KINEMATIC ANALYSIS OF THE TYING PHASE OF CALF ROPING

by

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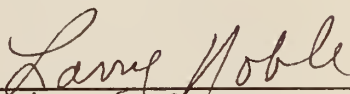submitted in partial fulfillment of the

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DEDICATION

This thesis is dedicated to my parents, Dr. Roy Harris and Marie Harris, and to my wife Laurie. Their constant support and encouragement is deeply appreciated.

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CHAPTER 1

INTRODUCTION

The popularity of the sport of rodeo has grown
consistently over the last 50 years. In 1936, fewer than 75
members formed the first professional organization for the
sport (Morrison, 1986). In 1986, the Professional Rodeo
Cowboys Asssociation (PRCA) was comprised of over 10,000
members (Morrison, 1986). In addition, numerous other rodeo
athletes compete in various levels of amateur rodeo
competition.

Rodeo's appeal to the spectator also is flourishing.
It was estimated that over 12 million people attended the
more than 600 PRCA sanctioned rodeos contested in 1985
(Professional Rodeo Cowboys Association, 1985).
Additionally, prize money has reached an all-time high.
Over $16 million was paid out during the 1986 rodeo season,
with $1.9 million of that being paid during the National
Finals Rodeo (Morrison, 1986).

The emergence of rodeo as a popular and profitable
sport has changed the way in which rodeo skills are learned.
Most of the contested events in rodeo are adaptations of
actual tasks used by working ranch cowboys. Therefore, many
of the skills involved in rodeo were originally developed as
a necessary requirement of worker responsibilities.
Automation and agricultural advancements have decreased the
frequency with which the skills displayed in rodeo are used

in ranch work. The rodeo cowboy has become more of an
athlete than simply a ranch hand testing his skills against
other ranch hands. The skills displayed by the current
rodeo athlete often are learned from coaches and developed
through hours of practice. Rodeo schools for both the timed
events (calf roping, team roping, steer wrestling, and steer
roping) and the rough stock events (bareback bronc riding,
saddle bronc riding, and bull riding) also have become
popular means of learning and refining rodeo skills.

Despite the growing popularity of the sport of rodeo,
no effort has been taken to analyze and describe the skills
of the rodeo athlete in an objective fashion. In fact, only
limited information exists where rodeo's leading authorities
have described the techniques involved in the various rodeo
events. Of the literature available, the timed events, in
particular calf roping, have received a considerable share
of attention.

Calf roping is an event where a mounted rider chases a
calf which has generally been given a head start. The rider
(roper) must rope the calf, dismount from the horse, go to
the calf, and throw it by hand. Once the calf has been
thrown, the roper must cross and tie three legs of the calf
with a length of small rope known as a "piggin' string".
For a qualified run, the legs of the calf must remain tied
for six seconds after the roper has remounted the horse and
allowed slack in the catch rope. Performance is based on
the time to complete the task. Therefore, both the

efficiency and effectiveness of movement must be optimized.

All phases of a calf roping run require a synergistic effort between the horse and the roper. This is especially true when attempting to rope and throw the calf. During the tie, however, the roper must rely more on his own skills and less on those of the horse.

During a "normal" run in which the calf has been roped around the neck, Cooper (1984) suggested that the roper perform the following sequence of steps when tying the calf:

1. The roper grabs the top foreleg of the calf and places and tightens the loop of the piggin' string around the foreleg. Simultaneously, the roper steps across the calf's body with the right leg.

2. The roper tosses (pitches) the tail of the piggin' string so that it is clear of the calf's legs.

3. The roper scoops the hind legs of the calf with the right hand and crosses the legs over the strung foreleg.

4. With the piggin' string, the roper applies two wraps and a half hitch around the crossed legs of the calf.

The literature dealing with calf roping emphasizes the techniques of successful execution of the event. Cooper (1984) has mentioned a number of variables that he considers important to a skillfully executed tie. Among those variables are: (a) the position of the roper's torso during the tie, (b) the distance the calf's legs are kept from the

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ground during the tie, (c) the pathway that the hand travels when applying the wraps, (d) the position of the elbow when tying, and (e) the timing of the step across the calf's body.

Mansfield (1961) emphasized that the following variables were important for optimizing tying speed: (a) the upper body position of the roper during the tie, (b) the amount of string between the legs of the calf and the right hand of the roper during the tie, and (c) the position of right foot plant after stepping across the calf's body. While authorities claim that there are a number of variables that are important to executing a fast tie, no mention has been made in the literature as to which are the most and least critical of those variables. In addition, no quantitative data exist to support the claims of the authorities.

Statement of the Problem

The purpose of this investigation was to describe the mechanical characteristics of the skilled execution of the tying phase of calf roping. More specifically, the following variables were examined and their contribution to the overall time of the tie were determined:

1. The distance from the ground to the upper foreleg of the calf at the top of the first wrap, the top of the second wrap, and the top of the half-hitch.

2. The distance from the ground to the upper foreleg

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of the calf at the bottom of the first wrap, the bottom of the second wrap, and the bottom of the half-hitch.

3. The vertical displacement of the right elbow joint during the first wrap, the second wrap, and the half-hitch.

4. The difference in calf leg-to-hand distances between the top of wrap two and the top of wrap one, and between the top of the half-hitch and the top of wrap two.

5. The difference in calf leg-to-hand distances between the bottom of wrap two and the bottom of wrap one, and between the bottom of the half-hitch and the bottom of wrap two.

Total tying time was defined as the time period when the loop of the piggin' string first broke the plane of the calf's hoof (when the foreleg was being strung) to when the roper clearly signaled the end of the tie. The clear indication of tie completion was determined as: (a) the point where the roper's hands were raised to their highest position overhead, or (b) the point where the roper's hands reached their greatest distance from the sides of his body (via shoulder joint abduction and elbow extension). The appropriate completion point was selected based on the technique used by each roper.

Significance of the Study

The importance of examining specifically the tying phase of calf roping is evident by looking at the role of the tie in the event. If the tie is not well executed and the calf kicks free before a required six seconds have

passed, "no time" will be recorded for the contestant (Professional Rodeo Cowboys Association, 1986). A no time indicates an unsuccessful or unqualified run. Also, since the tie occurs at the end of the calf roping run, it is the last opportunity a roper has to make up time that may have been lost previously. The need for research such as that proposed is compounded by the fact that no objective data exist on the skill.

In an attempt to provide justification for examining the tying phase of the event, the following procedures were undertaken:

1. Videotaped performances of 78 competitive calf roping runs were viewed and analyzed.

2. Each run was divided into three phases: the catch, the dismount and flank (throw), and the tie.

3. The mean and standard deviation were determined for total run times and individual phase times (Table 1).

4. Pearson Product Moment correlation coefficients were calculated between each phase time and the total run time and between the individual phase times (Table 2).

The correlation coefficients calculated between the individual phase times indicated that the phases acted independently of one another. Additionally, no single phase demonstrated a greater association with the total run time than any of the other phases.

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Table 1

Means of Total Run Times and Constituent Phase Times

	Total Time	Catch Time	Dismount & Flank Time	Tie Time
n	78	78	78	78
Mean (s)	10.92	3.52	4.13	3.25
S.D. (s)	2.24	1.04	1.23	1.01

Table 2

Correlations Coefficients Between Phase Times and Total Run Times (TRT) and Between Individual Phase Times

Phase	TRT	Catch	Dismount/Flank	Tie
TRT	1.00	0.73	0.67	0.68
Catch	----	1.00	0.19	0.40
Dismount/Flank	----	----	1.00	0.08
Tie	----	----	----	1.00

Other factors considered in the selection of variables for examination were:

1. The human movement components of the event are of primary interest for analysis purposes.

2. The actions of the horse and the calf must be controlled to most effectively analyze the human movement aspects of the event.

3. The human movement component acts most independently from the actions of the horse during the tying phase. Thus, the effects of the horse are minimized during the tying phase.

The aforementioned observations favor the selection of the tying phase for analysis. Cooperative efforts of the horse are minimized during the tie. Furthermore, the position of the calf can be effectively controlled. Thus, quantitative data can be obtained from a film record of the tying phase.

Since animal-related variables or "luck of the draw" cannot easily be controlled, the roper must demonstrate great skill in the movement components of the event to compete successfully. A cinematographic analysis was used in this investigation to aid in identification of the most effective patterns of human movement for the skill.

Delimitations

This investigation was delimited to thirteen male subjects. The subjects were either competing collegiate or professional calf ropers. Each subject was required to flank and tie four calves in a designated tying area. Furthermore, the subjects were instructed to flank and tie each calf in the same manner as they would in actual competition. The filming situation was a compromise between efforts to control calf movement and efforts to approximate the conditions found in actual competion. Therefore, it is possible that all findings may not hold true during

competition settings.

Limitations

The major limitation of the study was the calves' cooperation when being thrown and tied. The calves may not have acted in a similar fashion for each subject. Futhermore, it is possible that the actions of the calves differed from those actions occuring in competition. The absence of the calf being chased and roped may have been responsible for any changes.

Although precautionary were taken to eliminate perspective error, some movements may have occured in a plane which was not parallel to the film plane.

CHAPTER 2

REVIEW OF LITERATURE

The search for literature on this topic revealed no directly related research. In addition, information pertaining to the leading authorities' description of calf roping was very limited. This chapter provides a review of the available literature on the tying phase of the rodeo event of calf roping. A synopsis of the rules governing calf roping also is provided to aid in the reader's understanding of the event's constraints.

Tying Sequence

The first step in the sequence of the tie involves pulling the top foreleg of the calf toward the midline of the calf's body with the left arm. The piggin' string then is placed just above the fetlock joint of that leg (Figure 1). The loop in the string is tightened around the foreleg as the roper simultaneously steps across the calf's body with the right leg (Cooper, 1984). The plant of the right foot should occur near the outside of the calf's hind legs (Cooper, 1984; Mansfield, 1961). Mansfield (1961) suggested a similar first phase of the tie. He did not stress the need for simultaneously stepping across the calf's body while stringing the calf's foreleg, however. Rather, he recommended stepping across the calf's body while pitching the tail of the piggin' string clear of the calf's legs.

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Figure 1

Step One of the Tying Sequence:
Stringing the Foreleg

The second phase of the tie was described by Cooper (1984) as beginning with the pitch of the tail of the piggin' string and ending with hind legs of the calf crossed over the strung foreleg (Figure 2). The tail of the piggin' string should lie approximately five inches from the hind legs of the calf after being pitched (Cooper,1984; Mansfield, 1961). Cooper's method for crossing the calf's legs involved: (a) grabbing the calf's lower hind leg with the right hand, (b) crossing the calf's hind legs by flexing the right wrist, and (c) moving the hind legs toward the strung foreleg. Cooper mentioned that steps "b" and "c" should be performed simultaneously.

Mansfield (1961) noted that the calf's hind legs should be "scooped" with the right hand and moved foward and upward to a point where they are crossed over the strung foreleg. It was further noted that the roper's right leg should assist in moving the calf's hind legs. The right thigh should be used to support the weight of the calf's hindlegs after they have been crossed (Mansfield, 1961).

The actual tying or wrapping motion begins after the crossing of the calf's legs. The piggin' string is first picked up with the right hand (Cooper, 1984; Mansfield, 1961). Mansfield claimed that the foreleg of the calf should be pulled toward the roper's body, placing the string in a more reachable position. Mansfield (1961) also suggested that once in the roper's right hand, approximately 12 inches of string be allowed to slide through the hand
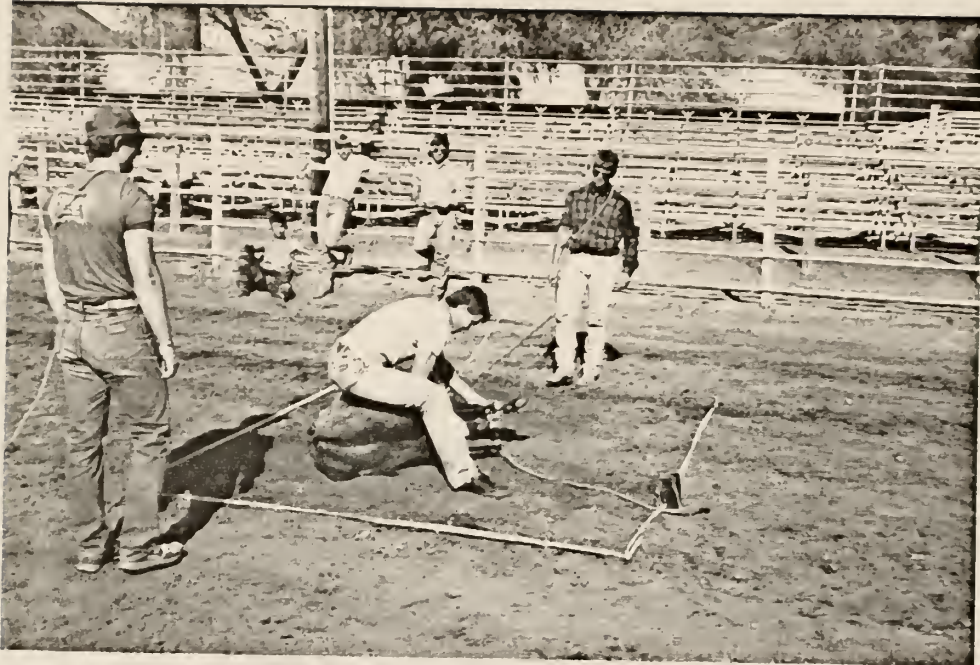
Figure 2

Step Two of the Tying Sequence:
Crossing the Legs

before taking the first wrap.

Both Cooper (1984) and Mansfield (1961) advocated taking two wraps around the calf's legs before applying the half-hitch, and noted that the left hand should continue to hold the calf's foreleg during those wraps (Figure 3). Furthermore, Cooper (1984) recommended that the calf's legs be kept relatively low to the ground throughout the tie. Cooper (1984) and Mansfield (1961) stated that the roper's left hand should release the foreleg of the calf when forming the half-hitch. The hand then is positioned against the length of piggin' string which extends from the crossed legs of the calf to the right hand of the roper. Cooper (1984) felt that the left hand should grab that length of string, thereby positioning the string between the thumb and forefinger. Mansfield (1961), however, favored placing the base of the thumb against the string.

The half-hitch differs from the previous wraps taken around the calf's legs. Only the left hand of the roper and the hind legs of the calf are encircled by the piggin' string (Cooper, 1984; Mansfield, 1961). By taking the piggin' string around the left hand, a small loop is formed in the piggin' string. This loop is needed for completing the half-hitch knot. The actual half-hitch knot is formed by pulling the string through the "V" shaped space between the hind legs and foreleg of the calf (Cooper, 1984; Mansfield, 1961). The half-hitch knot is completed by

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Figure 3

Step Three of the Tying Sequence:
Applying the Wraps

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pulling the tail of the piggin' string through the small
loop in the string formed earlier (Figure 4).

Body Position During the Tie

Cooper (1984) noted that during the tie, the roper
should lean foward slightly over the calf, and there should
be flexion in the cervical spine to keep the chin near the
sternum. Mansfield (1961) recommended that the roper's
torso remain erect, and the cervical spine extended. His
justification was that such a position would help the roper
to exert a greater downward force on the calf. In addition,
Mansfield felt that the erect upper body position would help
the roper to maintain his balance.

The position of the elbow joint is an important
consideration during the tie. The right shoulder joint
should be abducted, so that the right elbow joint is
positioed away from the roper's body throughout the tie
(Cooper, 1984; Mansfield, 1961). Additionally, Cooper
suggested that the pathway the hand travels when applying
the wraps should be relatively small. No reference to the
roper's precise leg position was found in the literature.

Alternative Tying Methods

Other tying methods may be employed, depending on the
cooperation of the calf, and the sequence of events leading
to the tying phase of the calf roping run. One of the
common methods used for tying a straining or kicking calf is
the two-handed tie (Cooper, 1984).

The sequence of actions and the body position of the

Figure 4

Step Four of the Tying Sequence:
Applying the Half-Hitch

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roper during the two-handed tie is similar to that occurring in the one-handed tie. The difference is that in the two-handed tie, the left hand releases the foreleg and is used to assist in pulling the piggin' string tight on each wrap (Cooper, 1984).

The Rules of Calf Roping

The rules established by the Professional Rodeo Cowboys Association place certain constraints on the performer, both prior to, and during the tie. The rules state that for the tie to be legal, there must be at least one wrap around all three legs plus a half-hitch. After the legs are tied, the tie must hold and the legs must remain crossed until the field judge approves the tie. Furthermore, after the roper has signaled the completion of the tie, the calf may not be touched until after the field judge has completed an examination of the tie. The calf must remain down and tied for six seconds after the roper has remounted the horse and has taken a step foward to allow slack in the catch rope. Should the calf kick free and/or stand up before the six seconds have passed, the roper will receive a "no time". A thirty-five second time limit will be imposed on any calf roping run. Should the roper fail to meet the requirements for a complete run, a "no time" will be recorded (Professional Rodeo Cowboys Association, 1986).

CHAPTER 3

METHODS

Methods employed in this investigation are presented in
this chapter. Pertinent information on subjects,
cinematographical procedures, film analysis and data
reduction techniques, and statistical procedures are
provided.

Selection of Subjects

Thirteen male subjects participated in the study. Each
subject had to meet at least one of the following
requirements: (a) he must be a competing collegiate calf
roper, and (b) he must be a competing professional calf
roper. All subjects were informed of the nature of the
study and signed an informed consent form prior to their
participation (Appendix A).

Cinematographical Procedures

Animal and Arena Preparation

The calves used in the study varied in size and weight
but were within the specifications outlined in rule 7.13.19
of the Professional Rodeo Cowboys Association. This rule
states that for native bred calves, their minimum weight
shall not be under 200 pounds, and their maximum weight
shall not exceed 350 pounds. For both Brahma and crossbred
calves the minimum and maximum weights shall be 200 pounds
and 300 pounds. In addition, there can be no more than a 50
pound deviation in weight from the lightest to the heaviest

calf in a given herd (Professional Rodeo Cowboys Association, 1986).

One end of a standard lariat rope was tied around the neck of the calf. The other end of the rope was tied to a fence. The calf was placed in a designated tying area approximately twelve meters from the fence. To assist in keeping the calf in the designated tying area prior to being thrown and tied, the head and the tail of the calf were held by assistants. A rectangle three meters in length, and two meters in width, was marked off with tape on the arena floor to designate an area in which each calf was to be thrown and tied (Figure 5).

Preparation and Instruction of Sujects

For ease in identifying body landmarks, circular adhesive dots (3/4 in. diameter) were applied to the roper's right shoulder joint, the right elbow joint, the right wrist joint, and the right fifth metacarpophalangeal joint. Subjects were allowed to practice flanking and tying calves prior to being filmed. Calves used in the study were accustomed to being tied. However, they were not used for tying practice the day of filming.

Each subject was filmed performing four successful trials. Each trial was performed using a different calf. Specifically, calf "A" was tied by each of the subjects. Calf "A" then was removed from the tying rectangle, and calf "B" was brought in. This sequence was followed for four calves (A-D). The subject sequence was changed for each
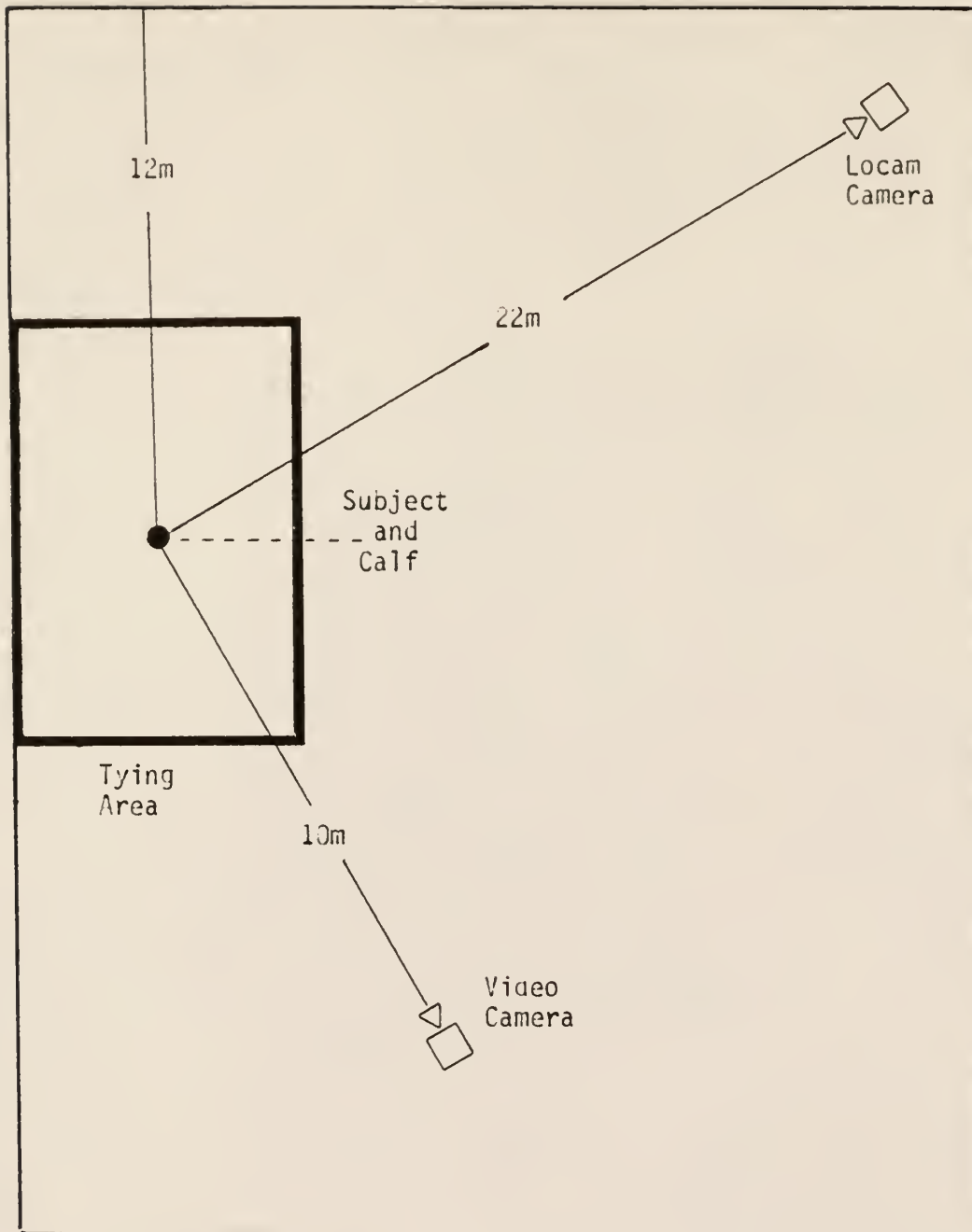
Figure 5

Overhead View of Filming Set-Up

calf tied. The order in which the subjects tied each calf
appears in Appendix B.

Cinematographical Specifications

A 16mm Redlake Locam Camera (Model 51-0003) was used in
this study. The camera was placed on a stationary tripod at
a height of one meter. A camera to subject distance of 22
meters was used. The exposure time was 1/450 of a second,
arrived at by combining a shutter factor of 1/4.5 with a
frame rate of 100 frames per second. An internal light
emitting diode set at 100 pulses per second provided an
accurate time base. Kodak Color Reversal film with an ASA
rating of 80 in daylight conditions was used. The camera
was equiped with a 12 - 120mm f2.8 Angenieux zoom lens.

The optical axis of the camera was placed at a 90
degree angle to the plane of subject motion. A video camera
was positioned to obtain a sideview of the subject.
Videotape was used to aid in the general movement
description of the skill.

Identification of Subjects and Record of Trials

An event marker identified the subject by number. The
marker was placed in the photographic field of the camera.
A record of each filmed trial also was kept which included
the name of the subject, the subject's skill level, the
trial number, the calf used, the subject's perceived rating
of performance, and any other pertinent comments.

Analyzing the Films

The films were viewed using a 16mm NAC (model DF-16B)
variable speed projector. Time measurements were computed
by multiplying the seconds per frame (.01) by the number of
frames displaced. Selected distance measurements were
measured by hand. All distance measurements were converted
from their projected values, to their actual values using a
multiplier. The multiplier was computed by filming a known
reference distance in the plane of subject motion. The
actual size of the reference distance divided by its
projected size yielded the multiplier.

The precise location in which the calf would be tied
could not be known prior to its occurence. Therefore, three
multipliers were calculated. One multiplier corresponded to
the back of the tying rectangle, another corresponded to the
middle of the tying rectangle, and the third multiplier
corresponded to the front of the tying rectangle. Before
any data were extracted from the films, the films and
videotape were viewed to determine the appropriate
multiplier for each subject.

Data Reduction Procedures

Twenty-three measurements (18 distance variables and 5
time variables) were obtained from each filmed trial. The
18 distance variables were three distance measurements taken
at six different instances during the tie. The three
measurements included: (a) the distance from the ground to

the upper foreleg of the calf (GCL), (b) the distance from the ground to the right elbow joint of the subject (GE), and (c) the distance from the upper foreleg of the calf to the right hand of the subject (CLH). Measurements were taken at: (a) the position of greatest ground-to-hand height at the beginning of the first wrap (TW1), (b) the lowest hand position during the first wrap (BW1), (c) the point of greatest ground-to-hand distance during the second wrap (TW2), (d) the point of lowest hand position during the second wrap (BW2), (e) the point of maximum ground-to-hand distance during the half-hitch (THH), (f) the minimum ground-to-hand distance during the half-hitch (BHH).

The precise points of highest and of lowest hand position during each of the wraps and the half-hitch were determined by plotting the pathway of the hand. A subjective assessment of the highest and lowest hand position was made first. The right hand and the right elbow joint location then were plotted for 10 frames prior to and for 10 frames following the initial subjective assessment point. This procedure was done to verify the precise frame from which each measurement was to be obtained. The highest and the lowest elbow position during each wrap and the half-hitch corresponded to the highest and lowest hand position.

For measurements which meaningfully and accurately depicted the mechanics of the tie, a number of new variables were created from the original 23 measurements. The ground to elbow joint distances were used to determine the vertical

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displacement of the elbow joint during the first wrap, the second wrap, and the half-hitch. Thus, three new variables were derived as follows:

1. GETW1 - GEBW1 = GEDW1 (ground-to-elbow joint displacement during wrap one)

2. GETW2 - GEBW2 = GEDW2 (ground-to-elbow joint displacement during wrap two)

3. GETHH - GEBHH = GEDHH (ground-to-elbow joint displacement during the half-hitch)

The right shoulder joint angle could not be obtained from the films due to perspective error. However, elbow joint vertical displacement values would indicate whether or not the shoulder joint remained abducted throughout each wrap and the half-hitch. Furthermore, the amount of vertical displacement of the elbow joint would indicate whether the wrapping motion occurred more toward the tranverse or the sagittal plane.

The difference in calf leg-to-hand distances between the top of wrap two and the top of wrap one and between the top of the half-hitch and the top of wrap two were derived from the original calf leg-to-hand measurements. The difference in calf leg-to-hand distances between the bottom of wrap two and the bottom of wrap one and between the bottom of the half-hitch and the bottom of wrap two also were formulated from the original calf leg-to hand measurements. Therefore, four new variables were created,

as follows:

1. CLHTW2 - CLHTW1 = CLHT1 (difference in calf leg-
to-hand distance between top of wrap two and top of wrap
one)

2. CLHTHH - CLHTW2 = CLHT2 (difference in calf leg-
to-hand distance between top of half-hitch and top of wrap
two)

3. CLHBW2 - CLHBW1 = CLHB1 (difference in calf leg-
to-hand distance between bottom of wrap two and bottom of
wrap one)   4. CLHBHH - CLHBW2 = CLHB2 (difference in
calf leg-to-hand distance between bottom of half-hitch and
bottom of wrap two)   These new variables were used to
describe the amount of piggin' string which was allowed to
slide through the roper's hand while applying the wraps.
This in turn helped to describe the pathway traveled by the
hand in applying a wrap relative to the pathway used during
the previous wrap.

The mechanics of the tie were more meaningfully
depicted using the elbow joint displacement variables than
the ground-to-elbow joint distance variables. Therefore,
the ground-to-elbow joint distance values were not entered
into the statistical analysis procedures. The same rational
was used for including the difference in calf leg-to-hand
distances between the wraps, and excluding the original calf
leg-to-hand distances.

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Reliability Measures

The original 23 measurements were taken twice on each of the filmed trials. At least 48 hours elapsed between the two measurements. Standard errors were computed for each of the 23 original variables and the variables derived from them. The standard errors for the variables entered into the statistical analysis procedures appear in Appendix C.

Statistical Procedures

In order to predict, in a prioritized manner, the most and least significant factors involved in the tie, a general linear regression model was used. More specifically, a stepwise procedure using backward elimination was employed. Dummy variables were used to account for the effects of the subjects and the calves. The total time for the tie was the dependent variable. The following kinematic measurements were the independent variables:

1. The distance from the ground to the upper foreleg of the calf at the top of the first wrap (GCL1A), the top of the second wrap (GCL2A), and the top of the half-hitch (GCL3A).

2. The distance from the ground to the upper foreleg of the calf at the bottom of the first wrap (GCL1B), the bottom of the second wrap (GCL2B), and the bottom of the half-hitch (GCL3B).

3. The vertical displacement of the right elbow joint during the first wrap (GEDW1), the second wrap (GEDW2), and

the half-hitch (GEDHH).

4.   The difference in calf leg-to-hand distances between the top of wrap two and the top of wrap one (CLHT1), and between the top of the half-hitch and the top of wrap two (CLHT2).

5.   The difference in calf leg-to-hand distances between the bottom of wrap two and the bottom of wrap one (CLHB1), and between the bottom of the half-hitch and the bottom of wrap two (CLHB2).

CHAPTER 4

RESULTS AND DISCUSSION

The results of this investigation were based on kinematic analyses of 48 filmed trials of calf tying. A general linear regression model was used to analyze the kinematic measurements extracted from the films. A stepwise regression procedure using backward elimination was employed. The stepwise procedure allowed for the formulation of a regression equation in which all remaining variables had a significant effect on the total tying time.

The constituent phases of the tie also were examined. Identical regression procedures generated prediction equations for the constituent phase times during which measurements were taken. The variables most significantly related to a particular phase time (of those variables measured during that phase) were retained in each of the final constituent phase regression models.

Subject Characteristics

Thirteen male subjects participated in the study. Each subject met at least one of the following requirements: (a) the subject was a competing collegiate calf roper, and (b) the subject was a competing professional calf roper. The mean age of the subjects was 21.08 $\pm$ 2.60 years. The subjects' collegiate calf roping experience ranged from one to four years. The professional calf roping experience for the subjects ranged from zero to four years. Descriptive

characteristics of the subjects appear in Table 3.

Total Tying Time

The total time for the tie (TOTIME) was the dependent variable in the regression procedure. The mean total tying time for the 48 observations was 3.44 ± 0.851 seconds. Times ranged from 2.54 seconds to 7.40 seconds. In order to gain insight into the composition of the total tying time, it was divided into five constituent phases, including:

1. The time from when the piggin' string first broke the plane of the hoof of the calf's upper foreleg to when the roper's right hand first touched the hindlegs of the calf (T1).

2. The time from when the roper first touched the hindlegs of the calf to when the right hand was at its highest point prior to the first wrap (T2).

3. The time from when the roper's right hand was at its highest position prior to the first wrap to when it was at its highest point prior to the second wrap (T3).

4. The time from the roper's right hand was at its highest point prior to the second wrap to when it was at its highest point prior to the half-hitch (T4).

5. The time from when the roper's right hand was at its highest position prior to the half-hitch to when the roper had clearly signaled for completion of the tie (T5).

The constituent phase times were examined as absolute time values (T1-T5) and values relative to the total tying time (T6-T10). The phase of the tie which demonstrated the

Table 3

Descriptive Characteristics of Subjects

| Subject | Height(cm) | Weight(kg) | Age(yr) | Experience(yr.) | |
				College	Prof.
BB	182.88	86.18	19	1	0
BS	188.00	95.25	21	4	3
CH	180.34	68.04	21	3	3
CR	182.88	81.65	28	4	4
DB	185.42	83.91	20	2	2
DH	182.88	79.38	19	1	0
HV	177.80	81.65	19	1	1
JS	187.96	74.84	20	2	2
KC	185.42	74.84	23	3	2
KW	180.34	83.91	24	3	0
MO	182.88	90.72	20	2	0
SP	182.88	72.57	21	4	2
TG	182.88	81.65	19	1	0

lowest mean absolute time (0.394 ± 0.231 s.) and lowest mean relative time (11.50 ± 4.60%) was the first wrap phase. The highest mean absolute time (0.981 ± 0.292 s.) and highest mean relative time (28.90 ± 5.50%) was found during the crossing of the legs phase. Table 4 presents the means, standard deviations, and ranges for the absolute and relative time values of the various phases involved in the tie.

Predictor Variables

In the regression model, contributing effects of the subjects and calves were accounted for using dummy variables. In addition to the subjects and the calves, 13 kinematic measurements were originally included as predictor variables in the regression model. Means, standard deviations, and ranges for each of the original predictor variables appear in Table 5.

The stepwise procedure using backward elimination operated under the following null and research hypotheses:

1. H_o: After the introduction of all other variables, independent variable "x" did not significantly explain the behavior of the dependent variable.

2. H_a: After the introduction of all other variables, independent variable "x" did significantly explain aspects of the behavior of the dependent variable.

The contribution and significance of each independent variable was examined after all other variables were

Table 4

The Means, Standard Deviations, and Minimum and Maximum
Values for Total Tying Time and Its Constituent Phase Times

Variable	n	x̄(s)	S.D.(s)	Min.(s)	Max.(s)
TOTIME	48	3.43	0.850	2.54	7.40
T1	48	0.724	0.333	0.51	2.33
T2	48	0.981	0.292	0.65	2.59
T3	48	0.394	0.231	0.30	1.63
T4	48	0.467	0.236	0.30	1.45
T5	48	0.898	0.338	0.57	1.88
* T6	48	20.90	5.40	12.80	45.30
* T7	48	28.90	5.50	14.90	45.70
* T8	48	11.50	4.60	5.80	33.30
* T9	48	13.40	4.30	7.40	30.00
* T10	48	26.20	6.60	17.90	45.90

* Reported as a Percentatage of the Total Tying Time.

T1 and T6: Stringing the foreleg phase time

T2 and T7: Crossing the legs phase time

T3 and T8: First wrap phase time

T4 and T9: Second wrap phase time

T5 and T10: Half-hitch phase time

Table 5

Means, Standard Deviations, and Minimum and Maximum Values
of Kinematic Variables Entered in the Original Overall
Regression Model

Variable	n	M(cm)	S.D.(cm)	Min.(cm)	Max.(cm)
GCL1A	48	48.72	5.61	33.79	62.40
GCL1B	48	53.28	5.95	38.34	67.43
GCL2A	48	48.61	6.94	36.35	67.43
GCL2B	48	50.62	7.70	34.25	67.43
GCL3A	48	39.54	7.08	25.49	56.42
GCL3B	48	44.02	6.29	29.25	59.15
GEDW1	48	27.37	9.64	8.56	44.76
GEDW2	48	33.62	11.36	13.47	79.04
GEDHH	48	27.50	9.08	10.51	45.54
CLHT1	48	-8.38	10.64	-28.98	19.03
CLHT2	48	3.75	10.68	-15.67	32.49
CLHB1	48	1.37	6.62	-12.16	17.96
CLHB2	48	-9.23	7.92	-24.87	7.10

GCL1A: Ground-to-calf leg distance, beginning of wrap one.

GCL1B: Ground-to-calf leg distance, bottom of wrap one.

GCL2A: Ground-to-calf leg distance, beginning of wrap two.

GCL2B: Ground-to-calf leg distance, bottom of wrap two.

GCL3A: Ground-to-calf leg distance, beginning of half-hitch.

GCL3B: Ground-to-calf leg distance, bottom of half-hitch.

Table 5 (Cont.)

GEDW1: Linear deviation of right elbow joint, wrap one

GEDW2: Linear deviation of right elbow joint, wrap two

GEDHH: Linear deviation of right elbow joint, half-hitch

CLHT1: Difference in calf leg-to-hand distances measured at the top of wrap two and the top of wrap one.

CLHT2: Difference in calf leg-to-hand distances measured at the top of the half-hitch and the top of wrap two.

CLHB1: Difference in calf leg-to-hand distances measured at the bottom of wrap two and the bottom of wrap one.

CLHB2: Difference in calf leg-to-hand distances measured at the bottom of the half-hitch and the bottom of wrap two.

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introduced into the model. Therefore, F tests and p-values
corresponding to the Type III sum of squares were used in
determining which variables would remain in the model. The
variable with the highest p-value was eliminated at each
step of the regression procedure. The stepwise procedure,
using backward elimination, was continued until all
remaining variables had a significant influence ($p<.05$) on
the total tying time.

The final regression model was comprised of the
following four kinematic predictor variables:

1. The distance from the ground to the upper foreleg
of the calf measured at the bottom of the second wrap
(GCL2B).

2. The distance from the ground to the upper foreleg
of the calf measured at the beginning of the half-hitch
(GCL3A).

3. The difference in calf leg-to-hand distances
measured at the bottom of wrap two and measured at the
bottom of wrap one (CLHB1).

4. The difference in calf leg-to-hand distances
measured at the bottom of the half-hitch and measured at the
bottom of wrap two (CLHB2).

The influence of the subjects and calves also were
included in the final model. Since subjects and calves were
accounted for throughout the stepwise procedure as dummy
variables, 48 individual regression equations were
generated. The Beta coefficients for the four kinematic

predictor variables remained the same in each equation. Individual intercept estimates were formulated for each subject (Bs) and each calf (Bc). The following regression equation was found to be the most significant predictor of total tying time:

TOTIME = 6.04893174 + Bs + Bc - 0.09451463*GCL2A + 0.04991871*GCL3A + 0.05253139*CLHB1 - 0.06400404*CLHB2

The order in which the non-significant variables were eliminated appears in Table 6. Table 7 provides the individual subject and calf intercept estimates. A summary of the final linear regression model appears in Table 8.

Table 6

Order of Variable Elimination and Corresponding Change in Adjusted R^2 and M.S.E. for Overall Regression Model

Elim. Order	Variable Eliminated	Adj. R^2	M.S.E.
1	GEDHH	0.9127	0.3497
2	CLHT1	0.9082	0.3333
3	GCL3B	0.9038	0.3185
4	GCL2A	0.8992	0.3052
5	GCL1A	0.8940	0.2947
6	CLHT2	0.8874	0.2885
7	GCL1B	0.8870	0.2914
8	GEDW2	0.8674	0.2914
9	GEDW1	0.8605	0.2850

Table 7

Subject and Calf Intercept Estimates for Final Overall
Regression Model

Subject	Intercept Est.	Calf	Intercept Est.
BB	-0.08462700	A	0.58704718
BS	-0.30703890	B	0.21975451
CH	-0.88790104	C	0.05916500
CR	-0.20674602	D	0.00000000
DB	-1.37413331		
DH	-0.73926690		
HV	-1.63028154		
JS	-1.84459260		
KC	-0.86942876		
KW	-0.16863662		
MO	0.13619116		
SP	-0.63148129		
TG	0.00000000		

Table 8

Statistical Summary of the Final Overall Regression Model

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value	Adj. R^2
Model	19	26.104	1.374	4.82	0.0001	0.8605
Error	28	7.981	0.285			
Corrected Total	47	34.085				

The final model explained 86 percent of the variance in total tying time, with p = .0001. The variable with the highest level of significance to total tying time was the distance from the ground to the right foreleg of the calf at the bottom of the second wrap (GCL2B) (p=.0001). This was followed, in order of statistical significance, by the difference in calf leg-to-hand distances measured at the bottom of the half-hitch and measured at the bottom of the second wrap (CLHB2) (p=.0017), the distance from the ground to the right foreleg of the calf at the top of the half-hitch (GCL3A) (p=.0173), and the difference in calf leg-to-hand distances measured at the bottom of wrap two and measured at the bottom of wrap one (CLHB1) (p=.0239). Table 9 provides the individual siginificance levels for the final predictor variables.

A negative Beta coefficient was associated with variable GCL2B. This indicated that a higher ground-to-calf leg distance at the bottom of the second wrap would lead to

a lower time for the tie. A negative Beta coefficient was
also associated with variable CLHB2. The greater the
difference in calf leg-to-hand distances between the bottom
of the half-hitch and the bottom of the second wrap, the
faster the total tying time. The variable GCL3A had a
positive Beta Coefficient associated with it. This
demonstrated that a low ground-to-calf leg distance at the
beginning of the half-hitch would lead to a lower time for
the tie. A positive Beta coefficient was found with
variable CLHB1. Therefore, the smaller the difference in
calf leg-to-hand distances between the bottom of the second
wrap and the bottom of the first wrap, the lower the time
for the tie.

Table 9

Individual Significance Levels of Final Model Predictor
Variables

Source	DF	Type III Sum of Squares	F-Value	P-Value
Subj.	12	10.572	3.09	0.0068
Calf	3	1.583	1.85	0.1608
GCL2B	1	6.782	23.80	0.0001
GCL3A	1	1.824	6.40	0.0173
CLHB1	1	1.625	5.70	0.0239
CLHB2	1	3.449	12.10	0.0017

An examination of the residual plots (Appendix D)
confirmed the acceptibility of the regression equation to

estimate the total time for the tie.

Constituent Phase Time Regressions

The total time for the tie was divided into five constituent phase times (T1-T5). The phases during which measurements were taken (T3-T5) acted as dependent variables in additional linear regression models. The kinematic measurements which were taken during a particular phase acted as the independent variables. The effects of the subjects and of the calves were accounted for through the use of dummy variables. Due to similarities to a repeated measures design, contributing effects of subjects and calves were included in all final constituent phase regression models. The stepwise procedure using backward elimination was performed to identify the variables which were the most important predictors of the constituent phase times. The contribution and significance of each independent variable was examined after all other variables were introduced into the model. The F tests and p-values corresponding to the Type III sum of squares were used in determining which variables would remain in the model. The variable with the highest p-value was eliminated at each step of the regression procedure. The backward elimination process was continued until all remaining variables had a significant influence ($p < .05$) on the constituent phase time.

The First Wrap Phase

Five kinematic variables were measured during the first

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wrap phase (T3). Those variables included:

1. The distance from the ground to the right foreleg of the calf at the beginning of the first wrap (GCL1A).

2. The distance from the ground to the right foreleg of the calf at the bottom of the first wrap (GCL1B).

3. The difference in calf leg-to-hand distances measured at the beginning of wrap two and the beginning of wrap one (CLHT1).

4. The difference in calf leg-to-hand distances measured at the bottom of wrap two and the bottom of wrap one (CLHB2).

5. The difference in ground-to-elbow joint distances measured at the bottom of wrap one and the top of wrap one (GEDW1). The five variables were entered into the first step of the backward elimination process. The final model in which all remaining variables had a statistically significant influence on the time required to apply the first wrap was comprised of one kinematic predictor variable, CLHTI, plus the subjects' and calves' effects. Table 10 presents the order in which the non-significant variables were removed from the model.

The final regression equation for predicting the the first wrap phase time was:

T3 = 0.31658329 + Bs + Bc + 0.02020306*CLHTI

The final model was significant at p=.0035, and explained 75 percent of the variability in time required to apply the first wrap. A summary of the final model appears

in Table 11. The residual plots (Appendix E) associated with the final model indicated that a higher order regression model was needed to explain the first wrap phase time.

Variable CLHTI possessed a positive Beta coefficient. Therefore, the smaller the difference in calf leg-to-hand distances, measured at the top of the second wrap and measured at the top of the first wrap, the shorter the time for the first wrap.

The individual subject and individual calf intercepts estimates are listed in Table 12.

Table 10

Order of Variable Elimination and Corresponding Change in Adjusted R^2 and M.S.E. for Constituent Phase Regression Model Using T3 as the Dependent Variable

Elim. Order	Variable Eliminated	Adj. R^2	M.S.E.
1	GEDW1	0.7929	0.0312
2	GCL1A	0.7831	0.0305
3	GCL1B	0.7685	0.0304
4	CLHB1	0.7458	0.0313

The Second Wrap Phase

The time taken to apply the second wrap (Variable T4) acted as the dependent variable in the second constituent phase time regression model. The five kinematic variables

Table 11

Statistical Summary of the Final Constituent Phase Linear
Regression Model Using T3 as the Dependent Variable

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value	Adj. R^2
Model	16	1.545	0.0966	3.09	0.0035	0.7458
Error	31	0.969	0.0313			
Corrected Total	47	2.154				

measured during the second wrap and entered as predictor

variables were:

    1. The distance from the ground to the right foreleg

of the calf at the beginning of the second wrap (GCL2A).

    2. The distance from the ground to the right foreleg

of the calf at the bottom of the second wrap (GCL2B).

    3. The difference in calf leg-to-hand distances

measured at the top of the half-hitch and the top of the

second wrap (CLHT2).

    4. The difference in calf leg-to-hand distances

measured at the bottom of the half-hitch and the bottom of

wrap two (CLHB2).

    5. The difference in ground-to-elbow joint distances

measured at the bottom of wrap two and the top of wrap two

(GEDW2).

Contributing effects of subjects and calves were

accounted for using dummy variables.

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Table 12

<u>Subject</u> <u>and</u> <u>Calf</u> <u>Intercept</u> <u>Estimates</u> <u>for</u> <u>Constituent</u> <u>Phase</u>
<u>Regression</u> <u>Model</u> <u>Using</u> <u>T3</u> <u>as</u> <u>the</u> <u>Dependent</u> <u>Variable</u>

Subject	Intercept Est.	Calf	Intercept Est.
BB	0.27150191	A	0.20061150
BS	0.33563584	B	0.00332208
CH	-0.25108718	C	0.00408259
CR	0.24914357	D	0.00000000
DB	-0.02778023		
DH	0.36221287		
HV	0.24362426		
JS	0.45707007		
KC	0.27941544		
KW	0.33121367		
MO	0.17596940		
SP	-0.01220172		
TG	0.00000000		

The final model consisted of one statistically significant kinematic predictor variable, GCL2B. The order in which the non-significant variables were eliminated appears in Table 13. The final regression equation for predicting the second wrap phase time was:

T4 = 1.18543039 + Bs + Bc - 0.01668955*GCL2B

Table 14 presents a summary of the final linear regression model for predicting the time for the second wrap. The final model explained 65 percent of the variance in the time required to apply the second wrap and was significant at p=.0959.

Table 13

Order of Variable Elimination and Corresponding Change in Adjusted R^2 and M.S.E. for Constituent Phase Regression Model Using T4 as the Dependent Variable

Elim. Order	Variable Eliminated	Adj. R^2	M.S.E.
1	GEDW2	0.7299	0.0425
2	CLHT2	0.7088	0.0427
3	GCL2A	0.6784	0.0441
4	CLHB2	0.6505	0.0449

A negative Beta coefficient was associated with variable GCL2B. Thus, a higher ground-to-calf leg distance at the bottom of the second wrap would result in a lower time to apply the second wrap. The individual subject and individual calf intercept estimates are located in Table 15.

Table 14

Statistical Summary of the Final Constituent Phase Regression
Model Using T4 as the Dependent Variable

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value	R^2
Model	16	1.234	0.0772	1.72	0.096	0.6505
Error	31	1.392	0.0449			
Corrected Total	47	2.626				

An examination of the residual plots (Appendix F) associated with the final regression model indicated that a higher order regression model was needed to explain the time taken to apply the second wrap.

The Half-Hitch Phase

The following three kinematic variables were measured during the half-hitch phase and entered in the initial regression model:

1. The distance from the ground to the right foreleg of the calf at the beginning of the half-hitch (GCL3A).

2. The distance from the ground to the right foreleg of the calf at the bottom of the half-hitch (GCL3B).

3. The difference in ground to elbow joint distances measured at the bottom of the half-hitch and measured at the beginning of the half-hitch (GEDHH).

The subjects' (Bs) and calves' (Bc) effects as well as variable GCL3B were retained in the final model. Although

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Table 15

Subject and Calf Intercept Estimates for Constituent Phase
Regression Model Using T4 as the Dependent Variable

Subject	Intercept Est.	Calf	Intercept Est.
BB	0.20003432	A	0.24255165
BS	0.11229481	B	0.02798635
CH	-0.04305129	C	0.10942881
CR	0.02625436	D	0.00000000
DB	-0.01573694		
DH	-0.08038816		
HV	0.04125063		
JS	-0.02268532		
KC	0.07626021		
KW	0.09437291		
MO	-0.11470739		
SP	0.20030168		
TG	0.00000000		

variable GCL3B was the most significant predictor of half-
hitch phase time, it only was significant at p=.093. The
variables GEDHH and GCL3A were the first and second
variables eliminated from the original model, respectively.
The final regression equation for predicting the half-hitch
phase time was:

$$T5 = 1.79395434 + Bs + Bc - 0.01904041 * GCL3B$$

A summary of the final constituent phase linear

regression model using the time to complete the half-hitch as the dependent variable can be found in Table 16. The final regression model explained 56 percent of the variance in the time to complete the half-hitch phase. However, the final model was not significicnat (p=0.5203). In addition, information obtained from the residual plots (Appendix G) indicated that variable GCL3B would require a higher order regression equation to explain the time to apply the half-hitch. The individual intercept estimates for the subjects (Bs) and calves (Bc) appear in Table 17.

Table 16

Statistical Summary of the Final Constituent Phase Regression Model Using T5 as the Dependent Variable

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value	Adj. R^2
Model	16	1.778	0.111	0.96	0.5203	0.559
Error	31	3.597	0.116			
Corrected Total	47	5.375				

Summary of Regression Results

The stepwise procedure using backward elimination resulted in the generation of a four kinematic variable model for predicting total time. Those variables were: (a) GCL2B, (b) GCL3A, (c) CLHB1, and (d) CLHB2. The contributing effects of the subjects (Bs) and calves (Bc) were accounted for in the regression model through the use

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Table 17

Subject and Calf Intercept Estimates for Constituent Phase
Regression Using T5 as the Dependent Variable

Subject	Intercept Est.	Calf	Intercept Est.
BB	0.10011238	A	0.17846865
BS	0.04272462	B	-0.05949470
CH	-0.42507408	C	0.07961045
CR	-0.29719018	D	0.00000000
DB	-0.11655973		
DH	-0.24625669		
HV	0.09885405		
JS	-0.08073700		
KC	-0.04584735		
KW	-0.30171917		
MO	-0.10452791		
SP	-0.19375537		
TG	0.00000000		

of dummy variables. The final linear regression equation
was:

$$TOTIME = 6.04893174 + Bs + Bc - 0.09451463*GCL2B +$$
$$0.04991871*GCL3A + 0.05253139*CLHB1 - 0.06400404*CLHB2$$

The final model was significant at $p < .0001$ and explained 86
percent of the variance in total tying time.

When constituent phases of the total time were used as
dependent variables, and those measurements taken during a

particular phase acted as independent variables, the
following regression equations were generated:

$$T3 = 0.31658329 + Bs + Bc + 0.02020306*CLHT1$$

$$T4 = 1.18543039 + Bs + Bc - 0.01668955*GCL2B$$

$$T5 = 1.79395434 + Bs + Bc - 0.01904041*GCL3B$$

The final model for variable T3 was significant
(p=.0035) and explained 74 percent of the variance. An
examination of the residual plots indicated that a higher
power regression model was needed, however. The final model
for variable T4 was not significant at p<.05. The residual
plots also showed that higher order regression equations may
be warranted. The final regression model for variable T5
was not significant (p=.5203). The lack of statistical
significance along with the information from the residual
plots indicated that higher order regression models may be
needed to explain the time to apply the half-hitch.

Discussion

The purpose of this investigation was to contribute to
a more accurate description of the mechanical
characteristics of the skilled execution of the tying phase
of calf roping. Thirteen kinematic variables were used to
to depict the mechanics of the tie. Of those variables, six
were related to the distance that the calf's legs were kept
from the ground throughout the tie. Four variables were
concerned with the pathway traveled by the hand when
applying the wraps. The remaining three variables were

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associated with the right elbow joint position during the
tie. A discussion of the relationship of the findings of
this study to the optimal execution of the tying phase of
calf roping is presented in this section.

Ground-to-Calf Leg Distance

Cooper (1984) considered the ground-to-calf leg
distance important to the tie. He believed a relatively low
calf leg height would reduce the chance of the calf kicking
or straining. Results of the present study also indicate
calf leg height affects the mechanics of the tie. However,
an unvarying ground-to-calf leg distance was not found to be
conducive to a low tying time. The ground-to-calf leg
distance changed throughout tie. The legs of the calf were
held lower to the ground at the top of each wrap compared to
the bottom of each wrap. In addition, the calf's legs were
kept closer to the ground during the half hitch phase
compared to the first and second wrap phases (Table 5).

The techniques displayed by the subjects provided an
explanation for the change in calf leg height.
Specifically, as the hand proceeded toward the bottom of a
wrap, the roper's right hip joint was flexed. This acted to
increase the distance the calf's legs were kept from the
gound. After the right hand passed below the calf's legs,
the roper's right hip joint was extended slightly, causing a
lowering of the calf's legs.

The aforementioned techniques were employed on each
wrap and the half-hitch. However, the calf leg heights

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during wrap one and the first half of wrap two were not
found to be related to either the total tying time or the
first and second wrap phase times. The period of the tie
where the ground-to-calf leg distances were most important
was from the bottom of the second wrap to the beginning of
the half-hitch. The results supported the use of a high
calf leg height at the bottom of the second wrap and a low
ground-to-calf leg distance at the top of the half-hitch.

A decrease in ground-to-calf leg distance during the
half-hitch may result from a reduction in the force applied
to the calf's legs. The roper's right thigh and the left
arm each applied a force to the calf's legs during the first
two wraps (Figure 6). When the left hand was removed from
the calf's foreleg to assist in forming the half-hitch, one
of the applied forces was eliminated. Thus, part of the
mechanism supporting the calf's legs was lost. The roper's
right thigh did not appear to increase the force it was
applying to the calf's legs to compensate for the removal of
the left hand. Therefore, the ground-to-calf leg distance
decreased.

The timing of the left hand's release of the calf's
foreleg may be related to the ground-to-calf leg distance at
the bottom of the second wrap. Since current results
indicate that a high ground-to-calf leg distance at the
bottom of the second wrap is favorable for a fast tie, it
appears that the calf's foreleg should be held at least

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Figure 6

Forces Applied by the Right Thigh and
the Left Arm During the Tie

until the right hand has passed below the calf's legs on the final wrap.

In summary, the present study showed that the lower the ground-to-calf leg distance at the beginning of the half-hitch the lower the time for the tie. Futhermore, the higher the calf leg height at the bottom of the second wrap the faster the tie. It is hypothesized that the following two factors may lead to the desired ground-to-calf leg distances:

1. Extension of the roper's right hip joint after the right hand has passed below the calf's legs during the second wrap.

2. A release of the calf's foreleg during the time between the bottom of the second wrap and the beginning of the half-hitch.

These movements are necessary for a smooth transition from wrapping the legs, to forming the half-hitch knot. The transition period is important for the formation of a secure knot. Releasing the foreleg shortly after the bottom of the second wrap would provide more time to position the left hand for its role in forming the half-hitch knot. In addition, it would allow more time for gravity to exert its force on the calf's legs. Thus, it appears that the foreleg should be released early in the transition period.

Cooper (1984) and Mansfield (1961) suggested that the left hand should continue to hold the calf's foreleg until the completion of the second wrap. Findings in this study

are, therefore, inconsistent with the technique recommended by the authorities.

The most significant predictor of the half-hitch phase time was the ground-to-calf leg distance at the bottom of the half-hitch. However, the final regression model was not statistically significant (p=.5203). Factors other than the kinematic measurements taken during the half-hitch may have influenced the phase time. The end of the half-hitch phase was defined as the point were the roper had clearly signaled the completion of the tie. However, no measurements were taken after the bottom of the half-hitch. Actions occuring between the bottom of the half-hitch and the completion of the tie may have influenced the phase time.

Pathway of the Right Hand

Two of the four variables in the final regression model were related to the pathway the hand traveled while applying the wraps. In addition, the varible associated with the hand's pathway during the first wrap was the most statistically significant predictor of the first wrap phase time.

Results of this study showed that the smaller the difference between calf leg-to-hand distances measured at the bottom of the second wrap and the bottom of the first wrap, the faster the time for the tie. The range of differences in calf leg-to-hand distances (bottom of the second wrap less bottom of the first wrap) for the subjects

of this study was -12.16 to 17.96 centimeters. Furthermore, the results demonstrated that the smaller the difference in calf leg-to-hand distances measured at the top of the second wrap and the top of the first wrap, the lower the time to apply the first wrap. The range of differences in calf leg-to-hand distances (top of the second wrap less top of the first wrap) was -28.98 to 19.03 centimeters.

Cooper (1984) recommended that the hand travel a small cicumference when circling the legs of the calf. The aforementioned results indicate that the pathway traveled by the hand should remain constant for the first two wraps, or even decrease during the second wrap. The amount of string fed through the hand should be controlled so that the calf leg-to-hand distance either remains the same or decreases slightly during the first and second wraps. The length of string fed through the right hand should be equal to the circumference around the legs to be tied. String fed through the hand in excess of that amount would result in an unnecessary increase in the pathway traveled by the right hand.

It is hypothesized that by not increasing the calf leg-to-hand distance at the bottom of the second wrap the string is directed away from the "V" shaped space between the calf's hindlegs and foreleg (Figure 7). This is desirable since the string is not taken through "V" shaped space on the second wrap. In addition, the transition from the wraps to the half-hitch occurs after the string has passed below
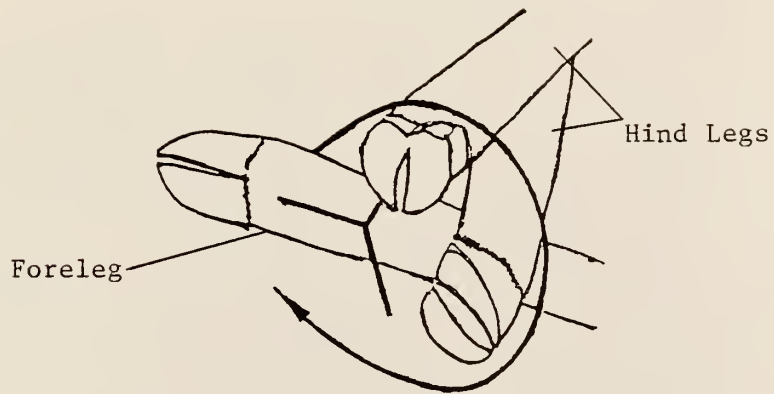
Figure 7

Hypothesized Effect of a Short
Calf Leg-to-Hand Distance at the Bottom
of the Second Wrap

the calf's legs on the second wrap. A close calf leg-to-hand distance, in which the string is directed around the calf's legs, may facilitate a more efficient transition period through proper string positioning.

Increasing the calf leg-to-hand distance at the top of the second wrap would require the right arm to travel a greater distance during the first wrap. Therefore, the time for the first wrap would increase unless the velocity of the arm increased.

A larger difference between the calf leg-to-hand distances measured at the at the bottom of the half-hitch and the bottom of the second wrap was associated with a lower tying time.   The increase in the difference between the two calf leg-to-hand measurerments may be related to the mechanics of forming the half-hitch knot. Only the left hand of the roper and the hindlegs of the calf are encircled during the half-hitch (Cooper, 1984; Mansfield, 1961). By taking the piggin' string around the left hand, a small loop is formed in the string. The actual half-hitch knot is formed by pulling the string through the "V" shaped space between the calf's hindlegs and foreleg. The knot is completed by pulling the string through the small loop formed around the left hand (Figure 8).

Increasing the calf leg-to-hand distance from the bottom of the second wrap to the bottom of the half-hitch results in a larger positive difference between the two
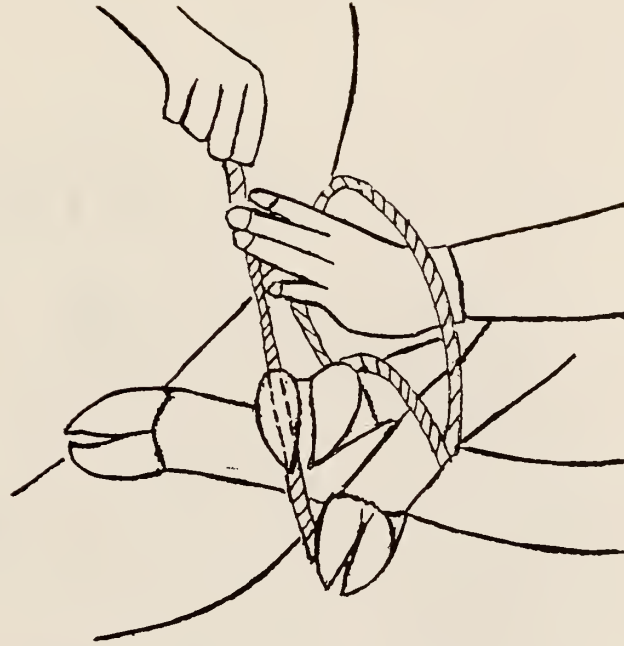
Figure 8

The Half-Hitch Knot

measurements. It is hypothesized that by increasing the
distance that the string is taken below the calf's legs on
the half-hitch, a more effective angle of approach for
forming the half-hitch knot is achieved. Allowing more
distance between the roper's right hand and the calf's legs
positions the string farther below the legs of the calf.
Pulling the string directly upward then places the string
near the apex of the "V" shaped space between the calf's
hindlegs and foreleg. Thus, the string is situated in close
proximity of the left hand (Figure 9).

A shorter calf leg-to-hand distance at the bottom of
the half-hitch compared to the bottom of the second wrap
results in a larger negative difference between the two
measurements. If the calf leg-to-hand distance is
decreased, and tension is not maintained in the length of
string between the calf's legs and the hand, the string can
be directed toward the "V" shaped space. This technique
requires that the slack in the string between the calf's
legs and the hand form a small loop. This loop should be
directed downward. Therefore, the string itself is
positioned farther below the calf's legs than the right hand
is. This allows the string to be directed toward the apex
of the "V" shaped space and in close proximity of the left
hand when the string is pulled upward (Figure 9).

The aforementioned technique was consistent with the
techniques demonstrated by the subjects of this study. This
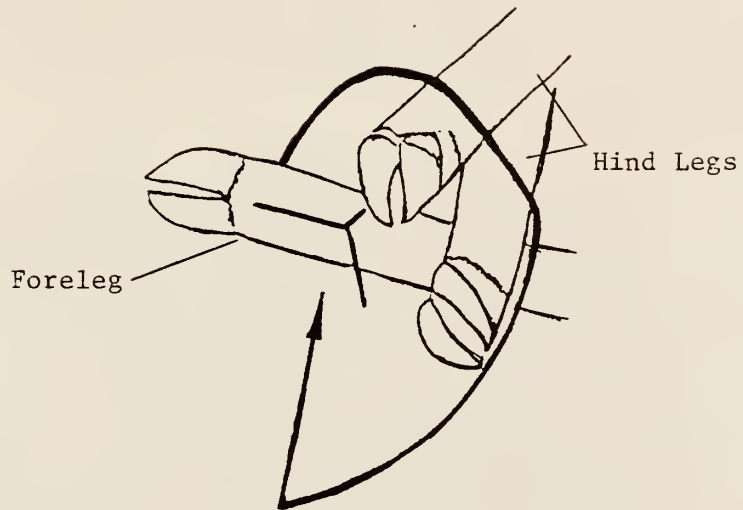was supported by the range of differences in calf leg-to-

Foreleg

Hind Legs

Figure 9

Hypothesized Effect of a Increasing the
Distance the String is Taken Below the Calf's
Legs at the Bottom of the Half-Hitch

hand distances (bottom of the half-hitch less bottom of the second wrap) for the subjects of this investigation (-24.87 to 7.10 centimeters).

It is hypothesized, that decreasing the calf leg-to-hand distance at the bottom of the half-hitch (while maintaining tension in the length of string between the calf's legs and the hand) would position the string away from the "V" shaped space between the calf's hindlegs and foreleg. This would result in the string being situated farther away from the left hand.

Elbow Position During the Tie

Cooper (1984) stated that the right elbow joint should be positioned away from the body throughout the tie. Therefore, the right shoulder joint should remain abducted. In this study, it was not possible to measure right shoulder joint angle accurately due to perspective error. A general indication of right elbow joint position and right shoulder joint position was obtained by measuring the vertical displacement of the right elbow joint during each wrap and the half-hitch. The results of the regression procedures showed elbow joint displacement to be non-significant to total tying time.

The general movement pattern used by the subjects demonstrated that full shoulder joint abduction only occurs during the beginning and ending stages of a wrap (Figure 10). Mean elbow joint displacement values (Table 5)

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Figure 10

Changes in Shoulder Joint Abduction
During a Wrap Phase

indicated that the elbow joint was not held completely away from the body throughout the tie. However, it is possible that lateral trunk flexion may have affected the elbow joint displacement values. Since lateral trunk flexion was not measured, its true effects could not be determined. Futhermore, the negative Beta coefficient associated with the ground-to-calf leg distance at the bottom of the second wrap, and the positive Beta coefficient associated with the ground-to-calf leg distance at the beginning of the half-hitch would necessitate vertical displacement of the right elbow joint.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS
FOR FUTURE STUDIES

Included in this chapter is a summary of the procedures
and results of this study. Conclusions drawn from the
results, and recommendations for future studies of a similar
nature also are provided.

Summary

The purpose of this study was to describe the
mechanical characteristics of the skilled execution of the
tying phase of calf roping. A number of kinematic variables
were used to describe the mechanics of the tie. The
variables were based on technique descriptions from calf
roping's leading authorities (Cooper, 1984; Mansfield,
1961). The thirteen kinematic variables selected for use
were related to: (a) the ground-to-calf leg distance during
the tie, (b) the right elbow joint position during the tie,
and (c) the pathway traveled by the right hand in the
application of the wraps.

Thirteen males who were competing collegiate calf
ropers and competing professional calf ropers volunteered as
subjects. Each subject was required to flank and tie four
calves in a designated tying area. The calf to be tied was
tethered to a fence and held in the tying area by
assistants.

A 16mm Redlake Locam Camera operating at 100 frames
per second was positioned with the film plane parallel to

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the plane of subject motion. A Panasonic video camera was positioned to obtain a sideview of the subjects.

The films were viewed and analyzed using a 16mm variable speed projector. The total time for the tie and the phase times constituting the total time also were computed. All distance measurements obtained were performed manually. A prediction and prioritization of the most and least significant factors involved in the tie was performed. This was accomplished through the use of a stepwise regression procedure using backward elimination. The effects of the subjects (Bs) and the calves (Bc) were accounted by using dummy variables. Similar regression procedures were performed using the constituent phase times as the dependent variables. Those measurements taken during a particular phase acted as the independent variables. In all, three additional regression models were generated.

The mean total tying time for the 48 observations was 3.44 $\pm$ 0.851 seconds. Times ranged from 2.54 to 7.40 seconds. Of the constituent phases, the lowest mean absolute time (0.394 $\pm$ 0.231 s.) and the lowest mean relative time (11.50 $\pm$ 4.60% of total tying time) was found during the first wrap phase. The highest mean absolute time (0.981 $\pm$ 0.292 s.) and highest mean relative time (28.90 $\pm$ 5.50% of total tying time) was found during the crossing of the legs phase.

The regression procedure, using total time as the dependent variable, resulted in a four variable model for

predicting total time. In order of significance, the variables were: (a) the ground-to-calf leg distance at the bottom of the second wrap (variable GCL2B, p=.0001), (b) the difference found when the calf leg-to-hand distances at the bottom of the second wrap was subtracted from the calf leg-to-hand distance at the bottom of the half-hitch (variable CLHB2, p=.0017), (c) the distance from the ground to the right foreleg of the calf at the beginning of the half-hitch (variable GCL3A, p=.0173), and (d) the difference in calf leg-to-hand distances measured at the bottom of wrap two and the bottom of wrap one (variable CLHB1, p=.0239). The following final linear regression equation was generated:

TOTAL TIME = 6.04893174 + Bs + Bc - 0.09451463*GCL2B + 0.04991871*GCL3A +0.05253139*CLHB1 - 0.06400404*CLHB2

The final model was significant (p=.0001) and explained 86 percent of the variance in total tying time.

The constituent phase time regression procedures revealed the following linear regression equations:

1. First wrap phase time = 0.31658329 + Bs + Bc + 0.02020306*CLHT1

CLHT1 = The difference in calf leg-to-hand distances measured at the top of wrap two and the top of wrap one.

2. Second wrap phase time = 1.8543039 + Bs + Bc - 0.01668955*GCL2B

GCL2B = The ground-to-calf leg distance at the bottom of the second wrap.

3.   Half-hitch phase time = 1.79395434 + Bs + Bc -
     0.01904041*GCL3B

GCL3B = The ground-to-calf leg distance at the bottom of the
half-hitch.

The final model for the first wrap phase was
significant ($\underline{p}$=.0035). The model explained 74 percent of
the variance in the time required to apply the first wrap.
The final models for the second wrap phase and the half-
hitch phase were not significant at $\underline{p}$<.05. The residual
plots for each of the three phase time regression models
indicated that higher order regression models are needed to
more accurately explain the dependent variables.

Conclusions

Within the limits of this study, it is concluded that
in the performance of the tying phase of calf roping:

1. During the first two wraps of the tying phase, the
right hand should remain a constant distance from the calf's
legs.

2. The distance from the right hand to the calf's legs
should decrease at the bottom of the half-hitch.

3. Higher calf leg heights at the bottom of the second
wrap are associated with faster tying times.

4. Lower calf leg heights at the beginning of the half
hitch are associated with faster tying times.

5. Right elbow joint displacement during the tying
phase is not related to to tying time.

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Recommendations for Future Studies

The following recommendations are made for future studies of a similar nature:

1. Three cameras should be used to most effectively record the actions of the tie. This arrangement would allow for quantification of the right shoulder joint angle and trunk angle. The suggested camera placement appears in Figure 11.

2. The regression equation for predicting total tying time should be tested with different populations.

3. A closer examination of the body segment movements occurring in the stringing of the foreleg phase and the crossing of the legs phase should be performed. The three camera set-up recommended previously would allow for such an examination.

4. The results demonstrated that most of the variables important to total tying time transpired from the bottom of the second wrap to the bottom of the half-hitch. Therefore, a critical analysis of that period of the tie may suggest the most effective movements for reducing total time.
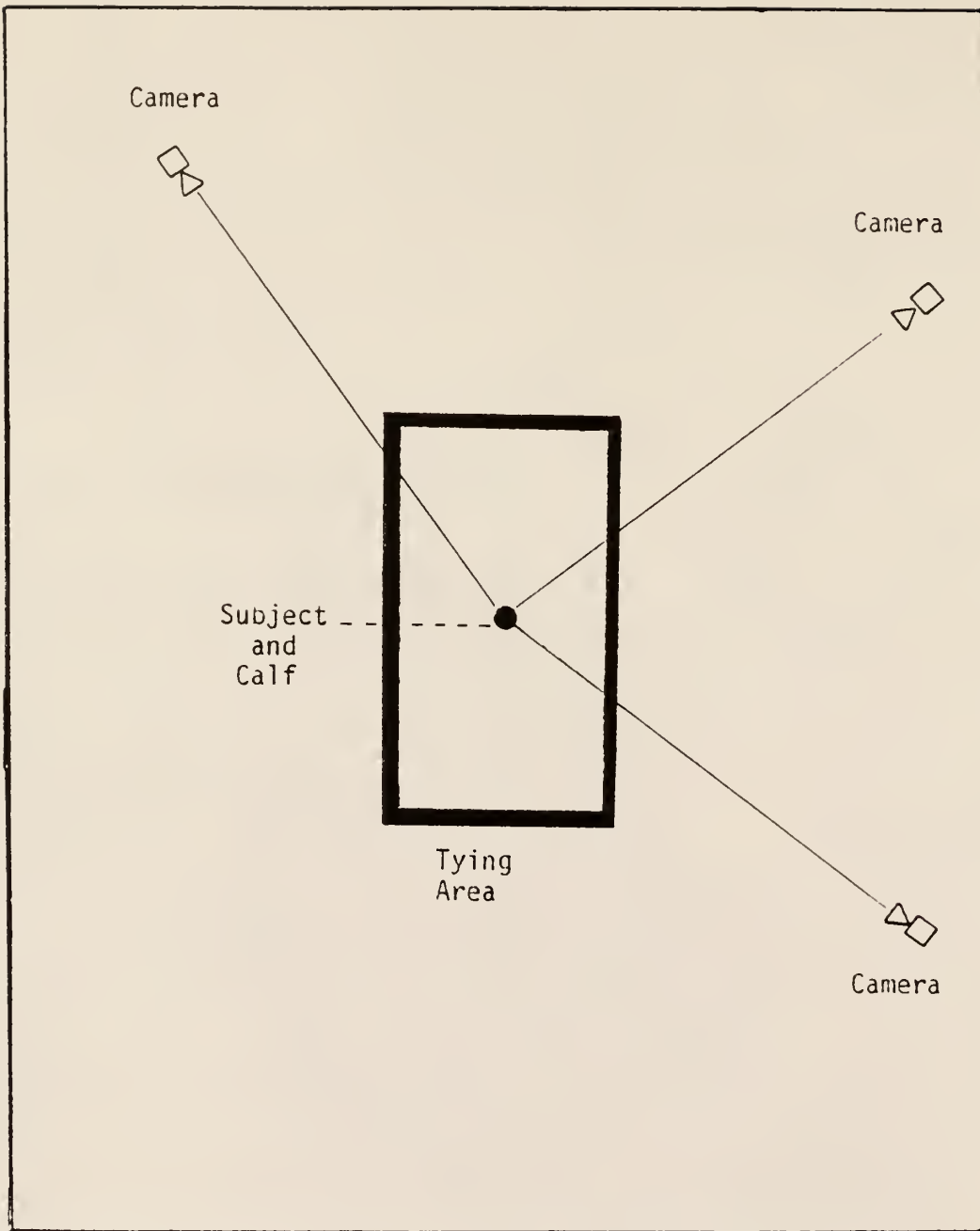
Figure 11

Overhead View of Suggested Camera
Locations for Future Studies

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    Horseman Inc.

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    Author.

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APPENDICES

Appendix A
Informed Consent Document

Purpose
      The purpose of this investigation is to describe the
mechanical characteristics of the skilled execution of the
tying phase of calf roping.

Procedures
      You will be required to flank and tie four calves. The
calves will be tied to a fence and held to prevent them from
moving prior to being thrown. You will be asked to flank
and tie the calves in the same manner as you would do in
actual competition. The following sequence of steps will be
used:
      (a) Your right shoulder, elbow, wrist, and 5th
metacarpal-phalangeal joints will be marked with tape.
      (b) You will successfully flank and tie the first calf.
      (c) A second calf will be brought in.
      (d) You will successfully flank and tie the second
calf.
      (e) The sequence will be continued until you have
flanked and tied four calves.
      One successful trial will be filmed from each of the
four calves you flank and tie. A 16mm camera will be used
to obtain a frontview and a video camera will be used to
obtain a sideview.

Risks and Discomforts
      The procedure used for flanking and tying the calves is
a common practice method. Only skilled subjects familiar
with the procedure will be used. Therefore, only minimal
risks or discomforts are anticipated as a result of
participation. The severity of the possible risks are not
expected to exceed minor sprains, strains, or contusions.

Benefits
      You may view the films and videotapes taken of the
trials. Individual consultation regarding the mechanical
characteristics involved in the tie will be available.

Inquires
      Any questions regarding the procedures or any other
aspect of the investigation are welcome. If you have any
questions please contact the project director.

Freedom of Consent
      Permission for you to perform this test is voluntary.
You are free to deny consent and discontinue participation
at anytime.

I have read the above statement and have been fully
advised of the procedures to be used in this project. I
understand the potential risks involved and hereby assume
them voluntarily.

_____   _____
        Date   Signature

Appendix B

Order of Subjects for Each Calf Tied

CALF	SUBJECT ORDER
A	1 2 3 4 5 6 7 8 9 10 11 12 13
B	5 6 7 8 9 10 11 12 13 1 2 3 4
C	9 10 11 12 13 1 2 3 4 5 6 7 8
D	13 1 2 3 4 5 6 7 8 9 10 11 12

Assigned Subject Numbers

Subject	Number
BS	1
MO	2
CR	3
HV	4
JS	5
TG	6
DH	7
DB	8
KC	9
BB	10
KW	11
SP	12
CH	13

Appendix C

Variable Means and Standard Errors for
First and Second Measurements

| Variable | Calf | Measurement Means | | Standard Error |
		M1(cm)	M2(cm)	
GCL1A	A	51.58	51.27	0.72
GCL1B	A	53.63	55.69	2.01
GCL2A	A	53.45	53.25	0.94
GCL2B	A	54.11	51.98	2.83
GCL3A	A	44.41	43.96	0.96
GCL3B	A	45.59	44.54	1.58
GEDW1	A	27.46	26.69	1.07
GEDW2	A	36.37	36.07	0.78
GEDHH	A	26.56	27.30	2.23
CLHT1	A	-7.10	-7.84	1.52
CLHT2	A	1.68	2.36	2.20
CLHB1	A	2.51	-0.04	1.63
CLHB2	A	-12.84	-11.99	2.01
GCL1A	B	49.49	50.72	1.38
GCL1B	B	54.42	54.86	2.18
GCL2A	B	49.04	49.74	1.74
GCL2B	B	52.00	53.04	1.89
GCL3A	B	39.29	39.93	1.58
GCL3B	B	46.38	47.27	1.59
GEDW1	B	27.47	27.11	1.01
GEDW2	B	32.93	31.99	1.03
GEDHH	B	26.27	25.40	0.93
CLHT1	B	-10.06	-9.86	1.99
CLHT2	B	0.40	1.92	2.23
CLHB1	B	1.83	2.27	1.64
CLHB2	B	-6.16	-7.68	2.56
GCL1A	C	44.98	45.13	1.98
GCL1B	C	51.30	51.05	1.16
GCL2A	C	44.38	44.70	0.73
GCL2B	C	51.41	50.89	2.05
GCL3A	C	35.75	35.80	0.94
GCL3B	C	44.32	43.39	1.62
GEDW1	C	27.34	27.81	0.64
GEDW2	C	32.24	32.07	0.94

| Variable | Calf | Measurement Means | | Standard Error |
		M1(cm)	M2(cm)	
GEDHH	C	26.81	26.40	1.15
CLHT1	C	-9.09	-8.68	0.96
CLHT2	C	7.28	6.91	0.75
CLHB1	C	3.22	2.76	1.53
CLHB2	C	-10.98	-9.83	1.43
GCL1A	D	47.69	48.45	0.82
GCL1B	D	51.64	52.40	0.87
GCL2A	D	46.41	47.56	0.76
GCL2B	D	46.20	47.69	1.38
GCL3A	D	38.08	38.76	0.72
GCL3B	D	40.04	41.18	0.68
GEDW1	D	27.92	27.16	0.75
GEDW2	D	31.79	31.71	0.71
GEDHH	D	28.86	28.65	0.83
CLHT1	D	-7.14	-7.48	1.08
CLHT2	D	5.23	4.63	1.59
CLHB1	D	-0.76	-0.26	1.64
CLHB2	D	-7.44	-7.35	2.24

Appendix D

Residual Plots for the Final Overall Regression Model

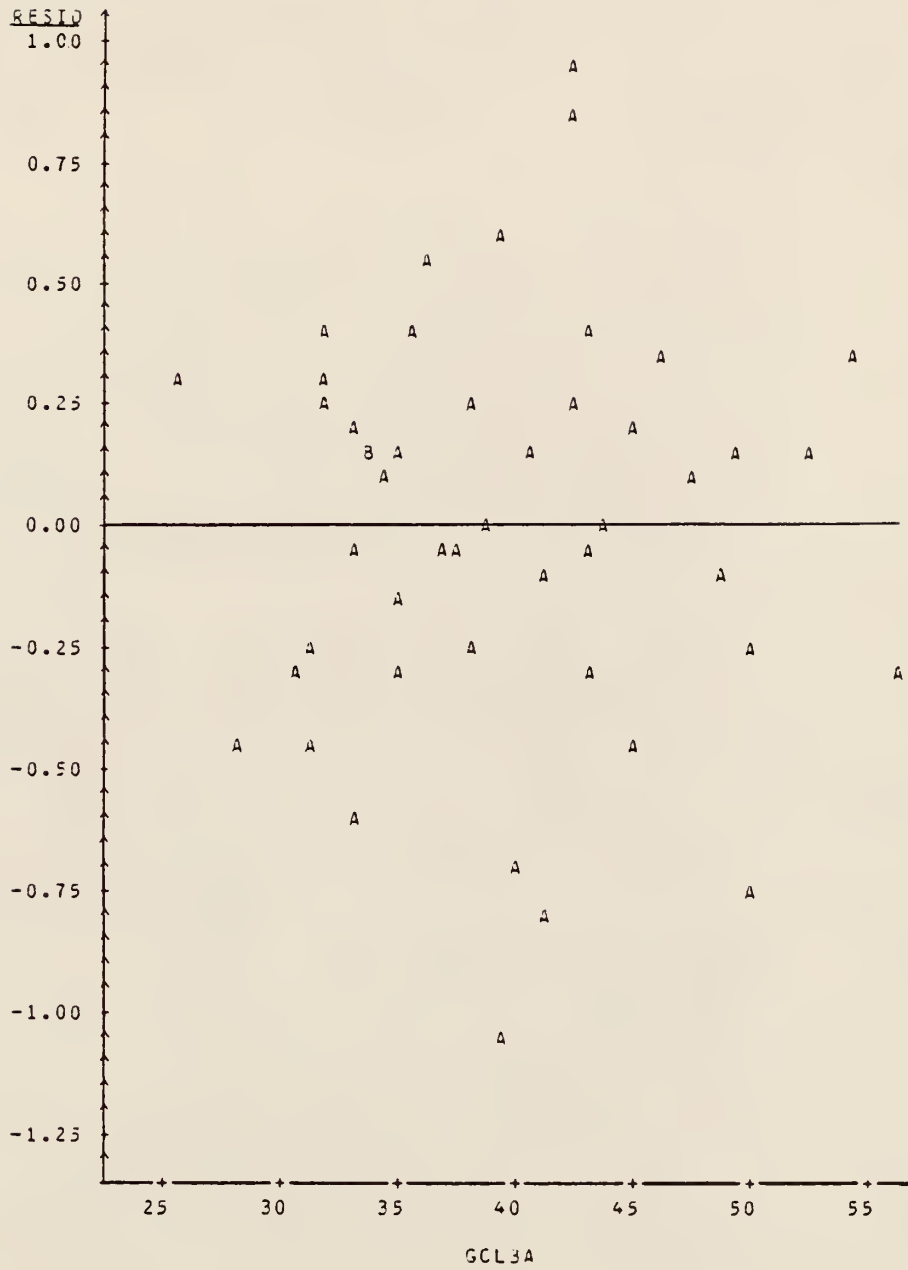PLOT OF RESID*TOTIME   LEGEND: A = 1 OBS, B = 2 OBS, ETC.
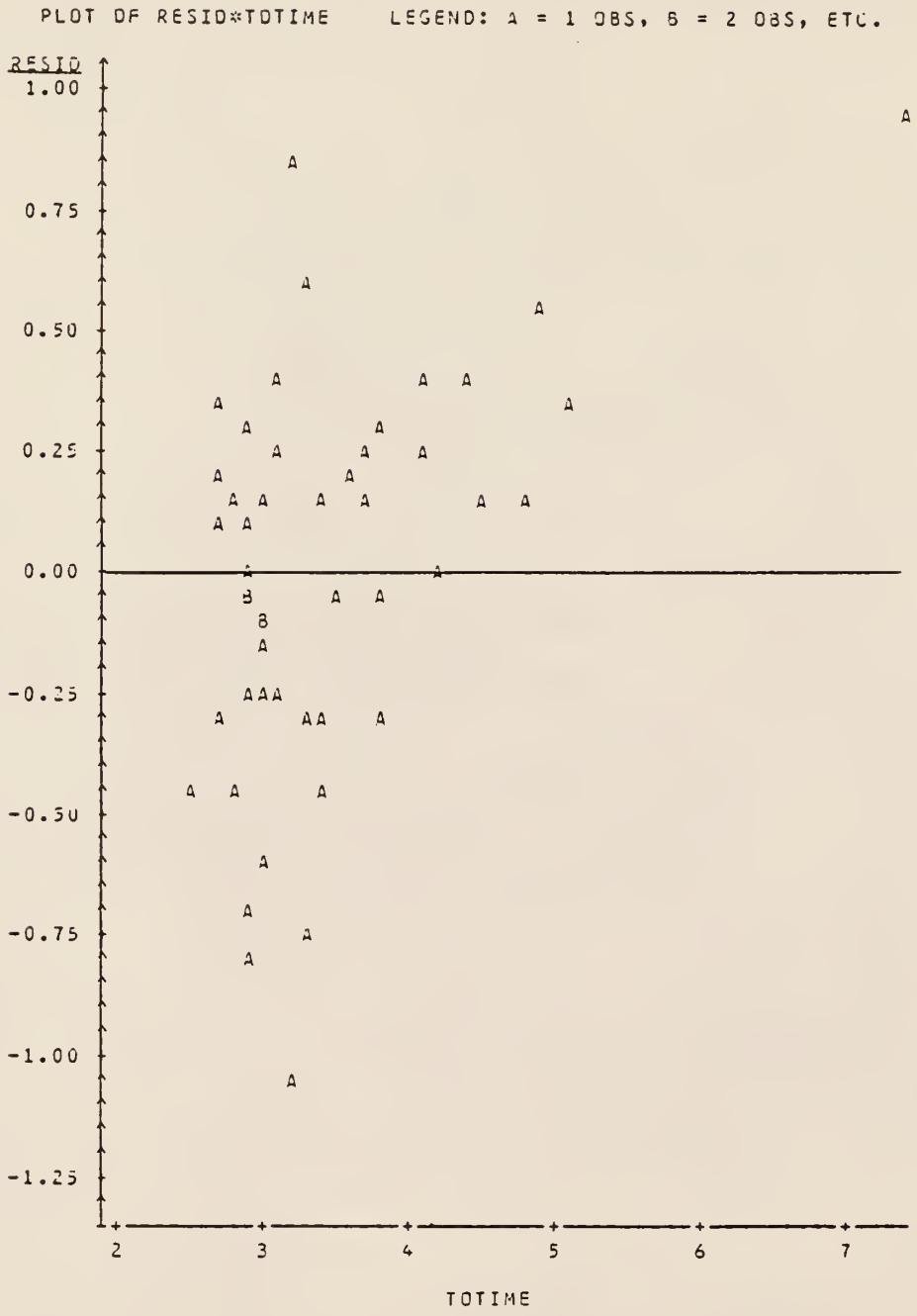
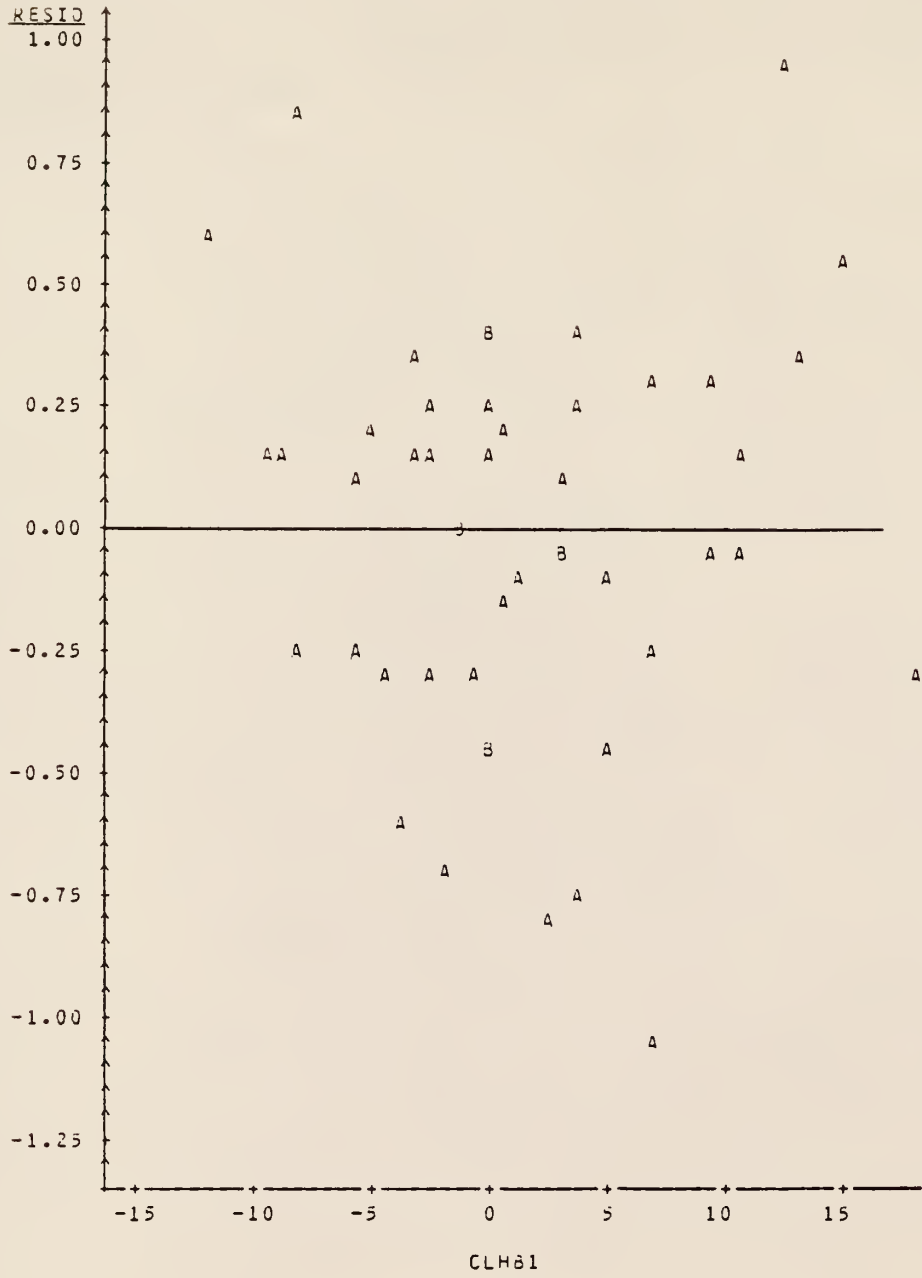PLOT OF RESID*YHAT   LEGEND: A = 1 OBS, B = 2 OBS, ETC.
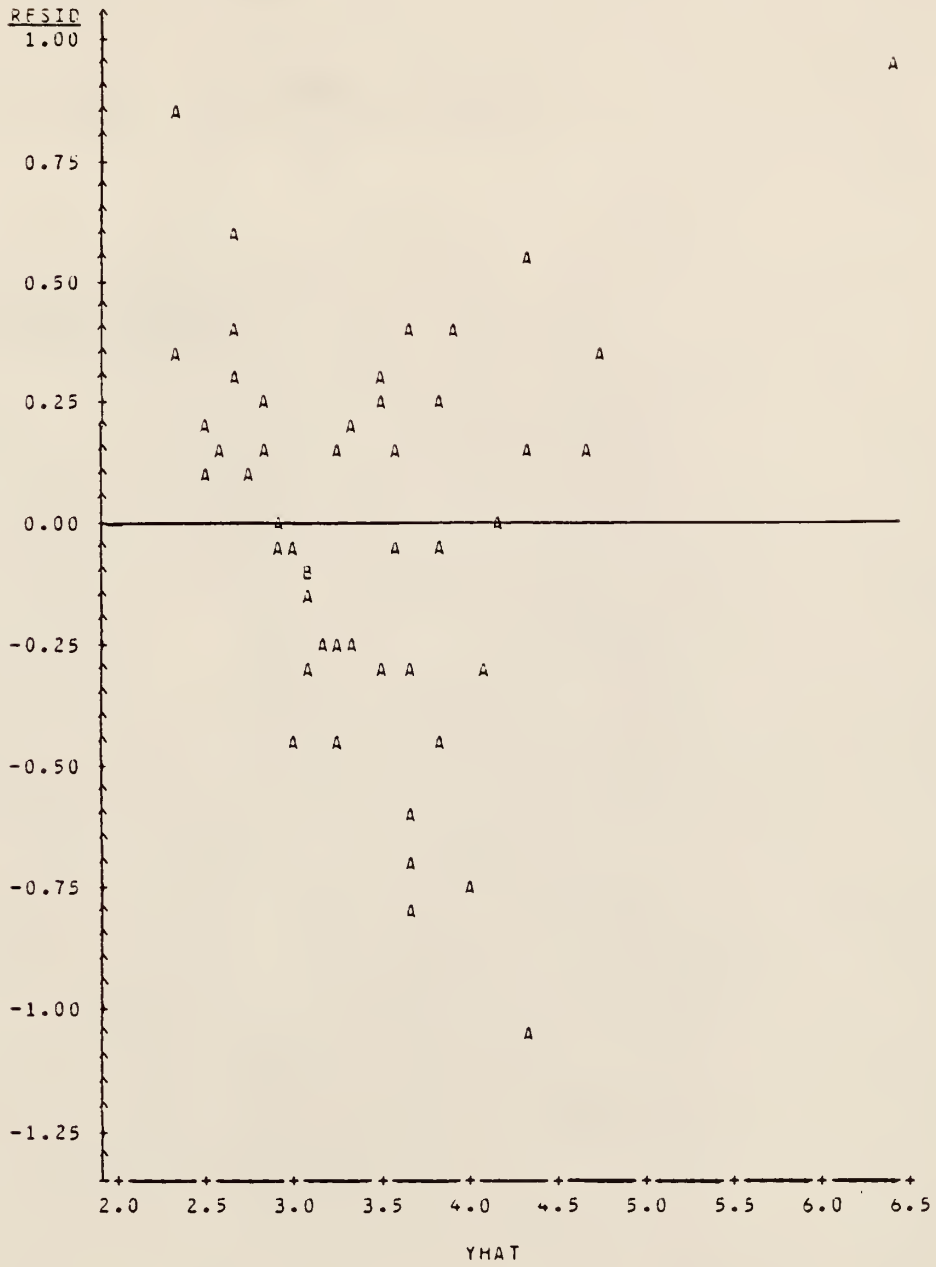
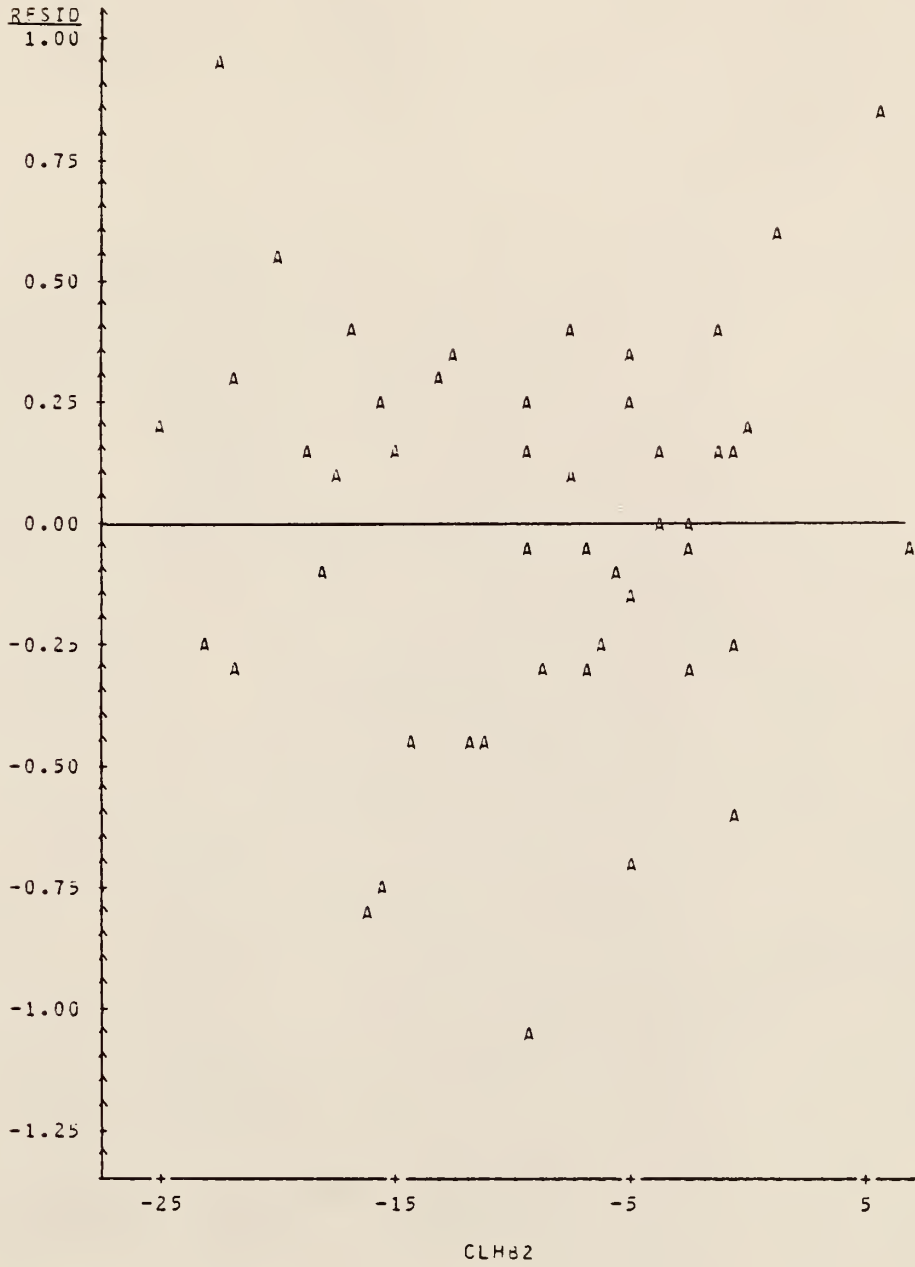PLOT OF RESID*GCL2B   LEGEND: A = 1 OBS, B = 2 OBS, ETC.
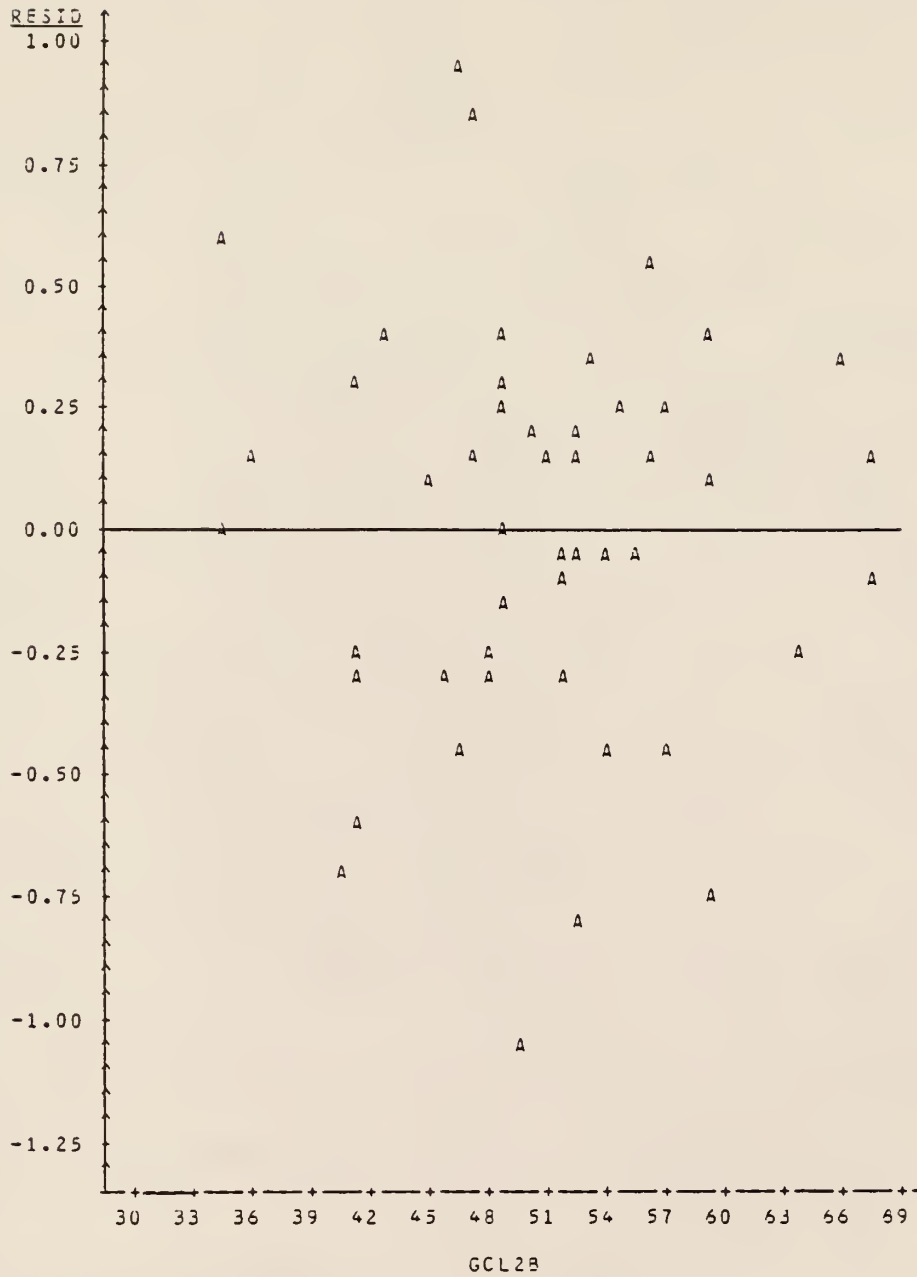
PLOT OF RESID*GCL3A   LEGEND: A = 1 OBS, B = 2 OBS, ETC.

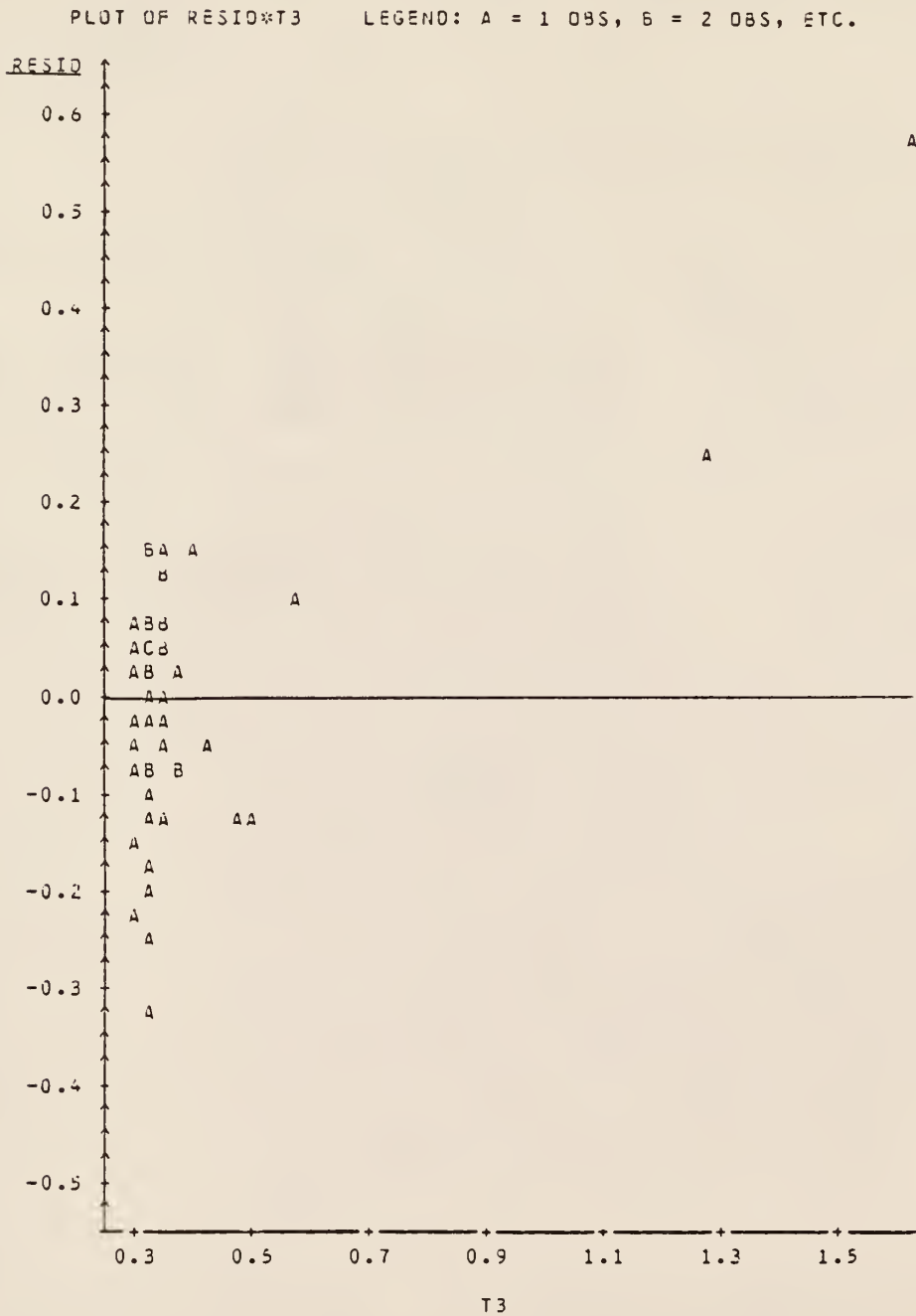PLOT OF RESID*CLHB1   LEGEND: A = 1 OBS, B = 2 OBS, ETC.

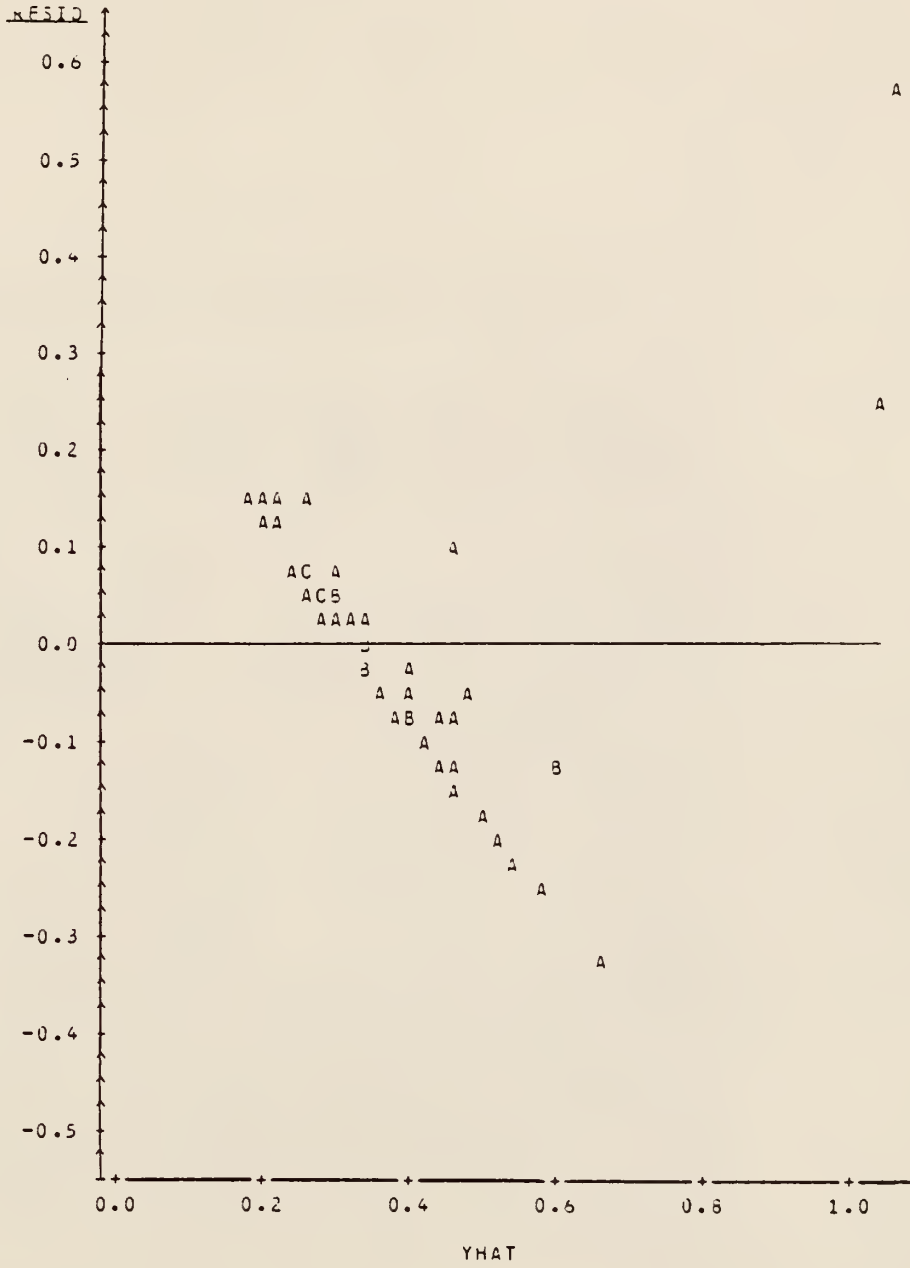PLOT OF RESID*CLH82   LEGEND: A = 1 OBS, B = 2 OBS, ETC.

Appendix E

Residual Plots for Constituent Phase Regression Model
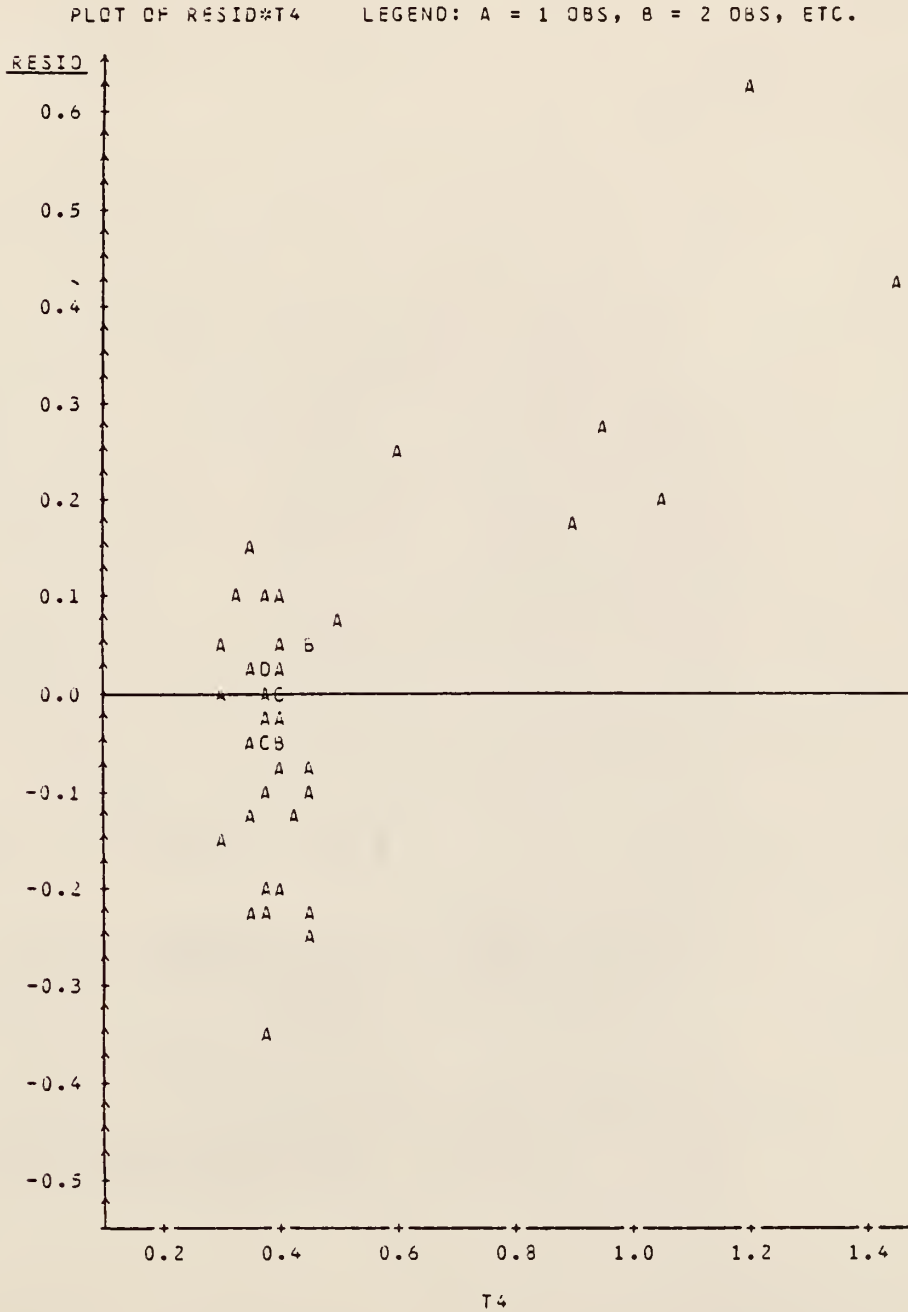## Using T3 as the Dependent Variable

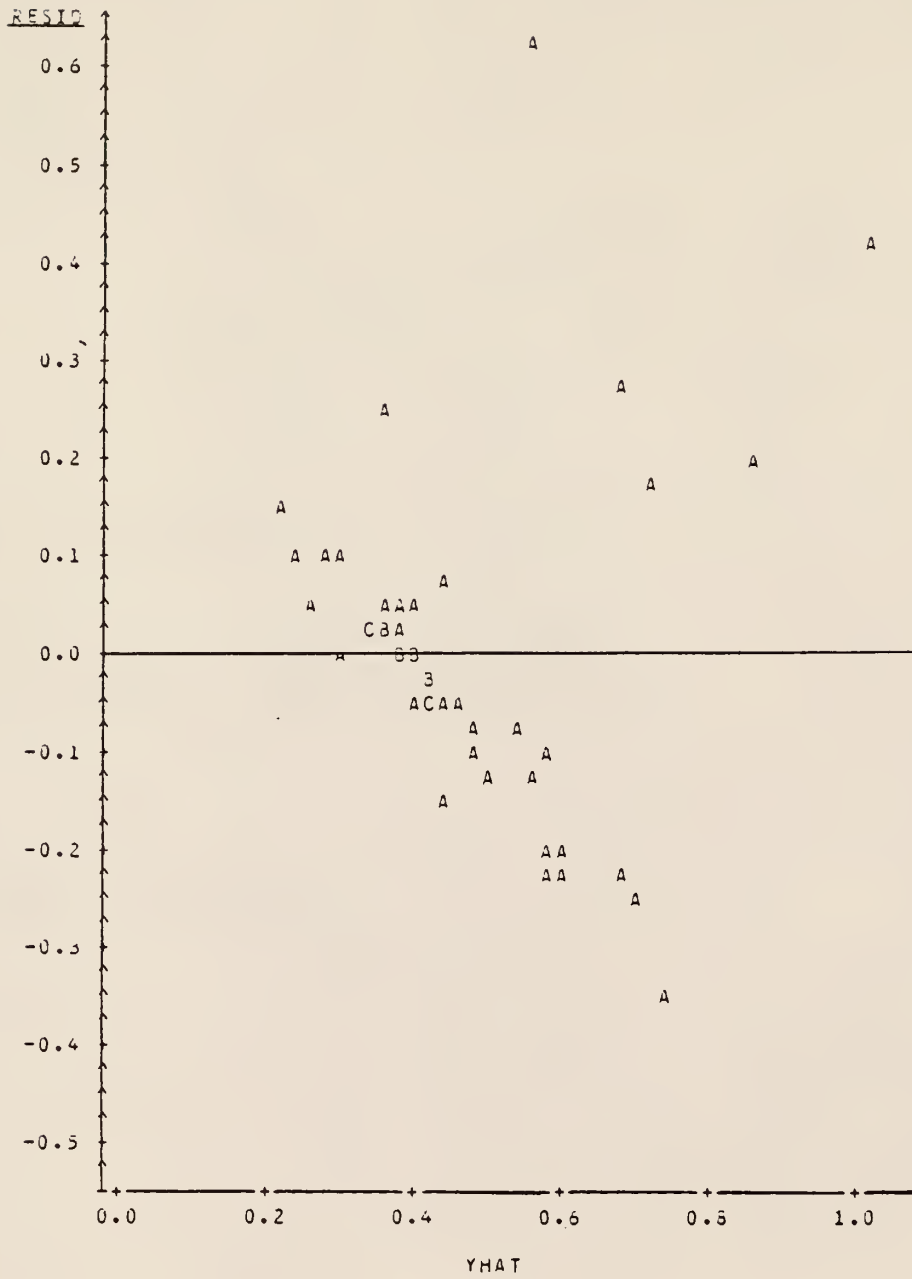PLOT OF RESID*T3   LEGEND: A = 1 OBS, B = 2 OBS, ETC.

PLOT OF RESID*YHAT   LEGEND: A = 1 OBS, B = 2 OBS, ETC.

RESID
   0.6 +   A

   0.5 +

   0.4 +

   0.3 +

   0.2 +   A

          AAA A
   0.1 +   AA   A
           AC A
           ACB
           AAAA
   0.0 +--
                B A
                 A A   A
               AB AA
                A
   -0.1 +   AA   B
               A
   -0.2 +   A
              A
             A
            A
   -0.3 +   A

   -0.4 +

   -0.5 +
       +--------+--------+--------+--------+--------+--------+--------
      0.0   0.2   0.4   0.6   0.8   1.0

                              YHAT

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PLOT OF RESID*CLHT1   LEGEND: A = 1 OBS, B = 2 OBS, ETC.
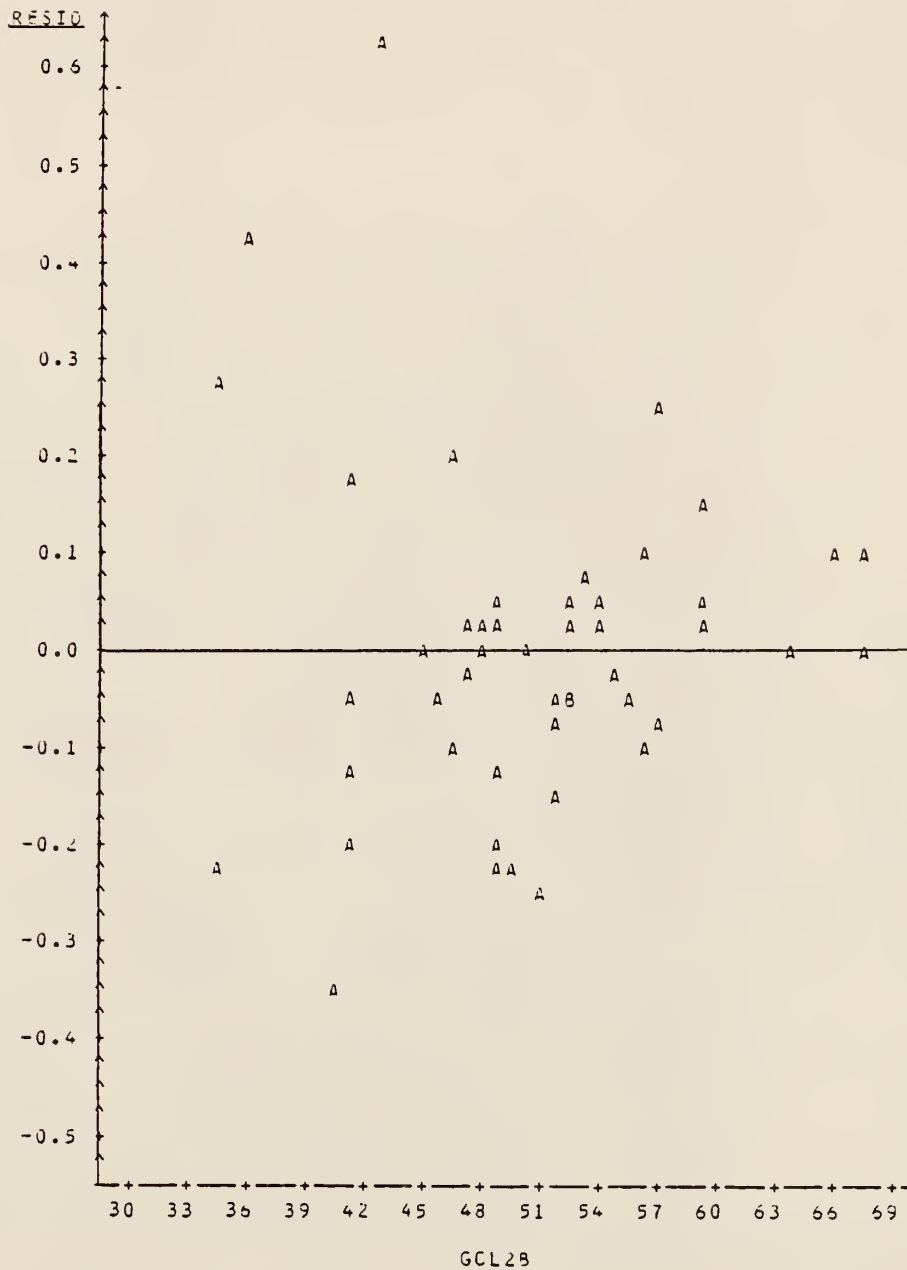
Appendix F

Residual Plots for Constituent Phase Regression Model
Using T4 as the Dependent Variable
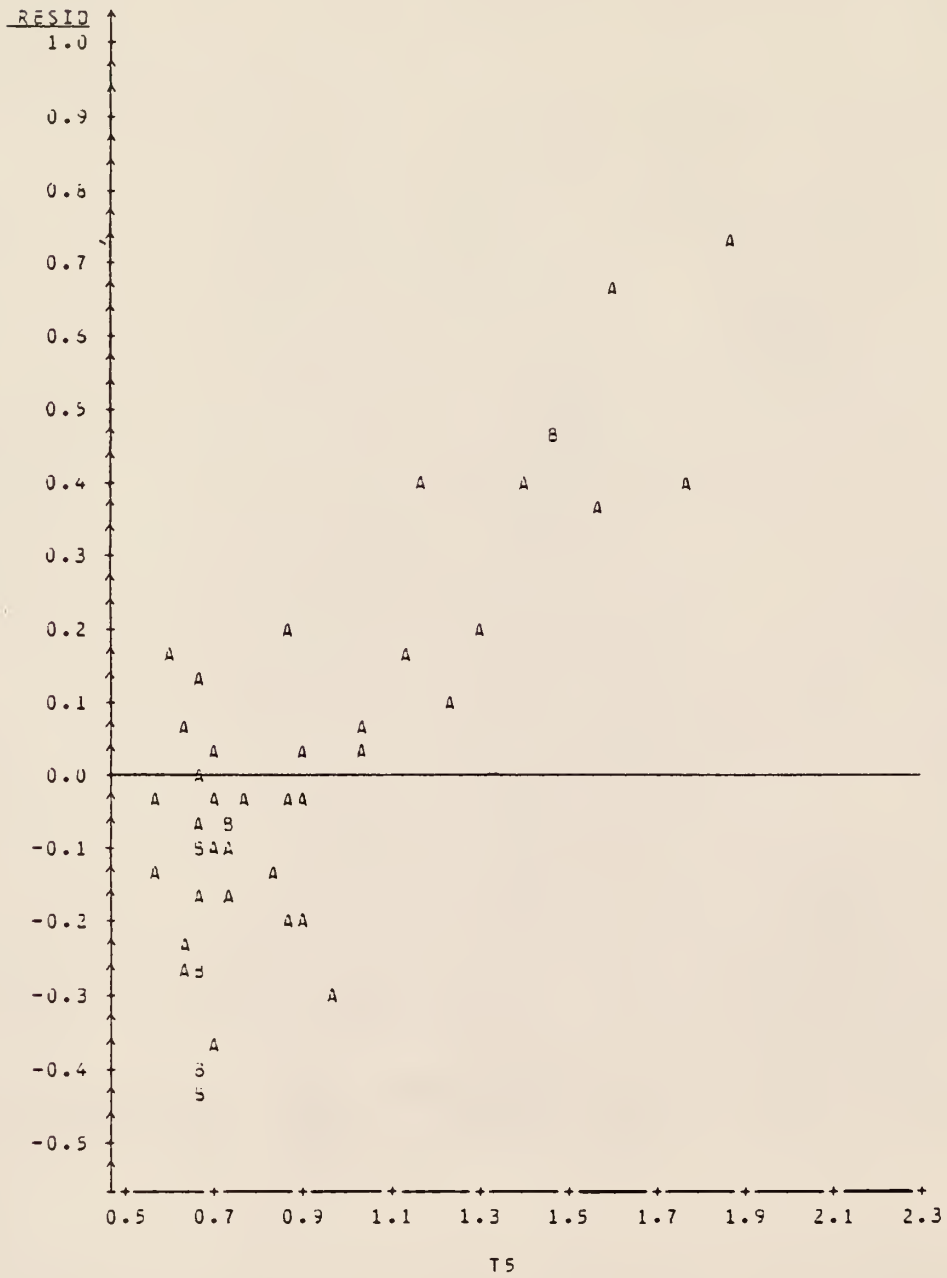

PLOT OF RESID*T4   LEGEND: A = 1 OBS, B = 2 OBS, ETC.

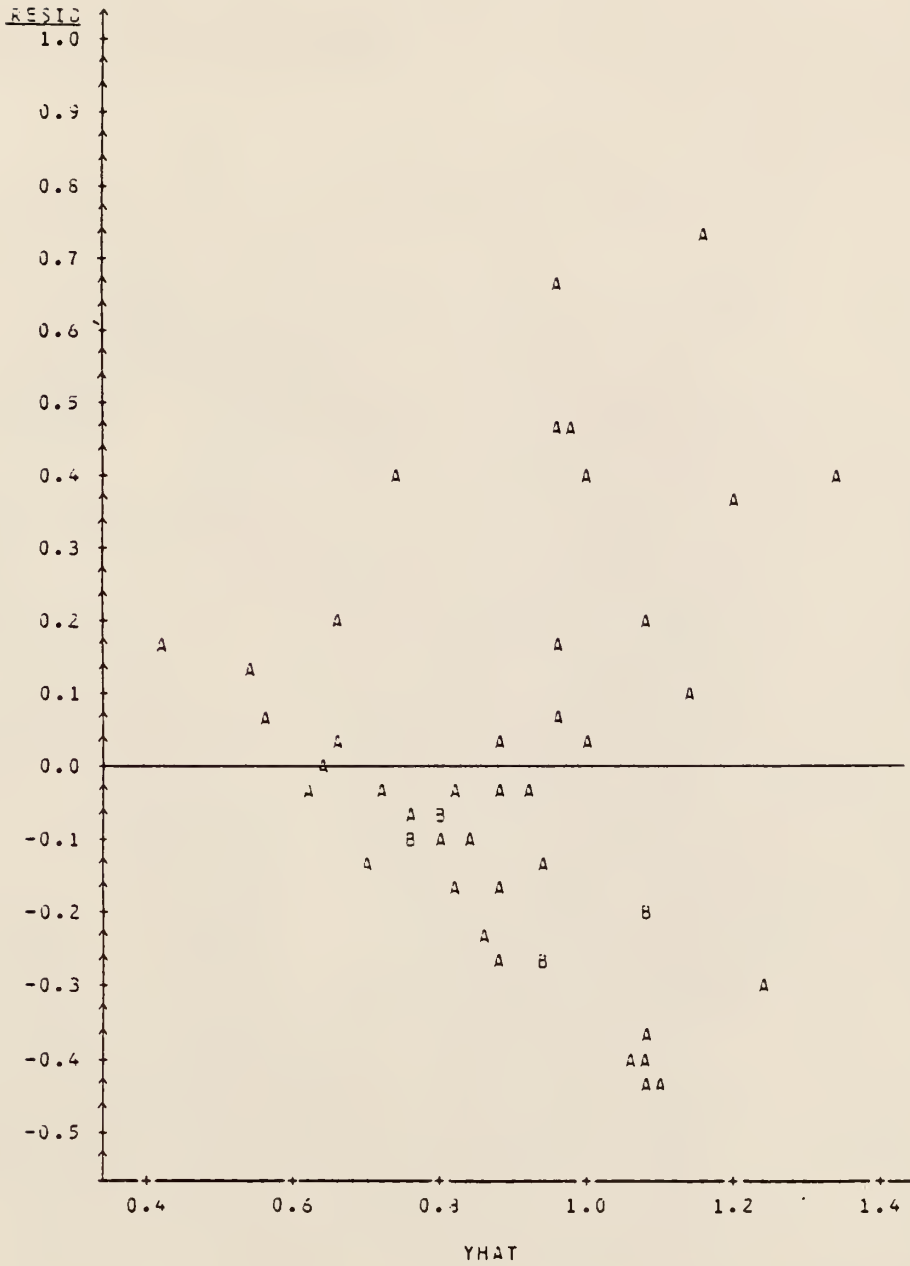PLOT OF RESID*YHAT   LEGEND: A = 1 OBS, B = 2 OBS, ETC.

PLOT OF RESID*GCL28   LEGEND: A = 1 OBS, B = 2 OBS, ETC.

Appendix G

Residual Plots for Constituent Phase Regression Model Using T5 as the Dependent Variable

PLOT OF RESID*T5.   LEGEND: A = 1 OBS, B = 2 OBS, ETC.
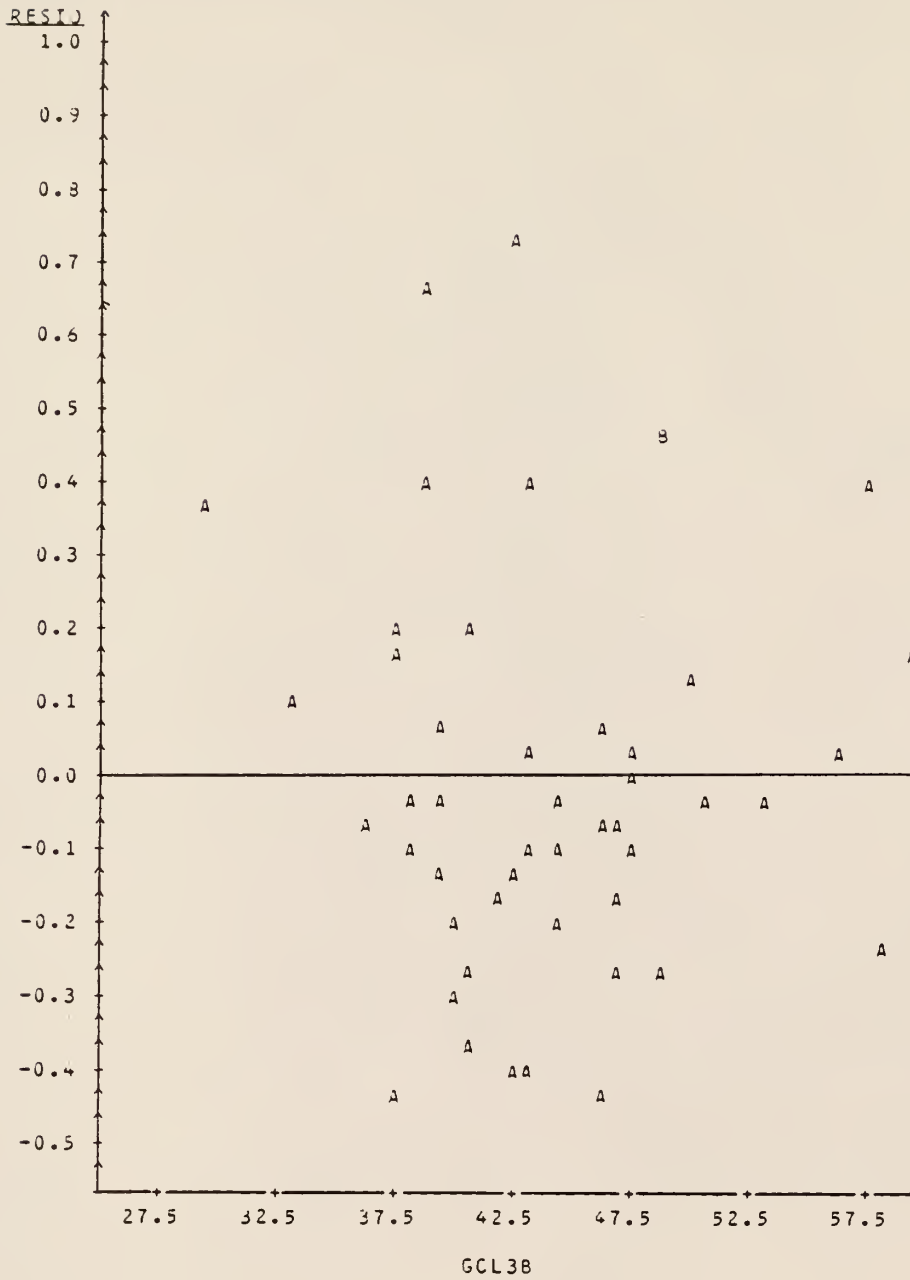
PLOT OF RESID*YHAT   LEGEND: A = 1 OBS, B = 2 OBS, ETC.

PLOT OF RESID*GCL3B   LEGEND: A = 1 OBS, B = 2 OBS, ETC.

KINEMATIC ANALYSIS OF THE TYING PHASE OF CALF ROPING

by

CHAD HARRIS

B.S., California Polytechnic State University,
San Luis Obispo, 1885

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Physical Education and Leisure Studies

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1987

The purpose of this investigation was to describe the mechanical characteristics of the skilled execution of the tying phase of calf roping. Thirteen males who were competing collegiate and professional calf ropers volunteered as subjects. Each subject tied four calves. A frontview of the subjects was filmed at 100 fps. A stepwise regression procedure using backward elimination was employed to determine the variables most significantly related to total tying time, and to generate a prediction equation for total tying time. Dummy variables accounted for effects of subjects (Bs) and calves (Bc). The variables most significantly related to total tying time were: (a) the ground-to-calf leg distance at the bottom of the second wrap (GCL2B, p=.0001), (b) the difference in calf leg-to-hand distances measured at the bottom of the half-hitch and the bottom of the second wrap (CLHB2, p=.0017), (c) the ground-to-calf leg distance at the top of the half-hitch (GCL3A, p=.0173), and (d) the difference in calf leg-to-hand distances measured at the bottom of wrap two and the bottom of wrap one (CLHB1, p=.0239). The final regression equation for predicting total tying time was:

TOTAL TIME = 6.04893174 + Bs + Bc - 0.09451463*GCL2B + 0.04991871*GCL3A + 0.05253139*CLHB1 - 0.06400404*CLHB2

The model was significant (p=.0001) and explained 86 percent of the variance.

Additional regression models, using constituent phases

of total tying time during which measurements were taken as dependent variables, were created. Measurements taken during a particular phase acted as independent variables.

Based on the results of this study, it was concluded that: (a) the distance from the calf's legs to the roper's right hand should remain consistent through the first two wraps, and decrease at the bottom of the half-hitch (b) higher calf leg heights at the bottom of the second wrap and lower calf leg heights at the beginning of the half-hitch are associated with faster tying times, and (c) right elbow joint displacement during the tying phase is not related to tying time.