squares[a]	F value
Station	2	4.1	88.81**
Year	3	2.2	32.23**
BG[1]	2	0.3	8.53**
Station*Year	3	0.1	13.70**
Year*BG	6	0.2	1.66
Station*BG	4	0.1	10.19**
Agepe	1	15.7	664.41**
Agepe*BG	2	0.7	16.07**
Error	3267	75.1	
Total	3290		

** $P < 0.01$ * $P < 0.05$

[a] Sums of squares of each factor expressed as a percentage of the total.
[1] Breed group.

Table 17. Analysis of variance for back fat thickness of test station bulls.

Source	DF	% Sums of squares[a]	F value
Station	2	0.1	317.58**
Year	3	4.2	49.68**
BG[1]	2	0	1.11
Station*Year	3	10.4	19.72**
Year*BG	6	1.4	3.41**
Station*BG	4	0	4.42**
Agepe	1	0	102.68**
Agepe*BG	2	0	0.79
Error	3267	81.5	
Total	3290		

** $P < 0.01$ * $P < 0.05$

[a] Sums of squares of each factor expressed as a percentage of the total.
[1] Breed group.

performance traits ($P < 0.05$). These models were also used to adjust for differences in performance parameters for the effects included in the model. Least square means of the performance traits for the different breed groups and station years are represented in Appendix Tables 1 to 8. These performance traits will not be discussed in detail because the emphasis of this work is pelvic dimensions.

Before arriving at this model several other models were fitted to test the significance of various variables and their interactions in the model. These models used breeds instead of the breed groups and also included age or weight as covariates, and their interaction with the main effects. Similar models were then tested using breed groups instead of individual breeds.

After removing most of the non-significant ($P > 0.05$) effects the final model contained station, year and breed group effects with interactions of breed with age as the covariate. A similar model using weight as the covariate was not used because interaction of breed group and weight was not significant ($P > 0.05$) (Appendix table 9) .

Due to the nature of our bull data structure, where certain breed groups were not represented in certain stations during certain years, the effects of station and year were combined into one factor, station-year for subsequent analysis as shown in Appendix Tables 10, 11 and 12 .

<u>Growth rate of pelvic area</u>

Pelvic area of bulls has been shown to have a linear relationship with age and weight of animals (Johnson and Deutscher 1986). In the present study, single measurements of pelvic area were taken for animals of varying ages and weights and the regression coefficients were determined for the different breeds. These give an indication of the growth rates of the pelvic areas of bulls of different breeds in relation to their age or weight pooled across years and stations. The weight coefficients ranged from 0.01 cm^2 kg^{-1} for the Tarantaise to 0.21 cm^2 kg^{-1} for the Blonde d'Aquitaine as shown in Table 18. This is quite a large range and the reason for some of these outcomes could be due to the small sample size in some breeds, therefore not being a representative sample of their breeds. This is particularly true for the Tarantaise and the Pinzgauer which were represented by 13 and 12 animals respectively. Their regression coefficients were also not significant different from zero ($P > 0.05$). The rest of the breeds which had substantial numbers showed a significant ($P < 0.01$) relationship of pelvic area with age or weight except for the Blonde d'Aquitaine which was represented by 27 animals whose coefficient for weight was significant at $P < 0.05$ level. Siemens et al. (1991) reported weight regression coefficients of 0.15, 0.22 and 0.18 cm^2 kg^{-1} for Angus, Hereford and Simmental respectively.

As for the regression of pelvic area regression on age the coefficients ranged from 0.11 cm^2 Day^{-1} for the Limousin to 0.46 cm^2 day^{-1} for the Blonde d'Aquitaine (Table 19). Again all of the coefficients were found to be significant ($P < 0.01$) except for the Tarantaise, Shorthorn, Pinzgauer and Limousin which were found to be non-significant ($P > 0.05$). Siemens et al. (1991) in a study of Angus, Hereford and Simmental found regression coefficients of pelvic area on age of 0.20, 0.32 and 0.20 cm^2 day^{-1} respectively.

Table 18. Regression coefficients for pelvic area on weights of test station bulls.

Breed	N	Weight Coeff. $cm^2\ kg^{-1}$.	Std. Error
Angus	120	0.09**	0.03
Blonde d'Aquitaine	27	0.21*	0.08
Charolais	1333	0.14**	0.01
Gelbvieh	113	0.18**	0.03
Hereford	498	0.16**	0.02
Limousin	178	0.14**	0.03
Maine Anjou	110	0.12**	0.03
Pinzgauer	12	0.16	0.09
Salers	168	0.11**	0.03
Simmental	627	0.15**	0.01
Shorthorn	92	0.17**	0.04
Tarantaise	13	0.01	0.11

** $P < 0.01$ * $P < 0.05$

Table 19. Regression coefficients for pelvic area on age of test station bulls.

Breed	N	Age coeff. $cm^2\ d^{-1}$	Std Error
Angus	120	0.17^{**}	0.07
Blonde d'Aquitaine	27	0.46^{**}	0.17
Charolais	1333	0.24^{**}	0.02
Gelbvieh	113	0.38^{**}	0.09
Hereford	498	0.26^{**}	0.04
Limousin	178	0.11	0.06
Maine Anjou	110	0.34^{**}	0.09
Pinzgauer	12	0.44	0.56
Salers	168	0.17^{**}	0.06
Simmental	627	0.27^{**}	0.03
Shorthorn	92	0.12	0.09
Tarantaise	13	0.13	0.36

** $P < 0.01$ * $P < 0.05$

When the bulls were grouped as described in the materials and methods the weight and age regression coefficients for pelvic area on weight or age were all significant ($P < 0.01$) and different from one another and are shown in Figure 4. Grouping the breeds absorbed some of the effects of samples that were not representative of the populations from which they were derived. The average for the regression coefficients is in close agreement with the findings of Siemens et al. (1991) who found an average of 0.21 $cm^2\ day^{-1}$ for age coefficients while weight coefficients were 0.15 $cm^2\ kg^{-1}$ for the combined breeds. This is also in close agreement with the findings of Deutscher (1988a) and Neville et al. (1978).

It is quite evident from our study that breed group 1 had the highest growth rate relative to age followed by breed group 2 and lastly breed group 3. This is to be expected because breed group 1 comprised the large, faster maturing breeds as described by Brown et al. (1982) of Charolais, Maine Anjou and Simmental. This result is also in agreement with the findings of Neville et al. (1978) who suggested that growth patterns were different between breeds of beef cattle and differences in management and feeding regimes during growth affect growth patterns of pelvic dimensions. The regressions of pelvic area on weight breed groups were not significantly different ($P > 0.05$). This suggests that pelvic area may represent a relatively constant proportion of body size, at least for the range of body sizes of the breeds in this study.

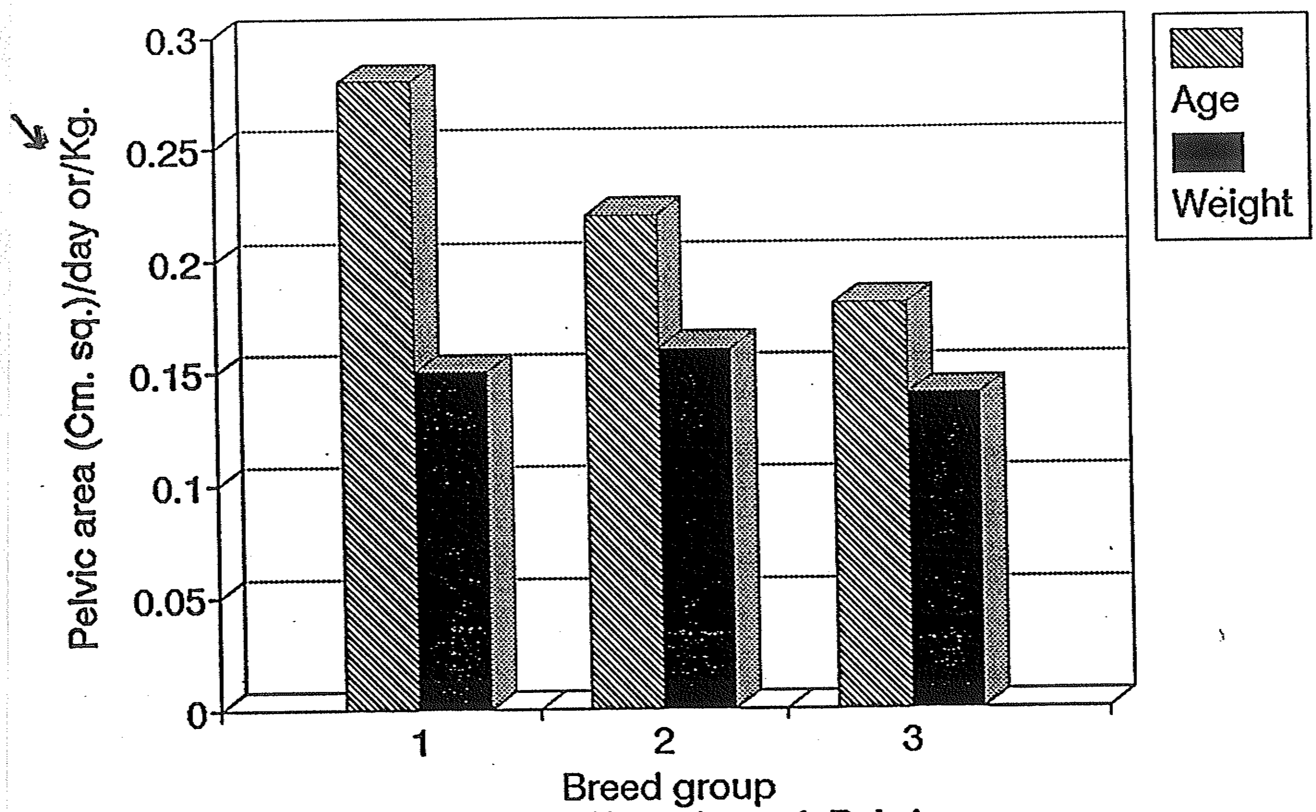

Figure 4. Growth rates of Pelvic areas for age and weight of the breed groups

(S.E. for age was 0.017 to 0.036 while that for weight was 0.007 to 0.016)

<u>Breed and environmental effects on pelvic area.</u>

Least square means for the pelvic areas of various breed groups are shown in Figure 5. It is again evident that breed group 1 had the largest mean pelvic area followed by breed group 3 and lastly breed group 2. Breed group 1 comprising the larger frame sized breeds and was expected also to possess a larger skeletal size which could be reflected in larger pelvic areas. This is in agreement with the findings of Laster (1974) and Price and Wiltbank (1978b) who postulated that body weight is the most important factor affecting pelvic area, with larger cows having larger pelvic openings.

Breed group 2 comprised the traditional British beef breeds (Hereford, Angus and the Shorthorn) which are relatively smaller than the Continental European breeds that make up breed group 1. As for breed group 3 which was a mixture of less common European Continental breeds, their mean pelvic area measurements were larger than for the British breeds (breed group 2).

Least square means of pelvic areas for the three breed groups for the various station-years are represented in Figure 6. Breed group interaction with management and environments of the various station-years was a significant factor ($P < 0.05$) in determining pelvic size but did not have a large effect. It can be seen that breed group 1 has consistently larger pelvic areas followed by breed group 3 and lastly breed group 2. Breed groups ranked the same for pelvic size in all but one station-year.

Pelvic area means averaged across breed groups for the various years within stations showed that pelvic area means varied from year to year within stations (Figure 7). This difference could have been due to the different management systems from year

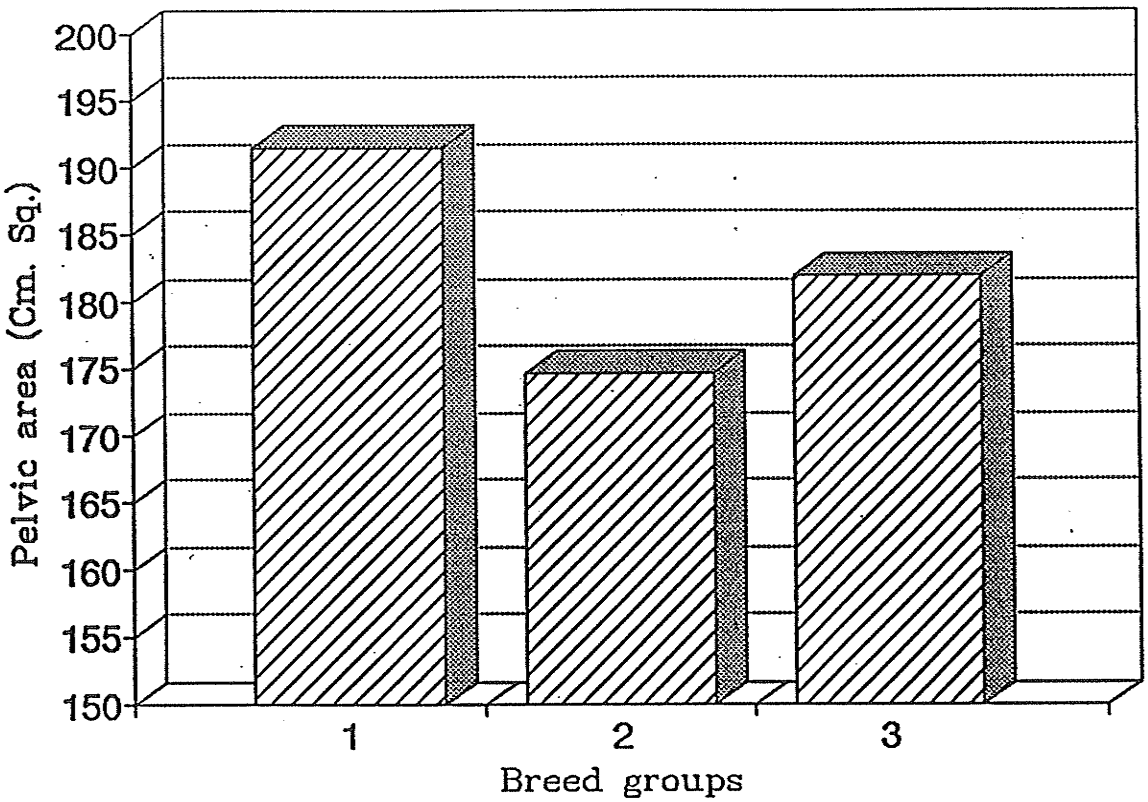

Figure 5. Pelvic area means for different breed groups

(S.E. of breed group means ranged from 0.5 to 1.2 Cm. Sq.)

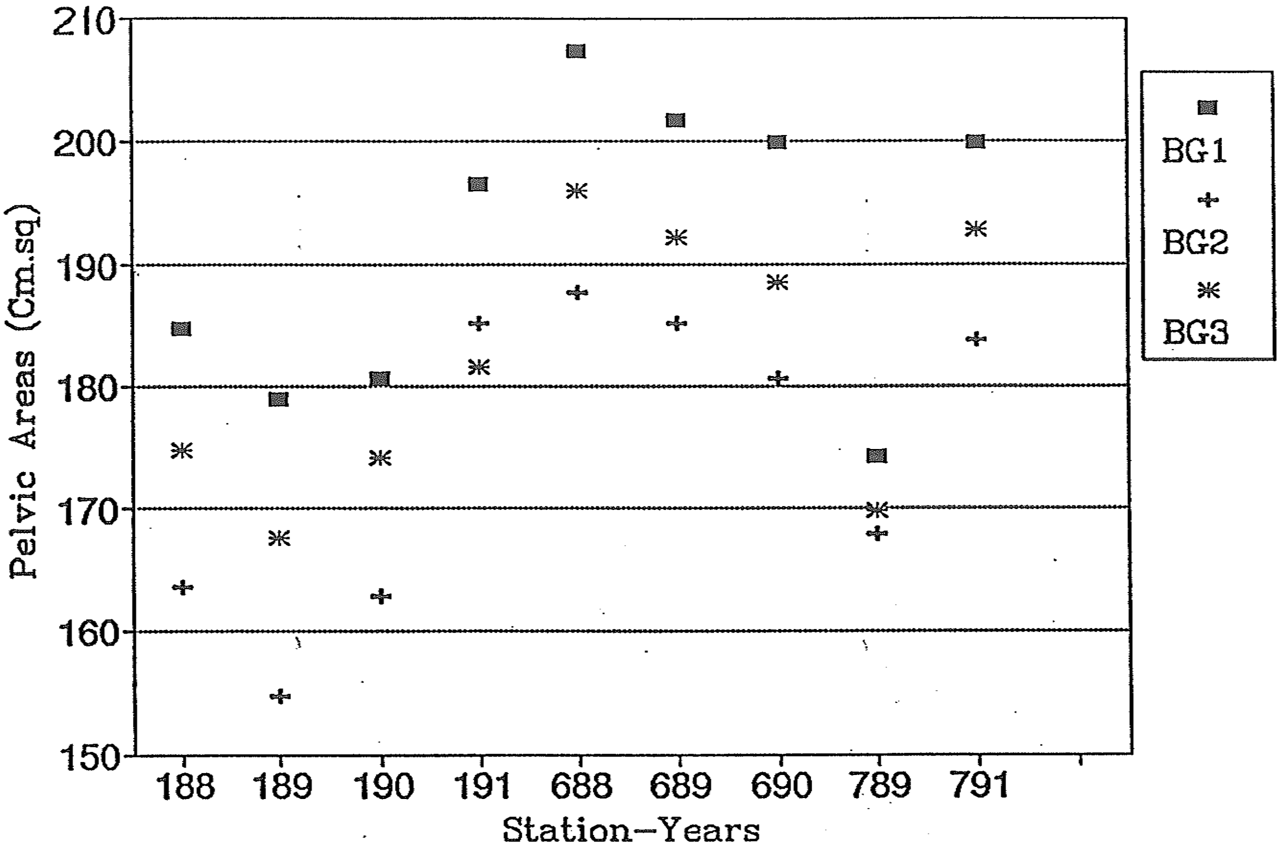

Figure 6. Pelvic Area Means for Station-Years for the Breed Groups
(S.E. ranged from 0.91 to 7.2 cm sq)

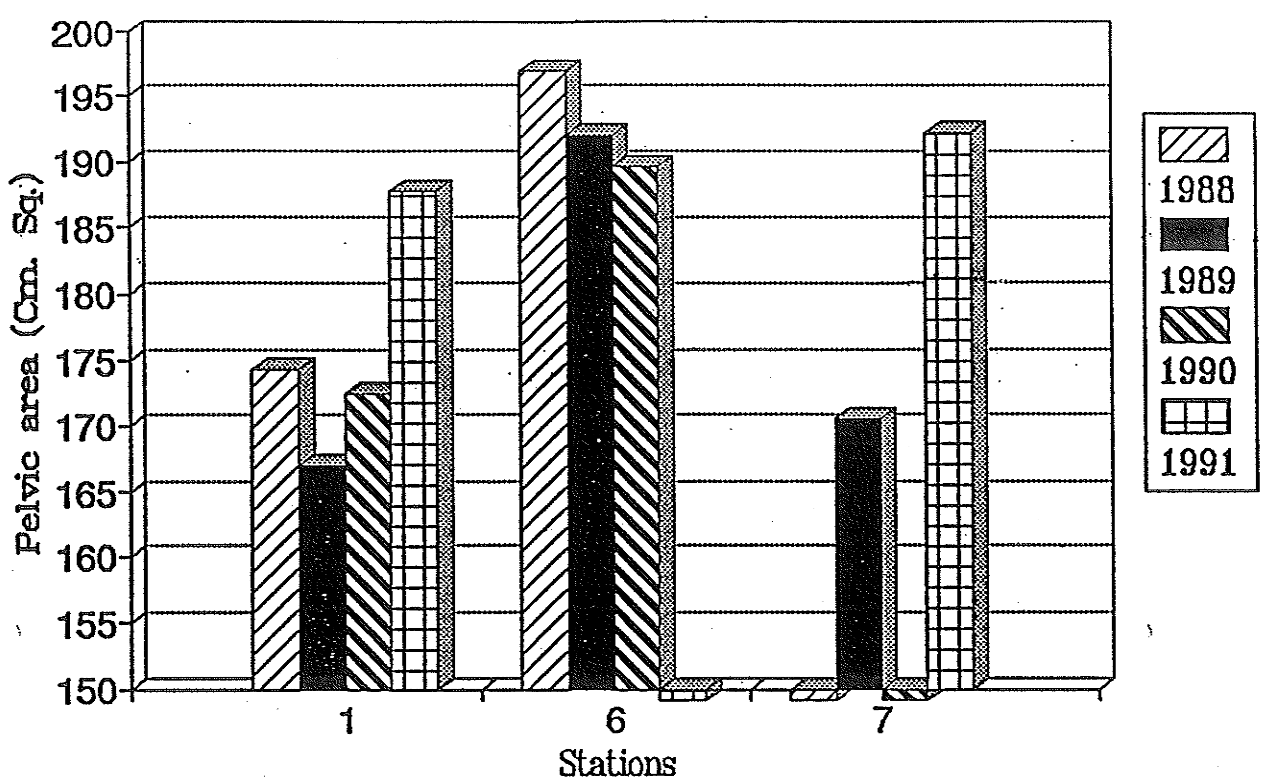

Figure 7. Pelvic area Means for various station years

(S.E. ranged from 0.92 to 2.75 Cm. sq.)

to year coupled with differences in environmental effects between years. Station 6 (Roblin) consistently showed larger pelvic areas for all the years of test as compared to the other stations. This could be an indication of either a favourable locality or better management as compared to the other stations.

The same trend was observed for pelvic heights and widths for the various years in the individual stations (Figures 8 and 9). This is expected because these are the two components from which pelvic areas are derived. In conclusion our results are in agreement with the findings of Neville et al. (1978) who found differences in pelvic dimension growth patterns between locations and between breeds within locations.

Correlation coefficients of characters studied.

Correlations are a measure of degree of association between two metric characters. There are two causes of correlation between characters, these are genetic and environmental causes. Phenotypic correlation is the association between two characters that are directly observable and comprises of the two causes of correlations mentioned. The genetic cause of correlation is basically due to pleiotropy, which is a property of genes affecting two or more characters and causes simultaneous variation (negative or positive) in the affected characters. Genetic correlation is important in selection because it can help us understand how improvement in one character influences its associated character through correlated response. The degree of genetic association expresses the extent to which the two characters are influenced by the same genes while the

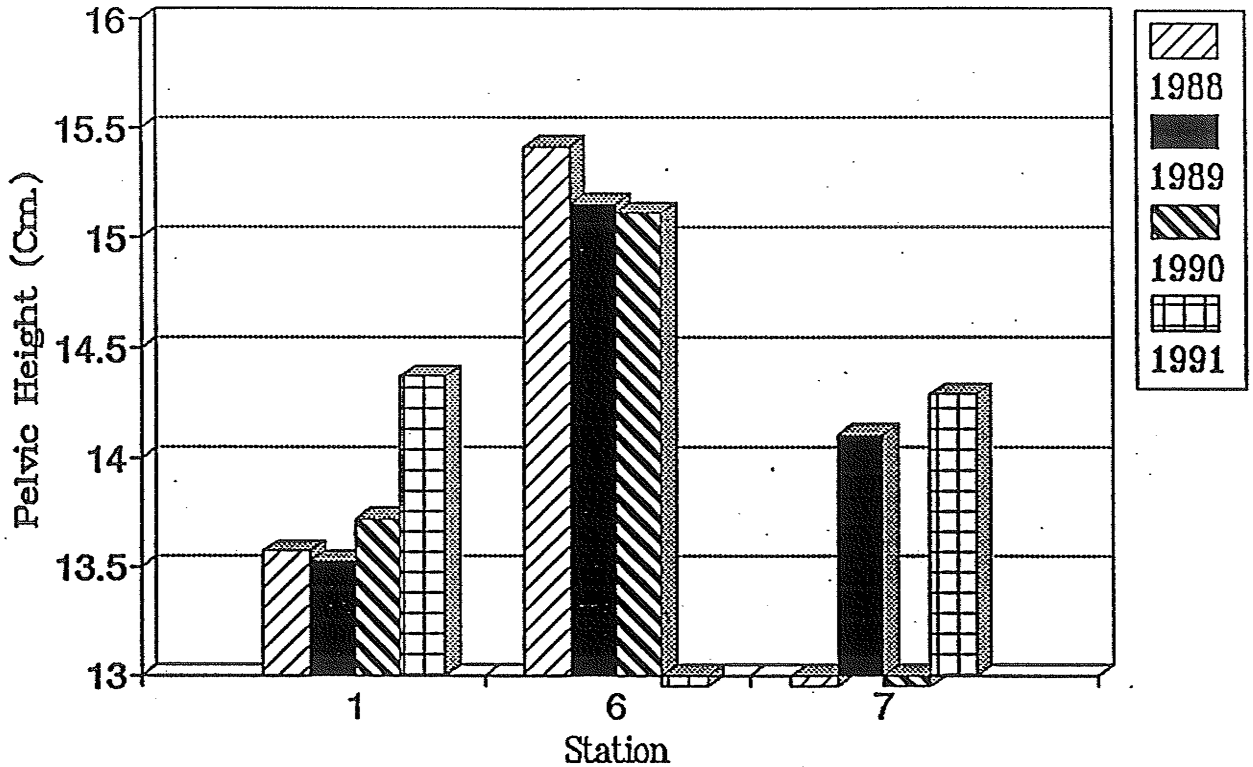

Figure 8. Pelvic heights for the Various Station-Years
(S.E. ranged from 0.04 to 0.13 cm)

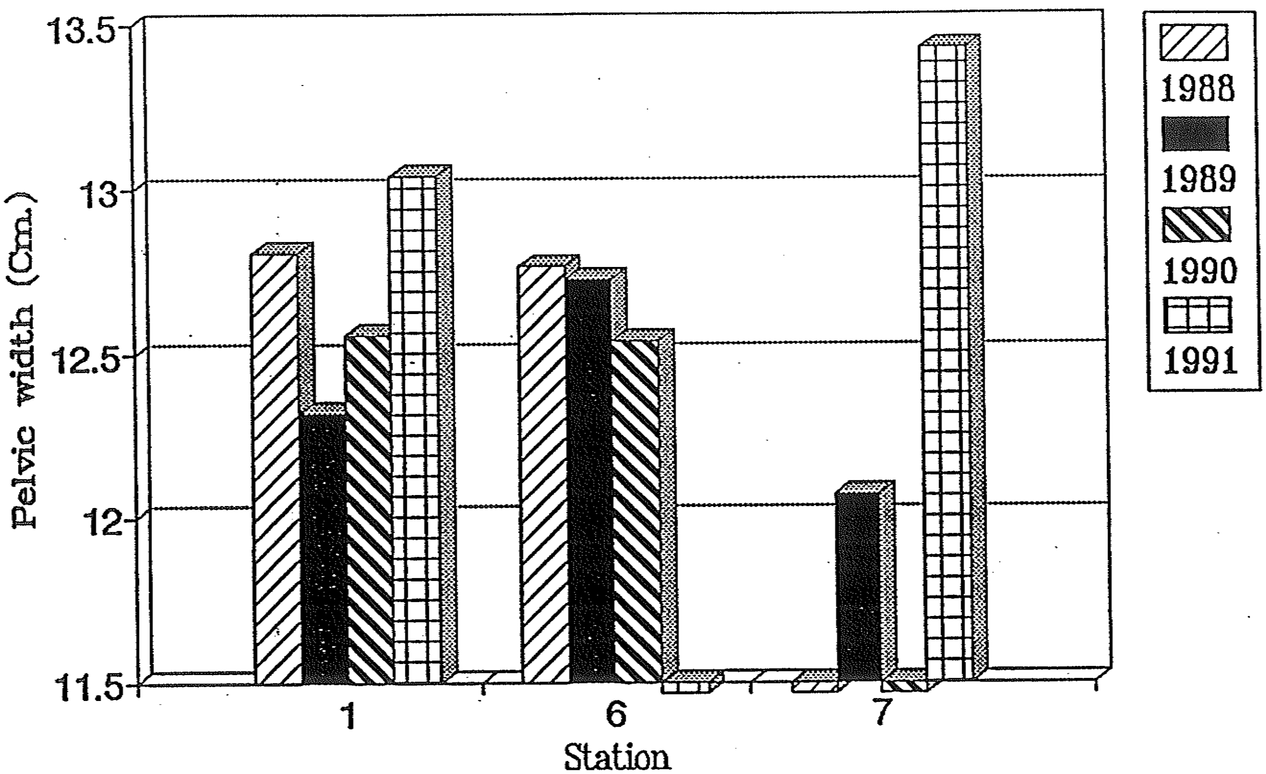

Figure 9. Means of pelvic widths of station bulls for various Station–Years
(S.E. ranged from 0.04 to 0.12)

environmental correlation is an indication of how the two characters are influenced by the same environmental conditions.

Phenotypic correlation is normally calculated by the formula below:

$$r_p = \frac{Cov_p}{\sigma P_x * \sigma P_y}$$

Cov_p Phenotypic covariance.

σP_x Standard deviation of character x.

σP_y Standard deviation of character y.

In general if both characters have low heritability then the phenotypic correlation is determined mainly by the environmental correlation and if heritabilities are high then the main component of the phenotypic correlation is genetic (Falconer 1989).

Phenotypic correlations for growth traits and pelvic dimensions were calculated and are shown in Table 20. End of test weight and test gain had significant ($P < 0.001$) correlations with all the pelvic dimensions of area, height and width, an indication that animals which were large in size and gained favourably on test also had larger pelvic dimensions. Pelvic area had highest phenotypic correlation with end of test weight than any of the other growth traits. This is probably because end of test weight was measured near the time when pelvic dimensions were also measured. Larger bulls as measured by higher body weight should thus have larger pelvic openings. If the genetic correlation is also positive then direct selection for growth should result in bulls with larger pelvic area which can be passed onto female offspring. Our findings are in close agreement with the

Table 20. Correlations of growth traits with pelvic dimensions of test station bulls (N=3291).

	BWT	SWT	EWT	TGAIN	PELHGT	PELWDT	PAREA	BF
BWT	1	0.2**	0.23**	0.13**	0.05*	0.02	0.04[a]	-0.02
SWT		1	0.79**	0.05**	0.18**	0.24**	0.26**	0.19**
EWT			1	0.65**	0.22**	0.28**	0.31**	0.21**
TGAIN				1	0.13**	0.16**	0.18**	0.11[a]
PELHGT					1	0.3**	0.81**	-0.03[a]
PELWDT						1	0.8**	-0.04*
PArea							1	-0.05*
BF								1

** $P < 0.001$ * $P < 0.01$ [a] $P < 0.05$

findings reported by Johnson and Deutscher (1986) and Morrison et al. (1986) in studies involving yearling bulls. Birth weight, however had a lower association with pelvic area implying that phenotypic effects on pelvic area and birth weight were not similar.

Although most of these associations were significant, their magnitude is small. A possible reason for this outcome is that growth measured by weight represents fat, protein and bone tissue while pelvic area measures are indicative of skeletal growth only, therefore the correlations are bound to be low because these tissue have different growth patterns.

Pelvic height and pelvic width had a significant positive association ($P < 0.001$) with each other suggesting that an increase in one measure results in a similar increase in the other. This seems logical because these are different measures of the same structure. Our findings are in agreement with those reported by Benyshek and Little (1982) and Morrison et al. (1986) who found phenotypic correlations of about 0.35. There were large phenotypic correlations of pelvic height and width with pelvic area as would be expected because pelvic area is simply the product of these two measures. Pelvic width had higher correlation to growth traits than pelvic height. This could possibly be due to the fact that pelvic width is the more easier measure to obtain and thus has a higher accuracy and repeatability than pelvic height (Wolverton et al 1990a).

Birth weight showed a significant phenotypic relationship with start, end of test weight and test gain (Table 20). This is an indication that heavier animals at birth tend to gain faster on test and also have higher end of test weights. It is thus interesting to note that correlation of birth weight and pelvic area was so low when pelvic area had relatively high correlations with the other growth traits. Associations between postnatal growth characteristics tended to be large as would be expected because they are basically measurements of the same thing taken at various stages of development.

An interesting outcome is the negative phenotypic correlation of back fat thickness with pelvic measures indicating that as backfat thickness increases pelvic dimensions decrease progressively. This could be due to the accumulation of fat in the pelvic region resulting in a constricted pelvis with a higher risk of dystocia. This is in agreement with the findings of Benyshek and Little (1982) and Bellows (1989).

The expected progeny differences (EPD's) for growth indicate how the progeny of a sire are expected to compare to the progeny of a breed average sire for growth. These values therefore provide useful comparisons for given traits for animals of the same breed and serve as useful selection tools in breeding programs. Correlation coefficients were calculated for pelvic measures and EPD's for growth traits of test station bulls as shown in Table 21. These correlations have a different interpretation from the phenotypic correlations just discussed. A correlation between a true breeding value for trait 1 (G_1) on an animal and phenotypic measurement on trait 2 (P_2) of the same animal ($r_{G1:P2}$) has an expected value of:

$$r_{G1:P2} = h_2 r_{G1:G2}$$

Where h_2 is the square root of heritability for trait 2 and $r_{G1:G2}$ is the genetic correlation between the two traits. The situation for the correlations between estimated breeding values (i.e. EPD's) and phenotypic measurements would be more complex than that just discussed. The magnitude of correlation would still be proportional to the heritability and

Table 21. Correlations of pelvic dimensions of bulls and EPD's for growth traits.

	Parea	Pelhgt	Pelwdt	EPDWG	EPDMWG	EPDYG
Parea	1	0.81**	0.79**	0.12**	-0.09*	0.13**
Pelhgt		1	0.30**	0.11**	-0.06a	0.12**
Pelwdt			1	0.09*	-0.09*	0.09*
EPDWG				1	-0.06b	0.93**
EPDMWG					1	-0.02
EPDYG						1

** $P < 0.001$ * $P < 0.01$ a $P < 0.05$ b $P < 0.1$

the genetic correlation but would also depend upon the amount and type of information used to calculate the EPD's. The significance of the relationship however, should be unaffected, as long as sufficient data are available (907 bulls in the present study). Pelvic area of bulls was positively associated to EPD's for weaning gain ($P < 0.001$). This would give an indication that animals with genetic potential to gain weight would also have larger pelvic measures. This also agrees with our earlier findings of association between growth traits and pelvic dimensions. Pelvic height and width also had significant associations ($P < 0.001$) and ($P < 0.01$) with EPD's for weaning gain respectively. The high genetic correlation between pelvic measures and growth traits as reported by Benyshek and Little (1982) suggested that faster growing animals would indeed posses genes for larger pelvic areas. Pelvic measures and EPD's for yearling gains also showed similar associations to those found for EPD's for weaning gain. Pelvic measures and EPD's for maternal weaning gain had negative but significant correlations of at least $P < 0.1$ as shown in Table 21. EPD's for maternal weaning gain give an indication of milking ability. It is not clear why pelvic measures should have a negative association with these except that maternal and direct growth EPD's have a negative correlation and pelvic area is another measure of size.

Neither pelvic area, height nor width had any significant relationship with EPD's for calving ease (Table 22). Several authors have indicated that pelvic dimension is an important factor related to the degree of dystocia but the issue has remained unsettled (Van Donkersgoed et al. 1991). In addition, most studies are on females while this study uses males only. This would lead us to conclude that pelvic dimensions of bulls from test

Table 22. Correlations of pelvic dimensions and EPD's for calving ease of test station bulls.

	PELHGT	PELWDT	PAREA	EPDCE	EPDMCE
PELHGT	1	0.3	0.81*	-0.01	0.04
PELWDT		1	0.79*	0.07	0.05
PAREA			1	0.03	0.05
EPDCE				1	-0.22*
EPDMCE					1

* $P < 0.001$

stations would not be good indicators of calving performance of bulls or their daughters. This is in agreement with the findings of Van Donkersgoed et al. (1991). EPD's for calving ease had a significant ($P < 0.001$) negative association with EPD's for maternal calving ease (Table 23). This was expected in that animals with genetic potential to produce calves born with dystocia (an indication of calf size) should also produce daughters that are large in size and hence calve easily.

Associations between test station growth traits and EPD's for calving ease are shown in Table 23. Birth weight had a negative association ($P < 0.001$) with EPD's for calving ease indicating that bulls with higher birth weights sire calves which are expected to have more difficulty at birth. End of test weight and test gain showed similar trends but were not significant ($P > 0.05$).

Prediction of progeny calving ease.

The frequency procedure (SAS 1988) was used to find out the relationship between either ease with which bulls were born, or pelvic dimensions of bulls with calving ease of their progeny. A significant relationship ($P < 0.05$) between the ease with which a bull was born and calving ease of progeny was found (Figure 10) and suggests that bulls born unassisted had a large proportion of their progeny born unassisted. Bulls born with hard pulls had a larger proportion of their progeny born with increased degree of difficulty. This is a reasonable result, consistent with the scientific literature even though it is based on only 37 bulls and their 520 progeny.

A logistic regression procedure was then used to test whether knowledge of

Table 23. Correlations of growth traits with EPD's for calving ease of bulls.

	BWT	EWT	TGAIN	EPDCE	EPDMCE
BWT	1	0.25**	0.16*	-0.13**	-0.03
EWT		1	0.68**	-0.05	0.05
TGAIN			1	-0.003	0.03
EPDCE				1	-0.22**
EPDMCE					1

** $P < 0.001$ * $P < 0.01$

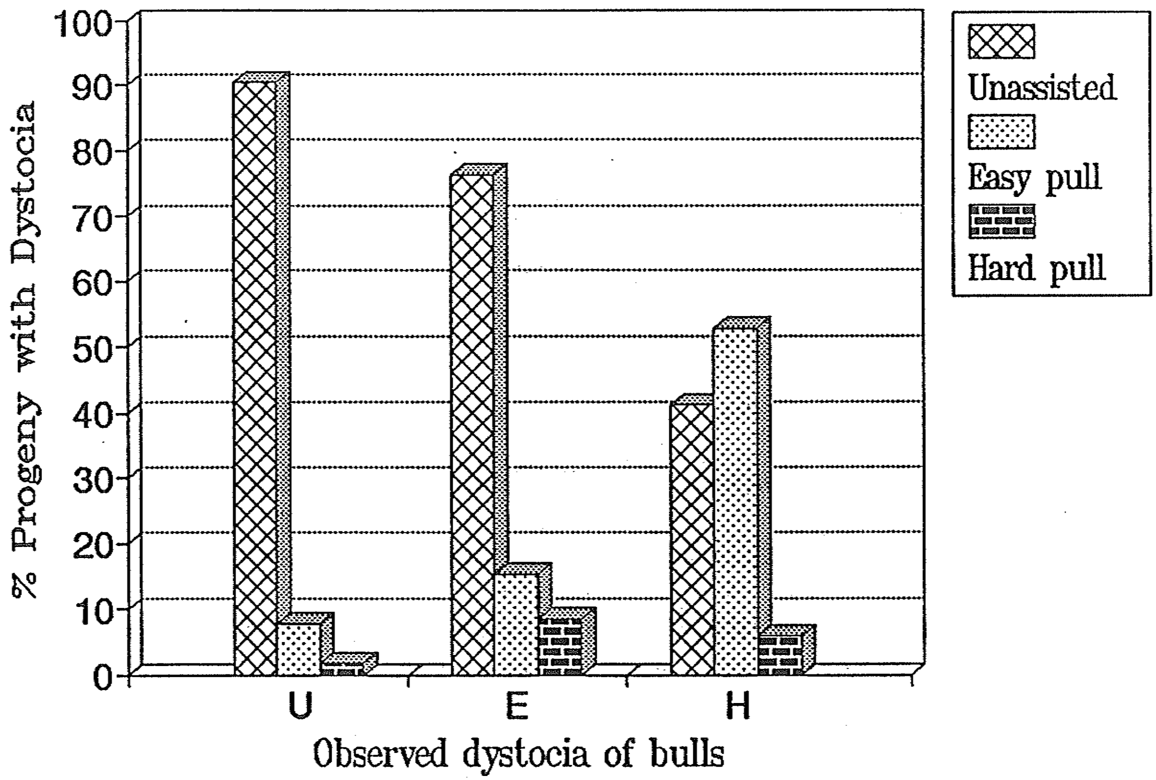

Figure 10. Distribution of Dystocia in
Progeny of Test Station Bulls

calving ease of bulls could be useful in predicting probable progeny calving ease outcomes. With bull calving ease as the predictor and progeny calving ease as the response variable, there was a significant ($P < 0.001$) relationship and the probabilities for calving ease categories are as shown in Table 24 (see Appendix B for the probability calculations). The nature of this relationship is that bulls born unassisted would have about 90% of their progeny born unassisted with 9% and 2% having easy and hard calvings respectively. For bulls with an easy pull the proportion of unassisted calving reduced to about 74% while the proportion of easy and hard calvings increased to 20% and 6% respectively. As for bulls born with hard pulls 50% of their progeny could be expected to be born unassisted while easy calvings and hard calvings increased to 35% and 15% respectively. The proportion of difficult calvings increased and unassisted calvings decreased in the progeny as calving difficulty of bulls changed from unassisted through to hard calving. This is likely due to the direct effects of sire on size of calf.

Pelvic areas of bulls did not show any significant ($P=0.25$) relationship with calving ease outcomes of their progeny (Table 25). The distribution of progeny calving ease did not change much from small pelvic size category bulls through to the large. There was, however, a slight trend for an increased proportion of unassisted calvings as pelvic area size increased from small to large. This would imply that bulls pelvic size was not a good indicator of calving ease outcomes of the progeny. Pelvic area was shown previously to be related to size of the bulls. It might have been expected that bulls with larger pelvic areas would have calves that are larger at birth and thus have more calving difficulty, but this was not the case in the present study. It was not possible with the

Table 24. Dependence of ease of calving of progeny on ease of calving of bulls (N=520)

	Calving ease of bulls	Ease with which calves were born	Chance of calving ease outcomes(%)
1	Unassisted	Unassisted	89
		Easy calving	9
		Hard calving	2
2	Easy calving	Unassisted	74
		Easy calving	20
		Hard calving	6
3	Hard calving	Unassisted	50
		Easy calving	35
		Hard calving	15

Variable	df	Parameter Estimate	Std Error	P > Chi-sq
Intercept1	1	3.20	0.32	0.0001
Intercept2	1	4.99	0.41	0.0001
Catss[1]	1	-1.06	0.21	0.0001

-2 Log-likelihood = 25.754 with 1 df (P = 0.0001)

[1] Bull ease of calving.

Table 25. Dependence of ease of calving of progeny on pelvic areas of bulls (N=520)

	Category of pelvic area	Ease with which calves were born	Chance of calving ease outcomes(%)
1	Small	Unassisted	83
		Easy calving	13
		Hard calving	4
2	Medium	Unassisted	86
		Easy calving	11
		Hard calving	3
3	Large	Unassisted	89
		Easy calving	8
		Hard calving	3

Variable	df	Parameter Estimate	Std Error	P > Chi-sq
Intercept1	1	1.30	0.45	0.0038
Intercept2	1	3.03	0.50	0.0001
Catparea[1]	1	0.25	0.22	0.2628

-2 Log-likelihood = 1.278 with 1 df (P = 0.2584)

[1] Pelvic area of bulls.

present data to evaluate calving ease expressed by daughters of the bulls studied. One of the relationships expressed by some researchers (Deutscher 1988a; Benyshek and Little 1982) is that bulls with large pelvic areas should have daughters with easier calving. The oldest daughters of the bulls in this study would have had their first calves in 1991 so there was not enough data on daughters of bulls for analysis.

A similar analysis done for pelvic heights (Table 26) and widths (Table 27) of test station bulls divided into three categories of small, medium and large showed that these measures did not have a significant relationship with the observed calving ease of their progeny ($P=0.71$ and $P=0.99$ respectively). Thus calving ease probabilities of the progeny did not show any differences in distribution between the different categories of the measures of pelvic size. We may therefore conclude that pelvic measures of bulls are not good indicators of direct calving ease of their progeny, however, observed bull calving ease may be a useful indicator of the degree of dystocia to expect in the bulls progeny.

When birth weight and end of test weight of bulls were used as the predictors there was no significant relationship with calving ease of progeny (Tables 28 and 29) an indication that various measures of size of bulls did not have a direct relationship with calving ease of progeny, suggesting that other factors like age of dam or it's pelvic size could be playing a more crucial role in the observed calving ease of progeny.

Table 26. Dependence of ease of calving of progeny on pelvic height of bulls (N=520)

	Category of pelvic height	Ease with which calves were born	Chance of calving ease outcomes(%)
1	Small	Unassisted	87
		Easy calving	10
		Hard calving	3
2	Medium	Unassisted	86
		Easy calving	11
		Hard calving	3
3	Large	Unassisted	85
		Easy calving	12
		Hard calving	3

Variable	df	Parameter Estimate	Std Error	P > Chi-sq
Intercept1	1	1.966	0.486	0.0001
Intercept2	1	3.687	0.539	0.0001
Catph[1]	1	-0.083	0.229	0.7166

-2 Log-likelihood = 0.134 with 1 df (P = 0.7142)

[1] Pelvic height of bulls.

Table 27. Dependence of ease of calving of progeny on pelvic width of bulls. (N=520)

	Category of pelvic width	Ease with which calves were born	Chance of calving ease outcomes(%)
1	Small	Unassisted	86
		Easy calving	11
		Hard calving	3
2	Medium	Unassisted	86
		Easy calving	11
		Hard calving	3
3	Large	Unassisted	86
		Easy calving	11
		Hard calving	3

Variable	df	Parameter Estimate	Std Error	P > Chi-sq
Intercept1	1	1.79	0.458	0.0001
Intercept2	1	3.52	0.513	0.0001
Catpw[1]	1	-0.001	0.222	0.9956

-2 Log-likelihood = 0.000 with 1 df (P = 0.9956)

[1] Pelvic width of bulls.

Table 28. Dependence of ease of calving of progeny on birth weight of bulls (N=520)

	Birth weight of Bulls	Ease with which calves were born	Chance of calving ease outcomes(%)
1	Small	Unassisted	85
		Easy calving	12
		Hard calving	3
2	Medium	Unassisted	85
		Easy calving	12
		Hard calving	3
3	Large	Unassisted	85
		Easy calving	12
		Hard calving	3

Variable	df	Parameter Estimate	Std Error	P > Chi-sq
Intercept1	1	1.83	0.42	0.0038
Intercept2	1	3.54	0.48	0.0001
Catbw[1]	1	-0.02	0.21	0.9365

-2 Log-likelihood = 0.006 with 1 df (P = 0.9369)

[1] Birth weight of bulls.

Table 29. Dependence of ease of calving of progeny on end of test weight of bulls (N=520)

	End of test weight of Bulls	Ease with which calves were born	Chance of calving ease outcomes(%)
1	Small	Unassisted	86
		Easy calving	11
		Hard calving	3
2	Medium	Unassisted	85
		Easy calving	12
		Hard calving	3
3	Large	Unassisted	84
		Easy calving	12
		Hard calving	4

Variable	df	Parameter Estimate	Std Error	P > Chi-sq
Intercept1	1	1.98	0.49	0.0001
Intercept2	1	3.71	0.54	0.0001
CatEw[1]	1	-0.094	0.23	0.6829

-2 Log-likelihood = 0.164 with 1 df (P = 0.6841)

[1]End of test weight of bulls.

SUMMARY AND CONCLUSIONS.

Performance data of beef bulls from three test stations in Manitoba from the years 1988-1991, consisting of twelve beef breeds were used in this study. This study was primarily designed to examine the association of bull adjusted pelvic measures with growth traits and expected progeny differences (EPD's) for direct and maternal calving ease. These associations were then used to determine whether bull growth traits or pelvic measurements would be useful indicators of calving ease.

Significant sources of variation in bull growth traits and pelvic area measurements were the effects of station, year, breed group and their two way interactions as well as bull age. Age by breed group interactions were significant ($P < 0.05$) for growth traits and pelvic areas of bulls, an indication that growth rates of these traits differed among breed groups. The above mentioned effects were used to adjust pelvic measurements and growth traits of bulls prior to calculation of correlations among traits.

End of test weight showed a highly significant ($P < 0.001$) positive association with pelvic area, an indication that body size of bulls at end of test was a good indicator of pelvic size, with large bulls having larger pelvic dimensions. A similar trend was exhibited by test gain. Therefore selection of bulls for pelvic size would result in bulls with larger end of test weight and test gain. However, birth weight showed a low ($r = 0.04$) but significant ($P < 0.05$) association with pelvic area implying that bulls with larger pelvic size may not necessarily result in increased birth weight of progeny. This is important because birth weight has been documented as a major cause of dystocia.

Pelvic area was found to have a positive significant ($P < 0.05$) association ($r = 0.12$) with EPD's for weaning gain and yearling gain, again indicating that bulls with potential for post-natal growth also have larger pelvic areas. None of the pelvic dimensions showed any significant associations ($P > 0.05$) with EPD's for calving ease (EPDCE) or maternal calving ease (EPDMCE). This would suggest that pelvic measures may not be good indicators of the potential to have easy calving either of the bull's progeny or of their daughters when giving birth. An interesting observation is the significant ($P < 0.05$) negative association ($r = -0.22$) between EPD's for calving ease and maternal calving ease: an indication that bulls with favourable EPDCE's would have calves that are born easily but would also tend to have unfavourable EPDMCE's (their daughters would have more difficulty when giving birth). This may be because the offspring are smaller at birth and have less difficulty on being born, but are also smaller at later ages and thus have difficulty giving birth because of feto-maternal disproportion.

There was also a significant ($P < 0.01$) relationship between observed ease of calving of bulls and how easily the bulls progeny were born (direct calving ease). This ease of calving of bulls could be used to estimate the probable proportions of degree of calving ease among its progeny. Bulls born without assistance would have about 89% of their calves born without any assistance, 9% would be born with easy pull while 2% would be born with hard pulls. As for bulls born with an easy pull only 74% of their progeny were born unassisted leaving 26% of the births assisted. The proportion of unassisted progeny births decreased substantially to 50% when the sire were born with hard pulls and 50% of all births had to be assisted during birth. We thus see a trend of increased dystocia as sire's degree of dystocia deteriorates (from unassisted to hard pull). This is basically a reflection of relative size in that large animals are born with difficulty and are expected to transmit these genes for size to their offspring, therefore resulting in increased dystocia levels amongst its progeny.

Pelvic dimensions (area, height and width) and growth traits (birth weight, and end of test weight) of bulls did not show any significant ($P > 0.05$) relationship with ease of calving of their progeny. This would be an indication that pelvic dimensions or size of bulls may not be a good indicator of how easily the progeny are born.

We may therefore conclude that in our study we found that pelvic dimensions of yearling beef bulls were not associated with calving ease expected in either a bulls progeny at birth or his daughters when giving birth.

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APPENDICES

Appendix A: Appendix tables.

Appendix Table 1. Least square means for birth weight for the various breed groups.

Breed group	Birth weight (kg)	Std. error
1	45.79	0.12
2	41.51	0.29
3	41.21	0.22

Appendix Table 2. Least square means for birth weight for the various station-years.

Station-year	Birth weight	Std. error
188	43.57	0.37
189	42.88	0.23
190	43.37	0.23
191	43.44	0.23
688	43.18	0.67
689	43.05	0.36
690	42.93	0.59
789	41.44	0.27
791	41.67	0.29

Appendix Table 3. Least square means for Start of test weight for the various breed groups.

Breed group	Start of test weight (kg)	Std. error
1	374.56	0.95
2	328.18	2.27
3	341.10	1.67

Appendix Table 4. Least square means for Start of test weight for the various station-years.

Station-year	Start of test weight (kg)	Std. error
188	355.36	2.82
189	351.26	1.72
190	354.22	1.75
191	343.62	1.72
688	362.96	5.11
689	357.22	2.69
690	354.29	4.50
789	319.37	2.03
791	333.22	2.18

Appendix Table 5. Least square means for test gain for the various breed groups.

Breed group	Test gain (kg)	Std. error
1	243.08	0.77
2	223.79	1.85
3	220.46	1.35

Appendix Table 6. Least square means for test gain for the various station-years.

Station-year	Test gain (kg)	Std. error
188	224.25	2.28
189	226.66	1.39
190	237.83	1.42
191	244.66	1.39
688	229.15	4.14
689	218.15	2.18
690	231.31	3.65
789	212.48	1.64
791	237.55	1.77

Appendix Table 7. Least square means for end of test weight for the various breed groups.

Breed group	End of test (kg)	Std. error
1	617.62	1.25
2	551.99	3.01
3	561.56	2.21

Appendix Table 8. Least square means for end of test weight for the various station-years.

Station-year	End of test (kg)	Std. error
188	579.58	3.72
189	577.94	2.26
190	591.96	2.31
191	588.25	2.27
688	592.09	6.74
689	575.37	3.55
690	585.59	5.95
789	531.93	2.68
791	570.76	2.88

Appendix table 9. Analysis of variance for pelvic areas of test station bulls when weight is used as the covariate.

Source	DF	% Sums of squares	F value
Station	2	7.2	157.07**
Year	3	8.9	117.33**
BG[1]	2	0	0.55
Station*Year	2	0.2	2.42
Year*BG	6	0.2	2.02
Station*BG	4	0.2	2.19
EWT	1	9.2	400.34**
EWT*BG	2	0	0.11
Error	3261	74.8	
Total	3284		

** $P < 0.001$

[a] Sums of squares of each factor expressed as a percentage of the total.
[1] Breed group.

Appendix table 10. Analysis of variance for pelvic area of the modified model.

Source	DF	% Sum of squares[a]	F Value
Styr	8	15.8	82.13**
BG[1]	2	0.1	1.85
Styr*BG	16	1.5	3.88**
Agepe	1	4.4	181.58**
Agepe*BG	2	0.2	3.63*
Error	3261	78.2	
Total	3290		

** $P < 0.01$ * $P < 0.05$

[a] Sums of squares of each factor expressed as a percentage of the total.
[1] Breed group.

Appendix table 11. Analysis of variance for pelvic height of the modified model.

Source	DF	% Sum of squares[a]	F Value
Styr	8	17.6	91.30**
BG[1]	2	0.0	0.81
Styr*BG	16	1.4	3.54**
Agepe	1	2.3	107.03**
Agepe*BG	2	0.0	0.42
Error	3261	78.4	
Total	3290		

** $P < 0.01$ * $P < 0.05$

[a] Sums of squares of each factor expressed as a percentage of the total.
[1] Breed group.

Appendix table 12. Analysis of variance for pelvic width of the modified model.

Source	DF	% Sum of squares[a]	F Value
Styr	8	13.8	69.45**
BG[1]	2	0.2	3.03*
Styr*BG	16	1.7	4.23**
Agepe	1	3.4	135.94**
Agepe*BG	2	0.3	6.24**
Error	3261	80.7	
Total	3290		

** $P < 0.01$ * $P < 0.05$

[a] Sums of squares of each factor expressed as apercentage of the total.
[1] Breed group.

Appendix B: Calculation of probabilities for calving ease of calves.

The logistic regression model has been used to explain the relationship between the response variable (calf ease of calving) and the independent variable (sire ease of calving) because they are categorical (discrete) traits. The independent variables in this model are often referred to as covariates.

In linear regression the conditional mean of the response variable (Y) given the independent variable (X) is given by:

$$E(Y|X)=\beta_o+\beta_1 x$$

However in the logistic regression model the conditional mean of the response variable given the independent variable is given by:

$$E(Y|X)=\frac{e^{\beta_o+\beta_1 x}}{1+e^{\beta_o+\beta_1 x}}$$

Where β_o and β_1 are intercept and regression coefficients respectively.

For analysis the logistic regression model has to undergo a logit transformation to acquire some properties of the linear regression model.

$$g(X)=\ln\left[\frac{E(Y|X)}{1-E(Y|X)}\right]=\beta_o+\beta_1 x$$

The logit g(x) is linear in its parameters, may be continuous and may range from $-\infty$ to $+\infty$ depending on the rang of x. When the response variable is discrete then the distribution of this variable follows a binomial distribution with a probability given by the conditional mean and is the basis of analysis of the logistic regression model.

Parameter estimates in the logistic regression model are obtained by the maximum likelihood function which expresses the probability of the observed data as a function of the unknown parameters and these are values which maximise the function (Lemeshow and Hosmer 1989).

In the logistic regression model $\beta_1 = g(x+1) - g(x)$, that is the slope coefficient represents the change in the logit for a change in one unit in the independent variable x. A logistic regression model with response variable consisting of three categories involves fitting two models.

Model I.

Intercept 1 was used to calculate the probabilities of the calving ease of calves born unassisted leaving the easy and hard calving probabilities together. Using our data as an example the propōrtion of unassisted calves given that the sires were born without assistance is given by the following formula.

$$g(\Pr(y \leq U_1 \mid U_2)) = \frac{e^{\alpha_1+\beta x}}{1+e^{\alpha_1+\beta x}}$$

Probabilities that calving ease outcomes of calves will be easy or hard pulls given that sires births were unassisted is given by this formula.

$$g(\mathrm{pr}\,(y=E_1 \text{ or } H_1 \mid U_2)) = \frac{1}{e^{\alpha_1+\beta x}}$$

α_1 = Intercept for model 1.

β = Slope coefficient of the logit.

$y = U_1$ = Calving ease category of calves (response variable- Unassisted birth)

$X = U_2$ = Calving ease category of sire (predictor variable- Unassisted birth).

E_1 = Easy calving of calves.

E_2 = Easy calving of sires.

H_1 = Hard calving of calves.

H_2 = hard calving of sires.

Summary of probability calculation of the combination of sire and calf calving ease categories are represented in the table below.

	Sires Birth Category (X)		
Calving ease of calves(Y)	Unassisted	Easy Pull	Hard Pull
Unassisted	$\Pr(U_1 \mid U_2) = \frac{e^{\alpha_1+\beta}}{1+e^{\alpha_1+\beta}}$	$\Pr(U_1 \mid E_2) = \frac{e^{\alpha_1+2\beta}}{1+e^{\alpha_1+2\beta}}$	$\Pr(U_1 \mid H_2) = \frac{e^{\alpha_1+3\beta}}{1+e^{\alpha_1+3\beta}}$
Easy or Hard Pull	$\Pr(E_1 \text{ or } H_1 \mid U_2) = \frac{1}{1+e^{\alpha 1+\beta}}$	$\Pr(E_1 \text{ or } H_1 \mid E_2) = \frac{1}{1+e^{\alpha_1+2\beta}}$	$\Pr(E_1 \text{ or } H_1 \mid H_2) = \frac{1}{1+e^{\alpha_1+3\beta}}$

As sire categories move from unassisted to hard pull the probabilities of calving ease outcomes of calves change by a unit of the regression coefficient.

<u>Model II.</u>

This model utilises intercept 2 for calculation of the probabilities of the response outcomes. The general formula when sire's birth is unassisted is as follows:

$$g(pr(y \leq E_1 \mid U_2) = \frac{e^{\alpha_2+\beta}}{1+e^{\alpha_2+\beta}}$$

The table for the various category combinations of both the sire and calf are represented bellow.

	Sires Birth Category (X)		
Calving ease of calves(Y)	Unassisted	Easy Pull	Hard Pull
Unassisted or easy pull	Pr(U_1 or E_1 $\mid U_2) = \frac{e^{\alpha_2+\beta}}{1+e^{\alpha_2+\beta}}$	Pr(U_1 or E_1 $\mid E_2) = \frac{e^{\alpha_2+2\beta}}{1+e^{\alpha_2+2\beta}}$	Pr(U_1 or E_1 $\mid H_2) = \frac{e^{\alpha_2+3\beta}}{1+e^{\alpha_2+3\beta}}$
Hard Pull	$\Pr(H_1 \mid U_2) = \frac{1}{1+e^{\alpha_2+\beta}}$	$\Pr(H_1 \mid E_2) = \frac{1}{1+e^{\alpha_2+2\beta}}$	$\Pr(H_1 \mid H_2) = \frac{1}{1+e^{\alpha_2+3\beta}}$

In summary, model I separates the probability of unassisted calving ease categories of calves from the easy and hard calving for each category of the sires birth while model II separates out the hard calving from the easy and unassisted calvings. Thus, by difference the probable calving categories of calves can then be determined. An example of how these probabilities are computed is represented bellow.

Variable	df	Parameter estimate
Intercept1	1	3.20 (α_1)
Intercept2	1	4.99 (α_2)
Sire calving ease	1	-1.06 (β)

Calculation of the probabilities for calves in model I:

$$\Pr(U_1 | U_2) = \frac{e^{\alpha_1+\beta}}{1+e^{\alpha_1+\beta}} = \frac{e^{3.20-1.06}}{1+e^{3.2-1.06}} = 8.499/9.499 = 89.5\%$$

$$\Pr(U_1 | H_2) = \frac{e^{3.20+3*-1.06}}{1+e^{3.20+3*-1.06}} = 50.9\% \quad \text{etc.}$$

Calculation of probabilities for calves in model II:

$$\Pr(U_1 \text{ or } E_1 | E_2) = \frac{e^{4.99+2*-1.06}}{1+e^{4.99+2*-1.06}} = 94.63\%$$ (contains 74% unassisted and 20% easy calving)

$$\Pr(H_1 | U_2) = \frac{1}{1+e^{4.99+3*-1.06}} = 14.1\% \quad \text{etc.}$$

See tables 24 to 29 for calculations for probabilities of calving outcomes for calves sired by test station bulls.