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CORRELATION OF BREECH EROSION GAGE TO ACCURACY FOR M16A1 RIFLE WITH CHROME PLATED BARREL BORES

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Army Materiel Command
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This research is designed to answer the following questions: (1) do calibrated gage rods act as good predictors of the accuracy parameter of extreme spread for M16A1 rifles; and (2) what gage rod diameter gives the better performance for the M16A1 rifle?

The data used to answer these questions was obtained from M16A1 rifles test fired at different firing rates for the life

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) of the rifles. For each rifle and gage, the accuracy parameter of extreme spread was recorded with the corresponding gage reading at periodic intervals of rounds fired. The data was analyzed for a relationship between the extreme spread and the gage reading.

Conclusions drawn from these analyses are as follows: (1) no support can be given to gage rods as an accurate predictor of extreme spread for M16A1 rifles; and (2) the gage rod of diameter .2206 inches gave the better prediction performance for the M16A1 rifle.

FOREWORD

The research discussed in this report was accomplished as part of the Product/Production Engineering Graduate Program conducted jointly by USAMC Intern Training Center and Texas A&M University. As such, the ideas, concepts and results herein presented are those of the author and do not necessarily reflect approval or acceptance by the Department of the Army.

This report has been reviewed and is approved for release. For further information on this project contact: Professor T. F. Howie, USAMC-ITC-PPE, Red River Army Depot, Texarkana, Texas 75501.

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During the course of this work, the author was employed by the US Army as a career intern in the AMC Product Production Engineering Graduate Program. He is grateful to the US Army for the opportunity to participate in this program.

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CHAPTER I

INTRODUCTION

A rifle is a heavily used military tool which demands dependability. The dependability of a rifle is not only a matter of the reliability of the working mechanisms of the rifle but also how well a rifle functions in terms of accuracy. Extensive use of military rifles provides a need for periodic tests to determine if a rifle barrel has exceeded its useful life in terms of the accuracy decaying beyond a desirable point.

It is not always simple or handy to perform an accuracy test on a particular rifle, especially in a field situation. There is then a need for a quick and simple test to determine reliably if a rifle can attain a desired accuracy level.

One such simple test would consist of inserting a calibrated gage rod into the breech bore of a test rifle in the manner similar to a go-no-go test. The depth of penetration of the rod into the breech bore would indicate whether the rifle could meet desired accuracy levels or not. If the results of this test were then dependable, the chances of discarding a useful rifle barrel would be reduced along with reducing the chances of keeping in service a rifle barrel which is no longer dependable.

The remaining problem then would be to find a gage diameter and a depth of penetration which would correlate well to a desired parameter of accuracy. The purpose of the study here is to determine if such a relationship between accuracy and breech bore wear exists so as to allow a reliable test.

The method of solution will be a statistical analysis of data received from an extensive test at Rock Island Arsenal where new M16A1 rifles were fired to the end of their servicable life. The accuracy parameter of extreme spread was recorded periodically during the testing of each rifle as was data of penetration depths for nine sizes of gage rods. A curve fit will be performed on the data for each gage and rifle, and the functional relation between extreme spread and gage penetration depth will be determined. After choosing an optimal cut-off-point for extreme spread and each gage, a test of hypotheses will be used to determine if the cut-off-point corresponds to the optimal value of depth measurement.

The results of a literature search to determine the previous work accomplished in the area of developing such a gage will be presented in Chapter II. Experiment description will follow in Chapter III, which also shows the origin of the test data and the test methods. Chapter IV will discuss the analysis procedure and methods used to reduce the data, and final data analysis will be discussed in Chapter V. The conclusion and overall results will be presented in Chapter VI.

CHAPTER II

LITERATURE SURVEY

During the accomplishment of the literature survey, two general areas were researched. The first section presented below involves responses to correspondence with major rifle manufacturing companies. The second section presents results obtained through a survey of published tests which bore a similarity to this study.

Correspondence Survey

Inquiring about information from competitive manufacturing companies on what they may have done in the area of bore wear measurements measured by gages resulted in two responses.

Rifle manufacturing companies which do not manufacture military rifles are not greatly concerned with bore wear since a sporting rifle is not fired enough for bore wear to be greatly significant. This was the type of response received from Brophy (3), Macfarland (11), Pardee (12), and Thimmes (13).

Manufacturing companies which do produce military rifles are reluctant to release information which may be either confidential in a military respect or confidential in the respect of competitive companies making use of the information. Response of this type was received from Browning (4), Dean (5), and Howe (8).

Similar Studies Survey

As result of the responses of the previous section, the United States Defense Department proved the most open source of information on the subject through the Defense Documentation Center (10).

The Defense Department presently has a gage used for breech bore barrel erosion measurement on the M16 rifle. The gage, #C7799792, was developed at Springfield Armory prior to 1966 thru tests on rifles with unplated barrel bores. The development of the gage was based on experimental results from which it was determined that an advancement of rifling with a diameter of .2200 inches further than 3.625 inches from the origin would give an extreme spread average of 9 inches or greater with the 9 inches being the cut-off limit for barrel service life for overseas use.

There are two factors which have changed since the development of the #C7799792 breech bore gage. The first is that an extreme spread of 7 inches is now the cut-off limit for barrel service life for overseas use. The second is that chrome-plated barrel bores are now being used on the M16 rifles.

The most important differences in this study and the previous development are that a particular gage will not be studied as such and statistical analysis will be used instead of experimental analysis. A more general approach using a set of 9 gages ranging in size from a diameter of .2204 inches to .2234 inches will be used to determine the gage which will better indicate a desired cut-off point. The final statistical analysis should indicate which gage will perform the most reliably. The overall result of this study is to select the gage which is the most reliable predictor of extreme spread.

CHAPTER III

EXPERIMENT DESCRIPTION AND ORIGIN OF THE TEST DATA

The experiment that provided data for this analysis was designed to calibrate the breech erosion penetration gage as a field criterion for determining the accuracy and serviceability of M16A1 Rifle barrels with chrome plated bores. Rifle barrels were used from three manufacturers; Colt, General Motors, and Maremont. Identification markings for the rifle barrels used in this analysis were C1, C5, and C7 for the Colt barrels; GM1, GM5, and GM7 for the General Motors barrels; M1, M5, and M7 for the Maremont barrels.

In each case the rifle would be fired for 1000 rounds then a gage would be inserted into the breech and the length of the gage extending would be recorded. This process would be repeated until a rifle had worn beyond serviceable use. Different firing rates were used on the rifles. Rifles G1, GM1, and M1 were fired at a rate of 20 rounds per minute. Rifles C5, GM5, and M5 were fired at a rate of 60 rounds per minute. Rifles C7, GM7, and M7 were fired at a rate of 100 rounds per minute. Rifles were picked for analysis from the group tested so that one of each rate for each manufacturer would be included in the analysis.

Nine different gage sizes were used and data taken for each on each rifle at the increments of 1000 rounds fired. The different gage sizes in inches were as follows; 0.2204, 0.2206, 0.2208, 0.2210, 0.2212, 0.2218, 0.2223, 0.2228, and 0.2234. These gages are refered to as G1 thru G9 respectively.

Extreme spread measurements were determined after each 1000 rounds fired and at the same time as gage measurements were recorded. The extreme spread measurement was arrived at by taking the extreme spread from each of three groups of ten rounds fired with ammunition qualified for accuracy and averaging the three extreme spreads. This method served to reduce effects of random factors on the measurements.

It should be noted here that in all calculations for analysis to follow that the measurement of gage length extending from the breech was used and not the gage length penetrating the breech.

The procedure used to analyze the data is discussed in Chapter IV.

CHAPTER IV

ANALYSIS PROCEDURE

The procedure used to analyze the test data was to first fit a representative model to the data by means of a least squares curve fit (14) and use this model in a statistical analysis of the data.

The method used to perform the least squares curve fit was by utilization of the Statistical Analysis System (1) on the IBM 1130 computer.

Once the most representative model was determined it was used to evaluate the different gages and select the gage showing the best characteristics.

Curves of extreme spread versus gage length extending for each rifle and for each manufacturer were prepared using the most representative model of the data. The different manufacturers were tested for significant difference and a curve was developed from a combination of all the data.

The representative model, with parameters determined from the data of each of the individual manufacturers, was used to calculate an operating characteristic curve for each of the manufacturers for the gage determined as most suitable. These operating characteristic curves were then used to demonstrate the suitability of the gage for predicting accuracy for each of the manufacturers. An operating characteristic curve was then developed, using the combined data to develop the model parameters, which displays the gage operating range when used for all manufacturers.

The following chapter, Chapter V, will discuss the steps of the procedure in detail.

CHAPTER V

FINAL DATA ANALYSIS

To judge or measure the range of useful information to be received from the use of rod gages, operating characteristic curves will be needed. The equation used to determine the operating characteristic curve is

$$d = \frac{u_0 - u}{\sigma}.$$

Where u_0 is chosen to equal 7.0 inches extreme spread and u is an arbitrary value of extreme spread selected for calculation of a value of d.

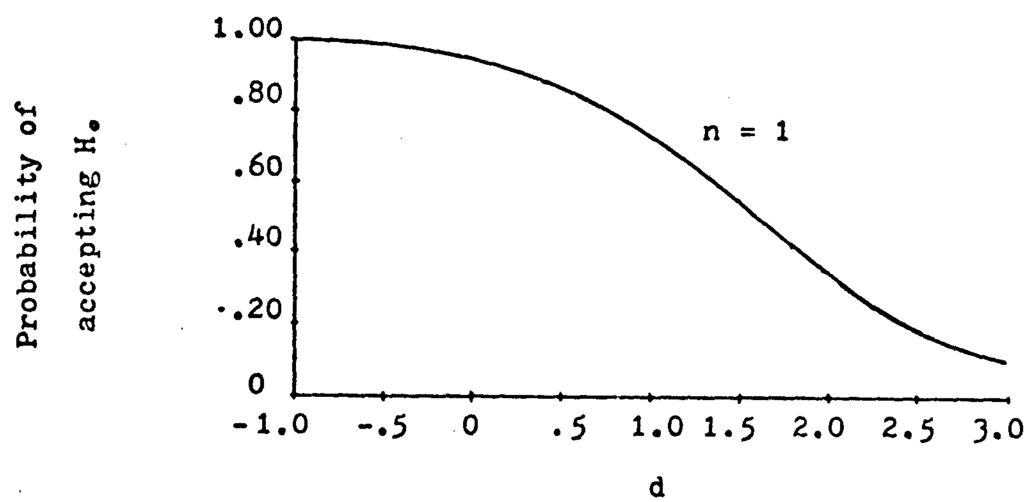


FIGURE 1A

The H_0, shown in Figure 1A, represents a hypothesis statement concerning the conclusion that a rifle has reached or has exceeded the predetermined wear-out point of seven inches extreme spread. Hypothesis testing involves the assumption that a statement called H_0 is true unless it can be rejected in favor of an alternate statement H_1. The hypothesis assumed true is then $H_0 : u \geq u_0$ and may be rejected in favor of the alternate statement $H_1 : u < u_0$. The probabilities shown in Figure 1A are the probabilities associated with accepting $H_0 : u \geq u_0$. The acceptance region for the operating characteristic curves will be $(-K_\alpha , \infty)$. K_α is the 100α percentage point (normal deviate corresponding to α) of the normal distribution. The level of significance for the operating characteristic curve will be $\alpha = .05$. This corresponds to saying that when u is actually greater than or equal to u_0 the probability of concluding that u is less than u_0 is equal to 5%.

The t statistic would normally be used when working with data for which the standard deviation is not known. That is not done in this case, however, since the approach used to evaluate the rod gages is from the point of view of the gage user. That is to say, the gage would be used to make a single measurement of penetration of depth and the decision concerning acceptance or rejection would be based on this single sample. The loss of one degree of freedom with the use of the t statistic would not allow its use in this case.

The parameters of the equation must be determined from the data. As can be seen, the standard deviation is the factor which must be determined from the test data for the rifles. To determine the standard deviation for the data, the mathematical relationship between the extreme spread and rod gage measurements must be found. This will be accomplished through the use of regression models.

For the operating characteristic curve to be valid it is apparent that the standard deviation must be a constant throughout the range of extreme spreads to be investigated. One method of testing for constant standard deviations is to use the standard deviation of several data points at a particular extreme spread and test this standard deviation against that of data at another value of extreme spread for equivalence. This type of test can not be utilized here since only one measurement is made at each extreme spread thus not providing enough information to test for equivalent standard deviations. A part of the regression model requirement will then be to minimize any change in standard deviation for various values of extreme spread. The indicator of standard deviation to be used in minimizing changes in standard deviation is the residuals obtained from the regressions of the data. The residual being the difference between the mathematical models prediction and the actual data value of extreme spread at any given gage rod measurement.

To support the assumption of constant standard deviation, a model will be chosen so as to, in effect, smooth the residuals. That is, eliminate any patterns in the residuals that show increasing or decreasing trends. Once this is accomplished, the standard deviation to be used in calculating the operating characteristic curve will be determined from the regression of the data.

Other problems to be dealt with arise from the fact that three manufacturers are represented in the data. The possibility exists that while each manufacturer would be represented by the same equation form the equation parameters might vary widely. This possibility will also be examined.

Each of the three companies is represented by data taken from three rifles for each company. It was found initially that rifle M7 from the Maremont company regressed very well and the assumption was made that a satisfactory mathematical model for this rifle would be valid for all other rifles. The behavior of the data for the different rifles and companies is illustrated later in Figures 7, 8, 9. Observation of the data points in these figures will explain the reason for rifle M7 regressing to models better than the other rifles. As will also be seen, this rifle performed with less erratic extreme spreads as the rifle was subjected to wear.

Developing The Model

The development of the mathematical model of the data will be taken as the first step in progressing to the operating characteristic curves.

The method of analysis used on the following models is by regression of the extreme spread data on the rod gage measurements data. The values received from the regression for the correlation coefficient of regression (R^2) and the F-test probability were used to judge the effectiveness of the model. R^2 is a regression value defined as the measure of the " proportion of total variation about the mean $\bar{Y}$ explained by the regression." (14) It is determined from the ratio of the sum of squares due to regression over the total sum of squares corrected for mean. The F ratio follows an F-distribution and is determined from the ratio of the mean square due to regression and the mean square due to residual variation. The F-test is used as a test of the hypothesis $H_0 : \beta_1 = 0$. β_1 is a parameter of the regression model. The ratio is compared with the $100(1 - \alpha)$ % point of the tabulated $F(1, n-2)$ distribution in order to determine whether β_1 can be considered nonzero on the data used (14). If the F ratio determined from the data is greater than the tabulated F(1, n-2) value, the hypothesis $H_0: \beta_1 = 0$ can not be accepted and support is given to a value of β_1 that is non-zero. This test is referred to as the F-test. Once the F ratio and the tabulated F(1, n-2) values are known, the probability that the F ratio is smaller than the tabulated F(1, n-2) can be determined.

β_1 is the parameter of the true relationship between the extreme spread and the rod gage measurements. This value would only be determined precisely if there were no measurement errors or random variations associated with the data observations. Since variations between the data and the true relationship exist, β_1 will be approximated by b_1 which will be the estimate that produces the least possible value of the sum of squares of deviations from the true relationship.

A simple regression model was first approached.

$$EXSPR = b_0 + b_1 G$$

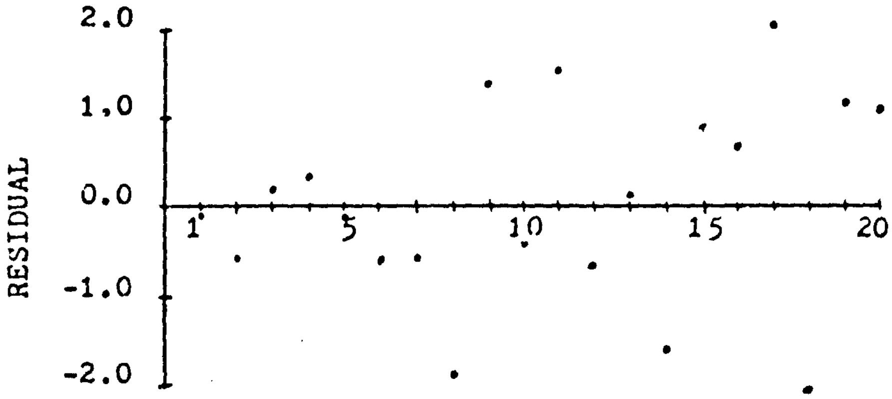
The tool used in performing this and all following regression calculations was the Statistical Analysis System (1). The results of applying this model to the data can be seen in Table 1 where values for the correlation coefficient (R^2), the F value, and the F-test probability are listed for rifles M7 and C7.

The residuals of this regression were investigated for rifle M7 (see Figure 1B) and an increasing trend was noted in the data. This implied that the model as used

TABLE 1

LISTING OF REGRESSION VALUES

Gage	RIFLE M7 R^2	RIFLE M7 F Value	RIFLE M7 Probability $B_i = 0$	RIFLE C7 R^2	RIFLE C7 F Value	RIFLE C7 Probability $B_i = 0$
G1	0.8426	96.4	.0001	0.8251	84.9	.0001
G2	0.8740	124.9	.0001	0.8399	94.4	.0001
G3	0.8574	108.2	.0001	0.8539	105.2	.0001
G4	0.8606	111.1	.0001	0.8264	85.7	.0001
G5	0.8655	115.8	.0001	0.8124	77.9	.0001
G6	0.8525	104.0	.0001	0.8066	75.1	.0001
G7	0.8331	89.9	.0001	0.8148	79.2	.0001
G8	0.8125	78.0	.0001	0.8238	84.2	.0001
G9	0.7376	50.6	.0001	0.7707	60.5	.0001



TIME ORDER PLOT OF RESIDUALS

MODEL: EXTREME SPREAD = $b_0 + b_1$ (GAGE LENGTH EXTENDING)

FIGURE 1 B

was not that desired and that a time weighted factor was needed.

The investigation of this model was continued by extending the model to include multiple gage data as can be seen by models 2, 3, 4, 5, and 6 in Table 2. While these resulted in better models than the single gage model, they were not considered feasible to the solution of the defined problem of determining the single best performing gage. These models also do not incorporate a time weighted factor as suggested by the residuals of the simple regression model first investigated.

A polynomial regression was next applied with the result being that it could give no improvement over the simple regression model. The results in Table 2 for model 7 show that higher order terms do not add significance to the model.

Models 8 and 9 in Table 2 were investigated as an attempt to discover if the time weighted factor might be obtained from these forms of regression equation. As the data shows, there was no great improvement over the initial simple model.

The data for number of rounds fired at each sampling was incorporated into models 10, 11, 12, 13, 14, and 15 of Table 2 to investigate the amount of contribution made by this time factor on the regressions of the models. A good improvement can be seen in the results of models

TABLE 2

EVALUATED MODELS

Using Rifle M7 Data

	MODEL	R^2	F	VARIABLE COEFFICIENT	F-test Probability
1	$EXSPR = b_0 + b_1 G2$	.8740	124.9	b_1	.0001
2	$EXSPR = b_0 + b_1 G1 + b_2 G2$	.8828	64.0	b_1	.0001
				b_2	.0274
3	$EXSPR = b_0 + b_1 G1 + b_2 G2 + b_3 G3$	.8873	42.0	b_1	.0001
				b_2	.0296
				b_3	.4326
4	$EXSPR = b_0 + b_1 G1 + b_2 G4$	.8712	57.5	b_1	.0001
				b_2	.0690
5	$EXSPR = b_0 + b_1 G1 + b_2 G4 + b_3 G8$	.8720	36.3	b_1	.0001
				b_2	.0771
				b_3	.7524
6	$EXSPR = b_0 + b_1 G5 + b_2 G9$	.8707	57.2	b_1	.0001
				b_2	.4225
7	$EXSPR = b_0 + b_1 G2 + b_2 G2^2 + b_3 G2^3 + b_4 G2^4$	.8742	59.1	b_1	.0001
				b_2	.8901
				b_3	1.0000
				b_4	1.0000
8	$EXSPR = b_0 + b_1 G2^2$	.8859	139.8	b_1	.0001
9	$\sqrt{EXSPR} = b_0 + b_1 G2$	.8739	124.7	b_1	.0001
10	$EXSPR = b_0 + b_1 G2 + b_2 RNDS$	.8741	59.0	b_1	.0001
				b_2	.9557
11	$EXSPR/RNDS = b_0 + b_1 G2$	.2764	6.9	b_1	.0173

TABLE 2 Continued

	MODEL	R^2	F	VARIABLE COEFFICIENT	F-test PROBABILITY
12	$LOG(EXSPR) = b_0 + b_1 LOG(G2) + b_2 LOG(RNDS)$	.8895	68.4	b_1	.0001
				b_2	.3006
13	$LOG(EXSPR) = b_0 + b_1 G2 + b_2 LOG(RNDS)$	.8902	68.9	b_1	.0001
				b_2	.3252
14	$EXSPR = b_0 + b_1 G2 + b_2 LOG(RNDS)$	.8745	59.2	b_1	.0001
				b_2	.8117
15	$LOG(EXSPR) = b_0 + b_1 G2 + b_2 RNDS$	.8898	68.7	b_1	.0001
				b_2	.3408
16	$LOG(EXSPR) = b_0 + b_1 G1 + b_2 G2$	.8865	66.4	b_1	.0001
				b_2	.0093
17	$LOG(EXSPR) = b_0 + b_1 G1 + b_2 G2 + b_3 G3$	.8906	43.4	b_1	.0001
				b_2	.0104
				b_3	.4485
18	$LOG(EXSPR) = b_0 + b_1 LOG(G2)$	.8821	134.7	b_1	.0001
19	$LOG(EXSPR) = b_0 + b_1 G2^2$	.8342	216.3	b_1	.0001
20	$LOG(EXSPR) = b_0 + b_1 G2$	.8836	136.6	b_1	.0001

G = Length of gage extending from breech.

EXSPR = Extreme spread.

RNDS = Number of rounds fired.

12, 13, and 15 which also have incorporated a log function.

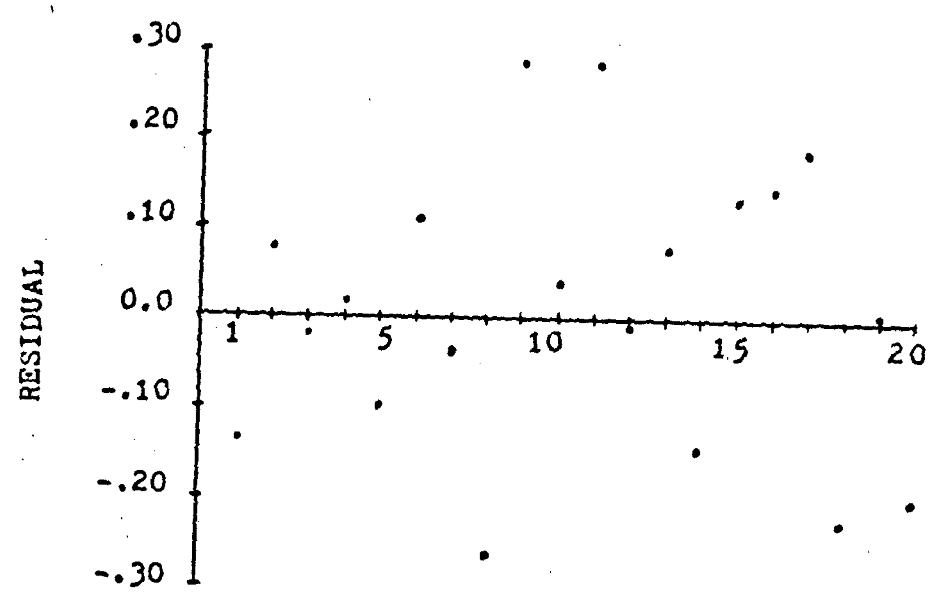
The time factor of number of rounds fired would add improvement to the model. Due to the difficulties required in keeping such records on individual rifles in service, this factor will not be useful in solving the problem of analyzing the rod gages for field use.

The improved solutions also included log factors as well as the rounds fired. Models 16, 17, 18, 19, and 20 of Table 2 were then investigated to determine the affect of logs on the regression models. Once again multiple gage data models (models 16 and 17) were looked at to determine their results even though they are not considered as good solutions to this study due to restricting the analysis to the one most effective gage.

Model 20 of Table 2 regressed the data very well. The model is not complicated and requires measurement data from only one gage. The plot of residuals (Figure 2) for the M7 rifle data does not show increasing or decreasing trend patterns. These are the requirements desired in the model of the data. This model will then be used to determine the standard deviations required for calculating the operating characteristic curves. (see Table 3 for a listing of the standard deviations.)

Selecting The Most Accurate Gage

Only the three smaller diameter gages were invest-



TIME ORDER PLOT OF RESIDUALS

MODEL: LOG(EXTREME SPREAD) = b_0 + b_1 (GAGE LENGTH EXTENDING)

FIGURE 2

TABLE 3

COMPARISON OF GAGES

RIFLE	G1 R^2	G1 F	G1 σ	G2 R^2	G2 F	G2 σ	G3 R^2	G3 F	G3 σ
MAREMONT									
M1	.8894	96.5	.1704	.8853	92.6	.1735	.8680	78.9	.1861
M5	.9333	126.0	.0978	.8596	55.1	.1420	.9021	82.9	.1186
M7	.8290	87.3	.1953	.8836	136.6	.1611	.8657	116.0	.1731
Total	.8179	193.1	.1943	.8334	215.1	.1858	.8190	194.6	.1936
COLT									
C1	.8002	64.1	.1611	.8242	75.0	.1511	.8078	67.2	.1580
C5	.7934	53.8	.1898	.7715	47.3	.1997	.7382	52.1	.1922
C7	-	-	-	.8113	77.4	.1687	-	-	-
Total	.7605	165.1	.1834	.7711	175.2	.1793	.7648	169.1	.1817
GENERAL MOTORS									
GM1	.6673	44.1	.1806	.7634	71.0	.1523	.7689	73.2	.1505
GM5	.0374	0.5	.3626	.0524	0.8	.3597	.1145	1.8	.3477
GM7	.2656	6.5	.3070	.6437	32.5	.2139	.6926	40.6	.1986
Total	.1222	8.1	.3122	.2071	15.2	.2967	.2342	17.7	.2916
ALL RIFLES	.3625	89.3	.3074	.4406	123.7	.2880	.4520	129.5	.2850

Values determined from regression of data using model

$$LOG(EXSPR) = b_0 + b_1 G.$$

Probability that $b_1 = 0$ is .0001 in all cases.

igated closely for the best performing gage. All the larger diameter gages were eliminated after performing similarly in each model to the results shown in Table 1. Table 3 shows regression values for gages G1, G2, and G3 for each of the nine rifles analyzed using the simple log model.

Figure 2 is a time-order-plot of residuals for the regression of gage G2 measurements on extreme spread using the simple log model for the Maremont rifle M7. On the basis of this plot, it is not unreasonable to assume that the standard deviation is a constant along the regression curve. The standard deviations, determined in the regressions of G1, G2, and G3 measurements on extreme spread for each of the manufacturers (see Table 3), were then used to determine the operating characteristic curves for these gages for each of the manufacturers as can be seen in Figures 3, 4, and 5.

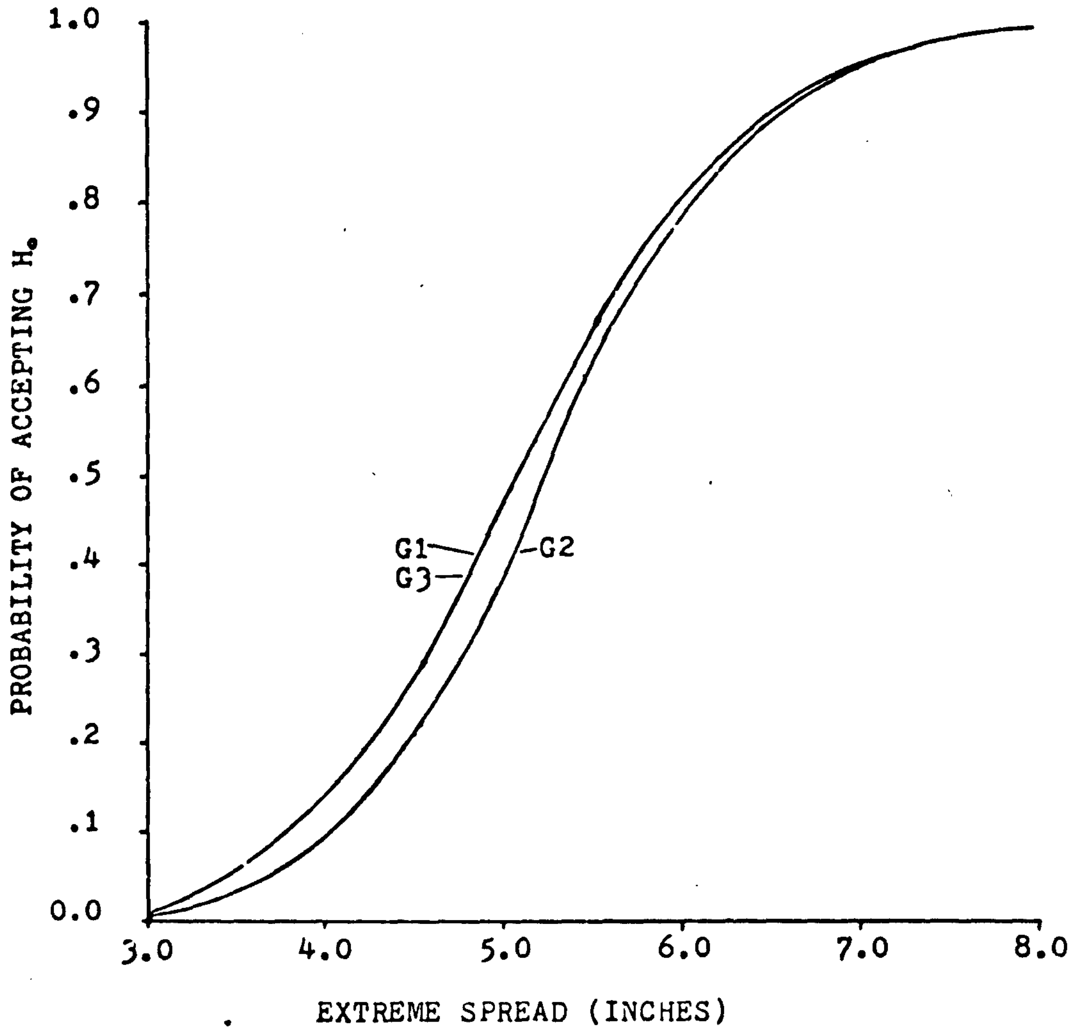
Based on Figures 3, 4, and 5 and the data in Table 3, gage G2 is determined to be the better performing gage of those analyzed.

Testing For Significant Difference Between Manufacturers

The simple log model was used to develop the regression curves for each of the rifles and for each manufacturer as well as an overall curve for all the data. These curves show the variation between rifles and manufacturers. (See Figures 7, 8, 9, 10.)

THE OPERATIONAL CHARACTERISTIC CURVE
FOR MAREMONT RIFLES

G1 GAGE DIAMETER = .2204 inches, $\alpha = .05$
G2 GAGE DIAMETER = .2206 inches,
G3 GAGE DIAMETER = .2208 inches



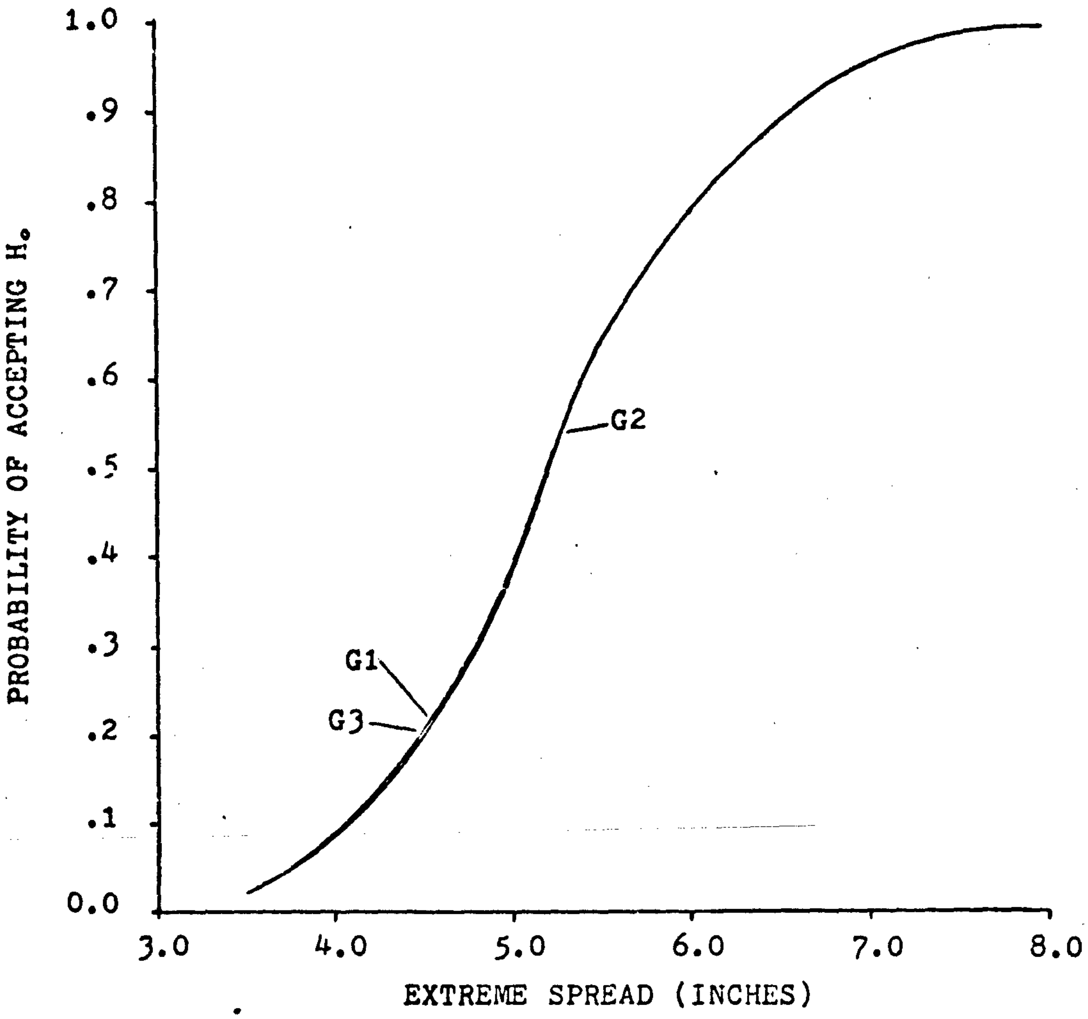
$H_o: u \geq u_o$

$H_1: u < u_o$

FIGURE 3

THE OPERATIONAL CHARACTERISTIC CURVE
FOR COLT RIFLES

G1 GAGE DIAMETER = .2204 inches, α = .05
G2 GAGE DIAMETER = .2206 inches
G3 GAGE DIAMETER = .2208 inches



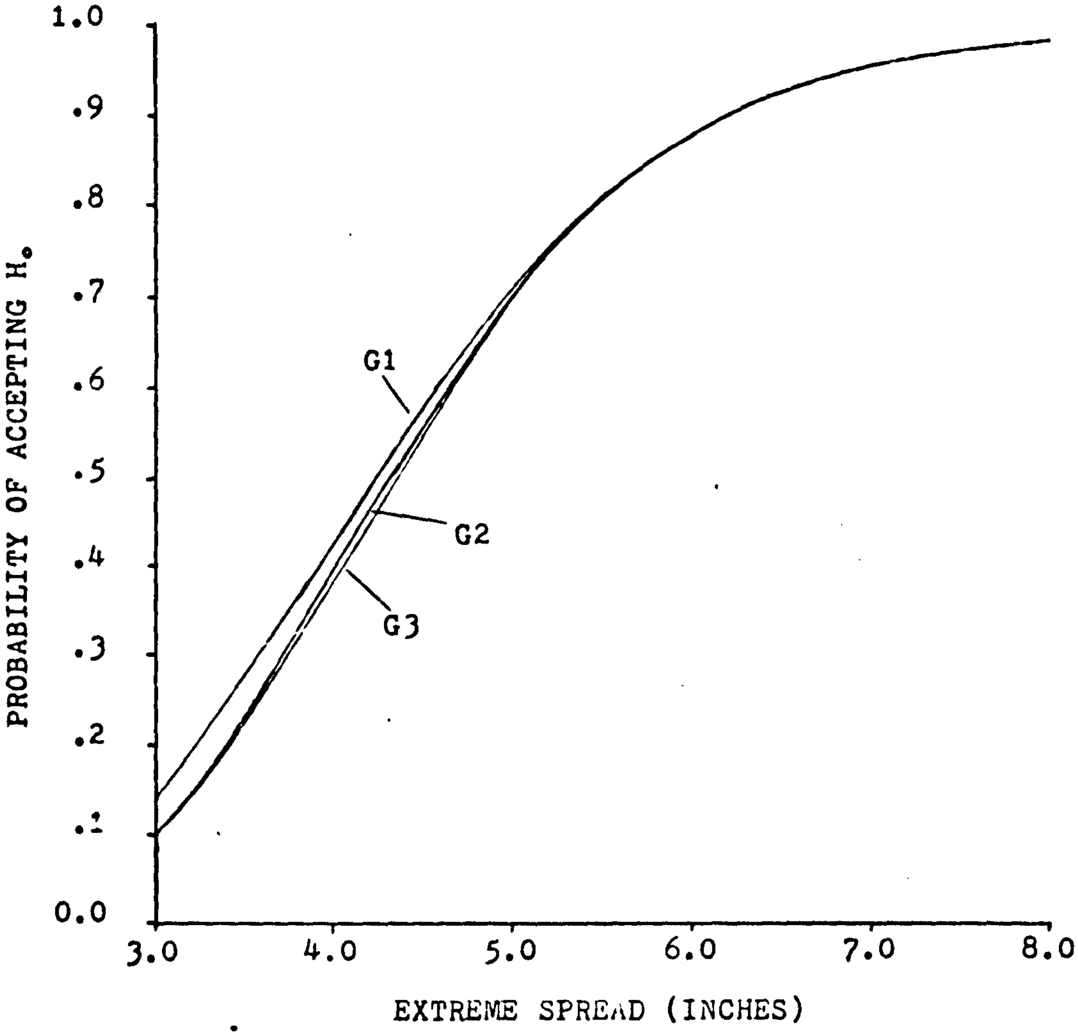
$H_0: u \geq u_0$

$H_1: u < u_0$

FIGURE 4

THE OPERATIONAL CHARACTERISTIC CURVE
FOR GENERAL MOTORS RIFLES

G1 GAGE DIAMETER = .2204 inches, $\alpha = .05$
G2 GAGE DIAMETER = .2206 inches
G3 GAGE DIAMETER = .2208 inches



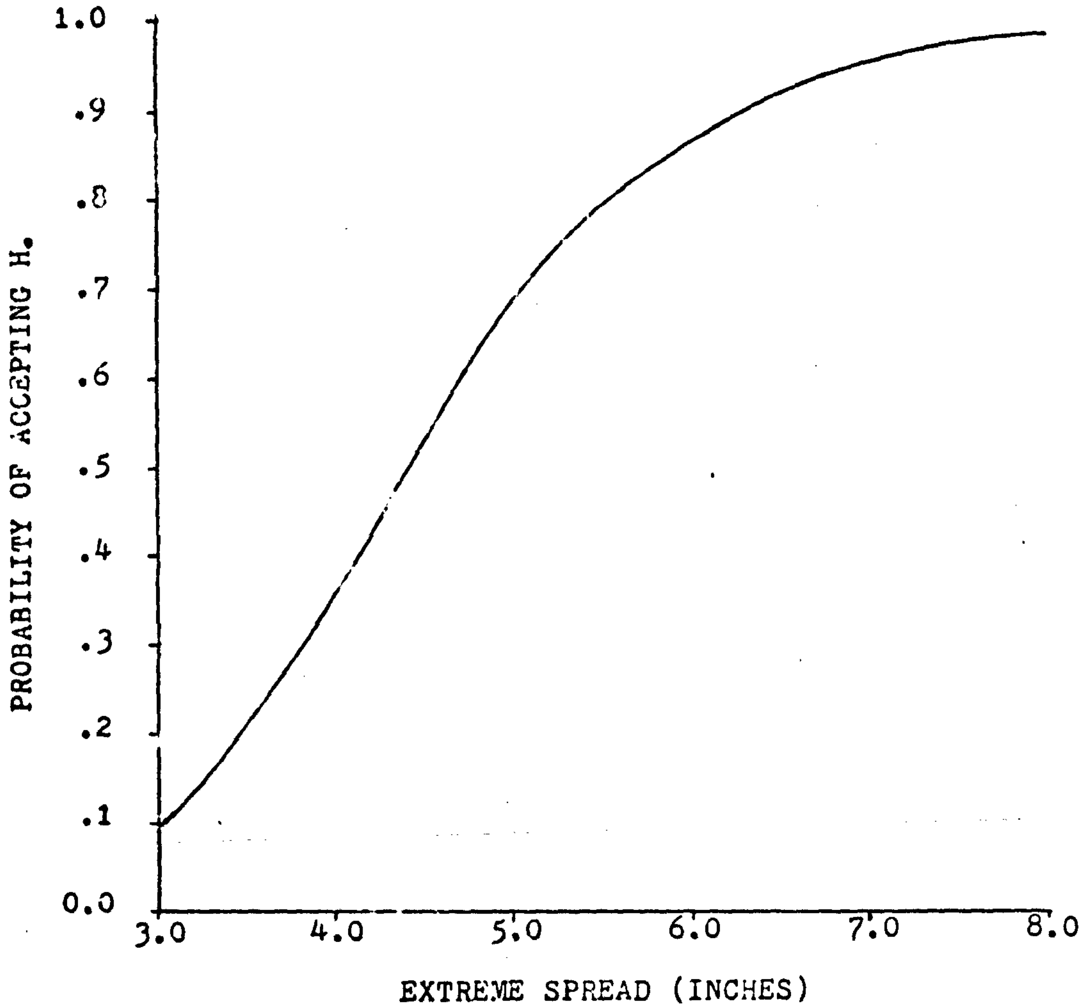
H_0: $u \geq u_0$

H_1: $u < u_0$

FIGURE 5

THE OPERATIONAL CHARACTERISTIC CURVE
FOR COMBINED RIFLES

GAGE DIAMETER = .2206 inches, $\alpha = .05$

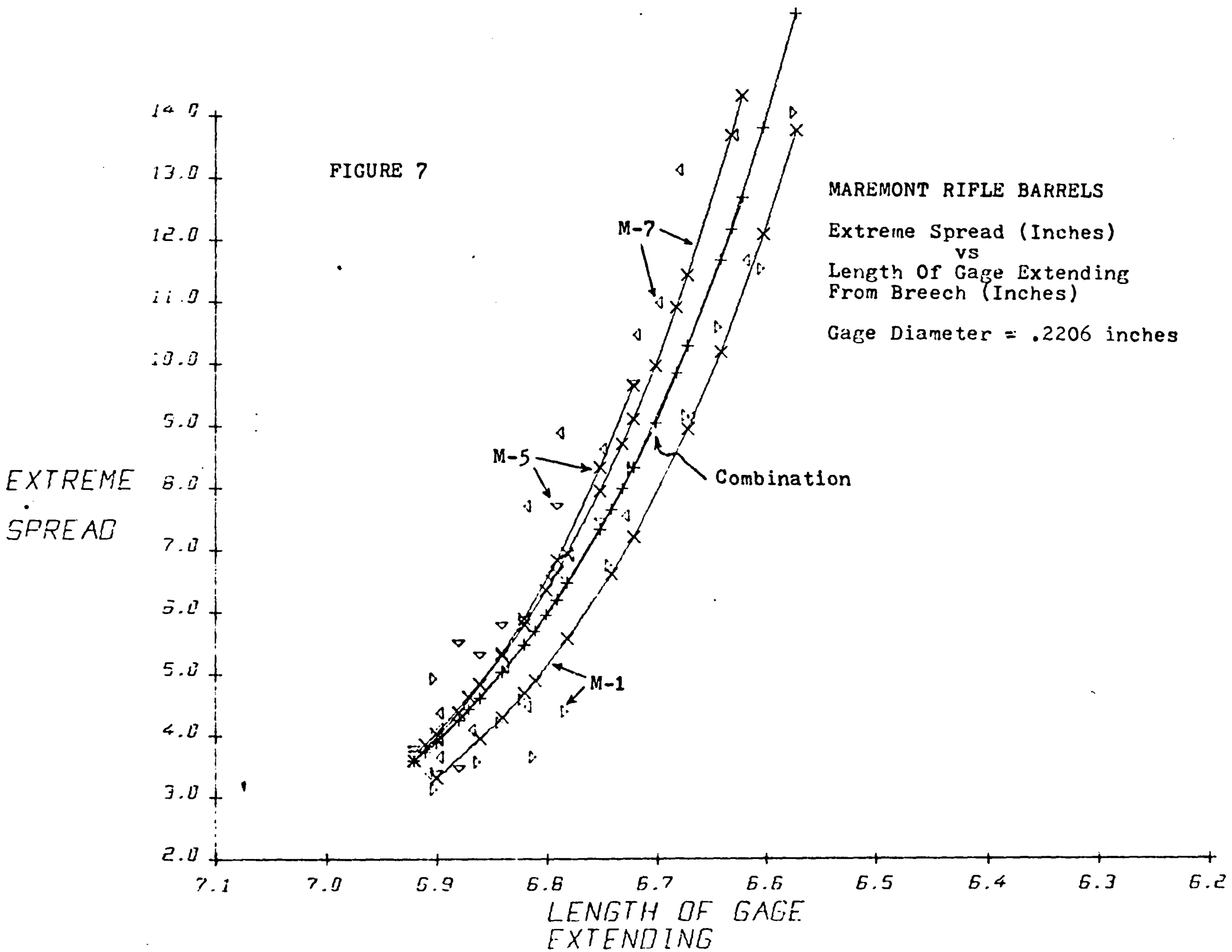


$H_0: u \geq u_0$

$H_1: u < u_0$

FIGURE 6

FIGURE 7



MAREMONT RIFLE BARRELS
Extreme Spread (Inches)
vs
Length Of Gage Extending
From Breech (Inches)
Gage Diameter = .2206 inches
EXTREME SPREAD
LENGTH OF GAGE EXTENDING
M-7
M-5
M-1
Combination
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
7.1
7.0
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2

FIGURE 8

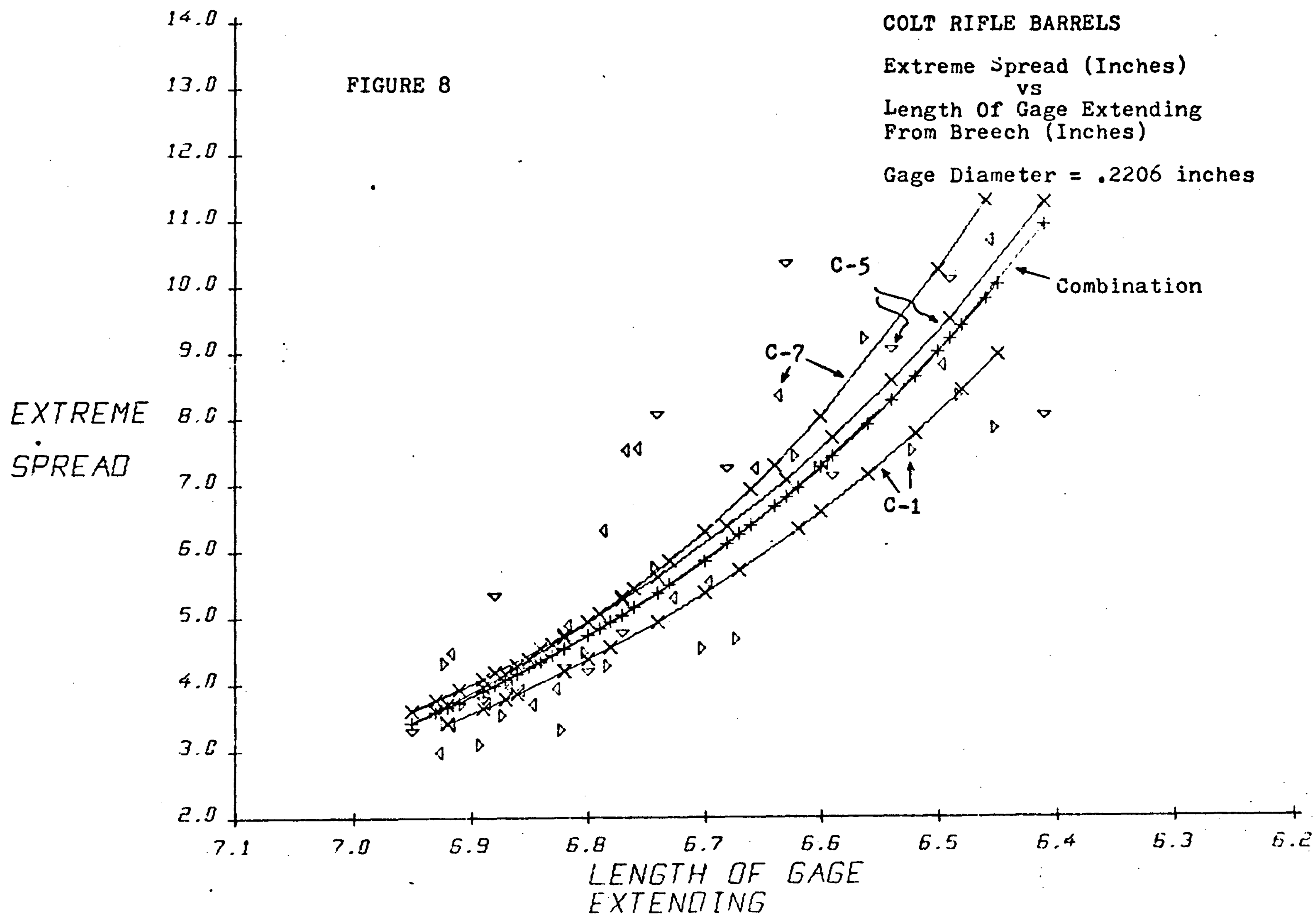

COLT RIFLE BARRELS
Extreme Spread (Inches)
vs
Length Of Gage Extending
From Breech (Inches)
Gage Diameter = .2206 inches
C-5
C-7
C-1
Combination
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
EXTREME
SPREAD
7.1
7.0
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
LENGTH OF GAGE
EXTENDING

FIGURE 9

GENERAL MOTORS RIFLE BARRELS

Extreme Spread (Inches)
vs
Length Of Gage Extending
From Breech (Inches)

Gage Diameter = .2206 inches

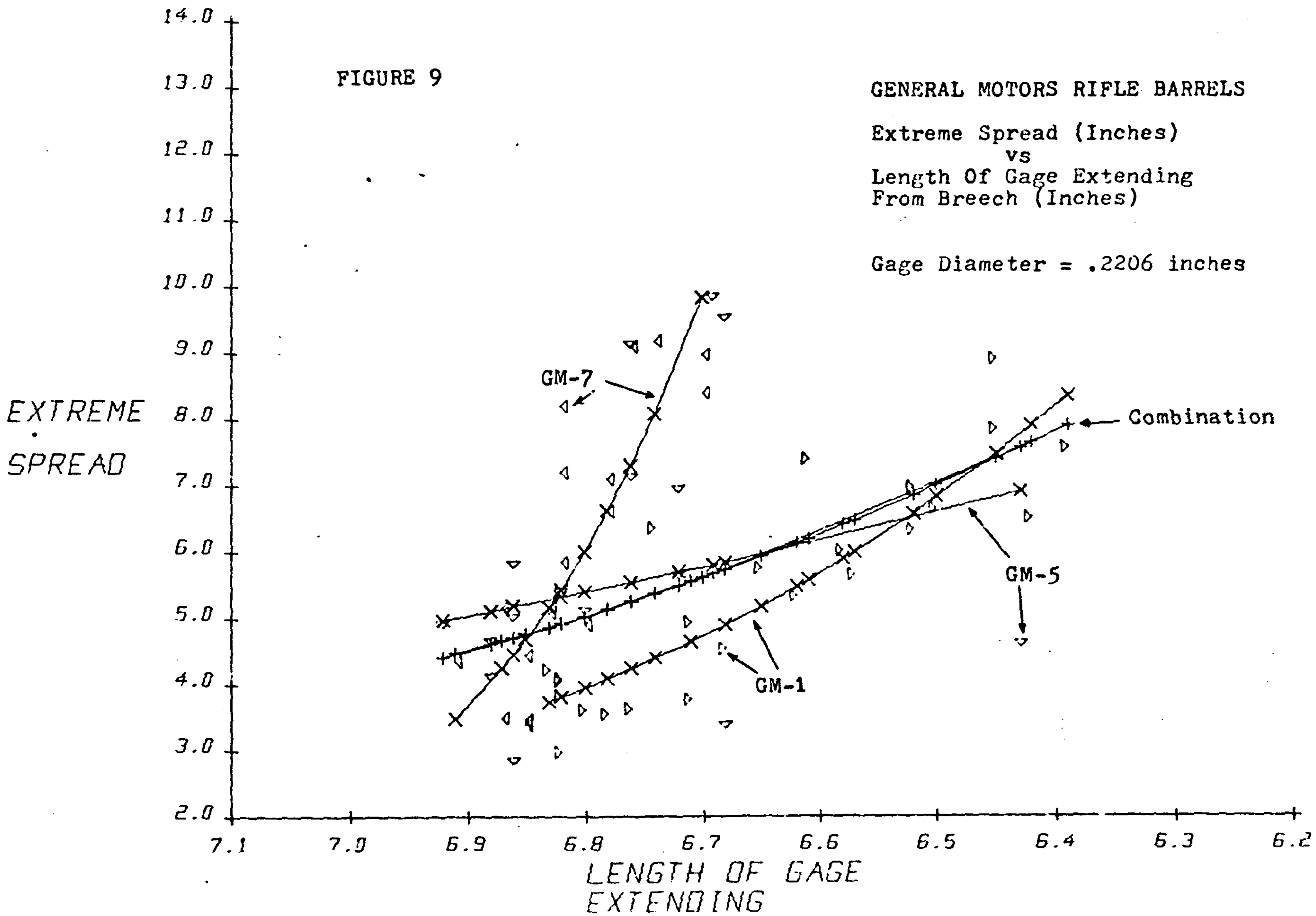


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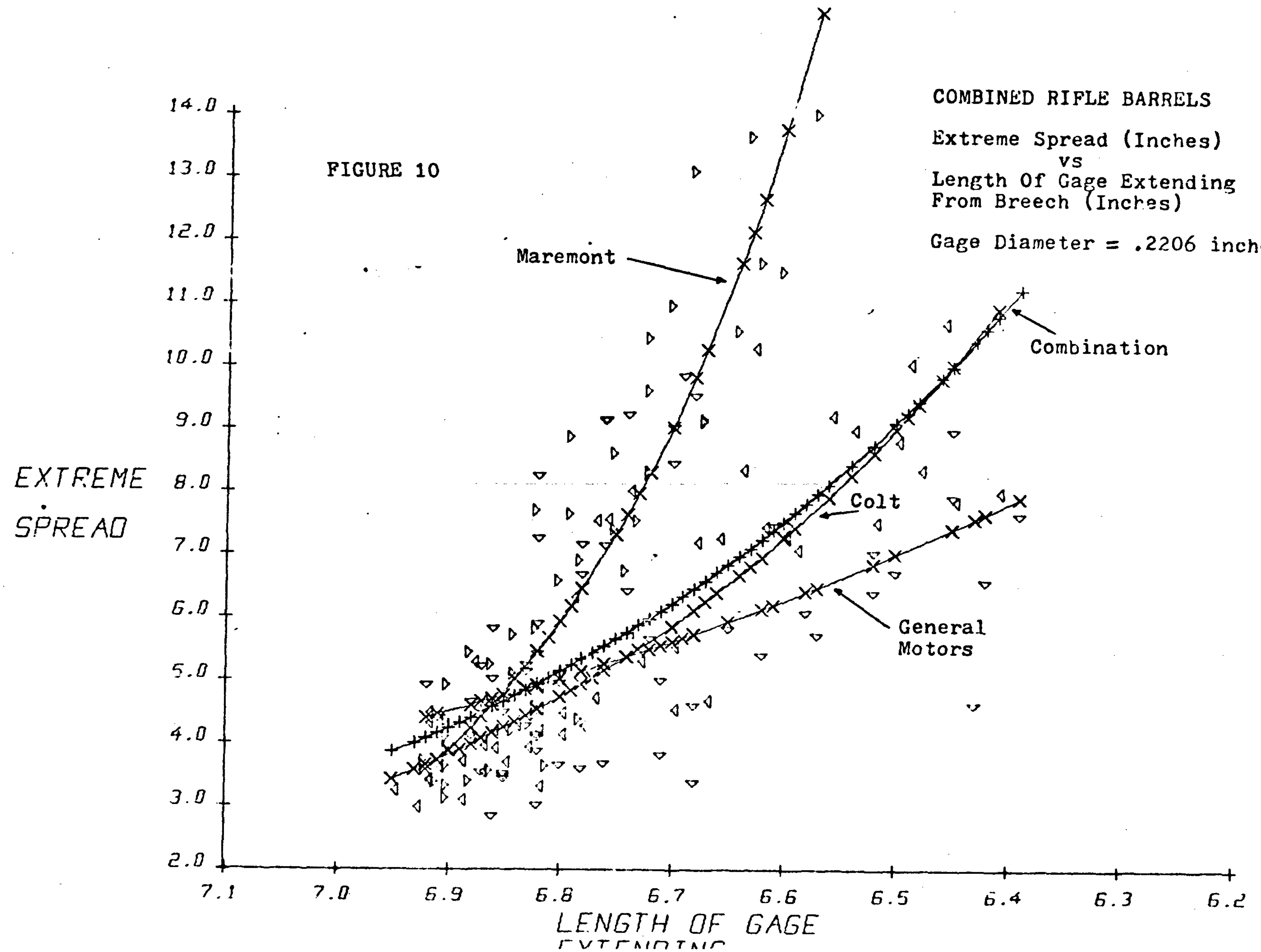
FIGURE 10

COMBINED RIFLE BARRELS

Extreme Spread (Inches) vs Length Of Gage Extending From Breech (Inches)

Gage Diameter = .2206 inches



A variation between rifles would have been predictable due to the different rates of firing during testing. The combination of data for a manufacturer and from these rifles is assumed to give a representative curve for a rifle used in a general manner since the data for all the rifles from a given manufacturer are combined with equal weight.

The data originates from three manufacturers. It should be investigated for distinct levels in the variables considered in the regression equation. In order to make this test, some variables will be assigned to the manufacturers with assigned values. These variables will reflect the fact that the various manufacturers may have separate deterministic effects on the response.. The variables of this sort are referred to as "dummy" variables (14). The method of their use is to assign a dummy variable to the data of two of the three separate manufacturers. This alters the regression equation to this form

$$\text{LOG(EXSPR)} = b_0 + b_1(\text{G2}) + b_2\text{X1} + b_3\text{X2}.$$

X1 and X2 are the dummy variables in this case. The value of 1 is assigned to X1 for all General Motors data and 0 for Maremont, and Colt data. The value of 1 is assigned to X2 for all Colt data and 0 for Maremont, and General Motors data. Maremont was assigned no dummy variable. A regression is then performed using all the available data for all the three manufacturers combined. If either b or b would result in being significant in the regression then the corresponding manufacturer would be considered to be on a distinct response level from that of Maremont.

The result of the regression for this case was a value of -.243 for b_2 and -.238 for b_3. The F-test probabilities (test of hypothesis that b = 0) were .0138 for b_2 and .0001 for b_3 . These results show the significant difference in response levels of General Motors and Colt data to that of Maremont.

The differences in the curves representing the manufacturers is illustrated in Figure 10. A curve representing a model for all the data combined is also shown but it is only for illustration. The operating characteristic curve in Figure 6 will show that it is not very desirable to attempt predicting extreme spread for all the manufacturers as a group.

Suitability Of Gages As Predictors

Mention was made in the previous section of the operating characteristic curve for the combined data of all the manufacturers. As can be seen from Figure 6, the probability of concluding that a rifle has an extreme spread equal to or greater than the seven inch limit (for CONUS use) is 70% when the actual extreme spread is only five inches.

Better results are received when attempting to predict extreme spread for rifles of a particular manufacturer but these results are still far from being desirable. The probabilities for concluding that a rifle has an extreme spread of equal to or greater than seven inches when the actual extreme spread is only five inches are 38%, 38%, and 70% for Colt, Maremont, and General Motors respectively. These results can be observed in the operating characteristic curves of Figures 3, 4, and 5.

The following chapter, Chapter VI, will state the conclusion and final results of the analysis.

CHAPTER VI

CONCLUSIONS

The analysis performed on the gage rods is begun by developing a regression model of the data from extreme spread and gage rod depth of penetration measurements. The purpose of the model was to provide a standard deviation of extreme spread for use in the hypothesis testing. The model chosen as best representing the data was:

$$LOG(EXSPR) = b_0 + b_1 \text{ (gage measurement).}$$

The selection of the gage giving the better performance of the nine tested was the next determination. This was accomplished by comparison of values received from regressions of the data using the regression model chosen above. The gage selected was gage 2 with a diameter of .2206 inches.

A test for significant difference between the rifle barrels manufactured by the three companies was performed by use of the dummy variables technique. The test indicated a significant diffe ence in the data received from the Colt and General Motors rifles to that data received from the Maremont rifles.

Operating characteristic curves were determined so that the consequences of using the gage rods to predict the accuracy of a rifle could be demonstrated. The curves show that predictions, concerning the extreme spread of a rifle, are not accurate enough to give the desired results. The probability of concluding that a rifle has a large extreme spread, when it actually does not, is too high in the range of extreme spread from 5 inches to 7 inches.

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