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APPLICATION OF ADAPTIVE MATHEMATICAL MODELS TO A T-37 PILOT PERFORMANCE MEASUREMENT PROBLEM

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13. ABSTRACT
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FOREWORD

This study was initiated by the Advanced Systems Division, Air Force Human Resources Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The research was conducted by Melpar, Falls Church, Virginia, under Contract F33615-69-C-1415. The work is in support of Air Force Project No. 6114, "Simulation Techniques for Aerospace Crew Training," Task No. 611412 "Automated Simulator Instruction and Performance Evaluation."

Melpar's principal investigators were Mr. E.M. Connelly and Dr. A.R. Schuler. Mr. F.J. Bourne was the chief programmer and Mr. J.E. Whelchel contributed some of the appendix material for Melpar.

Miss Patricia A. Knoop was Project Engineer for the Air Force and participated in the program in an active and significant manner. The authors wish to thank the Air Force personnel who provided direct support to this study through flying the T-37 aircraft and calibrating the flight data that was used. In particular, the authors thank the performing pilot, Capt. W.N. Johnson, Perrin Air Force Base; the flight-test pilots, Maj. B. Higdon and L/C R.C. Zimmerman, Wright-Patterson Air Force Base; and the data analysis personnel, Mr. E.H. G[illegible]ie, Mr. R.J. Andy, and Mr. R.W. Roan, Wright-Patterson Air Force Base.

This report documents research work performed from February 1969 to August 1970. The report was submitted by the authors January 1971. This technical report has been reviewed and is approved.

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ABSTRACT

This report documents experimental research on a new method of deriving performance measures and criteria for use in automated pilot performance evaluation. Data recorded on-board a T-37B aircraft (tail number 58-1948) were submitted to a previously implemented system of adaptive mathematical models (AMM). The results were analyzed to determine the practical capability of the AMM in automatically deriving measures and criteria.

Flight data for a series of performances of the Lazy 8 and Barrel Roll maneuvers were processed first by a set of Boolean functions. These functions describe the data in the form of Boolean time sequences (BTS), which are then operated upon by the AMM to derive three types of performance measures: (1) State Transfer Measures, which are based on overall trends in the performance; (2) Absolute Measures, which are based on a comparison of actual performance with some reference; and (3) Relative Measures, which are based on relations among performance variables.

The results show that the AMM system can be used to effect a systematic attack on the problems of performance measurement using representative flight data. Face-validity of measures derived by the AMM is illustrated by comparison with performance evaluations made by an instructor pilot.

SUMMARY AND RESULTS

PROBLEM

The problem was to investigate the potential of an adaptive mathematical models approach to perform measurement work using real (T-37) data. A system of models designed for use in deriving performance measures and criteria was implemented in an earlier study, but had only been tested using hypothetical data. The availability of T-37 data from another on-going Air Force measurement study afforded the opportunity to test the models more realistically. Also, insights to performance measurement gained through use of the math models approach could be applied to a concurrent Air Force study of undergraduate pilot training maneuvers.

APPROACH

Performance data and accompanying instructor-pilot ratings for 46 Lazy 8's and 45 Barrel Rolls were recorded digitally on-board a T-37 aircraft. These data were processed by a system of mathematical models that is designed to derive methods of automated performance measurement. Results were analyzed by (1) comparing the model's predicted "score" for each maneuver with the instructor-pilot's subjective rating; and (2) examining the effect (on the ability of the models to "score" performance) of adding to or deleting from the system different performance variables.

RESULTS

Using single-variable measures, discrimination of only two skill levels was possible. This was achieved using an airspeed measure on the Lazy 8, and the demonstrated utility of this measure is supported by results obtained in another Air Force study. Using multiple-variable measures, a noticeable increase in skill level discrimination was observed. General agreement between model-scores and instructor scores was achieved; in some cases where lack of agreement was noted, recorded instructor comments about the maneuver and his rating for it suggest that the models have achieved improved discrimination over that provided by the instructor and used as an initial guide by the models. Also, an inherent capability of the models that was not previously recognized was discovered, i.e., its separation of the maneuver into parts and the ability to identify portions of the maneuver that are most difficult to perform.

CONCLUSIONS

A useful and powerful tool for performance measurement research exists in the adaptive mathematical models technique. Measurement is a long-standing difficult area of research, and while this experiment, using T-37 data and the math models approach, showed no decrease in overall difficulty of the task, it showed great value in systematizing the investigation. The time and scope of the study were limited, and not nearly all of the results could be analyzed completely. Those that were analyzed showed that the models are capable of deriving automated measurement methods as designed, but good validation remains a problem. Future work should utilize a refined system of models, based on observations made in this study, and an increase in automation of the analysis, summary, and presentation of results.

This summary was prepared by Patricia A Knoop, Simulation Techniques Branch, Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio.

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1. INTRODUCTION

This report documents the first application and empirical test of a new approach to deriving pilot performance measures and criteria. The approach represents the first extensive use of computer-implemented mathematical modeling for investigating the performance measurement problem. Details of the approach are provided in Reference 1, which documents the initial modeling work and preliminary tests.

The objective of the research is to develop techniques for deriving methods of automated pilot performance measurement. Briefly, the approach is to operate on actual pilot performance data with a system of mathematical models that effectively "learns," as an adaptive system, to evaluate performance. Initial guidelines for the models are provided in the form of subjective skill-ratings for each performance made by qualified evaluators. The task of the models is to "learn" to score performance, automatically, at least as well as the evaluators. The task of the present study is to assess the models' ability to do this; to determine whether, in fact, the models succeed in improving skill-level discrimination over that achieved solely by qualified evaluators, and to extract from the models and attempt to validate the measures and criteria essential for performance evaluation.

The performance data used for the model-tests documented in this report were recorded on-board a T-37B aircraft. The instrumentation and use of the T-37 for recording inflight data was instigated by a separate performance measurement study being conducted by the Air Force. It was the "matter-of-fact" availability of the T-37 data that resulted in its use in this study, plus the timeliness of testing the new approach concurrent with Air Force analysis of the same base-data using other more classical approaches. This provided, at the onset, a basis for comparison and cross-validation of the results of two approaches to measurement research—one using standard techniques which require a blend of manual and computer data analysis, and the other (this study) using computer implemented modeling techniques.

The rationale of the approach of this study and its inherent advantages over techniques tried in the past were presented in Reference 1, and for the sake of brevity, will not be repeated here. Instead we will concentrate on a straightforward presentation of the results of applying the system of models to T-37 flight data. Sections 2 and 3 include discussions of the data and the training maneuvers that were employed. These sections provide the information needed to familiarize the reader with the specific measurement problem of concern in this test/application study.

Section 4 includes a short description of the previously-implemented adaptive mathematical models system. Section 5 presents an analysis and discussion of the results obtained with the T-37 data. Appendices are included to present some of the data developed during the study and to describe various concepts and analysis-techniques used to manipulate binary-valued functions, transforms, and sequences.

The major result of this study consists of empirical evidence that the adaptive mathematical models approach provides a valid and, equally important, a systematic means of deriving automated performance measurement methods. As the discussion illustrates, the approach developed can be used to determine measures and criteria and to ascertain the relevance of individual measures to performance evaluation for (a) separate skill-levels and (b) separate regions of flight.

On the other hand, the work reported here cannot be considered complete validation of the techniques that were developed. The reason is that due to necessary limitations on the time and scope of the study and problems encountered in data collection, sufficient validating data were simply not used. In addition, the task of analyzing and interpreting the results produced by the models proved to be larger than originally envisioned. (It is one thing to apply the models to the data and accept the results, but quite another to break out the measures and criteria that were derived and validate them independently.) Therefore, a considerable number of results have been produced that have not yet been adequately analyzed.

In this report, we present typical results and their analyses and attempt to demonstrate face-validity through reference to the maneuver itself and accepted notions about pilot skill determination. We demonstrate the models' ability to "learn" to evaluate performance in a way which generally correlates with expert performance judgments. We also illustrate the possibility (and probability) that discrimination of many more than four levels of skill can be made using the outputs of the models, even though only four levels are provided as initial guides from the human evaluators. Finally, we show by example the effect on performance evaluation of adding or deleting various measures from the system.

2. FLIGHT MANEUVERS AND DATA

Two flight maneuvers used in the T-37 Undergraduate Pilot Training Program are employed in this study. The maneuvers are ones which Air Training Command recommended for study because of the variety of pilot skills that they require in their execution and the wide range of aircraft variables which their performance exercises. This makes them good selections for experiments in performance measurement.

The task undertaken in the adaptive mathematical models (AMM) study has been, simply stated, to develop a system to aid the researcher in deriving methods of automated performance measurement. The AMM system that has been developed does this empirically by analyzing representative flight data. This section of the report is devoted to a description of that flight data and of the maneuvers studied.

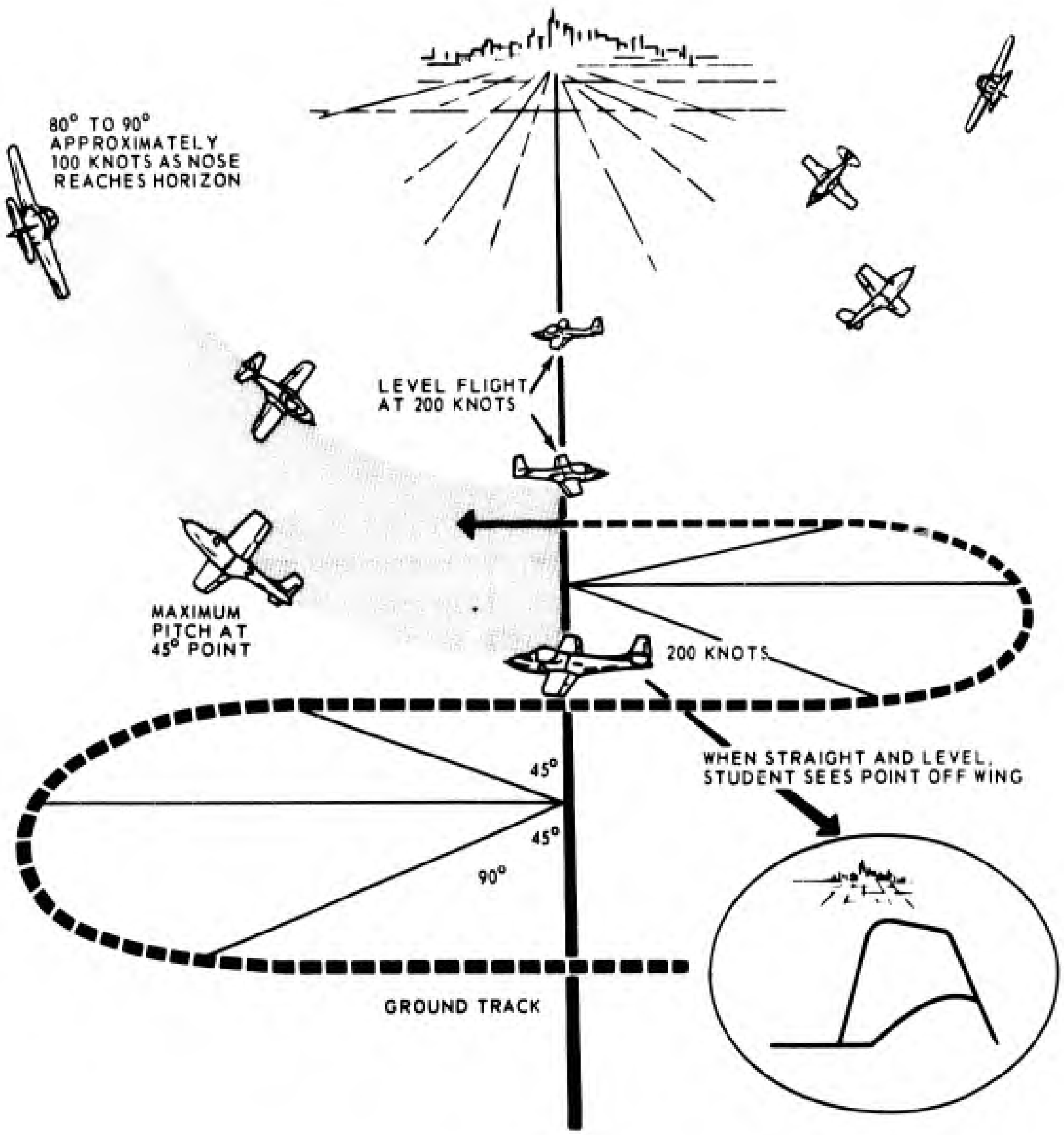
2.1 Lazy 8 Maneuver

The Lazy 8 maneuver involves a combination of climb, dive, and turn as shown in figure 1. Properly executed, the maneuver requires a 180° heading change followed by heading reversal back to the initial heading along with a continuous change of pitch and bank. Starting in straight and level flight with 90% rpm and 200 knots, with a reference point off a wing tip, a slow climbing turn is executed. Maximum pitch angle occurs when a 45° turn has been completed. Following this, the bank angle increases to 80° to 90° while the pitch angle decreases. The maximum bank angle of 80° to 90° occurs when the nose is pointing roughly toward the reference point on the horizon. At this state, pitch is zero and the airspeed is approximately 100 knots. The flight continues with pitch decreasing then increasing as roll decreases, so that when 180° turn is completed, level flight is achieved with an airspeed of 200 knots. The remaining half of the flight is completed in a similar way except the turn is accomplished in the direction opposite to that used initially.

Note that pitch angle through the first half of the maneuver starts at near zero, goes positive then negative, and back to level flight. During this time, roll angle is zero, goes positive (or negative) and back to zero. Thus, a plot of roll versus pitch looks like a Lazy 8.

2.2 Barrel Roll Maneuver

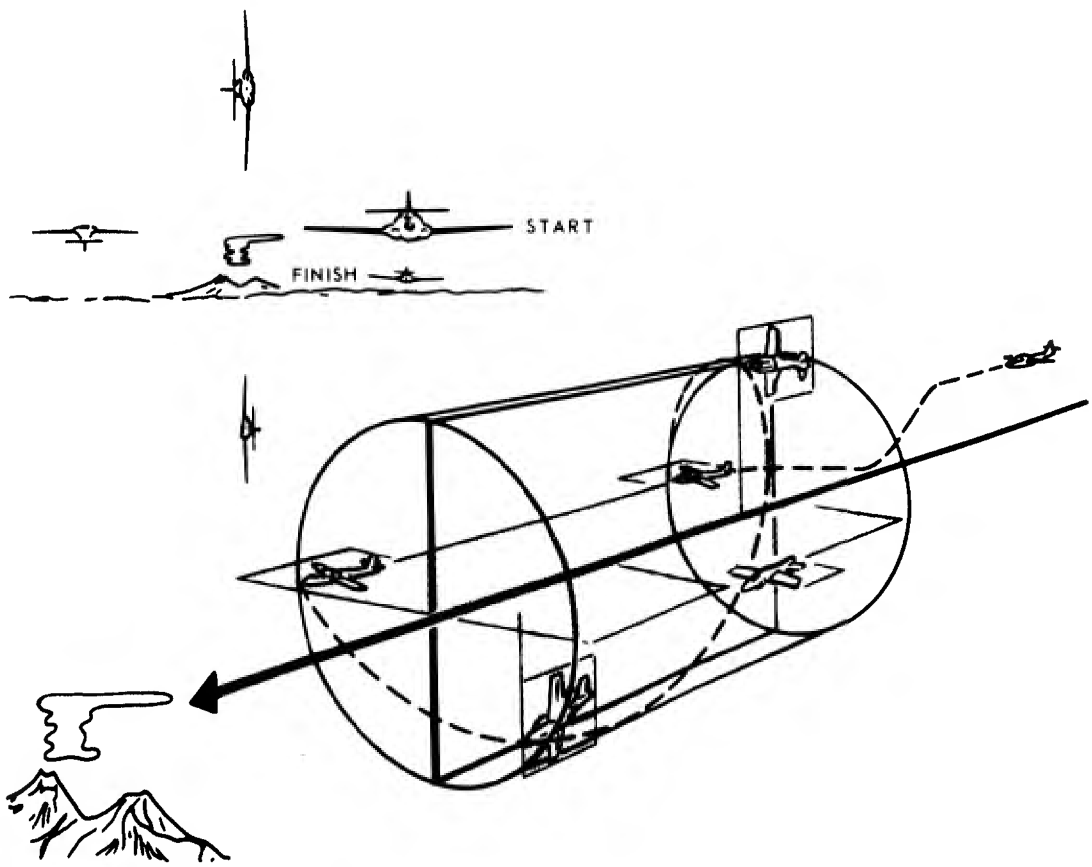
The flight path for the Barrel Roll is shown in figure 2. Throttles are set at 90% and a reference point is taken on the horizon ahead of the aircraft.



(Figure taken from reference 9.)

Figure 1. Lazy 8 Maneuver

(Note that this illustration of the Barrel Roll is slightly misleading insofar as specific aircraft parameters are concerned. Altitude, contrary to the illustration, reaches its highest point at the wings-inverted position. The diagram is intended primarily to show the apparent position of the reference point as viewed by the pilot.)



(Figure taken from reference 9.)

Figure 2. Barrel Roll Maneuver

A dive is used to attain an airspeed of 200 to 230 knots. A coordinated turn is used to establish a turn of 20° to 30° to the side of the reference point. It is intended to maintain this 20°-to-30° visual offset from the reference point throughout the maneuver. A rollout of the initial turn to wings level flight establishes this offset angle. Next a continuous roll through 360° is executed, maintaining a constant offset angle and returning to level flight with the reference point in the same position relative to the aircraft as when the roll was initiated. During the maneuver, pitch angle cycles from zero to positive, zero, negative, then back to zero. During this time, roll angle goes from zero to ±180° to ∓180° to zero. Thus, a plot of |roll| versus pitch tends to resemble a circle if suitably scaled.

2.3 Flight Data

The T-37B data were collected using a specially instrumented aircraft, digital flight recorder, and airborne data acquisition system.[1] The recording system and instrumentation were developed by an Air Force team at Wright-Patterson AFB, under a performance measurement study being conducted for the Air Training Command by the Air Force Human Resources Laboratory, Advanced Systems Division. Flight data are recorded on one-inch digital tape using a Leach MTR-3200 recorder. The data are later transferred to 1/2-inch magnetic tape compatible with data-processing equipment. This second tape is then used for calibration, formatting, and computation of additional flight variables. Results are placed on a third tape and used for measurement research of various types. A copy of this third tape was provided for use in this study.

The data used in this study consisted of a series of performances of the Lazy 8 and Barrel Roll maneuvers flown by an instructor of pilot-instructors from Perrin AFB. In addition to flying the maneuvers, the performing pilot also rated the performances in accordance with the four-point rating system currently used in Air Training Command. As he is trained and skilled to do, the pilot flew a variety of maneuvers to illustrate a range of representative performances. In some, he purposely illustrated common errors that would result in, say, a "fair" or "unsatisfactory" rating.

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[1]Complete documentation of the in-flight recording system and a separate performance measurement study is currently in preparation by Patricia Knoop and William Welde, Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio.

In others he attempted to fly the maneuver perfectly, and ratings for these were usually "good" or "excellent." A total of 46 Lazy 8's and 45 Barrel Rolls were flown, with rating distributions as illustrated in figure 3.

Some discussion is in order here regarding the data source, because obviously a single pilot evaluating his own performances cannot be considered an adequate sample from the standpoint of experimental design. Ideally, a large sample of students should provide the data, and each student should be rated on successive flights by a fair sample of skilled evaluators. The approach was initially designed, in fact, to be used in conjunction with a flight simulator, where a carefully controlled experiment could be conducted with several evaluators rating each performance. The considerations that led to the conduct of the study as reported herein include the following: (1) The scope of the study was purposely limited ("let us show evidence that the approach works with 'real live data' before we go to the expense of obtaining indisputable proof"); (2) The T-37 data collection effort is a new project, and obtaining large quantities of good flight data is not yet a simple matter; and (3) For purposes of this study, it was considered more appropriate to go in-depth on a single pilot than to use limited data on a number of pilots, which (small) number would not add to the validity anyway. All in all, the use of an instructor of pilot-instructors afforded the best opportunity to obtain a wide variety of performance, each rated by a man whose job is, in fact, to teach others to rate.

The flight data provided for this study included samples for 34 variables, as listed in table I. The first nine variables were sampled at 100 samples per second and the remaining variables at 10 samples per second. Figure 4 is a diagram giving the tape format for the data. Eight variables were extracted at a sampling rate of 10 per second for the study. These variables are:

- Roll
- Pitch
- Heading
- Altitude
- Airspeed
- Event Number
- Time
- Time Computed

Appendix I gives a list of the event numbers and instructor ratings for each maneuver recorded and used in this study. The event numbers are used primarily for identification of maneuvers. (The reason for a separate Melpar numbering system was to eliminate the necessity of using the date of the flight as well as a number, as employed in the Air Force system.) The instructor ratings are numerical designations for the standard subjective rating categories

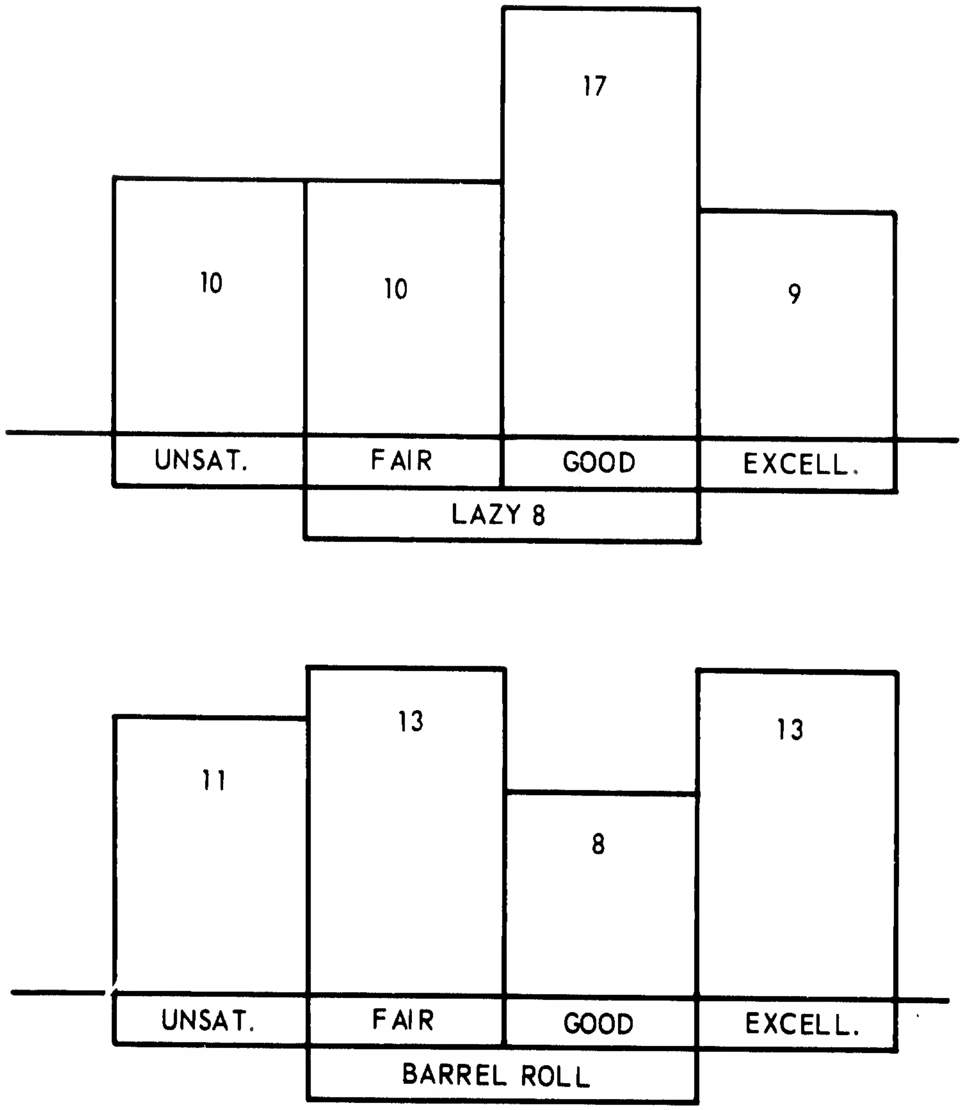

Figure 3. Subjective Rating Distributions for Maneuvers

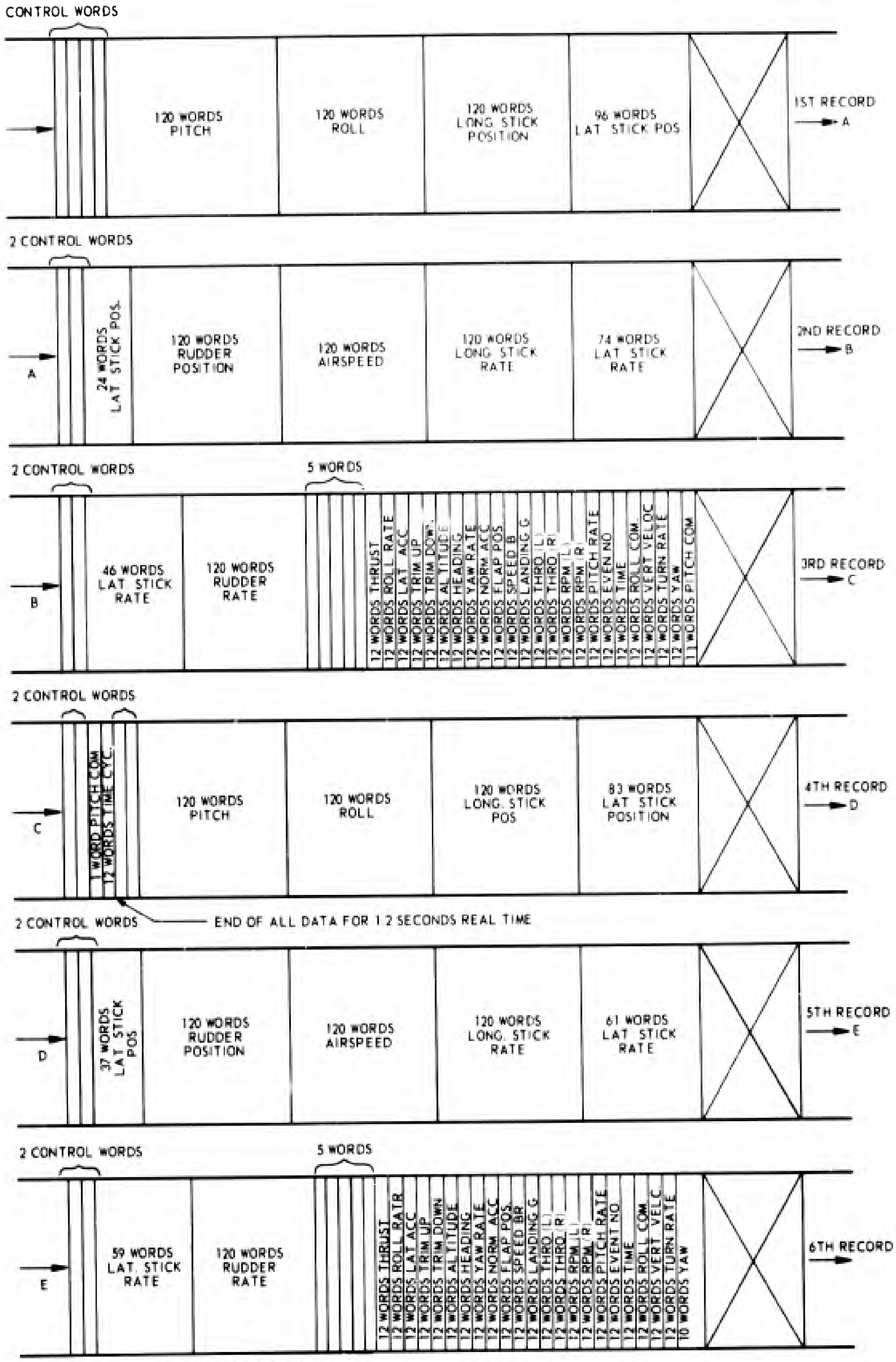

Figure 4. Magnetic Tape Format

used in Air Training Command: Excellent (80), Good (60), Fair (40), Unsatisfactory (20).

Computer prints of Pitch versus Roll for each of the Lazy 8 flight events are given in appendix II. While these figures are not intended to provide a complete picture of the maneuver, they provide some insight to the nature of two critical variables.

The plots are presented in order of decreasing instructor ratings. It was necessary to smooth or "DEGLITCH" the data in order to remove some discontinuities resulting from problems with the in-flight recorder. This involved test on a sample-to-sample basis to determine if the change in data value exceeds a pre-established value. If so, the value of that sample is set equal to the preceding sample. (While this technique smooths data weli, it also sometimes tends to oversmooth data. Oversmoothing occurred in several instances in the Lazy 8 data, such as event 67 in pitch, events 87, 85, 93 in roll, and 86 in pitch and roll. In the Barrel Roll, data oversmoothing occurred in flights 5738, 5741, and 5257 in the roil samples.)

Computer printouts indicating pitch versus |Roll| for the Barrel Roll maneuver are also presented in appendix II. Note that with the scaling employed, these figures are "lemon" shaped for excellent flights. Considerable difficulty was experienced in automatically detecting the actual start and stop of the maneuver. As a result, some of the computer plots show the preliminary clearing part of the maneuver in addition to the roll itself.

Tables in appendix II give the start and stop time for each flight event for the Lazy 8 and Barrel Roll maneuvers.

TABLE I

ORDER OF T-37 AIRCRAFT VARIABLES ON BINARY TAPE

Variable	Units	No. of Consecutive Samples in 1.2 Seconds
1. Pitch	Deg	120
2. Roll	Deg	
3. Long. Stick Pos	Deg	
4. Lat Stick Pos	Deg	
5. Rudder Position	Deg	
6. Airspeed	Knots	
7. Long. Stick Rate	Deg/Sec	
8. Lat Stick Rate	Deg/Sec	
9. Rudder Rate	Deg/Sec	120
10. Thrust Attenuator	Discrete	12
11. Roll Rate	Deg/Sec	
12. Lat Acceleration	G's	
13. Trim Tab Up	Discrete	
14. Trim Tab Down	Discrete	
15. Altitude	Feet	
16. Heading	Deg	
17. Yaw Rate	Deg/Sec	
18. Normal Acceleration	G's	
19. Flap Position	%	
20. Speed Brakes	Discrete	
21. Landing Gear	Discrete	
22. Throttle Pos (L)	Deg	
23. Throttle Pos (R)	Deg	
24. RPM (L)	%	
25. RPM (R)	%	
26. Pitch Rate	Deg/Sec	
27. Event Number	-----	
28. Time	Seconds	
29. Roll-Computed	Deg	
30. Vertical Velocity	Ft/Sec	
31. Rate of Turn	Deg/Sec	
32. Yaw	Deg	
33. Pitch-Computed	Deg	
34. Time-Computed	Seconds	12

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3. BOOLEAN FUNCTIONS

Boolean functions can be used to code continuous and multivalued sampled variables into a binary representation. It is clear that such an operation tends to reduce data storage requirements and allows easier manipulation of the data in a computer. The question of information loss versus retention of essential information depends on the Boolean functions selected with respect to the task at hand. It should be noted that the Boolean operation can easily add information, and as a result, the Boolean time sequence (BTS) generated can be of considerably more value than the original variables.

Boolean functions can be of several types. For example, the Boolean function (BF) can ask

1. $V > \text{Constant}$
2. $V = \text{Constant} \pm \text{tolerance}$
3. $V > f(\bar{X})$
4. $V = f(\bar{X}) \pm \text{Constant}$
5. $V = f(\bar{X}) \pm g(\bar{X})$

where V is a variable and $f(\bar{X})$, $g(\bar{X})$ are functions of one or many other variables. Thus Boolean functions provide a very flexible way of representing data, and a very effective way of introducing functions and relationships believed to be related to performance evaluation.

Flight data for each maneuver are presented to the adaptive mathematical models in the form of Boolean time functions (sequences). The functions are constructed to describe or represent all aspects of the data known or believed to be relevant to performance measurement. This allows us to make use of all we know about measurement of each maneuver, but yet does not require us to have *a priori* knowledge.

3.1 Barrel Roll Boolean Functions

A total of 18 BTF was constructed for the Barrel Roll maneuver. These are summarized in table II (right-most column). BTF's 1 and 2 represent two alternate measures of the pilot's skill in attitude control and,

TABLE II

BOOLEAN FUNCTIONS FOR BARREL ROLL			
BTS	Number of Changes	Activity Ordering	Description of Boolean Function
1	618	A_1	$(x_i-C_1)^2 + (SCALE*y_i) = R_1 + CII1$
2	438	A_2	$(x_i-C_2) + (SCALE*y_i) = R_2 + CII2$
3	7692	B_1	$\|D_i-D_{i-1}\| \leq 0.1$
4	191	C_4	$0 \leq \|R\| \leq 30$
5	302	C_1	$30 > \|R\| \leq 60$
6	202	C_2	$60 < \|R\| \leq 90$
7	182	C_5	$90 < \|R\| \leq 120$
8	181	C_6	$120 < \|R\| \leq 150$
9	194	C_3	$150 < \|R\| \leq 180$
10	66	D_6	$40 < P$
11	157	D_4	$20 < P \leq 40$
12	274	D_1	$0 \leq P \leq 20$
13	274	D_2	$-20 \leq P < 0$
14	167	D_3	$-40 \leq P < -20$
15	72	D_5	$P < -40$
16	312	E_3	$\|ROLL_i\| = \|ROLL_{1-i+2k}\| \pm 3$
17	336	E_2	$\|PITCH_i\| = \|PITCH_{1-i+2k}\| \pm 3$

TABLE II

BOOLEAN FUNCTIONS FOR BARREL ROLL (Continued)

BTS	Number of Changes	Activity Ordering	Description of Boolean Function
18	362	E_1	$\lvert PITCH_i \rvert = \lvert PITCH_{k+i} \rvert \pm 3, \; i<k$ $\lvert PITCH_i \rvert = \lvert PITCH_{i-k} \rvert \pm 3, \; i>k$

x_i sampled heading $\qquad D_i = \lvert ROLL_i - ROLL_{i-1} \rvert$

y_i sampled pitch

$CH1 = .1 * R_1$

$CH2 = .1 * R_2$

because of their complexity, relative to all other BTF's, a detailed explanation of their construction will be given next.

Possibly the most pertinent measure for the Barrel Roll is one reflecting the pilot's skill in attitude control. He is required to maintain a constant angle, θ, between his line of sight to the selected reference point and his line of sight projected forward and parallel to the longitudinal axis of the aircraft. This angle must remain constant throughout 360° of continuous roll, the suggested error tolerance being ± 10%.

The major difficulty of measuring this aspect of the performance is that no means exist, on the basis of recorded flight data, for determining the location of the selected reference point. Therefore, the criterion angle, θ, and the criterion flight path are both nebulous.

Two alternate approaches were developed for measuring this part of the performance directly. Both are based upon the computation of projected criterion flight paths, which are in turn based upon alternate assumptions about "correct" aspects of the performance. The first, represented by BTF 1, computes a criterion flight path based on the assumption that two of the pilot's actual heading angles are correct. Since he is free to select his own reference point, the assumption that his initial heading is correct is nonrestrictive. For the second point, we assume that his heading is correct at that point where heading differs most in absolute value from the initial heading, or roughly at the end of the second quarter of the maneuver. We then construct a criterion flight path by computing a circle (scaled), using the variables of heading and pitch, that pass through the points $(H_1, 0)$ and $(0, H_2)$, where H_1 and H_2 are actual heading angles at the measured points. The center of the circle is at

$$C_1 = \frac{1}{2} \left([H_1 + H_2] \bmod 360 \right).$$

For an alternate criterion flight path, represented by BTF 2, we again use the initial heading as a reference. For our second point, we use the pilot's largest positive pitch angle. This assumes (1) that the pilot's heading is correct at the start of the maneuver, a nonrestrictive assumption; and (2) that the pilot's pitch angle is correct when it reaches its first maximum, or roughly at the end of the first quarter of the maneuver. The criterion path again is a circle, this time with its center (C_2) at the heading held when the largest positive pitch angle is achieved.

BTF 3 is a measure of the constancy of roll rate. BTF's 4 through 9 represent absolute measures of roll angle, and BTF's 10 through 15 represent absolute measures of pitch. BTFs 16 through 18 measure the symmetry of the maneuver with respect to roll and pitch.

3.2 Lazy 8 Boolean Functions

A total of 40 BTF were constructed for the Lazy 8 maneuver. Collectively, these BTF's represent the flight performance information believed to be critical to valid performance evaluation. In a sense, each BTF may be considered a separate potential measure of performance, and it is the value or relevance of these measures (taken separately and collectively) that we want to assess.

The Lazy 8 BTF's are based upon three key flight variables: roll, pitch, and airspeed. They are summarized in table III (right-most column), BTF's 1 through 9 describe aircraft bank angle (B) both absolutely and from the standpoint of trend and direction. BTF's 10 through 15, similarly, describe pitch angle, and BTF's 24 through 28 describe airspeed. BTF's 29 through 38 reflect, to various candidate tolerances, a comparison of the actual roll/pitch relationship (R_θ) with a criterion relationship ($f(\theta)$) that was developed using actual T-37 flight data. (In a plot of roll versus pitch for the Lazy 8, R_θ and $f(\theta)$ are the familiar polar coordinates of the points.) Similarly, BTF's 39 through 48 compare, to various tolerances, the actual airspeed profile ($A_{s\theta}$) with a criterion profile (K_θ), where θ is the sampling point identified in the polar plot of roll versus pitch. (Thus, at $\theta = 40°$, actual airspeed ($A_{s\theta}$) is compared with criterion airspeed (K_θ).)

3.3 Boolean Function Activity

An initial test useful in selecting and grouping Boolean variables for subsequent processing is the examination of BTS activity levels. Tables II and III show these activity levels for all Boolean functions for both the Barrel Roll and Lazy 8 maneuvers. The activity is simply a count of the number of times each function changed value on all the flight events available. While it should be clear that high or low activity is not necessarily known to be related to score, the count does indicate how often each BTS is activated by the trajectories.

Consider the BTS's for the Barrel Roll. BTS 1 and 2 are derived from functions which approximate a reference flight path. With 45 events we see that these BTS change an average of 10 to 15 times per event. This indicates that the measure is activated (i.e., in the region of aircraft motion) and changes occur at an average rate not inconsistent with pilot reaction time. On the other hand, BTS 3, which is a measure of roll acceleration, produces such a high activity count and corresponding high activity rate per unit time, that it is believed to be activated by system noise. BTS 4 through 15 are quantized state indicators of roll and pitch and show reasonable activity counts. It is interesting to note that high activity is centered at entering and leaving the region where roll is from 30° to 60° rather than 0° to 30°. As expected, maximum pitch activity is centered in the +20° to -20° region, as indicated by BTS 12 and 13 counts. In reference to tables II and III, activity is listed to indicate ordering within a Boolean function category. Thus, for example, in table II, Boolean function 5 has the largest activity among the roll-indicating functions.

Lazy 8 Boolean functions show very high count values for rate-indicating functions 1, 2, 10, 11, 24, 25. An attempt was made to smooth the data as discussed previously; but, these high rates indicate noise activation which may have limited their usefulness. The quantized state indicators BTS 3 through 9 for roll, 12 through 15 for pitch, and 26 through 28 for airspeed again yield reasonable values. Reference flight path indicators are BTS 29 through 38 and 39 through 48, and these provide a range of activity levels which are intermediate to the rate BTS's and quantized state BTS's.

3.4 Representation of the BTS

Consider a Boolean time sequence where a single bit of the sequence is represented by BTS_{ij}^{k}. The first subscript (i) represents the Boolean function which generates the BTS, and the second subscript (j) identifies the jth element of that sequence. Thus, Boolean time sequence i is given by:

$$BTS_{ij}^{k} \; ; \; j = 1, M_k$$

where M_k is the number of elements in the sequence. The superscript (k) is used to indicate the flight event or flight manuever number associated with the Boolean sequence. It is seen that M_k is a function of k only and not i, because every Boolean sequence generated with data from flight event k has the same length. When reference is made to a total BTS for a specified flight event, the notation BTS_i^k is used.

TABLE III

BOOLEAN FUNCTION ACTIVITY FOR LAZY 8

BTS	Number of Changes	Activity Ordering	Description of Boolean Function
1	6246	A_2	$B_i > B_i -1$
2	6849	A_1	$B_i < B_{i-1}$
3	195	B_6	$0 \leq \|B_i\| \leq 15$
4	383	B_2	$15 < \|B_i\| \leq 30$
5	380	B_3	$30 \leq \|B_i\| \leq 45$
6	384	B_1	$45 \leq \|B_i\| \leq 60$
7	377	B_4	$60 < \|B_i\| \leq 75$
8	287	B_5	$75 \leq \|B_i\| \leq 90$
9	196	C	$0 \leq B_i$
10	10,060	D_1	$P_i > P_{i-1}$
11	4,710	D_2	$P_i < P_{i-1}$
12	388	E_2	$0 < \|P_i\| \leq 1/3\ P_m$
13	644	E_1	$1/3\ P_m < \|P_i\| \leq 2/3\ P_m$
14	286	E_3	$2/3\ P_m < \|P_m\| \leq P_m$
15	251	F	$0 \leq P_i$
16-23 All Zeroes*			
24	4664	G_1	$A_{si} > A_{si-N}$

TABLE III

BOOLEAN FUNCTION ACTIVITY FOR LAZY 8 (Continued)			
BTS	Number of Changes	Activity Ordering	Description of Boolean Function
25	4457	G_2	$A_{si} < A_{si-N}$
26	679	H_1	$A_{si} = 200 \pm 5$
27	428	H_2	$A_{si} = 100 \pm 5$
28	601	I	$100 \leq A_s \leq 200$
29	1462	J_1	$R_\theta = f(\theta) \pm 0.5\, g(\theta)$
30	1445	J_2	$R_\theta = f(\theta) \pm 1.0\, g(\theta)$
31	710	J_3	$R_\theta = f(\theta) \pm 1.5\, g(\theta)$
32	507	J_4	$R_\theta = f(\theta) \pm 2.0\, g(\theta)$
33	317	J_5	$R_\theta = f(\theta) \pm 2.5\, g(\theta)$
34	253	J_6	$R_\theta = f(\theta) \pm 3.0\, g(\theta)$
35	197	J_7	$R_\theta = f(\theta) \pm 3.5\, g(\theta)$
36	162	J_8	$R_\theta = f(\theta) \pm 4.0\, g(\theta)$
37	148	J_9	$R_\theta = f(\theta) \pm 4.5\, g(\theta)$
38	120	J_{10}	$R_\theta = f(\theta) \pm 5.0\, g(\theta)$
39	2506	K_2	$A_{s\theta} = K(\theta) \pm 1.0$
40	2727	K_1	$A_{s\theta} = K(\theta) \pm 2.0$
41	2450	K_3	$A_{s\theta} = K(\theta) \pm 3.0$

TABLE III

BOOLEAN FUNCTION ACTIVITY FOR LAZY 8 (Continued)

BTS	Number of Changes	Activity Ordering	Description of Boolean Function
42	2228	K_4	$A_{s\theta} = K(\theta) \pm 4.0$
43	2126	K_5	$A_{s\theta} = K(\theta) \pm 5.0$
44	1872	K_6	$A_{s\theta} = K(\theta) \pm 6.0$
45	1511	K_7	$A_{s\theta} = K(\theta) \pm 7.0$
46	1432	K_8	$A_{s\theta} = K(\theta) \pm 8.0$
47	1253	K_9	$A_{s\theta} = K(\theta) \pm 9.0$
48	1071	K_{10}	$A_{s\theta} = K(\theta) \pm 10.0$

B_i = Roll sample

P_i = Pitch sample

P_m = Maximum pitch value in maneuver

A_{si} = Airspeed sample

N = 5

$f(\theta)$ = Mean R function (of maneuvers rated excellent)

$g(\theta)$ = Standard deviation function

$K(\theta)$ = Mean airspeed function (of maneuvers rated excellent)

R_θ = A criterion function of $f(\theta)$ and $g(\theta)$

A_{Si} = A criterion function of $K(\theta)$ and a selected constant

* Boolean functions 16-23 were used in initial studies, but were not required here.

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4. PROCESSING PROGRAM

Figure 5 is a diagram of the general processing system. All data tapes were processed in the manner described and the results examined. After initial analysis of the results, additional special processing was often accomplished. The general processing is described in the following paragraphs, while the special processing is described in the next section.

The T-37 data tapes are converted from IBM 7094 format to XDS 910 format via programs DCT 371 or DCT 372. Program "DEGLITCH" removes noise from the data. Programs SUM T-37 and UPDAT 37 provide printed summaries and the capability of adding data (such as score information), respectively. Boolean time series for the Barrel Roll (BR) are generated by applying the data to program GBTFBR. The Lazy 8 Boolean time series were generated first with GBTFL8 and later with GBTFL8A via CFKL8A and CFGKL8A. The first set of Boolean functions did not seem to be sufficient and a second set was formed which requires more than one pass with the data. Thus, CFKL8A and CFGKL8A provide initial processing required to form the Boolean functions while GBTFL8A generates the Boolean time series (BTS).

Processing of the BTS is accomplished with the relative, state transfer and absolute computation techniques in several forms. In addition, informational programs such as SUMBTF and COUNT provide data on the BTS which are used in selection of Boolean variables for the three computational models. Additional analysis of the absolute computation data is accomplished via OLLREGR, an on-line regression analysis; and ANALYSIS, an analysis of variance.

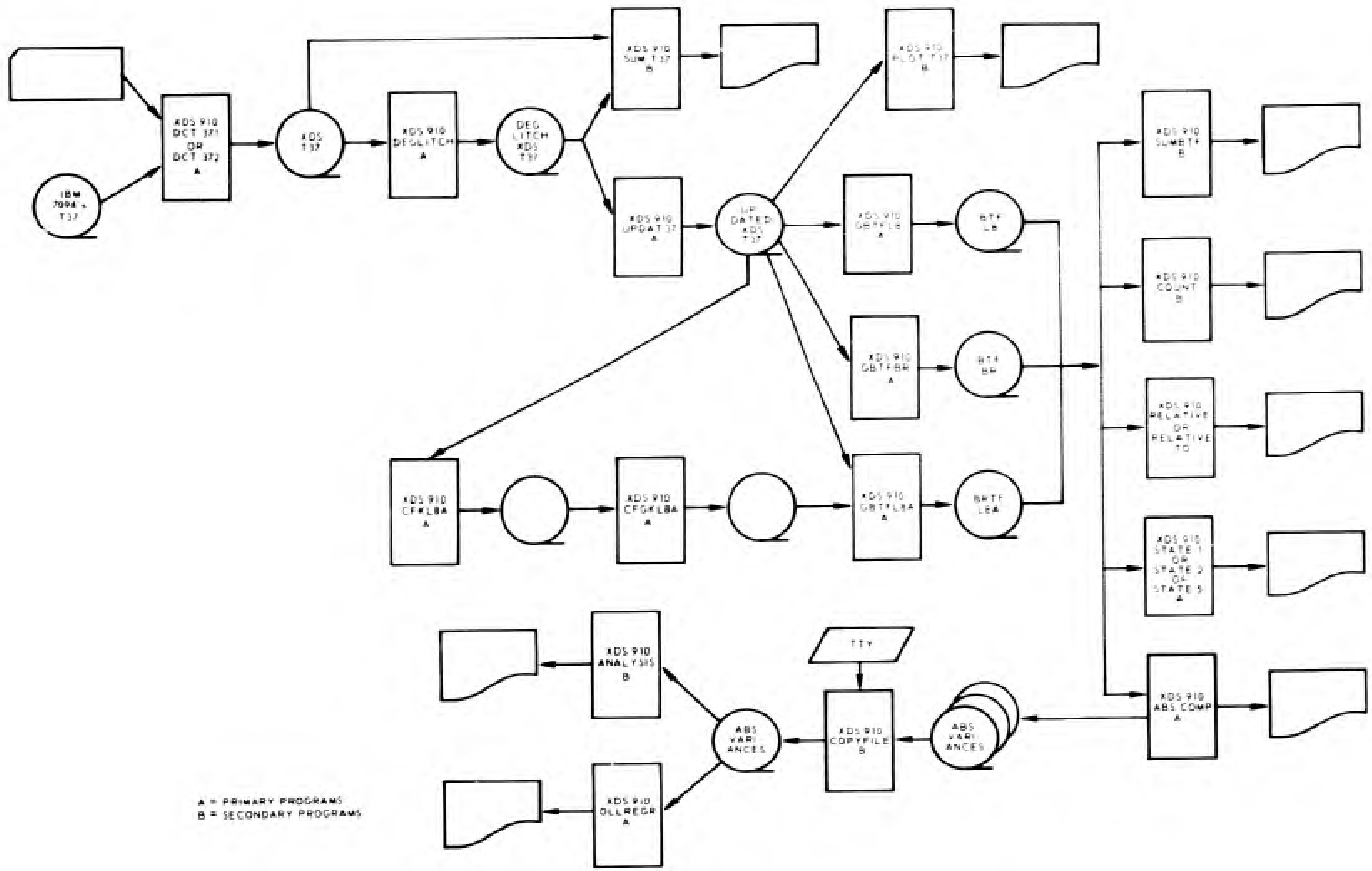

Figure 5. General Computer Program, Flow Chart

5. ANALYSIS TECHNIQUES AND RESULTS

The adaptive mathematical models (AMM) developed on the previous contract effort serve as the basic processor for the flight data as represented by Boolean functions. While it is expected that an operational performance measurement system would use the AMM (perhaps a simplified version) in a hands-off mode, the approach used in this effort was to attempt a more complete computation in order to isolate and evaluate specific performance measurement methods. The following presentation is organized to describe each math model and to present the results obtained. Due to time limitations on the study, it was not possible to present all data from the computations completed or to complete all computation that could have been accomplished. Instead, promising paths were followed and in some cases special analysis programs were written to aid in evaluating outputs of the AMM programs.

Experience gained in working with the data as well as the specific results that were obtained, indicate that the AMM/Boolean function approach provides a reasonably systematic attack on the problem of determining performance measures and criteria. In the following sections, we attempt to illustrate this through presentation and discussion of typical AMM results for the T-37 flight data.

5.1 Analysis with the Absolute Computation Mechanism

The absolute computation mechanism consists of a correlation of each BTS against a fixed set of functions or sequences (MacDonald Codes). This results in the transformation of a long sequence (BTS) into a new set of non-Boolean variables which in turn can be examined to determine if they are relevant to performance evaluation.

Correlation against an absolute reference allows a search for measurement-significance of particular sequences or patterns as they are generated by the Boolean functions. If it is found that some BTS pattern is likely to be associated with certain instructor evaluations, this information can serve as a basis for specification of automatic scoring systems as well as providing a clue as to how the instructor scores. The absolute measure also allows analysis employing a single BTS and several selected variables (the variables and number of variables can be selected) via a regression computation. This provides the tools required for a systematic study of which Boolean functions and combinations thereof are relevant to measurement.

5.1.1 Definition of the Absolute Computation

The absolute computation is defined as:

$$A^k_{\ell i} = \frac{1}{N_2 - N_1} \sum_{j=N_1}^{N_2} BTS^k_{ij} \times R_{\ell j}, \quad N_2 - N_1 \leq M_k$$

where $R_{\ell j}$ is an element in a reference sequence. The subscript (ℓ) indicates which reference sequence is being used. Note that the summation is not conducted over the total length of the BTS: rather, it is computed over a short interval of the BTS. There are two factors that lead to this approach. First, every flight does not require the same length of time and as a result M_k is not a constant. Thus, the summation must not be over an interval greater than the smallest value of M_k. Second, and far more important, is that the set of references $R_{\ell j}$ should be a set of orthogonal binary sequences in order to have an efficient reference set. (It can be shown that there are N such sequences N elements long, i.e., $R_{\ell j}$ is a square matrix. Methods of generating $R_{\ell j}$ are presented in appendix III.)

The reference set $R_{\ell j}$ has elements with values of +1 or -1 instead of 0, 1 as is the case with the BTS. The length of the reference set (and therefore the number of reference sequences) is taken to be 64. While there is no theoretical reason this number could not be different, a practical one—ease of computation—exists, as will be shown in the next section.

The computational procedure is to product and sum according to the above equation with

$$N_1 = 1$$

$$N_2 = 64$$

This yields one value of $A^k_{\ell j}$. So long as the BTS is longer than 64, a new value of $A^k_{\ell j}$ is then computed. In this second effort,

$$N_1 = 2$$

$$N_2 = 65$$

If the BTS is longer than 65, an additional shift is made, i.e., N_1 and N_2 are incremented by 1. This process is continued until $N_2 = M_k$ when the last A_i^k is computed. The total operation generates a sequence of values for $A_{\ell i}^k$. A subscript or superscript to indicate each value is not used because the notation is complicated already and the values generated are not used individually. Instead, the distribution (and measures of the distribution) of these values is employed in subsequent analysis.

The method described above is used for investigative purposes reported in this document. However, if an automated scoring system is to use an absolute computational mechanism, it might be implemented by first setting:

$$N_1 = 1,$$

$$N_2 = 64,$$

and next setting:

$$N_1 = 65,$$

$$N_2 = 128,$$

etc.

This would result in considerable computational savings.

5.1.2 Method of Investigation With the Absolute Computation Mechanism

The previous section described the absolute computation in terms of a correlation against a set of MacDonald Codes. The actual computation effort was conducted using a Hadamard transform approach. These two representations of binary-valued functions are fundamentally the same, as are the Walsh transform and Sequency spectrum concepts. Since these tools are of importance in this effort and will see increasing importance, in general, in the future, a definition of each representation along with a discussion of its properties is given in appendix III.

This section is devoted to a description of the experimental procedures and methods of analysis used. First it should be noted that the computation was implemented in the form of a Fast Hadamard transform on each 64-element sequence of the input BTS. This method employed considerable machine time but was required to insure completeness of analysis. An operational version of the system, however, could employ only those transform coefficients required, and could operate only on the K element BTS sequence as required. This suggests using the MacDonald Code approach where only those coefficients necessary (not all) would be correlated against (perhaps) successive K-element sequences rather than the overlapping sequences.

For this experiment, the Hadamard transform of each 64-element sequence of the input BTS is computed. This produces a distribution of coefficient values for each of the 64 Hadamard channels. For example, if the input BTS has 1064 elements, then 1001 Hadamard transforms are computed, each determining 64 coefficient values. Thus, each Hadamard coefficient has taken 1001 values, and our interest is centered on the distribution of these values.

Considerable success was obtained by representing the distribution by its mean and variance. Figure 6 is a typical printout histogram showing the distribution along with the mean and variance for each Hadamard coefficient. Note that some distributions have a large variance while others do not. This indicates that some channels are highly "tuned" to portions of the BTS waveform.

Figure 7 is a diagram representing the computational process just described, where the Hadamard transform of the BTS is determined followed by a computation of the mean and variance of each Hadamard coefficient distribution. Each flight event has been evaluated as poor (unsatisfactory), fair, good, or excellent. Flight data from each event is directed to the Hadamard transform process described previously. Thus, for each flight event, a number of BTS are generated, and for each of these Boolean time sequences, 64 Hadamard coefficient distributions are computed. A sample printout of the Hadamard coefficient distribution is given in figure 6. There are several flight events for each score range, as illustrated in figure 7. Thus, corresponding to each score range are several sets of BTS, each with the associated sets of distribution means and variances. It is clear that considerable data is available from this process and a systematic analysis approach is required. This analysis consists of several operations described in the following paragraphs.

5.1.3 Methods of Absolute Computation Data Analysis

Figure 7 has shown the computation system employed for investigation of relationships between performance score and the absolute computation

CORRELATION VALUES FOR INPUT SEQ 31 OF EVENT NO. 29

SCORE = 40.00

HISTOGRAM: -30 -27 -24 -21 -18 -15 -12 -9 -6 -3 0 3 6 9 12 15 18 21 24 27 30

HAC CODE	MEAN	VARIANCE	TOTAL																				
1	12.03	2262.32	718	203	5	10	5	10	5	10	5	10	5	10	5	10	5	10	5	10	5	10	380
2	.06	.89	718	0	0	0	0	0	0	0	0	0	0	619	99	0	0	0	0	0	0	0	0
3	.12	2.72	718	0	0	0	0	0	0	0	0	0	39	529	99	51	0	0	0	0	0	0	0
4	.00	.35	718	0	0	0	0	0	0	0	0	0	1	629	86	2	0	0	0	0	0	0	0
5	.25	11.36	718	0	0	0	0	0	0	0	0	62	53	408	50	114	31	0	0	0	0	0	0
6	.00	1.44	718	0	0	0	0	0	0	0	0	0	12	607	84	15	0	0	0	0	0	0	0
7	.00	4.35	718	0	0	0	0	0	0	0	0	6	58	504	84	59	7	0	0	0	0	0	0
8	.00	1.46	718	0	0	0	0	0	0	0	0	0	14	603	87	14	0	0	0	0	0	0	0
9	.49	42.52	718	0	0	0	0	0	10	40	19	53	26	359	24	56	41	51	26	13	0	0	0
10	.00	1.24	718	0	0	0	0	0	0	0	0	0	6	619	82	11	0	0	0	0	0	0	0
11	.00	3.66	718	0	0	0	0	0	0	0	0	3	52	522	82	55	4	0	0	0	0	0	0
12	.00	1.18	718	0	0	0	0	0	0	0	0	0	7	617	87	7	0	0	0	0	0	0	0
13	.00	13.49	718	0	0	0	0	0	0	0	0	84	52	408	42	88	41	3	0	0	0	0	0
14	.00	1.18	718	0	0	0	0	0	0	0	0	0	7	617	87	7	0	0	0	0	0	0	0
15	.00	3.51	718	0	0	0	0	0	0	0	0	3	52	521	87	52	3	0	0	0	0	0	0
16	.00	1.16	718	0	0	0	0	0	0	0	0	0	7	617	88	6	0	0	0	0	0	0	0
17	1.00	171.81	718	13	9	28	10	23	13	23	9	22	13	336	12	28	16	28	13	29	16	35	42
18	.02	1.32	718	0	0	0	0	0	0	0	0	0	6	615	82	15	0	0	0	0	0	0	0
19	.04	3.90	718	0	0	0	0	0	0	0	0	3	52	516	82	59	6	0	0	0	0	0	0
20	.00	1.26	718	0	0	0	0	0	0	0	0	0	9	613	87	9	0	0	0	0	0	0	0
21	.08	13.59	718	0	0	0	0	0	0	0	0	83	50	406	42	86	48	3	0	0	0	0	0
22	.00	1.10	718	0	0	0	0	0	0	0	0	0	5	621	87	5	0	0	0	0	0	0	0
23	.00	3.27	718	0	0	0	0	0	0	0	0	2	50	527	87	50	2	0	0	0	0	0	0
24	.00	1.08	718	0	0	0	0	0	0	0	0	0	5	621	88	4	0	0	0	0	0	0	0
25	.16	58.57	718	0	0	5	0	2	14	50	24	48	26	359	20	44	24	51	22	15	4	10	0
26	.00	1.30	718	0	0	0	0	0	0	0	0	0	10	611	87	10	0	0	0	0	0	0	0
27	.00	3.76	718	0	0	0	0	0	0	0	0	5	55	511	87	55	5	0	0	0	0	0	0
28	.00	1.36	718	0	0	0	0	0	0	0	0	0	11	609	86	12	0	0	0	0	0	0	0
29	.00	13.47	718	0	0	0	0	0	0	0	0	86	49	404	44	92	43	0	0	0	0	0	0
30	.00	1.03	718	0	0	0	0	0	0	0	0	0	4	623	88	3	0	0	0	0	0	0	0
31	.00	3.12	718	0	0	0	0	0	0	0	0	2	48	530	88	49	1	0	0	0	0	0	0
32	.00	1.06	718	0	0	0	0	0	0	0	0	0	4	623	87	4	0	0	0	0	0	0	0
33	.31	598.74	718	71	5	31	6	13	7	13	5	12	7	325	6	14	8	14	7	15	8	34	117
34	.02	1.08	718	0	0	0	0	0	0	0	0	0	0	627	82	9	0	0	0	0	0	0	0
35	.04	3.16	718	0	0	0	0	0	0	0	0	0	46	534	82	53	3	0	0	0	0	0	0
36	.00	1.01	718	0	0	0	0	0	0	0	0	0	3	625	87	3	0	0	0	0	0	0	0
37	.08	12.66	718	0	0	0	0	0	0	0	0	74	56	412	42	92	39	3	0	0	0	0	0
38	.00	1.34	718	0	0	0	0	0	0	0	0	0	11	609	87	11	0	0	0	0	0	0	0
39	.00	4.01	718	0	0	0	0	0	0	0	0	5	56	509	87	56	5	0	0	0	0	0	0
40	.00	1.32	718	0	0	0	0	0	0	0	0	0	11	609	88	10	0	0	0	0	0	0	0
41	.16	48.50	718	0	0	0	0	0	12	48	24	56	28	361	20	46	32	49	22	13	2	5	0
42	.00	1.22	718	0	0	0	0	0	0	0	0	0	8	615	87	8	0	0	0	0	0	0	0
43	.00	3.72	718	0	0	0	0	0	0	0	0	4	53	517	87	53	4	0	0	0	0	0	0
44	.00	1.28	718	0	0	0	0	0	0	0	0	0	9	613	86	10	0	0	0	0	0	0	0
45	.00	13.06	718	0	0	0	0	0	0	0	0	83	51	406	44	94	40	0	0	0	0	0	0
46	.00	1.12	718	0	0	0	0	0	0	0	0	0	6	619	88	5	0	0	0	0	0	0	0
47	.00	3.37	718	0	0	0	0	0	0	0	0	3	50	524	88	51	2	0	0	0	0	0	0
48	.00	1.14	718	0	0	0	0	0	0	0	0	0	6	619	87	6	0	0	0	0	0	0	0
49	.31	179.30	718	15	10	30	12	26	14	26	12	26	14	337	9	20	11	27	11	24	13	43	38
50	-.02	1.14	718	0	0	0	0	0	0	0	0	0	6	623	83	6	0	0	0	0	0	0	0
51	-.04	3.47	718	0	0	0	0	0	0	0	0	3	53	527	83	49	3	0	0	0	0	0	0
52	.00	1.20	718	0	0	0	0	0	0	0	0	0	7	617	86	8	0	0	0	0	0	0	0
53	-.08	12.64	718	0	0	0	0	0	0	0	0	83	55	410	42	92	36	0	0	0	0	0	0
54	.00	1.20	718	0	0	0	0	0	0	0	0	0	6	619	84	9	0	0	0	0	0	0	0
55	.00	3.62	718	0	0	0	0	0	0	0	0	3	52	522	84	53	4	0	0	0	0	0	0
56	.00	1.22	718	0	0	0	0	0	0	0	0	0	8	615	87	8	0	0	0	0	0	0	0
57	-.16	52.82	718	0	0	5	0	2	14	50	23	53	28	361	20	46	29	45	22	13	2	5	0
58	.00	1.32	718	0	0	0	0	0	0	0	0	0	8	615	82	13	0	0	0	0	0	0	0
59	.00	3.90	718	0	0	0	0	0	0	0	0	4	54	516	82	57	5	0	0	0	0	0	0
60	.00	1.26	718	0	0	0	0	0	0	0	0	0	9	613	87	9	0	0	0	0	0	0	0
61	.00	13.90	718	0	0	0	0	0	0	0	0	87	50	406	42	86	44	3	0	0	0	0	0
62	.00	1.10	718	0	0	0	0	0	0	0	0	0	5	621	87	5	0	0	0	0	0	0	0
63	.00	3.27	718	0	0	0	0	0	0	0	0	2	50	527	87	50	2	0	0	0	0	0	0
64	.00	1.08	718	0	0	0	0	0	0	0	0	0	5	621	88	4	0	0	0	0	0	0	0

Figure 6. Sample Hadamard Coefficient Distribution

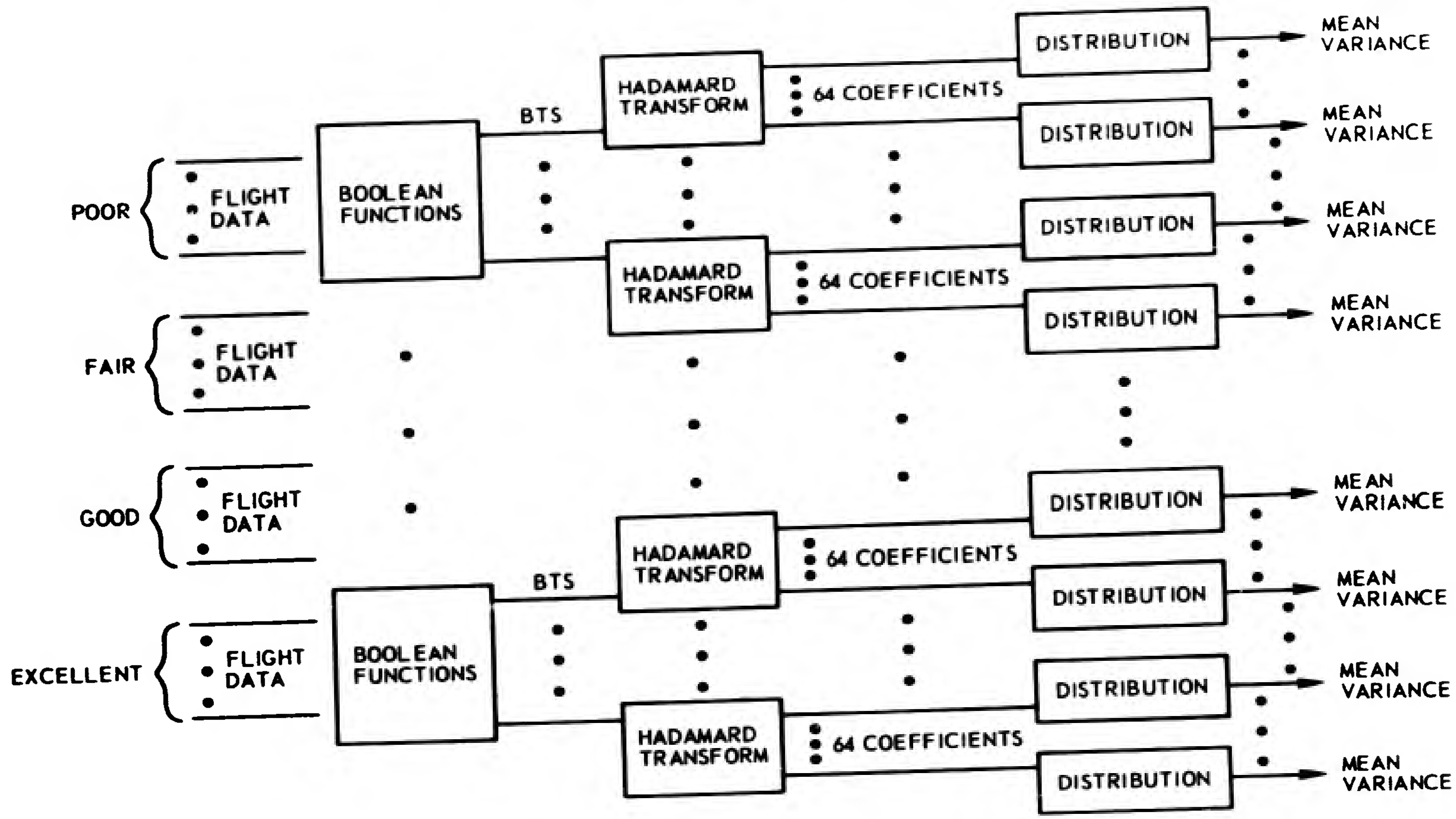

Figure 7. Absolute Computation and Analysis Method

mechanisms. Initially, several questions must be answered. First, which BTS or combination of BTS are of significance in score prediction, and second, which Hadamard coefficients are good measures of score information. Finally, we can ask how these variables related to score.

Three analysis approaches are examined:

a. Examine Hadamard coefficient distribution variances for each score range to determine how these are related to score.

b. Select variances believed to be related to score and run a regression analysis.

c. Convert to sequency spectrum and examine structure for possible score information.

These approaches and the results obtained are documented in the subsequent sections.

5.1.4 Analysis of Hadamard Coefficients for Score Discrimination

One straightforward (but time consuming) analysis is to examine the Hadamard coefficient distributions for each score range and determine if similarities within each score grouping are different from those at the other score groupings. With this approach, we simply generate a printout of distribution variance and examine for score discrimination. Appendices IV and V show a series of such printouts and indicate the discrimination possible with this approach as applied to the Lazy 8 maneuver.

For example, consider (appendix IV) the printout for BTS 40 (input sequence) processed via Hadamard channel 14 (indicated as MAC CODE 14). It is seen that all flights evaluated as poor (represented by a 20) are associated with distribution variances that are lower than those associated with an excellent (80) flight. Other Hadamard channels such as 10, 12, 15, and 16 provide the same discrimination capability. As a second example, consider appendix V which provides the printout for BTS 33 (input sequence). Examining the data associated with Hadamard channels 28 and 32, we see that the indicators for the excellent (80) flights are clearly less than for both poor (20) and fair (40) flights.

These data yield strong evidence that at least some flight performance categories can be discriminated with selected Boolean functions and Hadamard channels. If a sufficient number of discriminations can be found, then scoring could be accomplished with a simplified absolute computation. (If not, then of course a combination of methods must be evaluated.)

An additional method of examining the relation between score and the Hadamard coefficients consists of grouping variances according to score category for each Hadamard channel and computing the mean value for each group. Next the means for each group are compared channel by channel to determine a measure of consistency. Thus, if the mean for the excellent category for channel N is greater than the mean for the fair category for channel N, and the same is true for a great number of channels, then we have identified a possible basis for score discrimination of excellent and fair performance.[2]

This analysis was first attempted by hand with good success and was later programmed to automate the procedure. Figures 8, 9, and 10 show the results. Figure 8 is a printout of the means and standard deviations for each score category for each Hadamard channel (MAC Code) for the Lazy 8 maneuver data. Thus, for example, channel 1 has means of 568, 768, 866, and 909 for poor, fair, good, and excellent flights, respectively. It is easily observed that the means are monotonically increasing with improved pilot performance. Also other channels yield monotonically increasing mean values. This seems to relate Hadamard processing to score, and would be directly applicable to score prediction if (1) Several samples of each pilot's performance were available, and (2) The mean adequately represents the score distribution. In regard to the latter consideration, studies of the true score distribution would be required prior to use of the technique with any degree of confidence.

Independent of the distribution of pilot scores, the analysis method can be used to identify possible score relationships that can be used for score prediction. Consider the distribution variances associated with the data given in figure 8 which are listed in figure 9. Channel 1 (indicated as MAC Code 1) yields variance values ranging from 343 to 949 for the poor category. Clearly, these values overlap those found in other score categories and, as a result, channel 1 does not appear to have stro‸ correlation with score. However, with persistent search and with the aid of data presented as shown in figure 10, it is possible to extract existing score relationships. First, note that data in figure 10 is arranged to indicate the relative variance values in graphic form.

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[2]Note the logic here. We have considerable data printout and could expect to find all possible relationships with persistent search (also possibly independent of any actual relationship with score). Instead we can look for a consistent condition as a means for locating possible performance-related variables.

INPUT SEQ. 40, 48 EVENTS

FREQUENCY-SCORE	10-20		10-40		19-60		9-80	
MAC CODES	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
1	568.224	231.039	768.129	253.103	866.659	332.360	909.904	337.532
2	3.300	2.541	4.859	3.485	9.486	13.259	15.575	8.652
3	2.745	2.625	6.485	4.341	10.367	5.449	16.576	4.665
4	2.456	2.473	5.957	4.292	9.695	5.278	15.566	4.581
5	4.350	2.267	8.651	3.934	12.607	8.622	21.791	6.712
6	3.062	1.924	5.849	4.362	8.961	6.439	14.734	3.987
7	3.193	1.695	6.502	3.906	10.445	8.974	18.110	6.114
8	3.017	1.839	5.943	4.434	9.008	6.498	14.745	4.033

0-20>40,60,80*	0-40<20	0-60<40	0-8C<60
0-20>40,60	0-40>60,80	0-60<40,20	0-80<60,40
0-20>40	0-40>60	0-60>80	0-8C<60,40,2C
8-20<40	8-40<60	8-60<80	8-8C>60,40,2C
8-20<40,60	8-40<60,80	8-60>40,20	8-80>60,40
8-20<40,60,80	8-40>20	8-60>40	8-80>60

*The inequality should read as follows:
0 times, the mean value for score category 20 was greater than that for score category 40, or score category 60, or score category 80.

Figure 8. Mean and Standard Deviation for each Score Category

INPUT SEQ. 40, 48 EVENTS

SCØRE 20
MAC CØDES VARIANCES-10

1	359.1	401.7	949.9	366.1	864.2	343.9	494.8	361.3	832.8	708.4
2	3.4	.1	4.1	4.1	4.3	.0	1.8	.9	6.2	8.3
3	2.7	.3	3.8	2.6	2.2	.0	2.1	1.8	10.0	2.0
4	2.4	.2	3.3	2.5	1.8	.0	1.9	1.7	9.3	1.4
5	3.7	.7	5.9	5.3	4.1	.0	4.7	5.1	7.5	6.7
6	2.4	.3	5.6	3.3	3.2	.0	5.9	2.0	5.0	2.9
7	2.8	.3	4.4	4.5	2.5	.0	3.8	4.6	5.1	3.8
8	2.4	.3	5.5	3.3	3.1	.0	5.3	2.1	5.2	2.9

SCØRE 40
MAC CØDES VARIANCES-10

1	940.2	588.6	630.6	960.9	703.5	827.4	453.2	1078.3	1148.6	349.9
2	3.8	1.6	3.9	3.0	3.6	14.5	6.0	5.2	5.3	1.8
3	4.1	2.5	5.3	6.7	4.1	14.8	2.8	5.8	14.8	3.9
4	3.4	2.0	4.8	6.1	3.3	14.1	2.4	5.3	14.3	3.7
5	10.4	4.4	7.7	10.4	7.2	11.1	4.4	7.9	18.1	5.0
6	3.3	2.4	3.6	9.3	4.0	12.0	2.1	4.8	15.0	2.0
7	8.5	2.5	5.7	8.0	4.9	7.4	2.6	4.9	16.6	4.1
8	3.3	2.4	3.7	9.7	3.9	12.4	2.1	4.9	14.9	2.0

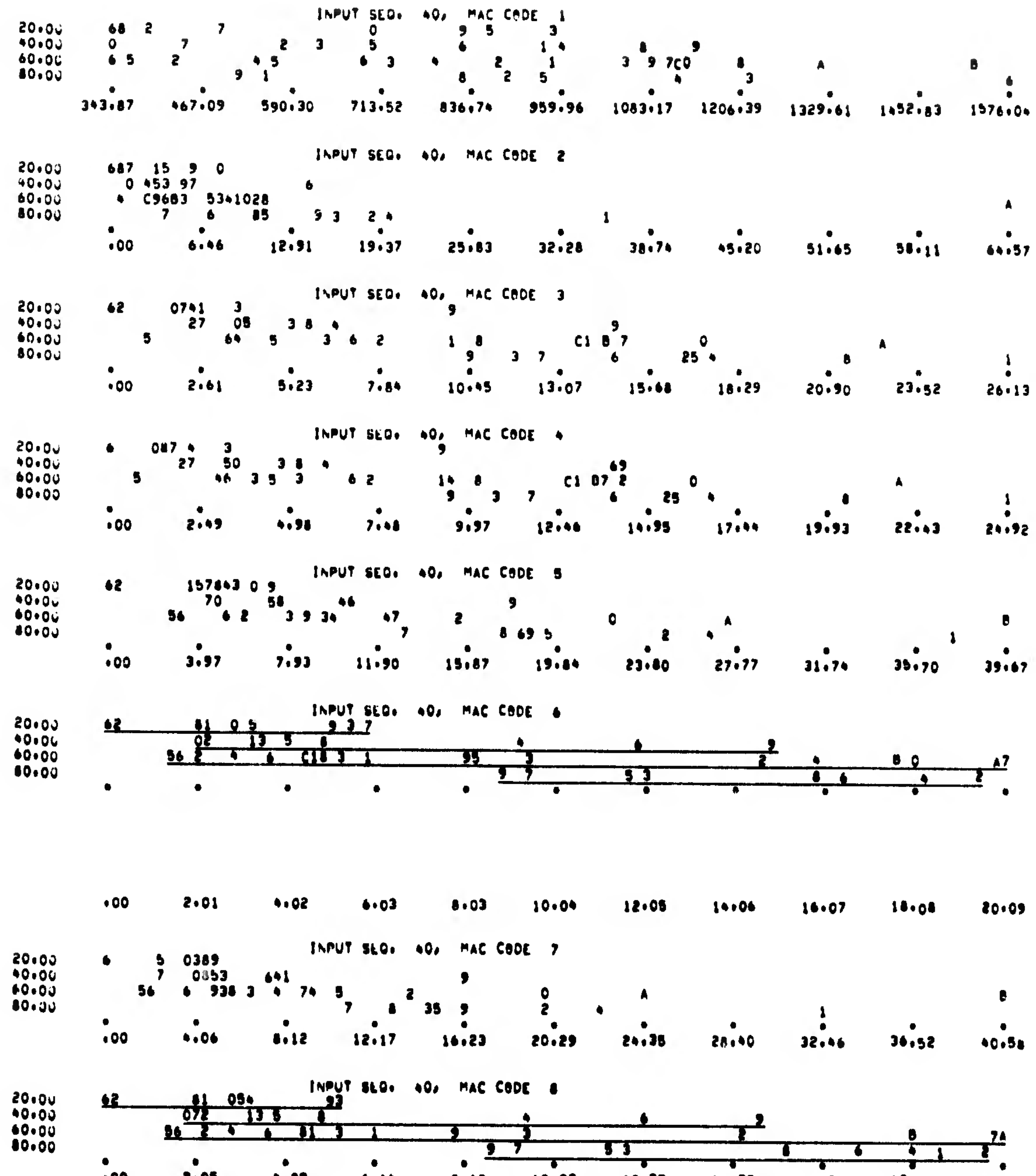
SCØRE 60
MAC CØDES VARIANCES-19

1	546.7	439.1	1056.3	796.4	568.5	344.3	1112.7	1211.6	1083.7	1140.1	1319.3	1529.3	1128.3	948.9	885.5
	737.2	541.6	377.1	699.9											
2	9.3	5.8	7.9	8.5	4.4	3.7	7.5	11.0	3.7	10.3	64.6	4.6	3.1	7.3	10.6
	5.2	1.1	7.2	4.4											
3	14.0	14.6	4.8	10.0	5.0	3.7	15.0	10.8	14.5	17.5	22.7	14.5	13.7	10.0	8.0
	6.3	3.8	1.2	7.2											
4	13.0	14.2	4.1	9.6	4.5	3.4	13.8	10.3	13.5	16.3	22.0	13.5	12.7	9.3	7.5
	5.4	3.2	.9	6.9											
5	12.3	6.1	8.3	12.3	12.7	3.3	12.7	9.1	9.0	22.6	27.6	39.7	10.2	9.7	15.7
	9.7	10.1	2.9	5.5											
6	5.9	2.2	5.3	15.9	8.2	1.8	20.1	4.9	8.2	18.2	20.0	17.8	4.6	4.6	14.8
	9.6	2.9	1.4	3.7											
7	9.2	5.3	5.6	9.5	10.6	2.2	9.2	6.1	5.3	19.9	24.7	40.6	7.8	7.9	13.9
	6.8	8.0	1.9	3.9											
8	6.2	2.3	5.3	14.7	8.1	1.8	20.4	4.7	8.1	18.6	20.5	18.5	4.8	4.7	14.6
	9.7	3.1	1.4	3.7											

SCØRE 80
MAC CØDES VARIANCES- 9

1	553.7	887.4	1230.8	1125.3	938.0	1576.0	519.8	829.6	528.5
2	35.7	19.3	16.2	20.1	11.1	7.7	4.2	10.8	15.1
3	26.1	16.8	11.8	17.7	17.1	14.8	12.7	21.6	10.6
4	24.9	15.6	10.7	16.7	15.9	14.1	11.9	20.7	9.7
5	37.6	24.9	19.0	26.8	19.5	18.4	13.4	17.8	18.8
6	19.7	19.7	12.1	18.4	11.8	16.5	9.5	15.9	8.9
7	32.8	20.0	14.8	22.6	15.2	16.6	11.2	13.2	16.6
8	19.0	20.1	12.0	18.5	11.6	17.2	9.5	15.7	9.0

Figure 9. Hadamard Coefficient Distribution Variances for BTS 40



NOTE:

The symbols plotted to indicate variance value refer to values in figure 11. Each variance along a row corresponds to a number in a number sequence which repeats after 13 units. The number sequence is 1, 2, 3, 4, 5, 6, 7, 8, 9, 0, A, B, C, 1, ... Variances associated with scores of 20, 40, and 80 do not repeat since there are 10 or less numbers. Variances for scores of 60 do use repeated numbers since there are 19 such numbers. As an example for MAC CODE 1 in figure 12, third row (score 60) the third element is a "2" and also the 9th element is a "2". Referring to figure 11 the first "2" indicates the value of 438.1 which is the second variance value shown in the matrix termed SCORE 60, MAC CODE 1. The second "2" indicates the variance value (885.2) of the 15th element along that same row.

Figure 10. Variance Distribution for BTS 40

For example, the third variance value for channel 1 (poor category) is 949.9 as shown in figure 9 and is indicated in figure 10 with a 3 (for third variance) in the location appropriate to its value. (Note that the 0 corresponds to 10, A to 11, and B to 12, etc., in a manner similar to the hexadecimal number system.)

Examination of figure 10 shows that channel 3 provides good separation of data for poor and excellent categories. Also channel 5 gives better discrimination of poor and excellent categories and reasonably good results in separating excellent from all other categories. Likewise, channels 7 and 8 appear to have variables which contain score information.

In addition to the observations indicated in the previous paragraphs, it is useful to return to computation of the variance means for each score category (refer to figure 8). It is desired to determine the frequency of score-indicating relationships along the Hadamard channels. For example, as shown in figure 11, inequalities for the 64 Hadamard channels for BTS 40 show that all channels yield a lower mean for poor flights than that for excellent, good, or fair flights. Also all channels produced a higher mean for excellent flights than that for good, fair, or poor flights. This implies that:

a. One or more channels are good candidates for discrimination between poor (20) and excellent (80) performance or,

b. A simpler measure for discrimination exists.

As a second example, inequalities associated with the input BTS 33 (figure 12) indicate that the mean for excellent flight performance is consistently less than that for all other flight categories. Similar results are obtained for BTS 43 and BTS 30 as shown in figures 13 and 14, respectively.

A similar analysis on the Barrel Roll maneuver data leads to a different observation. Selected results are tabulated in table IV. Note that BTS 1 (input seq 1) has a mean for the good (60) flight runs which is greater than those associated with the other performance categories with some consistency. Also we see for BTS 2 and especially 18 that good (60) performance consistently produces a lower mean than that obtained for the other flights. Clearly we do not have a monotonic increase or decrease of the mean with performance skill but instead, we tend to a peak or dip with certain performances.

0=20>40,60,80	0=40<20	3=60<40	0=80<60
0=20>40,60	0=40>60,80	0=60<40,20	0=80<60,40
0=20>40	3=40>60	0=60>80	0=80<60,40,20
64=20<40	61=40<60	64=60<80	64=80>60,40,20
64=20<40,60	61=40<60,80	61=60>40,20	64=80>60,40
64=20<40,60,80	64=40>20	61=60>40	64=80>60

Figure 11. Inequalities for 64 MAC Code Variances (BTS 40)

24=20>40,60,80	24=40<20	64=60<40	64=80<60
24=20>40,60	64=40>60,80	64=60<40,20	64=80<60,40
24=20>40	64=40>60	64=60>80	64=80<60,40,20
40=20<40	0=40<60	0=60<80	0=80>60,40,20
0=20<40,60	0=40<60,80	0=60>40,20	0=80>60,40
0=20<40,60,80	40=40>20	0=60>40	0=80>60

Figure 12. Inequalities for 64 MAC Code Variances (BTS 33)

0=20>40,60,80	0=40<20	13=60<40	1=80<60
0=20>40,60	3=40>60,80	0=60<40,20	0=80<60,40
0=20>40	13=40>60	1=60>80	0=80<60,40,20
64=20<40	51=40<60	63=60<80	60=80>60,40,20
64=20<40,60	51=40<60,80	51=60>40,20	60=80>60,40
64=20<40,60,80	64=40>20	51=60>40	63=80>60

Figure 13. Inequalities for 64 MAC Code Variances (BTS 43)

4=20>40,60,80	14=40<20	22=60<40	35=80<60
4=20>40,60	18=40>60,80	6=60<40,20	22=80<60,40
14=20>40	22=40>60	35=60>80	16=80<60,40,20
50=20<40	42=40<60	29=60<80	28=80>60,40,20
43=20<40,60	37=40<60,80	39=60>40,20	28=80>60,40
37=20<40,60,80	50=40>20	42=60>40	29=80>60

Figure 14. Inequalities for 64 MAC Code Variances (BTS 30)

TABLE IV

INEQUALITIES FOR BARREL ROLL

Input Seq 1

$52 - 20 < 40, \; 40 - 40 < 60, \; 57 - 60 > 80$

Input Seq 2

$55 - 20 < 40, \; 45 - 40 > 60, \; 45 - 60 < 80$

Input Seq 18

$43 - 20 > 40, \; 62 - 40 > 60, \; 64 - 60 < 80$

This result supports the belief that the character of the "score function" is probably not monotonic. Instead we might look for logic which says, for example: certain measures or conditions of certain variables must hold in order to achieve a score of good; but, these conditions (measures) may not be related at all or in the same way to performance in other categories.[3]

It is interesting to note that BTS 1 and 2 are developed from functions representing reference performance and should be expected to yield information about performance. However, the indication is not as consistent as that obtained from BTS 18, which is a measure related to the symmetry of the pitch angle profile generated during the maneuver. From these results one would expect that a condition on pitch symmetry is a significant indication of good (60) performance for the Barrel Roll maneuver.

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[3] This is precisely why valid measurement has remained an unresolved problem for so many years.

5.1.5 Regression Analysis on Absolute Computation Data

A visual examination of the Hadamard coefficient histograms, along with knowledge of the Boolean functions and the desired flight pattern, is used to select the BTS and associated Hadamard coefficients most likely to be related to score. From this selected list, a regression is run using single and multi-variable formulations. The approach is to run regression analyses on many variables and combinations of variables in order to discover those related to score. Results of this work showed that the variance of the Hadamard coefficient distribution was found to be related to score, and the regression uses the variances as a score prediction variable. After the regression is made, the prediction shows how each flight is scored by an automatic system using only those variables selected for the regression. A plot of the results demonstrates what flight events could be properly scored, as well as those which are scored with uncertainty using only absolute computation variables.

Figures 15 to 22 provide histograms of the predicted scores for each flight event. The histograms are grouped according to the instructor's evaluation for easy comparison of predictions in each category. Table V presents a list of the Hadamard channel variables (variance of coefficient distribution) associated with each BTS. Appendix VI provides printouts of the actual score prediction versus the instructor's evaluation (shown as "true" score).

Extensive runs were made with single variable predictions using the regression analysis. The results are typified by those presented in histogram No. 1 (figure 15). Also, computer runs were made with a single BTS and many of its channel variables, such as that presented in histogram Nos. 2 and 3 (figures 16 and 17). Results of these predictions, as indicated in the figures, show a limited score prediction capability. Note however, that there is a tendency for discrimination between two categories, i.e., (poor, fair), and (good, excellent). If BTS 40 variables are used in conjunction with BTS 33 variables as shown in histogram No. 4 (figure 18) a good separation of good and excellent flight occurs.

As expected, the score discrimination is improved as more than one BTS is used. This result is especially clear when BTS's associated with roll and airspeed functions of pitch (BTS 29 through 38 and BTS 39 through 48) are used. For example, histograms Nos. 5, 6, 7, and 8 include combinations of the above Boolean time functions and provide some separation of scores.

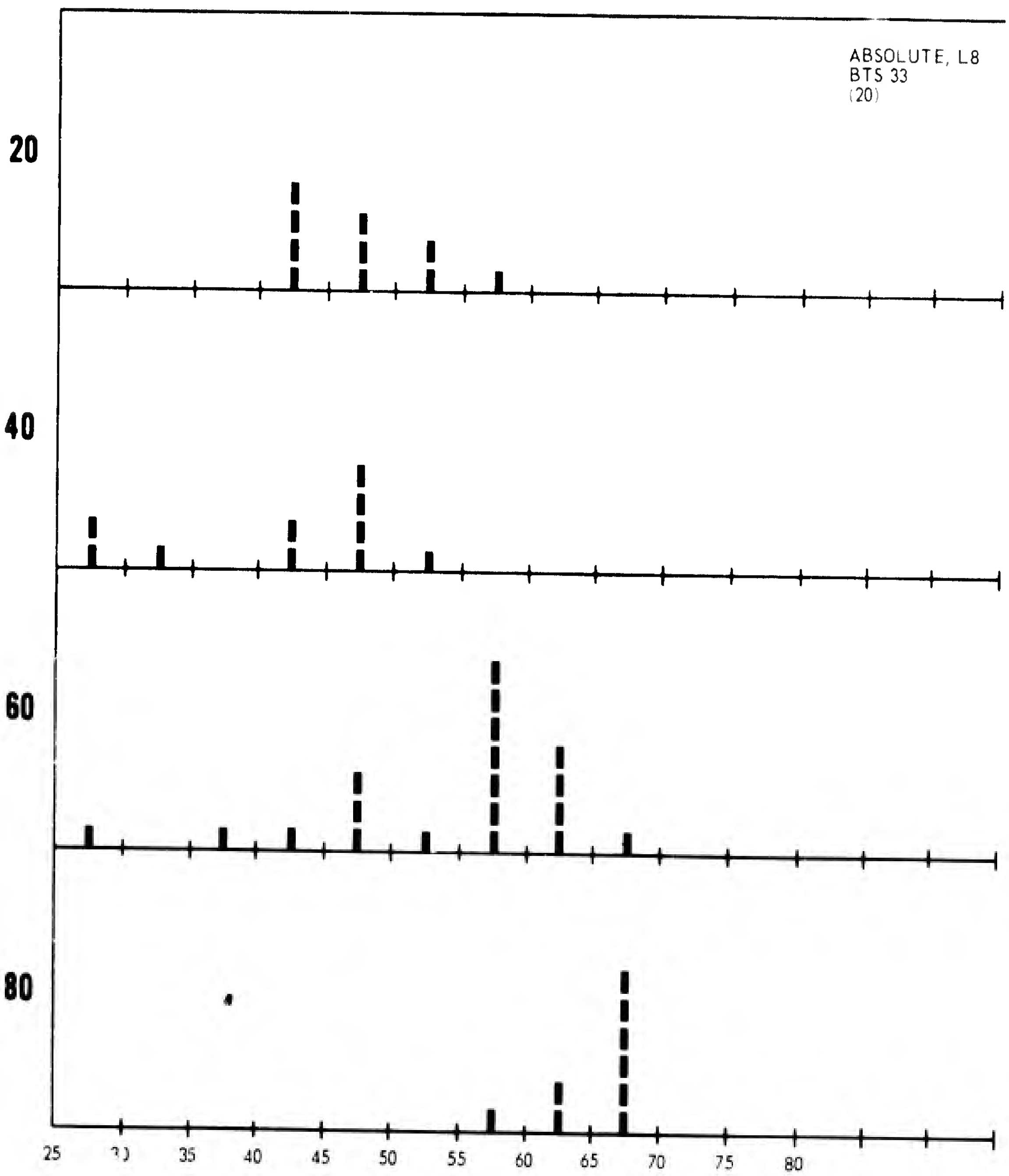

Figure 15. Histogram No. 1 Instructor Score versus Predicted Score

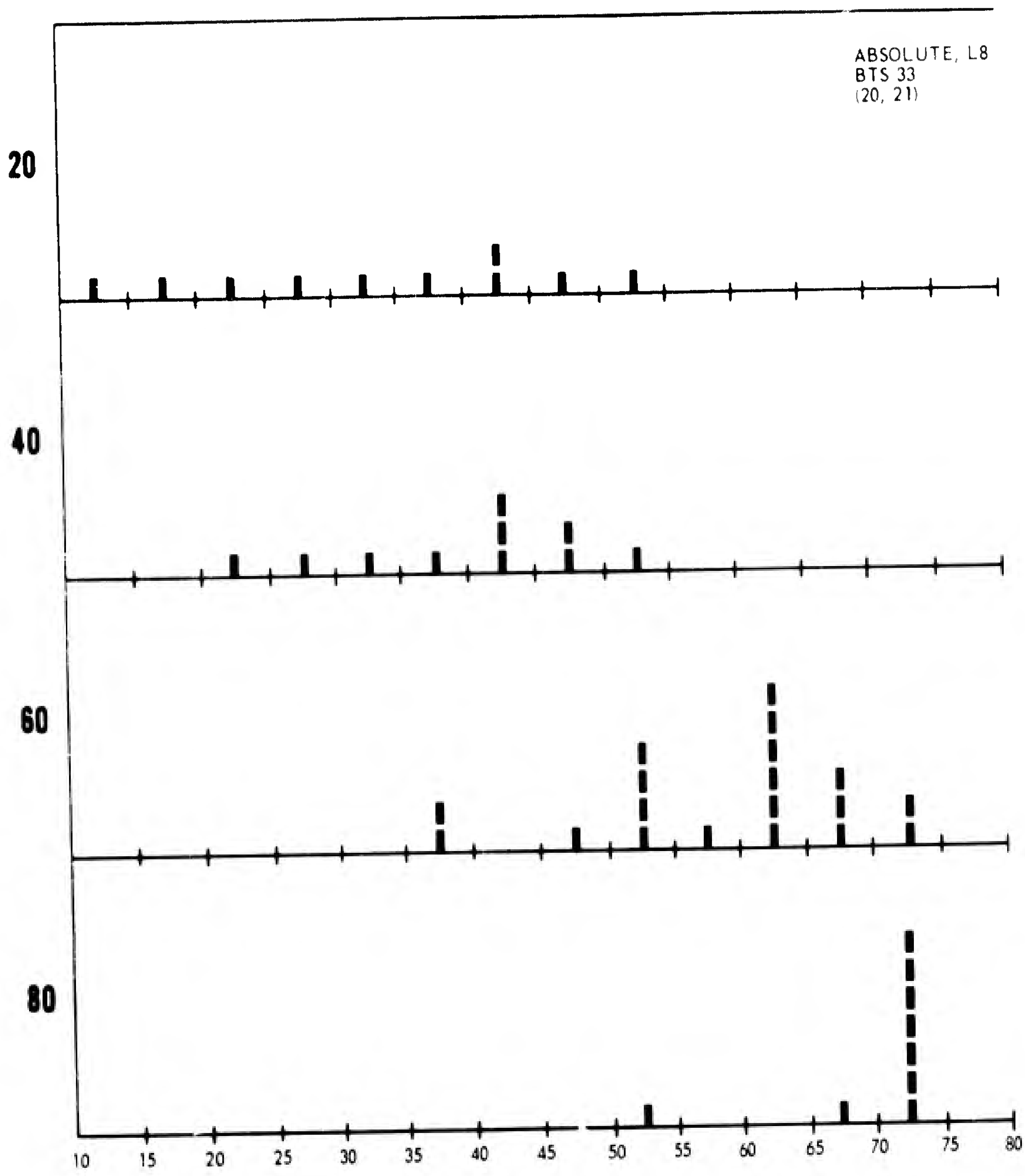

Figure 16. Histogram No. 2 Instructor Score versus Predicted Score

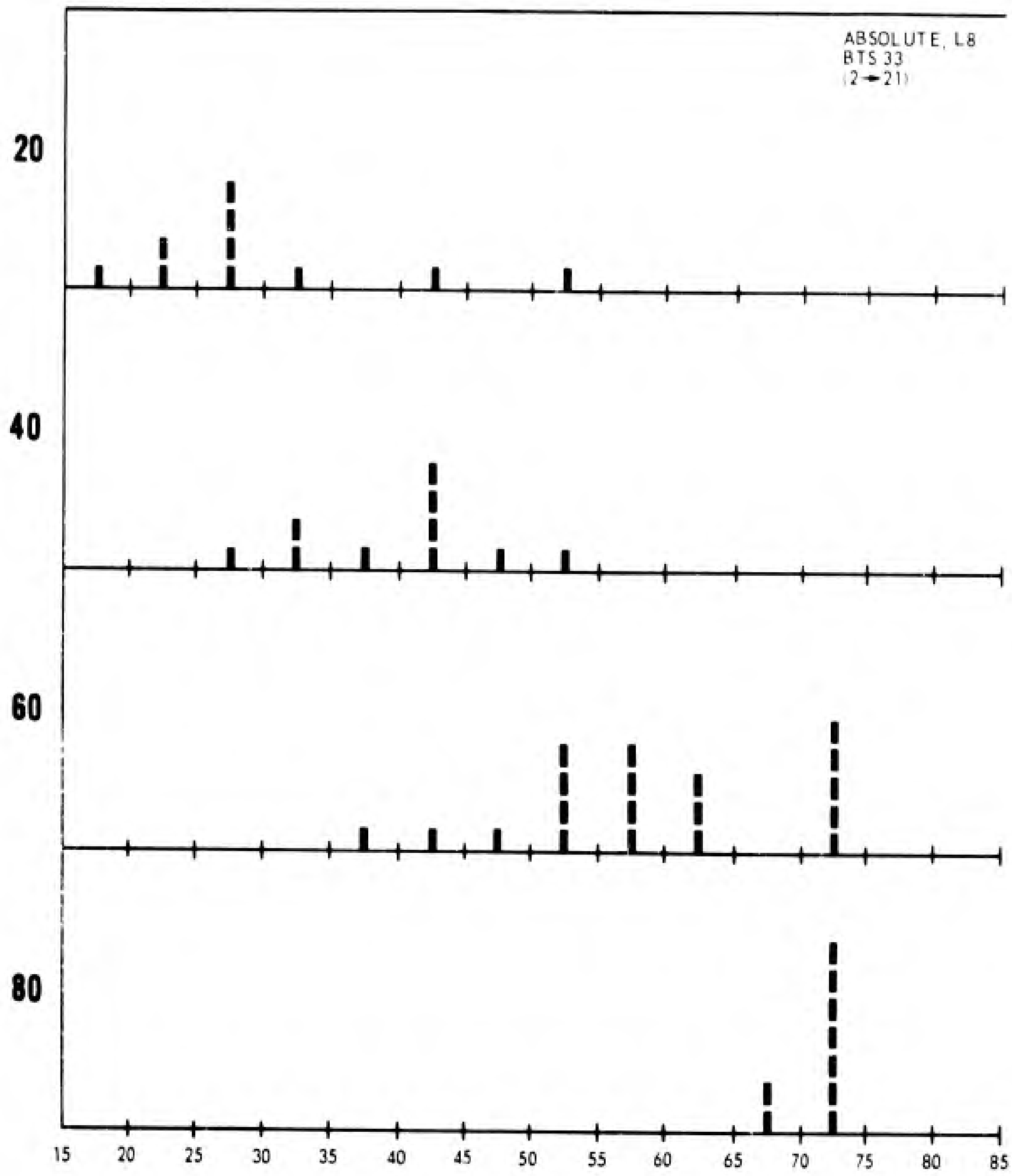

Figure 17. Histogram No. 3 Instructor Score versus Predicted Score

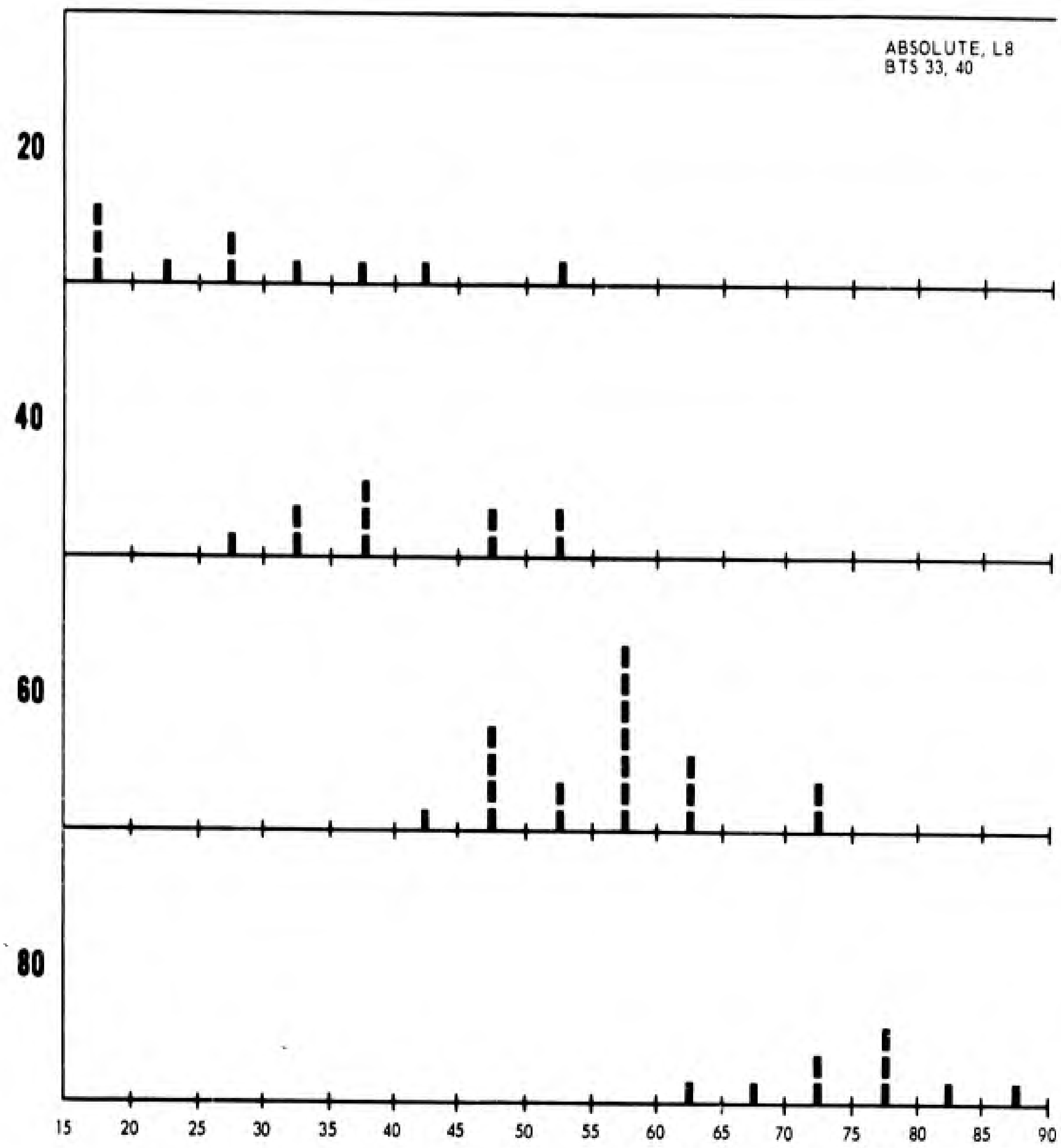

Figure 18. Histogram No. 4 Instructor Score versus Predicted Score

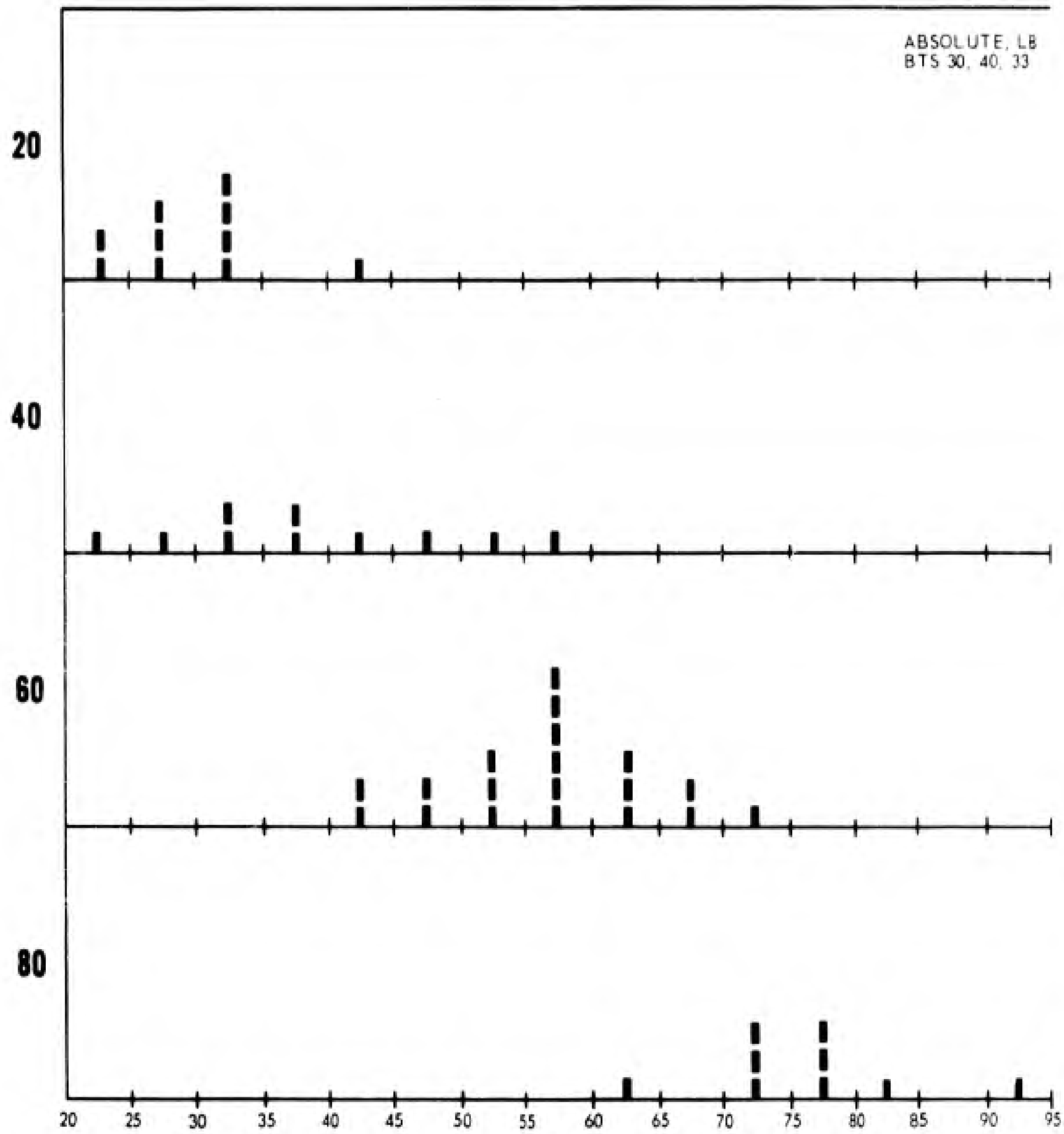

Figure 19. Histogram No. 5 Instructor Score versus Predicted Score

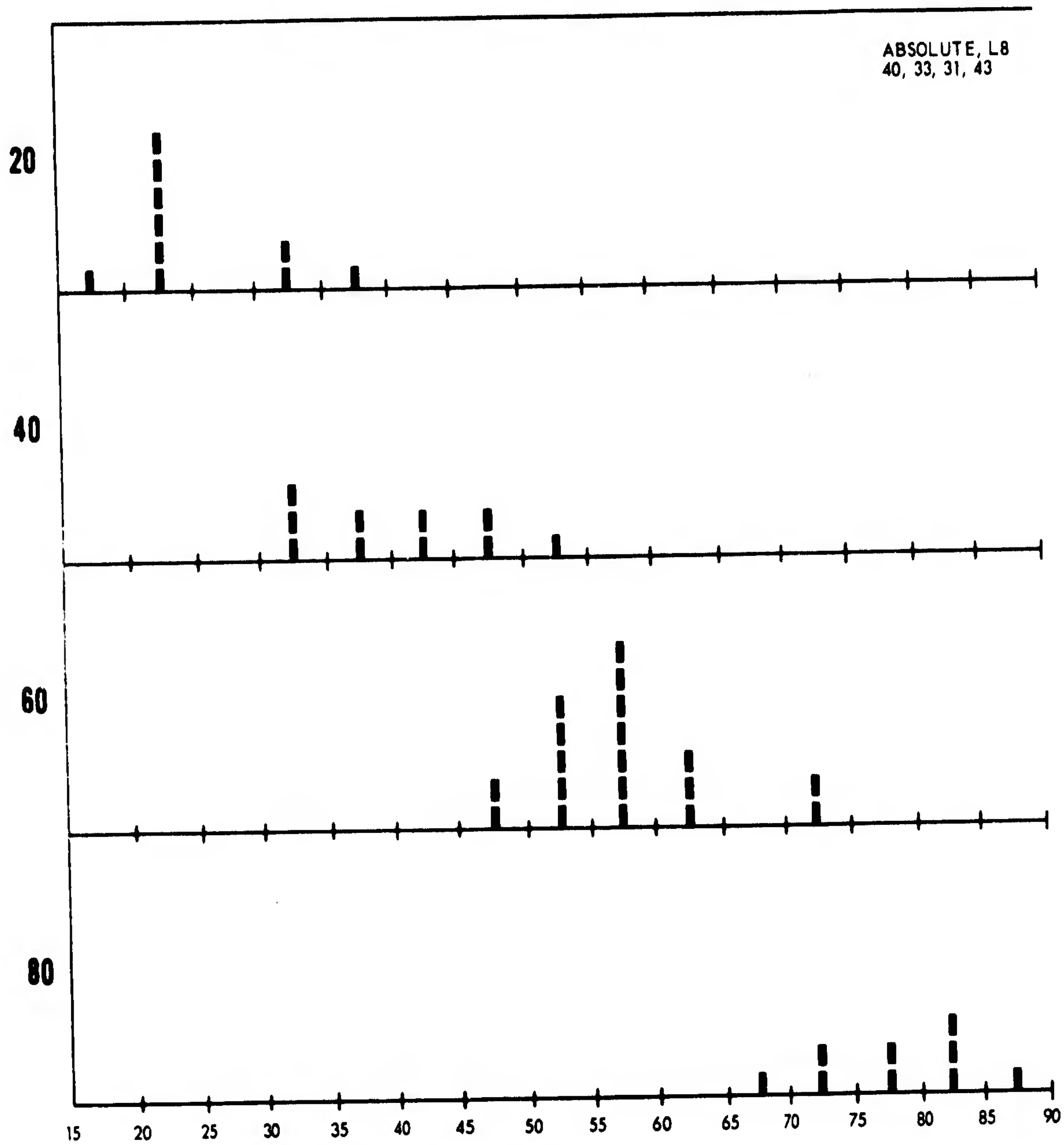

Figure 20. Histogram No. 6 Instructor Score versus Predicted Score

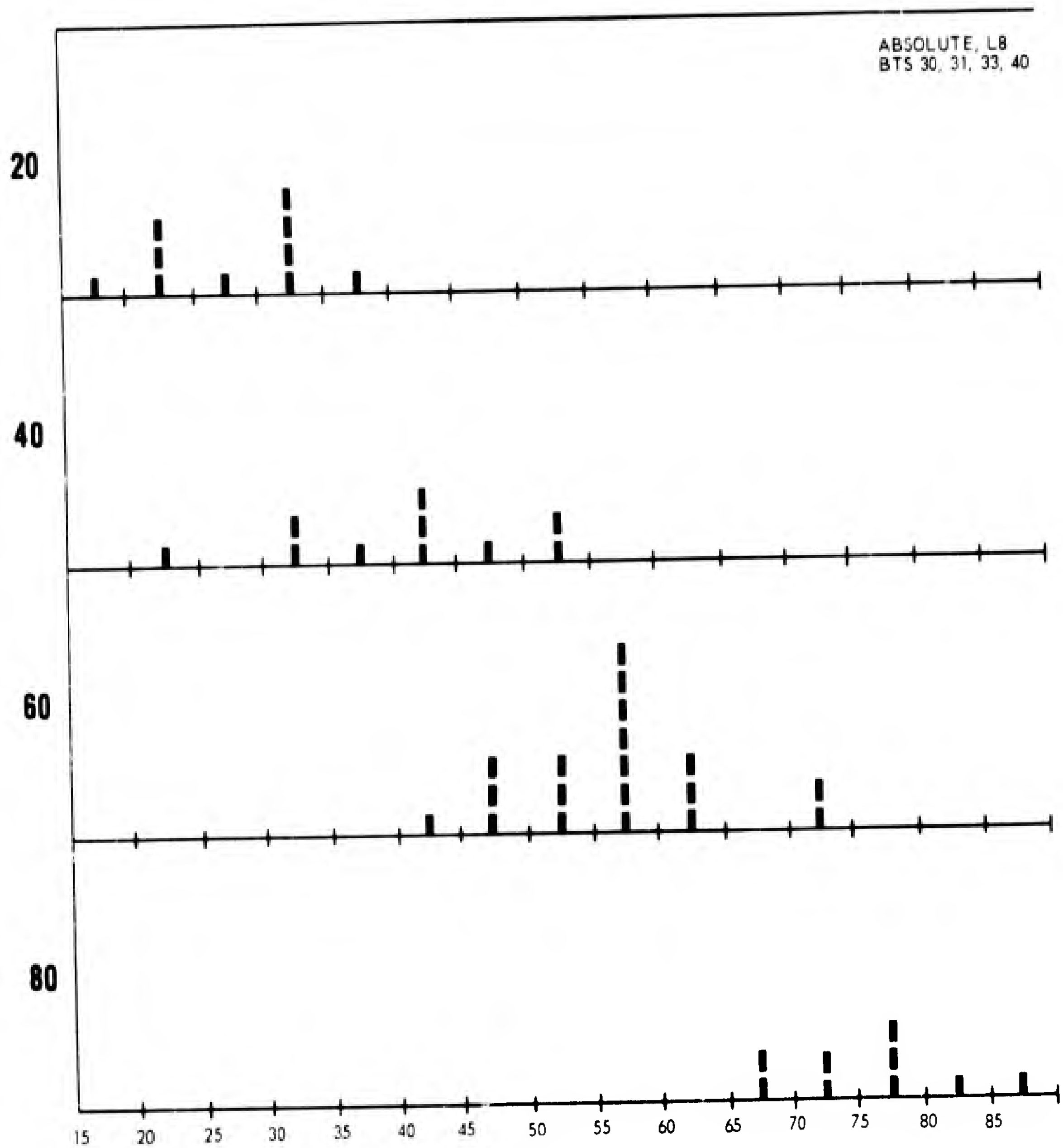

Figure 21. Histogram No. 7 Instructor Score versus Predicted Score

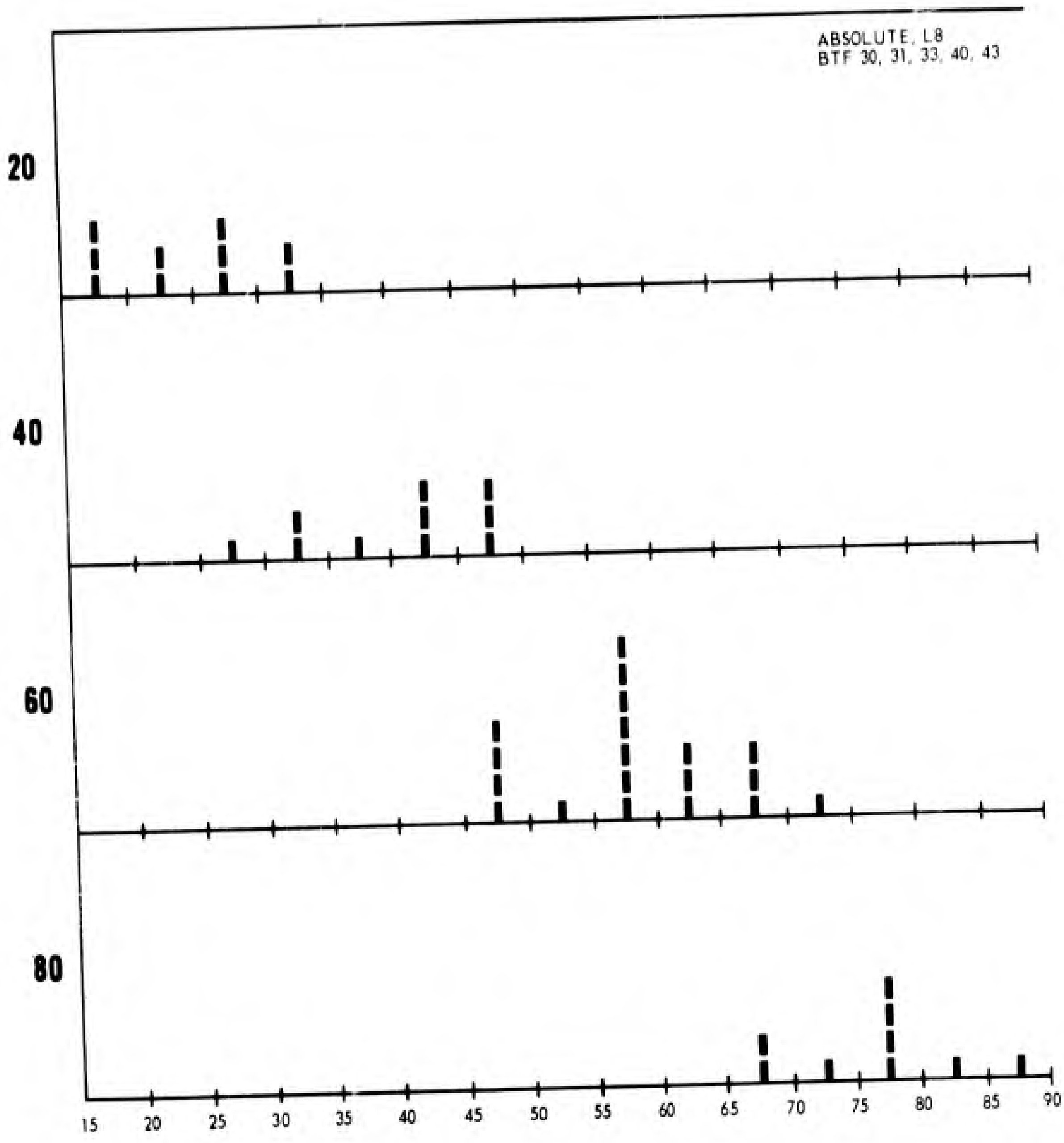

Figure 22. Histogram No. 8 Instructor Score versus Predicted Score

TABLE V

VARIABLES USED FOR REGRESSION ANALYSIS

BTS	Hadamard Channels
Regression #6	
40	8, 16, 24, 32, 40, 48, 56, 64
33	8, 16, 24, 32, 40, 48, 56, 64
31	8, 16, 24, 32, 40, 48, 56, 64
43	64, 56, 24, 32, 40, 48
Regression #7	
30	8, 16, 24, 32, 40, 48, 56, 64
31	8, 16, 24, 32, 40, 48, 56, 64
33	8, 16, 24, 32, 40, 48, 56, 64
40	8, 16, 24, 32, 40, 48
Regression #8	
30	8, 16, 24, 32, 40, 48
31	8, 16, 24, 32, 40, 48
33	8, 16, 24, 32, 40, 48
40	8, 16, 24, 32, 40, 48
43	8, 16, 24, 32, 40, 48
Regression #1	
33	20

TABLE V

VARIABLES USED FOR REGRESSION ANALYSIS (Continued)

Regression #2

BTS	Hadamard Channels
33	20, 21

Regression #3

BTS	Hadamard Channels
33	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21

Regression #4

BTS	Hadamard Channels
33	4, 8, 12, 16, 20, 24, 28, 32, 36, 42, 40, 48, 52, 55, 60
40	4, 8, 12, 16, 20, 24, 28, 32, 36, 42, 40, 48, 52, 56, 60

Regression #5

BTS	Hadamard Channels
30	4, 8, 12, 16, 20, 24, 28, 32, 36, 42
40	4, 8, 12, 16, 20
33	4, 8, 12, 16, 20

On the other hand, a single BTS variable such as BTS 33 shown in histogram No. 1 is not capable of discrimination in all four score regions. It should be noted that the flights rated excellent (80) are clearly separated from flights rated poor (20) and fair (40). The "good" flight predictions fall between the lower and upper categories. Note also that no apparent discrimination exists between flights rated poor and fair. If additional data were to be collected and processed, it would be interesting to determine if three categories (i.e., poor and fair; good; and excellent) or if two categories (i.e., poor and fair; good and excellent) are formed.

Table V provides a list of the Hadamard channels (variables used for each regression), the results of which are, of course, shown in the associated histogram. As shown in the table, histogram No. 1 represents the score prediction capabilities of one variable (BTS 33 channel 20). Histograms Nos. 2 and 3 employ 2 and 20 variables respectively and the score separation characteristic does not appear to change significantly. There does seem to be a change in the distribution within a score category, however. Histogram No. 1 shows a peaking of the poor category while histogram No. 2 (employing an additional variable) provides a broad, flat distribution. This implies that the additional variable (BTS 33, channel 21) provides an inappropriate measure of the poor category. It is difficult to interpret the associated distribution peaking factor in the third histogram which uses 20 variables from BTS 33. Thus, a trend indication cannot be established.

A rather remarkable property of the first three histograms is that each provides a sharp peak (low variance) to the predicted scores in the excellent category. This sharp peak is not maintained in the subsequent histograms (Nos. 4 through 8) even though an improved discrimination is obtained. We would like to suggest that BTS 33 and the indicated Hadamard variables are consistent indicators of excellent performance. In aircraft terms, the above statement means that the function relating roll to pitch (averaged over all flights rated excellent) when operated on by certain Hadamard channels produces variables that are consistent indicators of excellent performance. Note that these variables often confuse good and excellent performance and thus are not perfect discrimination variables.

From a different viewpoint we can examine predicted scores of individual flight events as a means of investigating the automatic scoring method using the absolute computation. Also, it will be seen in later sections, identification of individual flight predicted scores can help relate this scoring method to the state transfer and relative methods. The histograms show that certain flight events generated predicted scores in the same range even though the instructor rated flights differently. For example, in histogram No. 6, there are four events with predicted scores in the 45 to 50 range. These predictions corresponded to flight events 13, 16, 15 and 26. Note that the instructor rated events 15 and 26 as "fair" (40), and 13 and 16 as "good" (60). Thus, the overlap in these distributions indicates a difference in the predicted and instructor produced scores. It is difficult to draw any firm conclusions as to what such overlap means from this initial data; however, possible interpretations for these flights are:

a. The computation cannot discriminate properly

b. Additional variables (information) are required

c. Additional Boolean functions are required

d. Other combinations of variables are appropriate

e. The instructor incorrectly evaluated the performance

f. Data smoothing distorted variable time functions so as to effect score-related information

g. The instructor cannot discriminate as well as the model.

There is some evidence that the model has done a better job of evaluating performance than we are equipped experimentally to give it credit for at the present. Note, for example, that events 94 and 84, both rated "good" (60) by the instructor, have been scored at the high and low ends, respectively, of the "good" maneuvers (see figures 21 and 22). This suggests that event 94 is a high-good or low-excellent maneuver, and that event 84 is a low-good or high-fair maneuver. We examined the voice-tape transcript of the pilot's comments to see if there were indications to support the model's scoring of these maneuvers. Following performance of event 94, the pilot remarked, "Second half of that one would have been excellent, first half good. Overall good." This supports the model's rating of event 94 as a high-good or low-excellent maneuver.

For event 84, this was the pilot's narrative during and after performance: "As you know, the Lazy 8 is a maximum performance maneuver. We will attempt to fly the airplane through a wide range of airspeeds, bank angles, and pitch attitudes. Power is 90%, our entry airspeed is 200 knots, speed brake is up. To accomplish the maneuver, we will start a climbing turn very similar to a climb for a maximum performance climbing turn, planning to have our maximum pitch attitude after 45 degrees of turn, or right about now. Airspeed should be approximately 150 knots. The nose begins to come down at this time. Bank is still increasing. Nose through the horizon after 90 degrees of turn. Down to its lowest point. You will notice that the airspeed was high during the point the nose came through the horizon, down to the nose lowest after 135 degrees of turn. Back up to 200 knots and level flight now. Try to correct the mistake I made during the first half of that one by increasing my pitch more during the first half of this next part and getting my airspeed down, planning to come through after 90 degrees of turn. Airspeed still a little high, about 114 knots. Nose lowest after 135, back up to level flight after 180 degrees of turn. End of maneuver. Now I would have graded that one about a low-good or a high-fair. Lets call it a good maneuver."

Here again the model's scoring is justified by the pilot's comments. While this type of justification is only superficial, it tends to support the contention that, given only general guidelines, the model approach can be used to develop a highly discriminating measurement technique.

5.1.6 Sequency Analysis of Absolute Computation Data

Sequency, as described in appendix III, is that ordering of the Walsh spectra which yields an increasing number of zero crossings. A similar statement can be made about a reordering of the Hadamard transform as represented by its transform matrix. Thus, if we reorder the rows of the Hadamard so that the number of changes of element values along each row increases with the row index, we obtain sequency ordering. Interest in this representation is based on results others have obtained where sequency has been shown to have properties similar to frequency spectra.

The translation from the Hadamard coefficient number (often indicated in printouts as MAC CODE relating to MacDonald Codes which are codes related to the Hadamard transform) to sequency ordering is given in table VI. Note that great jumps in the Hadamard ordering are required, i.e., 1, 33, 49, 17, 25, etc.

All data from the absolute computation for the Hadamard coefficient distribution variances for the Lazy 8 were reordered and plotted by the computer. Selected sequency spectra are given in appendix VII. These plots provide the distribution variance in sequency ordering for two flight events in each of the four score categories. Plots are given for BTS 40 and 30, since these Boolean channels were shown to contain score information in the previous sections.

TABLE VI

MAC CODE TO SEQUENCY ORDERING

MAC Code	Sequency	MAC Code	Sequency
1	0	33	1
2	63	34	62
3	31	35	30
4	32	36	33
5	15	37	14
6	48	38	49
7	16	39	17
8	47	40	46
9	7	41	6
10	56	42	57
11	24	43	25
12	39	44	38
13	8	45	9
14	55	46	54
15	23	47	22
16	40	48	41
17	3	49	2
18	60	50	61
19	28	51	29
20	35	52	34
21	12	53	13
22	51	54	50
23	19	55	18
24	44	56	45
25	4	57	5
26	59	58	58
27	27	59	26
28	36	60	37
29	11	61	10
30	52	62	53
31	20	63	21
32	43	64	42

Consider the plots associated with BTS 40 (see appendix VII). Variances for the excellent performance category are generally greater than those for the other categories. In addition, the initial "roll-off" occurs at a higher sequency for the excellent category data than for the others. This property of Boolean function 40 (airspeed versus pitch function data) of being capable of distinguishing excellent flights was observed previously. The sequency format contains all the information described in the previous section and in addition the "frequency response-like" waveform shows the relationship of one channel to another. The format does suffer from the fact that it displays information related to only one BTS variable; whereas, we demonstrated previously that more than one variable is required to obtain good score prediction.

In spite of this problem and in spite of the fact that we fail to demonstrate a clear picture of accurate score prediction capability, the sequency approach is presented because of its potential information display capability. Interpretation of the sequency spectrum can proceed much like examination of the more familiar frequency spectrum. For example, a peaking in the sequency indicates that the BTS waveform was similar to the associated sequency waveform to a greater extent than to other sequency waveforms. The existence of relationships between peaks in the sequency spectrum for several BTS variables has not been investigated.

5.1.7 Results of Score Prediction With Absolute Computation

The absolute computation method operates on each BTS variable and provides a set of Hadamard coefficients. Each coefficient value is a measure of the degree of correspondence between the BTS "waveform" (sequency of ones and zeros) and the corresponding Hadamard "waveform." Since large numbers of correlations are made (i.e., the Hadamard "waveform" is short and the Boolean sequency is long), measures (mean, variance) of the coefficient distribution are used to determine possible score prediction.

Results of the work, while preliminary, indicate that single BTS, when operated on by the absolute method, generate variables that are not good score predictions. However, when more than one BTS is selected, score prediction is possible.

Boolean functions 30, 31, 33, 40, and 43, when used in various combinations for a regression analysis, gave good score prediction results. Functions 30, 31, and 33 are developed from a function relating roll to pitch averaged over flight data for the flight events rated excellent by the instructor. This function is of the form

$$R = f(\theta) + Kg(\theta)$$

where

$f(\theta)$ gives the mean value of roll for each value of pitch.

$g(\theta)$ is the standard deviation of the roll distribution for each value of pitch.

The other BTS functions 40 and 43 are generated in a similar way and relate airspeed to pitch angle.

This type of Boolean function is of interest because it is "self-generating" for any maneuver. Thus, if we were to introduce a new maneuver along with associated flight data and pilot instruction ratings, a new set of $f(\theta)$ and $g(\theta)$ functions would be derived from the data itself.

5.2 Analysis with the Relative Computation Mechanism

5.2.1 Definition of the Relative Computation Mechanism

The relative computation technique operates on up to five Boolean functions simultaneously to determine if logical relationships exist and, if so, how they are related to performance. Thus, as opposed to the absolute computation where operations are performed on a single BTS, the relative computational technique uses a "trainable logic" concept to detect possible relationships among BTS. Figure 23 is a block diagram of the relative computation procedure. As shown, some variables are selected and directed as inputs to the trainable logic, a block that has logic to detect each of the 16 possible input combinations. Variables used in this way are termed base variables, since functions of these variables are tested for correlation with other (predicted) variables.

Each time an input combination is detected, a record of this event is made in the associated counter. An additional counter is used to record the event that a given input combination has occurred and the predicted variable (BTS) is also true. These counter values can be converted to probabilities and conditional probabilities (after all data from a given flight is processed) by dividing by the total number of elements of the BTS.

The approach, then, is to select variables and conduct a correlation process to establish what relationship might exist. It is not necessary to limit the system to deterministic logic; instead, we can deal with probabilistic logic as well. Once existing relationships have been found, they can be tested for performance information via a regression analysis.

The specific method used in analysis of the T37 data is to select 4 BTS as base variables and a means of forming all 16 logical functions of the four variables. Thus, using the BTS notation introduced in section 3.2, the first combination is

$$C_0(j) = BTS^k_{dj}\ BTS^k_{cj}\ BTS^k_{bj}\ BTS^k_{aj}$$

where the first subscript indicates the BTS, and the superscript indicates the flight event. The second subscript (j) indicates the element in the sequence. Thus, the AND operation is conducted on a bit-by-bit basis. Therefore, the combination $C_m(j)$ has a binary value corresponding to each element in the BTS, i.e., $C_m(j)$ is a Boolean sequence itself.

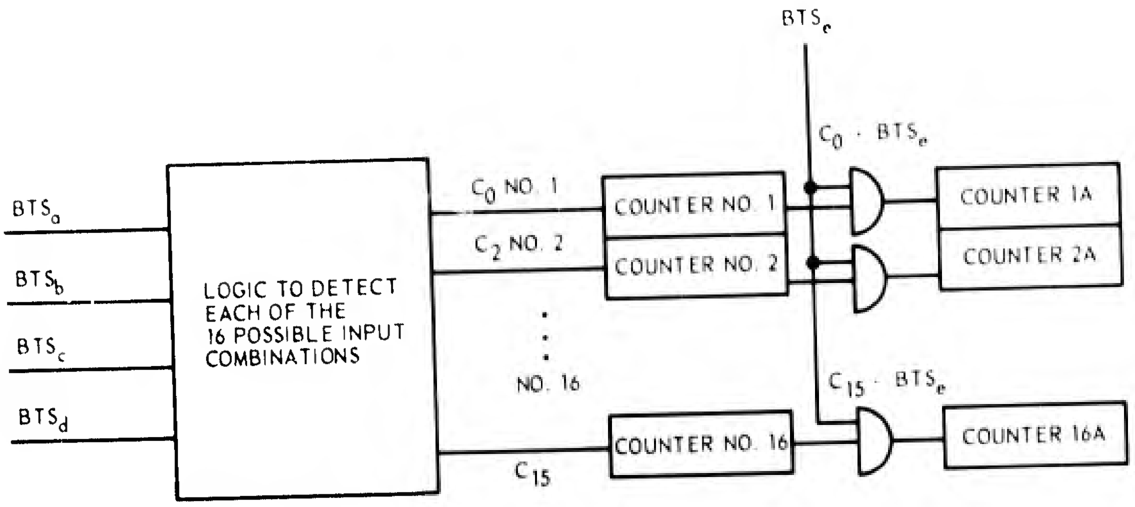

Figure 23. Method for Predicting Score Based on Logical Relationships Among Boolean Variables

As an example, we determine combination 5. It is convenient to represent n (or 5 in this case) by its binary form (0101). Thus, using the binary form of n to code the combination, we find

$$C_5(j) = \overline{BTS}^k_{dj}\ BTS^k_{cj}\ \overline{BTS}^k_{bj}\ BTS^k_{aj},$$

where $\overline{BTS}$ is an inverse function. Note that the second subscript need not be the same for each term, i.e., we can compute using relative time positioning by selecting (for example) second subscripts (j, j+2, j+1, j-1). While this flexibility is available it was not used extensively for the analysis.

The analysis consists of the following operations. First, a number, PD, is computed which is a count of the number of times each combination occurs during the flight event under study. Thus,

$$PD_n = \sum_{j=1}^{M_k} C_n(j).$$

A second count is formed which represents the number of times a BTS variable is true, given that combination C_n is true. Thus,

$$PN_n = \sum_{j=1}^{M_k} C_n(j)\ BTS^k_{ej}$$

Normally, the first subscript e would have a different value than those of the base variables. Next, the conditional probability that BTS^k_{ej} is true given that combination n has occurred is determined as

$$P_c(n) = \frac{PN_n}{PD_n}$$

This conditional probability serves to identify the logic between each combination of the base variables and the predicted variable. It is also convenient to compute the probability that a given base variable combination occurs AND the prediction variable is true. This is given by

$$\text{Total} = \sum_{n=0}^{15} PD_n,$$

$$P(n) = \frac{PN_n}{\text{Total}}$$

Examples of data printout are given in figures 24 through 28. In the printout, variables used above are:

Text	Printout
PD_n	PD
PN_n	PN
$P_c(n)$	P [minterm n]
P(n)	P(n)

Data was computed for each flight event and also summarized over all flights in each performance category. Summarized data is shown in figures 24 through 28. Figure 24 has the data summary for all flights rated poor (20) using variables (BTS) 9, 11, 15, 40, as base variables and BTS 33 as a predicted variable. The subsequent figures give data for fair, good, and excellent performance categories along with a summary over all flight events. As indicated, zero relative displacement for the BTS was used. An amazing amount of performance-relevant information is contained in these data summaries. In illustration of this, some discussion is devoted next to the information contained in figures 24 through 27 which represent relative computation output for just 5 of the BTS variables.

First, it is of interest to note that the set of BTS used in the example data naturally segments the performed maneuver into eights, allowing us to utilize and study measures over portions as well as all of the maneuvers. Figure 29 illustrates the state of each BTS for each minterm and the portion of the maneuver to which each minterm relates.

```
TOTAL PN, PD, P OF THE FALLOWINGS FOR THE SCORE  2C
     BTS VARIABLES
      9  11  15  40  33

     RELATIVE TIME SEQ POSITION FOR EACH BTS
      0   0   0   0   0
     PN =  1463.     PD =  2688.     P ( MINTERM  0 ) =   .544     P [ 0] =  .103
     PN =  1054.     PD =  1989.     P ( MINTERM  1 ) =   .530     P [ 1] =  .074
     PN =   327.     PD =  1073.     P ( MINTERM  2 ) =   .305     P [ 2] =  .023
     PN =   182.     PD =   828.     P ( MINTERM  3 ) =   .220     P [ 3] =  .013
     PN =  1332.     PD =  2272.     P ( MINTERM  4 ) =   .586     P [ 4] =  .093
     PN =  1524.     PD =  2159.     P ( MINTERM  5 ) =   .706     P [ 5] =  .107
     PN =   484.     PD =  1092.     P ( MINTERM  6 ) =   .443     P [ 6] =  .034
     PN =   323.     PD =  1145.     P ( MINTERM  7 ) =   .282     P [ 7] =  .023
     PN =    94.     PD =   122.     P ( MINTERM  8 ) =   .770     P [ 8] =  .007
     PN =   114.     PD =   124.     P ( MINTERM  9 ) =   .919     P [ 9] =  .008
     PN =     3.     PD =     3.     P ( MINTERM 10 ) =  1.000     P [10] =  .000
     PN =     0.     PD =    32.     P ( MINTERM 11 ) =   .000     P [11] =  .000
     PN =   291.     PD =   307.     P ( MINTERM 12 ) =   .948     P [12] =  .020
     PN =   299.     PD =   361.     P ( MINTERM 13 ) =   .828     P [13] =  .021
     PN =     2.     PD =    14.     P ( MINTERM 14 ) =   .143     P [14] =  .000
     PN =    16.     PD =    38.     P ( MINTERM 15 ) =   .421     P [15] =  .001
```

Figure 24. Relative Computation Probabilities for BTS (9, 11,15, 40, 33)

```
TOTAL PN, PD, P OF THE FALLOWINGS FOR THE SCORE  4C
     BTS VARIABLES
      9  11  15  40  33

     RELATIVE TIME SEG POSITION FOR EACH BTS
      0   0   0   0   0
     PN =  2192.     PD =  2726.     P ( MINTERM  0 ) =   .804     P [ 0] =  .129
     PN =  1760.     PD =  2412.     P ( MINTERM  1 ) =   .730     P [illegible] =  .103
     PN =   876.     PD =  1116.     P ( MINTERM  2 ) =   .785     P      =  .051
     PN =   466.     PD =   975.     P ( MINTERM  3 ) =   .478     P      =  .027
     PN =  1990.     PD =  2646.     P ( MINTERM  4 ) =   .752     P [ 4] =  .117
     PN =  1979.     PD =  2427.     P ( MINTERM  5 ) =   .815     P [ 5] =  .116
     PN =  1255.     PD =  1349.     P ( MINTERM  6 ) =   .930     P [ 6] =  .074
     PN =   805.     PD =  1133.     P ( MINTERM  7 ) =   .711     P [ 7] =  .047
     PN =   130.     PD =   182.     P ( MINTERM  8 ) =   .714     P [ 8] =  .008
     PN =   163.     PD =   228.     P ( MINTERM  9 ) =   .715     P [ 9] =  .010
     PN =     0.     PD =    10.     P ( MINTERM 10 ) =   .000     P [10] =  .000
     PN =    68.     PD =    94.     P ( MINTERM 11 ) =   .723     P [11] =  .004
     PN =   908.     PD =  1054.     P ( MINTERM 12 ) =   .861     P [12] =  .053
     PN =   485.     PD =   537.     P ( MINTERM 13 ) =   .903     P [13] =  .028
     PN =    26.     PD =    30.     P ( MINTERM 14 ) =   .867     P [14] =  .002
     PN =    87.     PD =   121.     P ( MINTERM 15 ) =   .719     P [15] =  .005
```

Figure 25. Relative Computation Probabilities for BTS (9, 11, 15, 40, 33)

```
TOTAL PN, PD, P OF THE FALLOWINGS FOR THE SCORE  6C
     BTS VARIABLES
      9  11  15  40  33

     RELATIVE TIME SEQ POSITION FOR EACH BTS
      0   0   0   0   0
     PN =  3762.     PD =  4229.     P ( MINTERM  0 ) =   .890     P [ 0] =  .118
     PN =  3875.     PD =  4562.     P ( MINTERM  1 ) =   .849     P [ 1] =  .121
     PN =  1413.     PD =  1585.     P ( MINTERM  2 ) =   .891     P [ 2] =  .044
     PN =  1255.     PD =  1521.     P ( MINTERM  3 ) =   .825     P [ 3] =  .039
     PN =  4410.     PD =  5072.     P ( MINTERM  4 ) =   .869     P [ 4] =  .138
     PN =  5245.     PD =  5603.     P ( MINTERM  5 ) =   .936     P [ 5] =  .164
     PN =  2023.     PD =  2215.     P ( MINTERM  6 ) =   .913     P [ 6] =  .063
     PN =  1755.     PD =  2217.     P ( MINTERM  7 ) =   .792     P [ 7] =  .055
     PN =   991.     PD =  1210.     P ( MINTERM  8 ) =   .819     P [ 8] =  .031
     PN =   601.     PD =   665.     P ( MINTERM  9 ) =   .904     P [ 9] =  .019
     PN =   284.     PD =   301.     P ( MINTERM 10 ) =   .944     P [10] =  .009
     PN =   275.     PD =   289.     P ( MINTERM 11 ) =   .952     P [11] =  .009
     PN =   810.     PD =   904.     P ( MINTERM 12 ) =   .896     P [12] =  .025
     PN =  1057.     PD =  1085.     P ( MINTERM 13 ) =   .974     P [13] =  .033
     PN =    64.     PD =    64.     P ( MINTERM 14 ) =  1.000     P [14] =  .002
     PN =   414.     PD =   468.     P ( MINTERM 15 ) =   .885     P [15] =  .013
```

Figure 26. Relative Computation Probabilities for BTS (9, 11, 15, 40, 33)

```
TOTAL PN, PD, P OF THE FOLLOWINGS FOR THE SCORE  80
         BTS VARIABLES
          9  11  15  40  33

         RELATIVE TIME SEQ POSITION FOR EACH BTS
          0   0   0   0   0

         PN =  2084.      PD =  2258.      P ( MINTERM  0 ) =   .923      P ( 0) =  .132
         PN =  1857.      PD =  1944.      P ( MINTERM  1 ) =   .955      P ( 1) =  .118
         PN =   862.      PD =   864.      P ( MINTERM  2 ) =   .998      P ( 2) =  .055
         PN =   565.      PD =   613.      P ( MINTERM  3 ) =   .922      P ( 3) =  .036
         PN =  2154.      PD =  2154.      P ( MINTERM  4 ) =  1.000      P ( 4) =  .137
         PN =  2076.      PD =  2076.      P ( MINTERM  5 ) =  1.000      P ( 5) =  .132
         PN =   812.      PD =   812.      P ( MINTERM  6 ) =  1.000      P ( 6) =  .051
         PN =   861.      PD =   889.      P ( MINTERM  7 ) =   .969      P ( 7) =  .055
         PN =   650.      PD =   650.      P ( MINTERM  8 ) =  1.000      P ( 8) =  .041
         PN =   520.      PD =   520.      P ( MINTERM  9 ) =  1.000      P ( 9) =  .033
         PN =   130.      PD =   130.      P ( MINTERM 10 ) =  1.000      P (10) =  .008
         PN =   292.      PD =   292.      P ( MINTERM 11 ) =  1.000      P (11) =  .019
         PN =  1092.      PD =  1092.      P ( MINTERM 12 ) =  1.000      P (12) =  .069
         PN =   778.      PD =   778.      P ( MINTERM 13 ) =  1.000      P (13) =  .049
         PN =   356.      PD =   356.      P ( MINTERM 14 ) =  1.000      P (14) =  .023
         PN =   341.      PD =   341.      P ( MINTERM 15 ) =  1.000      P (15) =  .022
```

Figure 27. Relative Computation Probabilities for BTS (9, 11, 15, 40, 33)

```
TOTAL PN, PD, P OF THE FOLLOWINGS FOR THE SCORE  ALL
         BTS VARIABLES
          9  11  15  40  33

         RELATIVE TIME SEQ POSITION FOR EACH BTS
          0   0   0   0   0

         PN =  9501.      PD = 11901.      P ( MINTERM  0 ) =  .798      P ( 0) =  .120
         PN =  8546.      PD = 10907.      P ( MINTERM  1 ) =  .784      P ( 1) =  .108
         PN =  3478.      PD =  4638.      P ( MINTERM  2 ) =  .750      P ( 2) =  .044
         PN =  2468.      PD =  3937.      P ( MINTERM  3 ) =  .627      P ( 3) =  .031
         PN =  9886.      PD = 12144.      P ( MINTERM  4 ) =  .814      P ( 4) =  .125
         PN = 10824.      PD = 12265.      P ( MINTERM  5 ) =  .883      P ( 5) =  .137
         PN =  4574.      PD =  5468.      P ( MINTERM  6 ) =  .837      P ( 6) =  .058
         PN =  3744.      PD =  5384.      P ( MINTERM  7 ) =  .695      P ( 7) =  .047
         PN =  1865.      PD =  2164.      P ( MINTERM  8 ) =  .862      P ( 8) =  .024
         PN =  1398.      PD =  1537.      P ( MINTERM  9 ) =  .910      P ( 9) =  .018
         PN =   417.      PD =   444.      P ( MINTERM 10 ) =  .939      P (10) =  .005
         PN =   635.      PD =   707.      P ( MINTERM 11 ) =  .898      P (11) =  .008
         PN =  3101.      PD =  3357.      P ( MINTERM 12 ) =  .924      P (12) =  .039
         PN =  2619.      PD =  2761.      P ( MINTERM 13 ) =  .949      P (13) =  .033
         PN =   448.      PD =   464.      P ( MINTERM 14 ) =  .966      P (14) =  .006
         PN =   858.      PD =   968.      P ( MINTERM 15 ) =  .886      P (15) =  .011
*JOB.
*REWIND MT1.
```

Figure 28. Relative Computation Probabilities for BTS (9, 11, 15, 40, 33)

MINTERM	EIGHTH OF MANEUVER	$AS = K_\theta \pm 2$	PITCH >0	PITCH DECREASING	BANK >0
BTS →		40	15	11	9
0	4	0	0	0	0
1	8	0	0	0	1
2	3	0	0	1	0
3	7	0	0	1	1
4	1	0	1	0	0
5	5	0	1	0	1
6	2	0	1	1	0
7	6	0	1	1	1
8	4	1	0	0	0
9	8	1	0	0	1
10	3	1	0	1	0
11	7	1	0	1	1
12	1	1	1	0	0
13	5	1	1	0	1
14	2	1	1	1	0
15	6	1	1	1	1

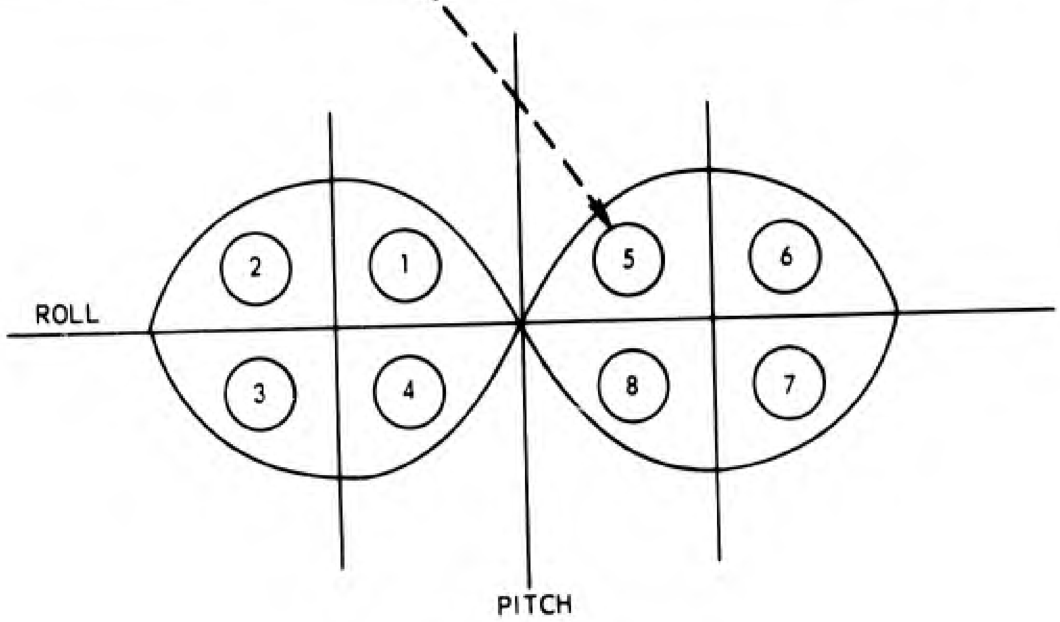

Figure 29. Portion of Lazy 8 Referenced by Minterms

Next, suppose we wish to examine airspeed, as represented by BTS 40, as an independent measure. Minterms 8-15 represent all of the instances where BTS 40 was true, i.e. Airspeed = K (θ) ±2 knots, where K (θ) is a constructed candidate criterion profile for airspeed. The ratio

$$\sum_{8}^{15} PD \Big/ \sum_{0}^{15} PD$$

gives us the fraction of total samples taken in which the candidate criterion was satisfied within tolerances. The corresponding fractions thus computed for all maneuvers in each skill-category are as follows

Skill category	Fraction of samples in which airspeed criterion is met
Unsatisfactory	0.07
Fair	0.13
Good	0.16
Excellent	0.26

A cursory examination of this information suggests that: (1) The tolerance of 2 knots is probably too tight, and (2) As a single-variable measure, airspeed may be expected to discriminate highly skilled performances from the rest but may not discriminate between performances of moderate or low skills.

Next, it is of interest to note the portions of the maneuver in which it appears most difficult (or easy) for pilots to achieve criterion performance on airspeed. This reveals information pertaining to:

a. The difficulty of various parts of the maneuver

b. The face validity of the measure

c. The relative weighting appropriate for the measure in different parts of the maneuver.

Figure 30 shows the percentages of the total samples for each eighth of the maneuver in which the airspeed criterion was met. A clear separation of

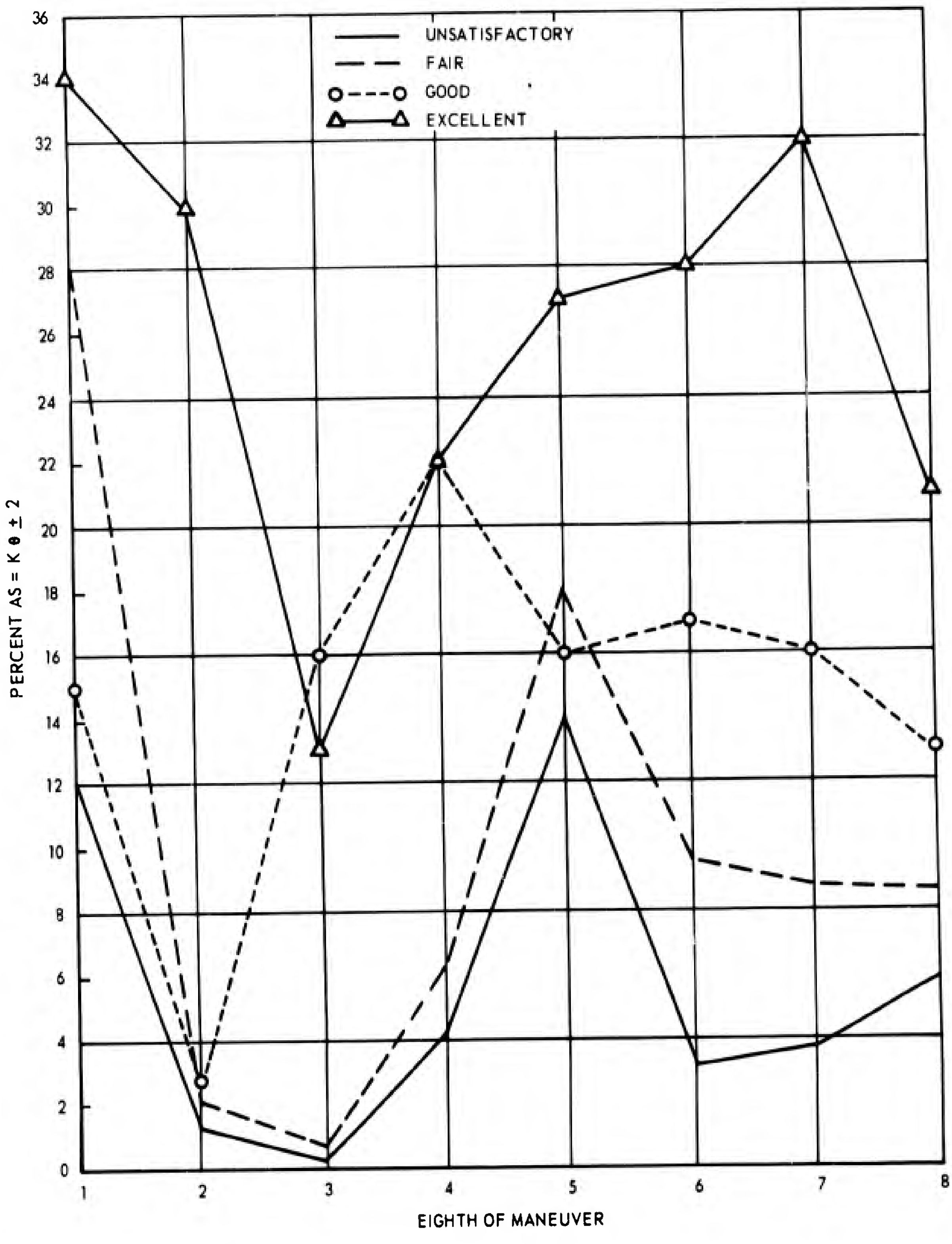

Figure 30. Percent of Samples in Each Eighth of Maneuver for which Airspeed Criterion was Met

all skill levels is noted, particularly in the last three-eighths of the maneuver, i.e., the last parts of the right-half of the Lazy 8. Also of interest is the second eighth, where excellent performances achieved a noticeable increase in criterion-satisfied samples over the other three skill levels. In addition, note that the low skill levels peak in the first and fifth eighths, where the aircraft enters a climbing turn from straight and level flight. Collectively, the data suggests the following:

a. Regions in which the aircraft is approaching or leaving maximum bank are most difficult from the standpoint of airspeed control, with the left part of the Lazy 8 somewhat more "difficult" than the right part.

b. Clear identification of excellent performances may be possible through examination of only the second eighth.

c. Best chances for discriminating all skill levels using airspeed alone lie in use of the right half of the maneuver.

d. Airspeed measures at the start of each half of the maneuver are not likely to contribute much to skill-level discrimination.

A similar analysis can be accomplished for the "predicted" BTS 33, which compares the actual roll/pitch relationship with a constructed standard. By summing all PN in each of figures 24 through 27 and dividing by the total samples, $\sum$PD, we can find the fractional number of samples in which the roll/pitch criterion was satisfied. The numbers are:

Skill category	Fraction of samples in which roll/pitch criterion is met
Unsatisfactory	0.53
Fair	0.77
Good	0.88
Excellent	0.98

An examination of this information suggests that:

a. The tolerance of 2.5-g is probably realistic

b. The roll/pitch measure may be expected to discriminate all skill levels well, with best discrimination in the lower-skill categories.

Figure 31 shows the percentages of the total samples for each eighth of the maneuver in which the roll/pitch criterion was met. We see an excellent separation of all skill levels for all eighths of the maneuver. The only possible exception is the second eighth, where fair and good performances are not discriminated. Contrary to the case of the airspeed measure, the roll/pitch criterion appears more difficult to achieve in the right half of the maneuver than in the left half. Also of interest is the improved discrimination between the two low-skill categories using roll/pitch criteria, compared with that noted using airspeed alone. Finally, as noted with the airspeed measure, performance of the right half of the maneuver appears somewhat more relevant to overall skill assessment than performance of the left half.

Examining the summary data of figures 24 through 28 we see also that the conditional probabilities (P(minterm(n))) are relatively low for flights rated poor and tend to increase with the flights rated higher. This observation indicates that performance information may be contained in the conditional probabilities themselves. In order to test this, a regression analysis was applied using the 16 probability variables P(0)..., P(15). (These are the probabilities that combination (n) is true AND the prediction variable is true.)

5.2.2 Regression Analysis on Relative Computation Data

The results of selected runs (on Lazy 8 data) of the regression analysis in the form of histograms are presented in figures 30 to 35. Data from which the histograms were generated are given in appendix VIII. Figure 32 is the histogram using base BTS variables 8, 9, 13, 15 and predicted BTS variable 28. Recall that, as with the absolute analysis, the regression is formed with data available on a first run and then an evaluation run is made using that same data. Thus, the histogram represents the best prediction available with this form of processing; but, a generalization to new data must be undertaken with great caution. Histogram No. 9 shows a slight tendency for score prediction. It is seen that some discrimination exists between poor (20) and fair (40) performance data. Note that separation of good (60) and excellent (80) is not substantial.

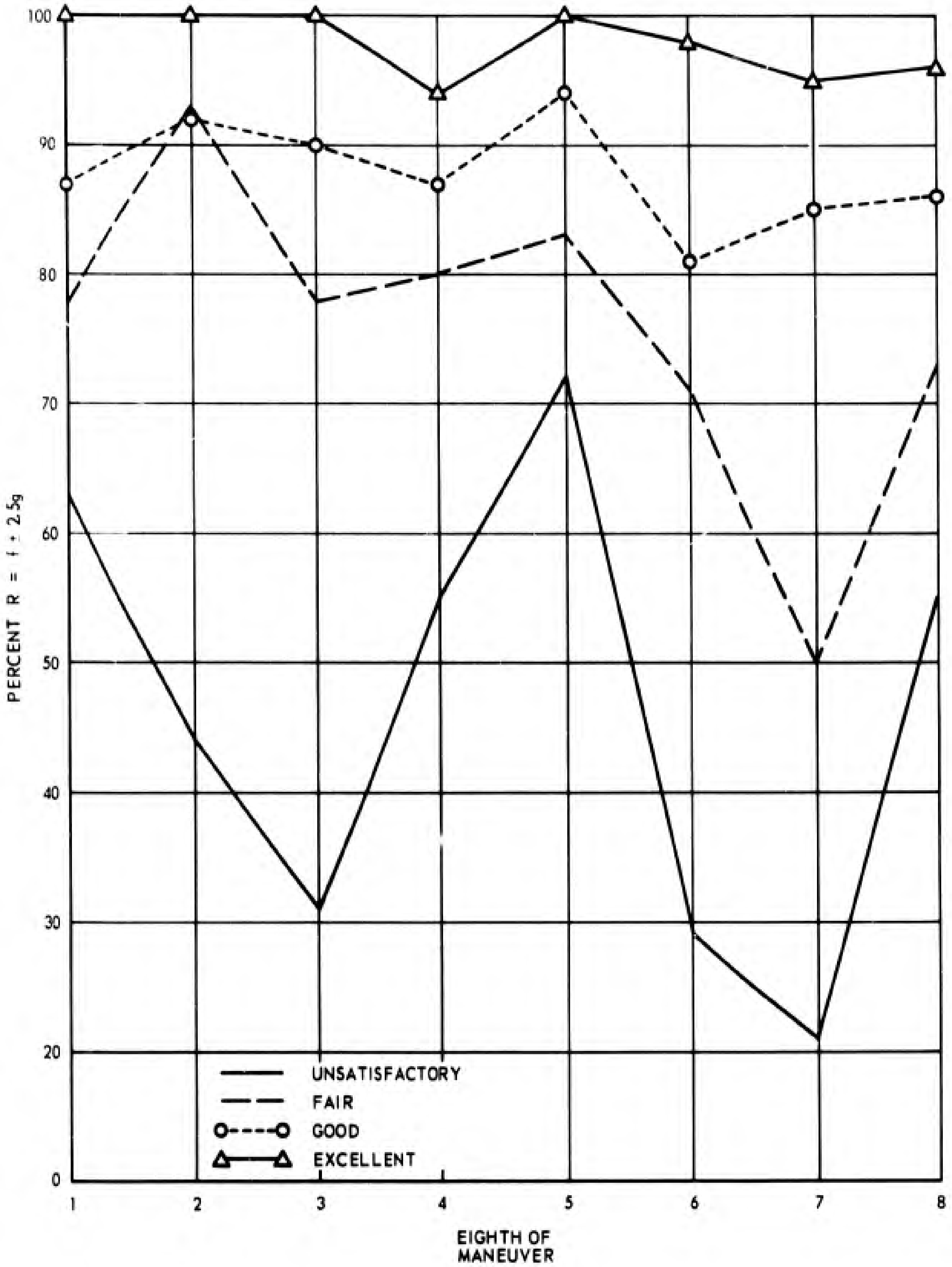

Figure 31. Percent of Samples in Each Eighth of Maneuver for which Roll/Pitch Criterion was Met

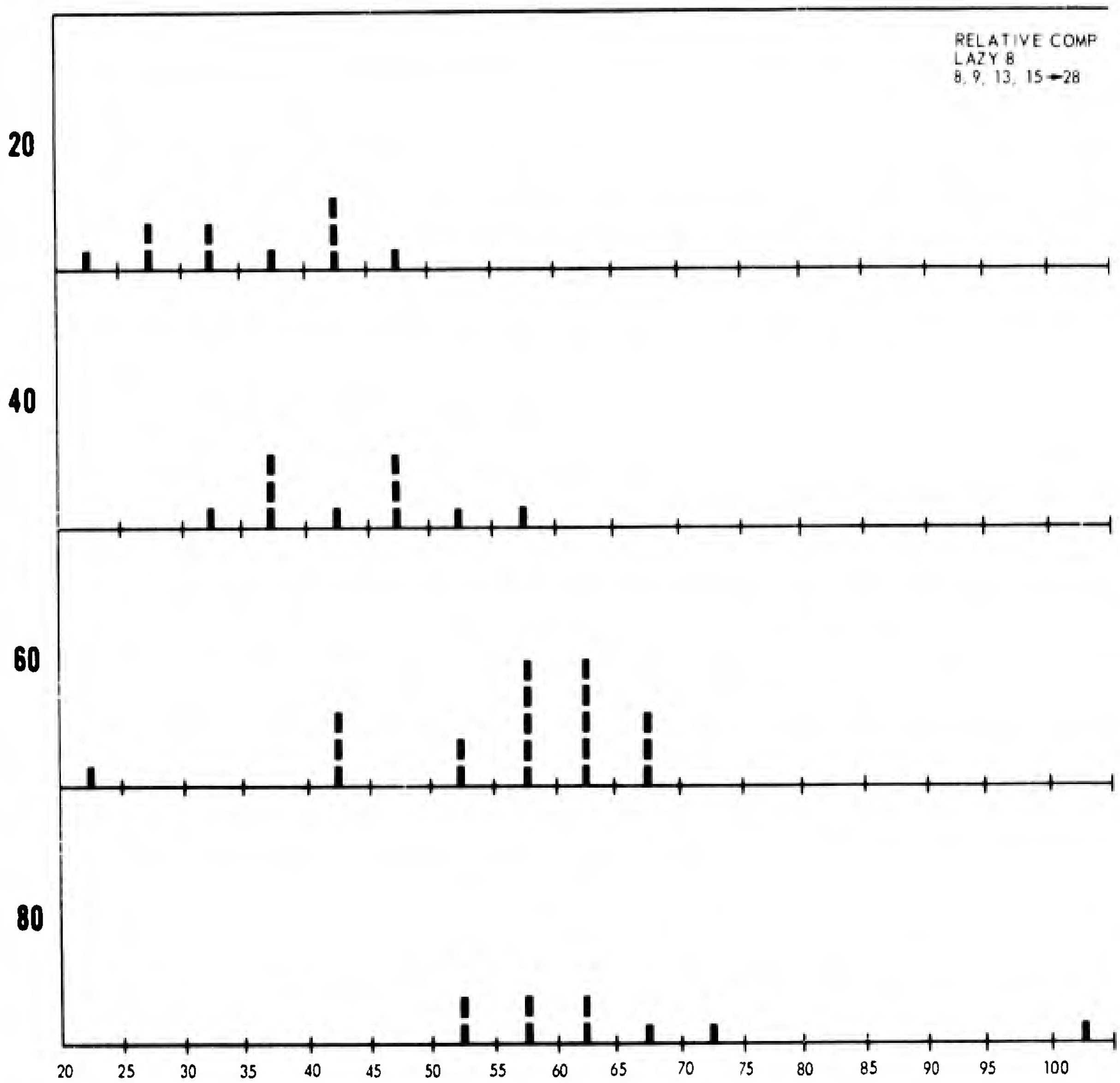

Figure 32. Histogram No. 9 Instructor Score versus Predicted Score

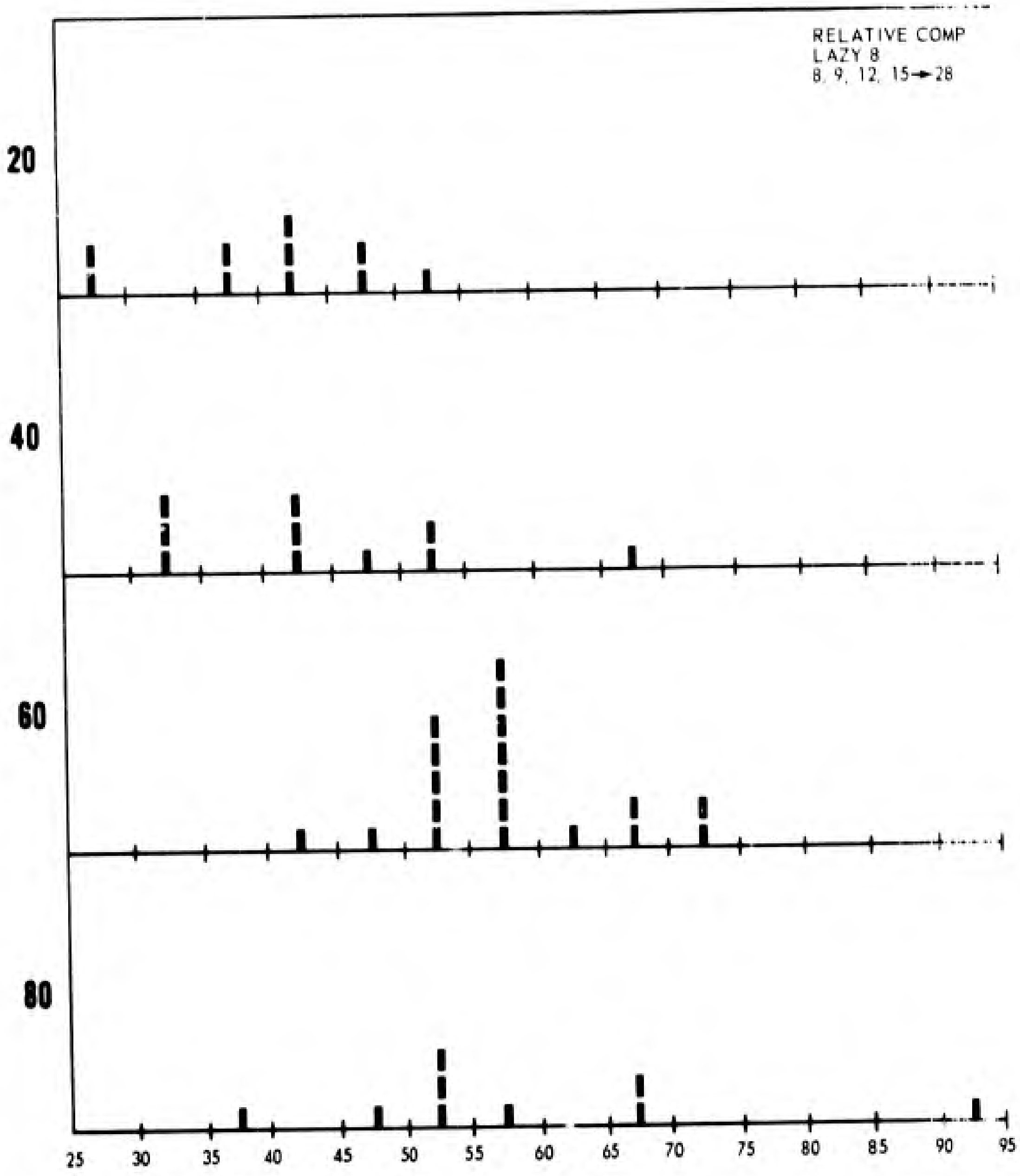

Figure 33. Histogram No. 10 Instructor Score versus Predicted Score

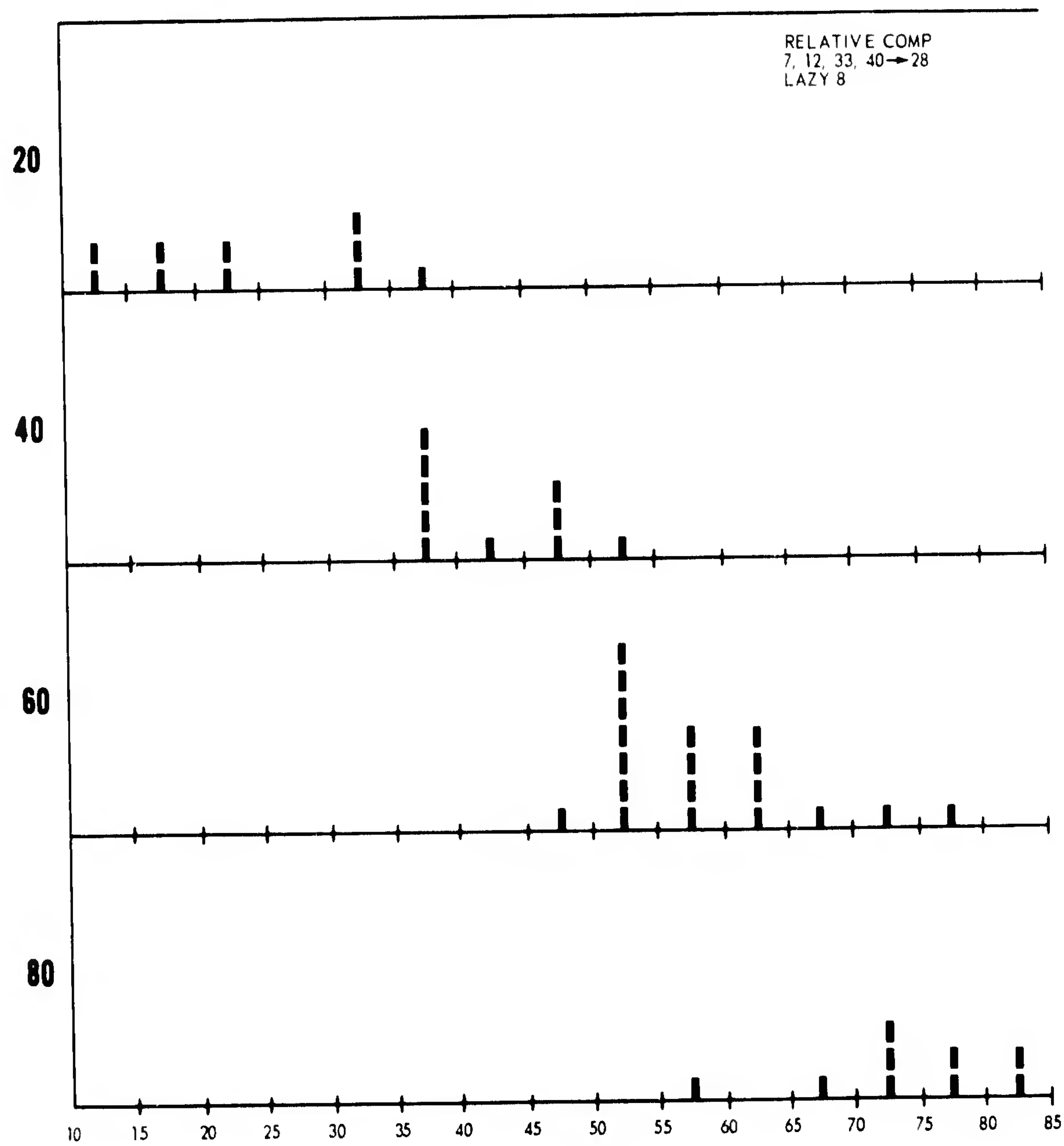

Figure 34. Histogram No. 11 Instructor Score versus Predicted Score

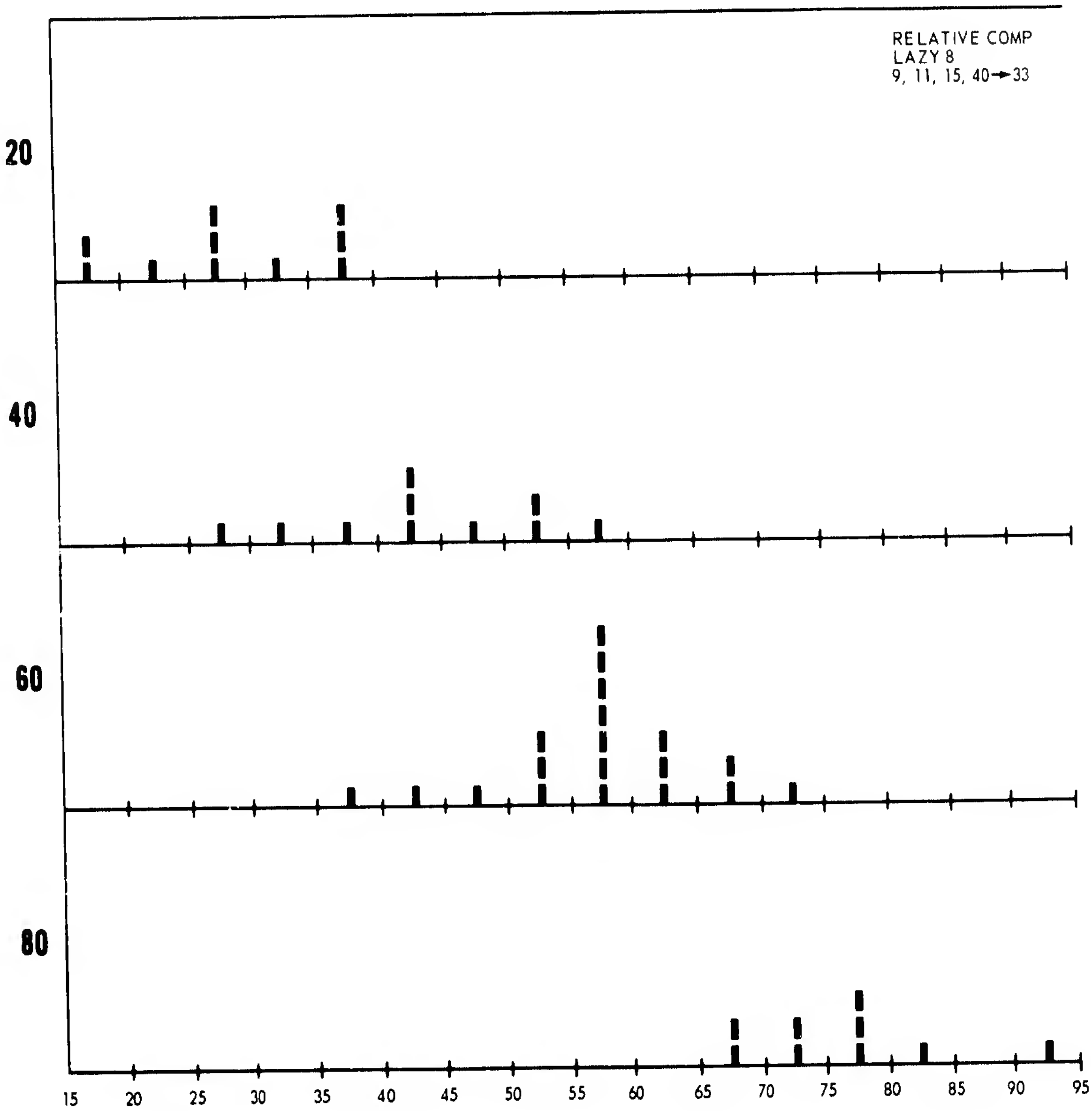

Figure 35. Histogram No. 12 Instructor Score versus Predicted Score

Histogram No. 10 gives the prediction results when BTS 13 is replaced by BTS 12 but otherwise the situation is the same as for Histogram No. 9. In this case, very poor structure of the excellent flight category is obtained. It is seen that the mark for excellent flights can fall anywhere quite independent of performance.

Histogram No. 11 is obtained using BTS 7, 12, 33, 40 for base variables and 28 as a predicted variable. As was found with the absolute processing, the use of reference flight trajectory-related Boolean functions (in this case 33 and 40) improves performance discrimination. In reference to histogram No. 11, a great improvement in discrimination of fair (40) category flight is possible which was not true with the absolute computational method. Histogram No. 12 illustrates the effect of using a different set and arrangement of Boolean functions. In this case BTS 9, 11, 15 and 40 are used as base variables and 33 as a predicted variable. The histogram indicates a tendency for improved good (60) and excellent (80) discrimination but less capability in detecting fair performance.

5.2.3 Results of Score Prediction with Relative Computation

The relative computation provides a means for forming logical functions of more than one BTS and testing the terms of that function for score-related information. Since a deterministic logic function is frequently not obtained, the resulting functional terms are conditional probabilities. These probabilities describe the frequency of occurrence of one Boolean event given that other Boolean conditions are satisfied. Boolean conditions are of course tests such as tolerance conditions, inequality conditions, etc. Thus, the relative computation model provides a means by which we can insert and subsequently check our ideas as to what functional relations might indicate each performance category.

An additional tool has also been suggested. The inequality functions incorporated in some Boolean functions can serve to break the flight maneuver into parts so that performance can be examined in each part. This observation identifies a new capability of the method where the apparent difficulty and score sensitivity of each portion of the maneuver can be described. This result should have considerable application in basic performance measure studies as well as in automatic scoring and adaptive training systems.

Results of the analysis employing the percent of samples in which BTS 33 (roll/pitch criterion) is true indicate that the criterion is an indication of performance. This is shown in figure 31. The reliability of this measure, however, has not been determined.

The capability and reliability of the measures is indicated by histogram Nos. 9 through 12. Recall that the histograms are derived from a regression analysis using probability variables as prediction variables. Histogram Nos. 9 and 10 show some capability, i.e., some separation of score category means but rather unreliable measures. A similar result is shown in histogram No. 10 except that the spread or variance of each category distribution is greater. The only difference is that BTS 13 was replaced by BTS 12 where:

BTS	Boolean Function
12	$0 < \lvert P_i \rvert \leq 1/3\ P_m$
13	$1/3\ P_m < \lvert P_i \rvert < 2/3\ P_m$

Now the effect of this type of Boolean function is to dichotomize the function space. Thus, when BTS 12 is used we have two sets of variables. One set associates with the BTS 12 in the true state and the other associates with a false BTS state. Each set of variables can be independently associated with score. Since histogram No. 9 has distributions with less variance than those of histogram No. 10, we conclude that BTS 13 must be of greater value to score prediction than BTS 12. Thus, the middle one-third of the pitch range must be more important in score prediction than the lower third.

Histogram Nos. 11 and 12, using BTS variables 7, 12, 33, 40, 28 and 9, 11, 15, 40, 33 respectively, provide greatly improved score discrimination. Histogram No. 11 is of special interest because of the reliable score prediction and the separation of poor (20) and fair (40) performance. Recall that reliable separation of poor and fair categories was not possible with the variables tested with the absolute computation mode.

5.3 Analysis with State Transfer Computation Mechanism

The state transfer computation mechanism is a means for determining if performance (or score) information is related to the sequence of pilot actions. It may be that pilot score is partially or totally a function of how well he corrects for errors, where he may or may not have caused the errors initially. In order to implement this computation and also provide a convenient means for compactly representing long Boolean time sequences, a transition matrix is formed which identifies how the sequence moves from state to state. Associated with the transition matrix is an incremental score matrix, in which each element is the incremental score value of the corresponding transition. Thus, each set of

BTS can be viewed as a sequence of states, and corresponding to each state transfer is an incr mental score value. The sequence of states provides a sequence of state transfers which is identified with a sequence of incremental score values. The average value of the incremental score values represents the predicted pilot score for that flight. Thus, it is necessary to compute from the flight data an incremental score matrix that yields good score prediction capability.

The process is illustrated in figure 36. A set of 4 Boolean variables is selected and applied as system inputs. The system provides a means for detecting which of the 16 possible input combinations exists. Each possible input combination is termed a system state, and interest is centered on how the system transfers from one state to another. These transitions can be identified as elements of a 16-by-16 matrix where each row is associated with a state at time N and each column is associated with a state at time N+1. Thus, if the matrix provides state transition probabilities, element (X, Y) represents the probability of transferring from State X to State Y. Note that such matrices may not contain probabilities; instead they may record the number of transitions or hold incremental score information.

5.3.1 Method of Analysis with State Transition Computation

The purpose of this section is to provide a description and interpretation of the computer data output of the state transfer computation. Figure 37 is a sample listing giving the state transfer (termed transtate) counts from which the transition matrix (TTRIX) is formed. The transition matrix is found by determining the sum of the counts across each row and dividing each raw element by the sum to get the associated probability.

Figure 38 gives a sample printout of a transition matrix and an associated incremental score matrix. The input data (Flight 67, Lazy 8) is rated excellent, and the score matrix has been updated in an attempt to predict excellent for that input. All elements of the incremental score matrix are set at 50 initially and it is seen that only a few of the elements have been modified. Note also that transtates which occur frequently generate a greater change in the associated score matrix elements than those which occur infrequently. After processing all flight data, most of the score elements are modified. Score discrimination is possible where flights from different rating categories produce different transition matrices.

Figure 39 provides summary data of all flights in each performance category associated with BTS 1, 4, 10, 24. Careful examination of the

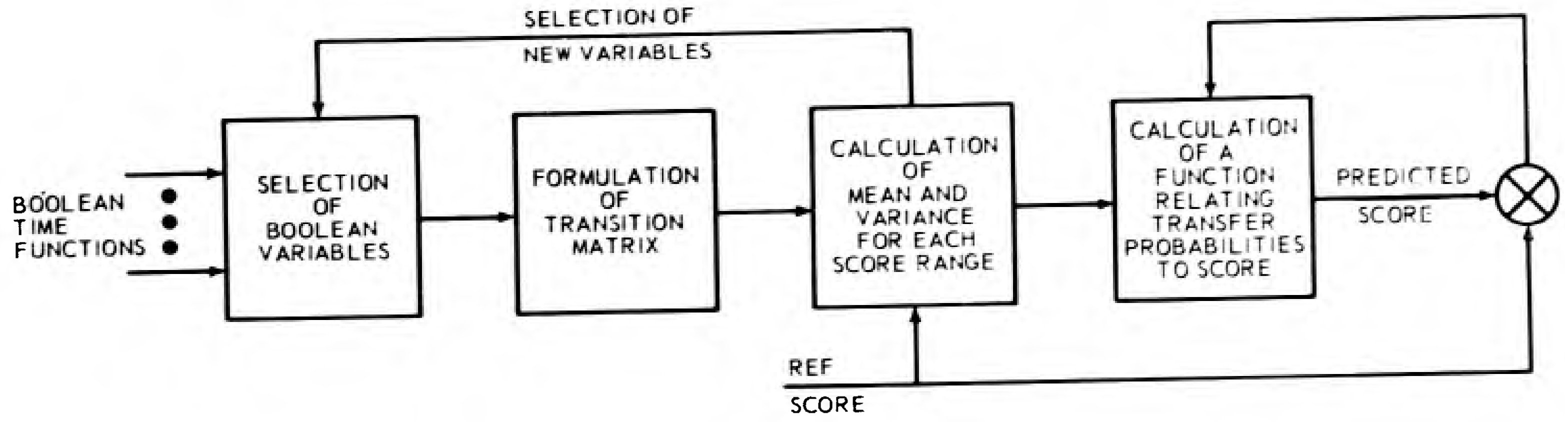

Figure 36. A State Transfer Computation Technique

ICOUNT

10	4	0	0	4	1	0	0	16	6	0	0	6	2	0	0
5	22	0	0	0	6	0	0	5	24	0	0	1	2	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	21	6	1	0	4	2	0	0	18	15	0	0
0	4	0	0	4	48	0	1	1	5	0	0	14	72	0	1
0	0	0	0	0	0	13	0	0	0	0	0	0	0	12	2
0	0	0	0	0	1	0	16	0	0	0	0	0	0	0	13
16	5	0	0	3	1	0	0	23	3	0	0	9	1	0	0
6	23	0	0	3	5	0	0	2	30	0	0	1	8	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	3	0	0	20	16	0	0	8	0	0	0	23	14	1	0
3	4	0	0	15	66	0	0	2	8	0	0	16	76	0	0
0	0	0	0	1	0	12	0	0	0	0	0	1	0	14	2
0	0	0	0	0	0	1	13	0	0	0	0	0	1	3	23

TTRIX

.20	.08	.00	.00	.08	.02	.00	.00	.33	.12	.00	.00	.12	.04	.00	.00
.08	.34	.00	.00	.00	.09	.00	.00	.08	.37	.00	.00	.01	.03	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.06	.00	.00	.00	.29	.08	.01	.00	.06	.03	.00	.00	.25	.21	.00	.00
.00	.03	.00	.00	.03	.32	.00	.01	.01	.03	.00	.00	.09	.48	.00	.01
.00	.00	.00	.00	.00	.00	.48	.00	.00	.00	.00	.00	.00	.00	.44	.07
.00	.00	.00	.00	.00	.03	.00	.53	.00	.00	.00	.00	.00	.00	.00	.43
.26	.08	.00	.00	.05	.02	.00	.00	.38	.05	.00	.00	.15	.02	.00	.00
.08	.29	.00	.00	.04	.06	.00	.00	.02	.38	.00	.00	.01	.10	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.04	.03	.00	.00	.22	.18	.00	.00	.09	.00	.00	.00	.26	.16	.01	.00
.01	.02	.00	.00	.08	.35	.00	.00	.01	.04	.00	.00	.08	.40	.00	.00
.00	.00	.00	.00	.03	.00	.40	.00	.00	.00	.00	.00	.03	.00	.47	.07
.00	.00	.00	.00	.00	.00	.02	.32	.00	.00	.00	.00	.00	.02	.07	.56

Figure 37. Transition Matrix

I0 67
INPUT SCORE = 80
TTRIX

.60	.05	.08	.04	.13	.01	.03	.01	.00	.00	.01	.01	.00	.00	.01	.00
.21	.55	.03	.10	.07	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.18	.10	.22	.22	.06	.06	.06	.04	.00	.00	.04	.00	.00	.00	.00	.00
.19	.19	.21	.28	.02	.00	.07	.00	.00	.02	.02	.00	.00	.00	.00	.00
.10	.02	.04	.00	.66	.04	.09	.03	.00	.00	.00	.00	.01	.00	.00	.00
.02	.01	.00	.01	.07	.60	.05	.24	.00	.00	.00	.00	.00	.00	.00	.00
.06	.00	.08	.00	.32	.06	.35	.11	.00	.00	.00	.00	.00	.00	.00	.00
.06	.00	.01	.01	.03	.37	.12	.37	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.04	.00	.00	.00	.00	.00	.39	.00	.52	.00	.00	.00	.00	.04
.00	.00	.00	.20	.00	.00	.00	.00	.00	.00	.00	.80	.00	.00	.00	.00
.03	.00	.01	.00	.00	.00	.00	.00	.18	.00	.68	.04	.00	.00	.05	.00
.00	.00	.00	.03	.00	.00	.00	.00	.00	.12	.09	.76	.00	.00	.00	.00
.00	.00	.00	.00	.20	.00	.00	.00	.00	.00	.00	.00	.80	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.11	.00	.44	.00	.00	.00	.33	.11
.00	.00	.00	.50	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.50	.00

TRUE SCORE = 80. PREDICTED SCORE = 47.
MSCORE

99	53	58	54	63	50	52	50	50	50	50	50	50	50	50	50
60	79	50	54	52	50	50	50	50	50	50	50	50	50	50	50
55	52	57	57	51	51	51	50	50	50	50	50	50	50	50	50
55	55	56	59	50	50	52	50	50	50	50	50	50	50	50	50
61	51	54	50	99	54	60	52	50	50	50	50	50	50	50	50
50	50	50	53	53	86	52	64	50	50	50	50	50	50	50	50
52	50	52	50	62	52	63	53	50	50	50	50	50	50	50	50
52	50	50	50	50	64	54	64	50	50	50	50	50	50	50	50
50	50	51	50	50	50	50	50	63	50	68	50	50	50	50	51
50	50	50	51	50	50	50	50	50	50	50	56	50	50	50	50
52	50	50	50	50	50	50	50	69	50	99	54	50	50	55	50
50	50	50	51	50	50	50	50	50	56	55	96	50	50	50	50
50	50	50	50	53	50	50	50	50	50	50	50	65	50	50	50
50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
50	50	50	50	50	50	50	50	51	50	55	50	50	50	54	51
50	50	50	51	50	50	50	50	50	50	50	50	50	50	51	50

Figure 38. Transition and Incremental Score Matrix

TASK NO. 1
FOR THE SCORE 80

PROBABILITIES

.27	.04	.00	.00	.10	.01	.00	.00	.37	.08	.00	.00	.08	.04	.00	.00
.03	.28	.00	.00	.01	.08	.00	.00	.07	.42	.00	.00	.01	.08	.00	.00
.00	.00	.00	.00	.00	.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.67	.00	.00	.00	.00	.00	.00	.00	.33
.07	.00	.00	.00	.30	.10	.00	.00	.05	.02	.00	.00	.26	.19	.01	.00
.00	.04	.00	.00	.05	.29	.00	.00	.00	.04	.00	.00	.13	.44	.00	.00
.00	.00	.00	.00	.02	.00	.42	.03	.00	.00	.00	.00	.02	.00	.47	.03
.00	.00	.00	.01	.00	.02	.04	.51	.00	.00	.00	.00	.00	.01	.02	.37
.31	.09	.00	.00	.06	.01	.00	.00	.36	.06	.00	.00	.10	.01	.00	.00
.05	.23	.00	.00	.01	.06	.00	.00	.04	.45	.00	.00	.02	.14	.00	.00
.00	.00	.00	.00	.00	.00	.00	.33	.00	.00	.00	.00	.00	.00	.67	.00
.00	.00	.00	.00	.00	.00	.00	.33	.00	.00	.00	.00	.00	.33	.00	.33
.04	.01	.00	.00	.21	.16	.00	.00	.05	.01	.00	.00	.33	.17	.01	.00
.01	.02	.00	.00	.07	.27	.00	.00	.00	.05	.00	.00	.08	.48	.00	.00
.00	.00	.00	.00	.01	.00	.33	.02	.00	.00	.01	.00	.02	.00	.55	.06
.00	.00	.00	.00	.00	.01	.02	.26	.00	.00	.00	.01	.00	.02	.05	.63

COUNTS

112	15	0	0	42	4	0	0	155	32	0	0	35	19	0	0
16	128	0	0	4	36	0	0	33	190	0	0	7	37	0	0
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1
46	2	0	0	187	61	2	0	29	13	0	0	164	120	4	0
2	43	0	0	53	311	1	6	4	42	0	0	136	473	0	3
0	0	1	0	4	0	85	6	0	0	1	0	4	0	96	6
0	0	0	3	0	4	9	109	0	0	0	1	1	3	5	80
145	41	0	0	27	5	0	0	172	28	0	0	48	6	0	0
36	171	0	0	11	44	0	0	29	330	0	0	12	106	0	0
0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0
0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1
36	11	0	0	174	134	2	0	42	9	0	0	268	138	7	0
12	40	0	0	124	474	1	1	8	95	0	0	141	852	1	7
0	0	1	0	2	0	95	7	0	0	2	0	6	0	160	18
0	0	0	0	0	3	6	82	0	0	0	2	1	6	16	198

BTF 1, 4, 10, 24

EXAMPLE: The element (15.7) i.e., the 15th row and 7th column is a 95. This means that the number of times the data changed from the 15th input combination to the 7th input combination is 95 for all the flights rated excellent. In the probability matrix it is seen that corresponding element is 0.33. This should be read "the probability is 0.33 of transferring from state 15 to state 7 given that the system is in state 15.

Figure 39. Summary Matrix

TASK NO. 1
FOR THE SCORE 60

PROBABILITIES

.20	.05	.00	.00	.10	.01	.00	.00	.35	.12	.00	.00	.10	.07	.00	.00
.03	.25	.00	.00	.00	.08	.00	.00	.08	.40	.00	.00	.02	.13	.00	.00
.00	.00	.00	.00	.00	.00	.50	.00	.00	.00	.00	.00	.00	.00	.50	.00
.00	.00	.00	.00	.00	.00	.06	.31	.00	.00	.00	.00	.06	.06	.12	.37
.07	.01	.00	.00	.28	.10	.01	.00	.05	.02	.00	.00	.27	.19	.00	.00
.00	.04	.00	.00	.05	.31	.00	.00	.01	.05	.00	.00	.10	.43	.00	.00
.00	.00	.01	.00	.01	.00	.45	.05	.00	.00	.01	.00	.01	.00	.40	.05
.00	.00	.00	.01	.00	.02	.02	.40	.00	.00	.01	.02	.00	.01	.03	.47
.28	.08	.00	.00	.06	.02	.00	.00	.33	.07	.00	.00	.12	.03	.00	.00
.06	.27	.00	.00	.02	.08	.00	.00	.05	.36	.00	.00	.02	.14	.00	.00
.00	.00	.00	.00	.07	.00	.14	.36	.00	.00	.00	.00	.00	.00	.28	.14
.00	.00	.00	.02	.00	.00	.02	.28	.00	.00	.00	.10	.00	.00	.05	.51
.04	.01	.00	.00	.21	.15	.00	.00	.07	.02	.00	.00	.33	.15,	.01	.00
.01	.04	.00	.00	.07	.29	.00	.00	.01	.06	.00	.00	.07	.44	.00	.00
.00	.00	.00	.00	.01	.00	.31	.05	.00	.00	.01	.00	.01	.00	.54	.05
.00	.00	.00	.01	.00	.00	.02	.30	.00	.00	.00	.02	.00	.01	.02	.60

COUNTS

149	37	0	0	72	9	0	0	259	89	0	0	75	51	0	0
30	248	0	0	5	81	0	0	77	407	0	0	25	130	0	0
0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0
0	0	0	0	0	0	1	5	0	0	0	0	1	1	2	6
81	8	0	0	333	125	8	0	65	22	0	0	320	227	7	0
11	93	0	0	126	704	0	11	15	112	0	1	224	972	1	3
0	0	3	0	5	0	171	18	0	0	3	1	6	1	155	19
1	0	1	5	1	13	16	267	0	0	4	11	3	5	21	310
263	79	0	0	58	21	0	0	316	66	0	0	113	34	0	0
85	381	0	0	26	114	0	0	71	519	0	0	34	196	0	0
0	0	0	0	1	0	2	5	0	0	0	0	0	0	4	2
0	0	0	1	0	0	1	11	0	0	0	4	0	0	2	20
67	15	0	0	330	237	3	0	112	26	0	0	503	232	15	0
35	142	0	0	233	967	2	6	34	188	0	0	229	1431	0	15
0	0	0	1	7	0	159	28	1	0	4	2	5	0	276	25
0	0	0	9	0	6	17	308	0	0	3	20	3	10	23	610

BTS 1, 4, 10, 24

Figure 39. Summary Matrix (Continued)

TASK NO. 1
FOR THE SCORE 40

PROBABILITIES

.28	.04	.00	.00	.12	.01	.00	.00	.32	.10	.00	.00	.06	.06	.00	.00
.03	.27	.00	.00	.00	.07	.00	.00	.08	.42	.00	.00	.02	.10	.00	.00
.00	.00	.00	.00	.00	.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	1.00	.00	.00	.00	.00	.00	.00	.00	.00
.08	.00	.00	.00	.32	.11	.00	.00	.04	.01	.00	.00	.24	.19	.01	.00
.00	.04	.00	.00	.06	.31	.00	.00	.01	.04	.00	.00	.10	.43	.00	.00
.00	.00	.00	.00	.02	.00	.49	.05	.00	.00	.00	.00	.02	.00	.36	.05
.00	.00	.00	.00	.00	.01	.07	.45	.00	.00	.00	.00	.00	.01	.04	.41
.21	.06	.00	.00	.04	.02	.00	.00	.42	.08	.00	.00	.13	.03	.00	.00
.04	.22	.00	.00	.00	.04	.00	.00	.05	.47	.00	.00	.02	.15	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.00
.03	.01	.00	.00	.18	.15	.00	.00	.08	.02	.00	.00	.36	.17	.01	.00
.00	.02	.00	.00	.07	.29	.00	.00	.01	.06	.00	.00	.07	.45	.00	.00
.00	.00	.00	.00	.01	.00	.29	.06	.00	.00	.01	.00	.02	.00	.56	.05
.00	.00	.00	.00	.00	.02	.03	.31	.00	.00	.00	.00	.00	.02	.05	.55

COUNTS

107	15	0	0	45	4	0	0	122	39	0	0	24	22	0	0
15	129	0	0	2	34	0	0	40	202	0	0	8	48	0	0
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
51	1	0	0	212	70	1	0	25	4	0	0	160	128	4	0
6	46	0	0	75	384	3	5	12	46	0	0	123	528	0	2
0	0	1	0	5	0	100	11	0	0	0	0	4	0	74	10
0	0	1	1	0	3	15	96	0	0	0	1	0	2	8	88
120	37	0	0	23	14	0	0	243	48	0	0	75	20	0	0
36	195	0	0	4	36	0	0	48	412	0	0	16	134	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
24	8	0	0	154	130	1	0	69	14	0	0	309	146	7	0
9	49	0	0	133	550	2	2	21	118	0	0	138	862	0	9
0	0	0	0	3	0	72	15	0	0	2	0	4	0	141	13
0	0	0	0	1	6	9	85	0	0	0	1	1	7	14	153

BTS 1, 4, 10, 24

Figure 39. Summary Matrix (Continued)

TASK NO. 1
FOR THE SCORE 20

PROBABILITIES

.35	.03	.00	.00	.36	.00	.00	.30	.38	.08	.00	.30	.04	.03	.00	.00
.03	.33	.30	.00	.00	.05	.00	.30	.38	.42	.00	.00	.02	.06	.00	.00
.00	.00	.00	.00	.00	.00	.00	.30	.00	.00	.00	.00	.50	.00	.50	.00
.00	.00	.00	.00	.00	.00	.00	.30	.00	.00	.00	.00	.00	.00	.00	1.00
.06	.00	.00	.00	.37	.09	.00	.30	.02	.31	.00	.00	.30	.14	.01	.00
.00	.03	.00	.00	.05	.40	.00	.30	.00	.04	.00	.00	.08	.38	.00	.00
.00	.00	.00	.00	.32	.00	.50	.03	.00	.00	.00	.00	.02	.00	.38	.03
.00	.00	.00	.00	.00	.02	.05	.55	.00	.30	.00	.00	.00	.05	.03	.29
.27	.07	.00	.00	.03	.01	.00	.00	.44	.08	.00	.00	.08	.01	.00	.00
.05	.31	.00	.00	.00	.06	.00	.00	.06	.42	.00	.00	.01	.07	.00	.00
.00	.00	.50	.00	.00	.00	.50	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.01	.01	.00	.00	.25	.10	.00	.00	.05	.00	.00	.00	.39	.15	.01	.00
.01	.02	.00	.00	.07	.34	.00	.00	.01	.03	.00	.00	.09	.43	.00	.00
.00	.00	.00	.00	.01	.00	.33	.03	.00	.00	.00	.00	.03	.00	.55	.03
.00	.00	.00	.00	.00	.00	.03	.36	.00	.00	.00	.00	[illegible]	.03	.04	.51

COUNTS

149	14	0	0	27	1	0	0	161	33	0	0	18	14	0	2
16	158	0	0	1	25	0	0	40	202	0	0	8	28	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
37	2	0	0	228	54	2	0	14	5	0	0	190	85	4	0
1	33	0	0	53	425	1	6	5	42	0	0	82	411	1	5
0	0	0	0	5	0	100	7	0	0	1	0	4	0	76	7
0	0	0	0	0	5	10	111	0	0	0	0	0	10	6	58
150	40	0	0	15	7	0	0	247	46	0	0	47	6	0	0
35	201	0	0	1	39	0	0	42	274	0	0	7	45	0	0
0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	7	0	0	197	82	2	0	41	2	0	0	305	119	9	0
9	23	0	0	93	427	0	4	8	41	0	0	109	545	0	5
0	0	0	0	3	0	78	8	0	0	1	0	8	0	130	7
0	0	1	1	0	0	6	64	0	[illegible]	0	0	0	5	8	90

BTS 1, 4, 10, 24

Figure 39. Summary Matrix (Concluded)

transition matrices indicates that some differences do exist and these differences may yield score discrimination.

5.3.2 Results of Score Prediction with State Transition

Results of score prediction using the state transition computation show the effectiveness of the reference flight-path related Boolean functions. Consider figure 40 which is a histogram of prediction scores achieved using Boolean variables 1, 10, 13, and 24. Recall that these Boolean functions test: Is roll increasing?, Is pitch increasing?, Is pitch in the central 1/3 region?, and, Is airspeed increasing?, respectively. BTS variables 1, 10, 24, were identified previously as potentially noisy. The associated histogram No. 13 demonstrates the non-existent relationship to score. It is seen that the mean for all categories falls in the 45-50 score range. Considerable improvement is obtained, however, by replacing BTS 13 with BTS 29, i.e., removing the pitch quantized state variable and substituting a BTS related to a reference flight path. Histogram No. 14 associated with this set of BTS is shown in figure 41. Considerable improvement is noted as the mean of each category is clearly ordered with score. However, substantial overlap in the distributions is still present.

Histogram No. 15 is associated with score prediction using variables 40, 33, 12, and 4 (i.e., using two Boolean functions related to reference flights, paths and also pitch state and roll state functions). See figure 42. In this case, an increase in discrimination is noted with complete separation of excellent from poor and fair categories. Also, it is seen that spreading of predictions within a category occurs. This may mean a discrimination within each category is possible.

Histogram No. 16 (figure 43) is related to BTS's 13, 28, 30, 41, and indicates that score discrimination with these variables is not as good as was obtained in BTS (40, 33, 12, 4). Comparing these two cases, we see that the change from BTS 4 to BTS 28 represents a shift from roll data to airspeed data. The other BTS variables remain in their respective categories. The noticeable changes in score prediction capability show clearly that the variables selected, as well as the Boolean functions formed, have a significant effect on score predictions. Such a conclusion is not and should not be surprising; however, the question is: What set of variables would provide optimal separation of score categories and how can these variables (and BTS) be specified?

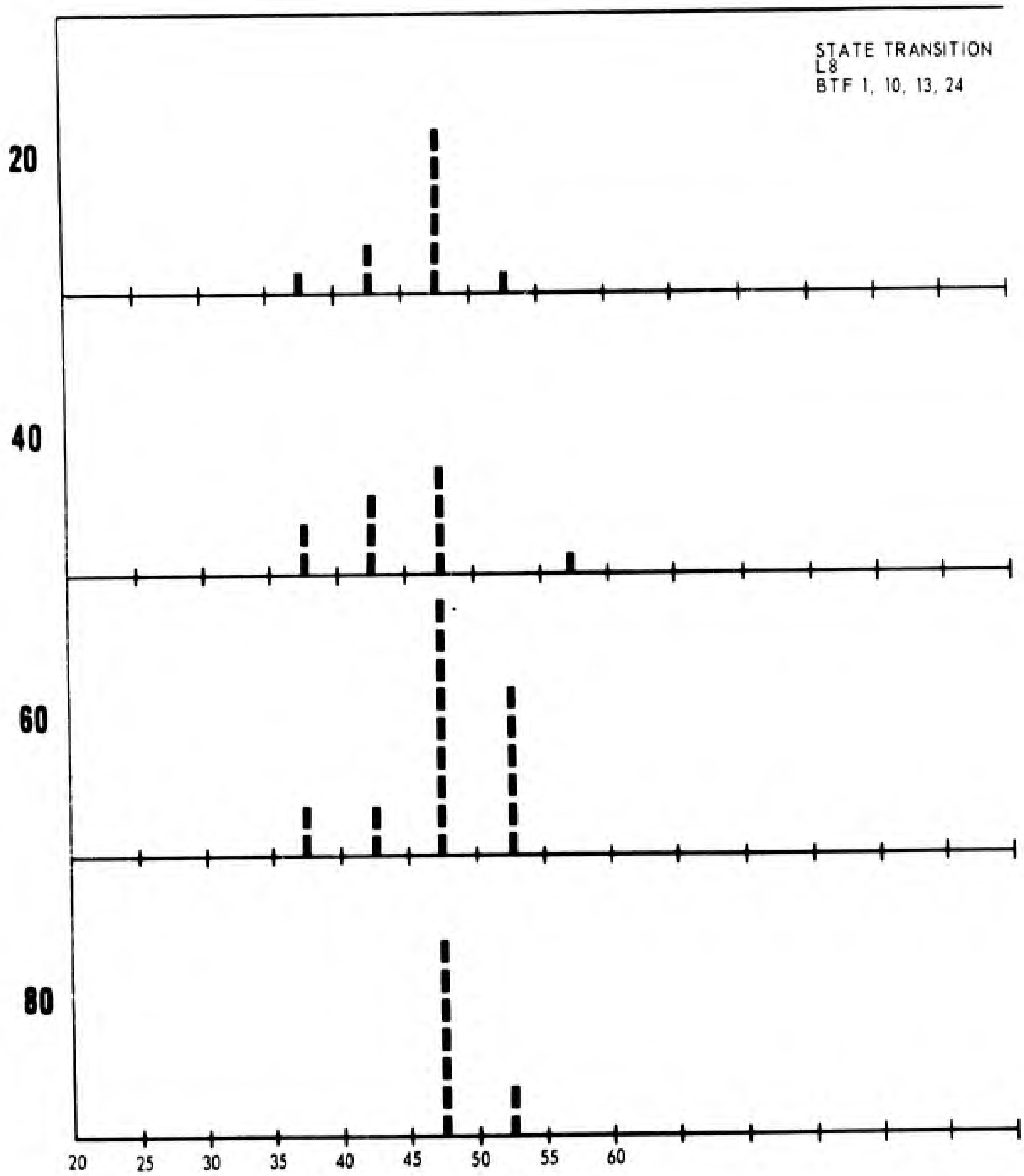

Figure 40. Histogram No. 13 Instructor Score versus Predicted Score

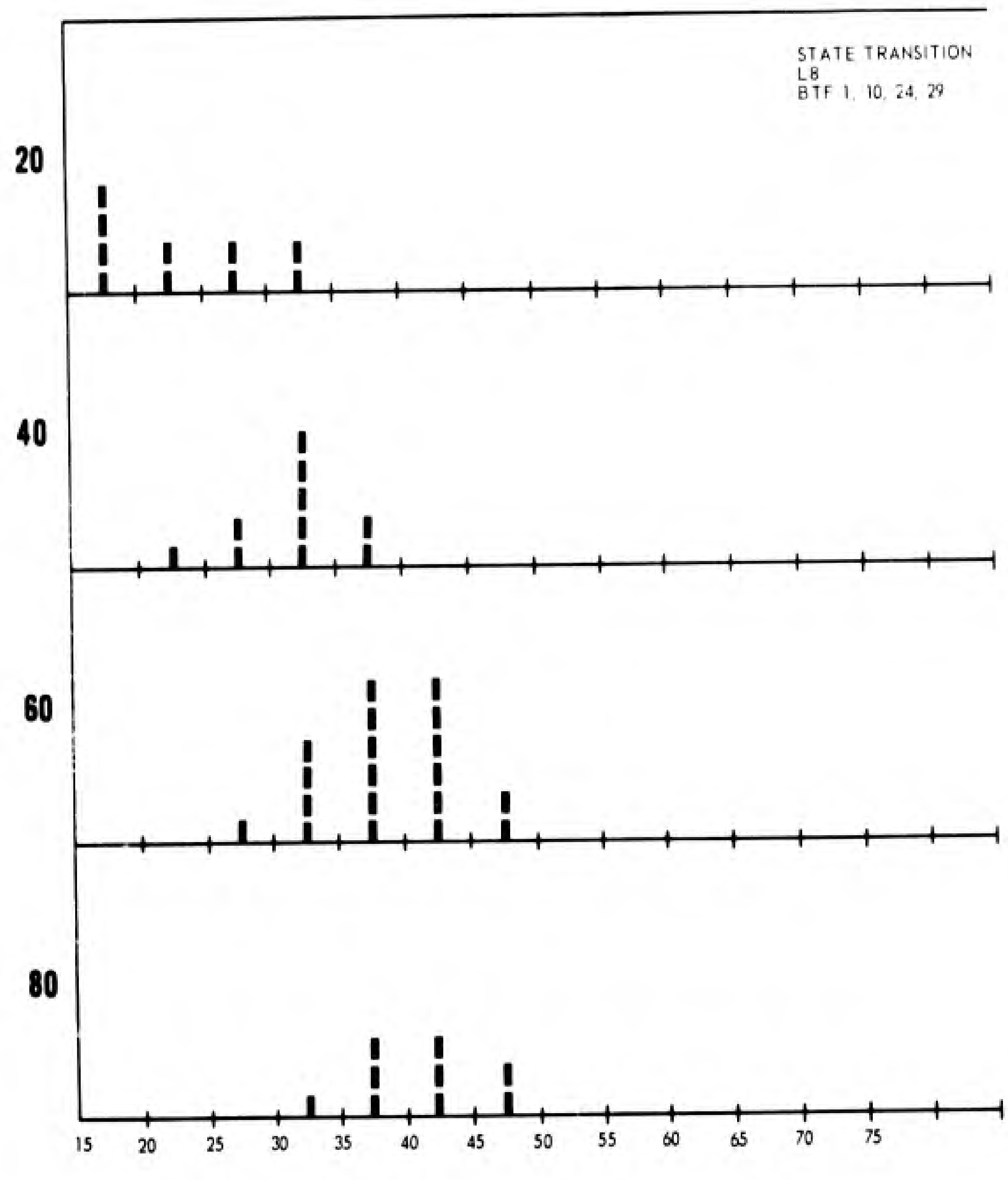

Figure 41. Histogram No. 14 Instructor Score versus Predicted Score

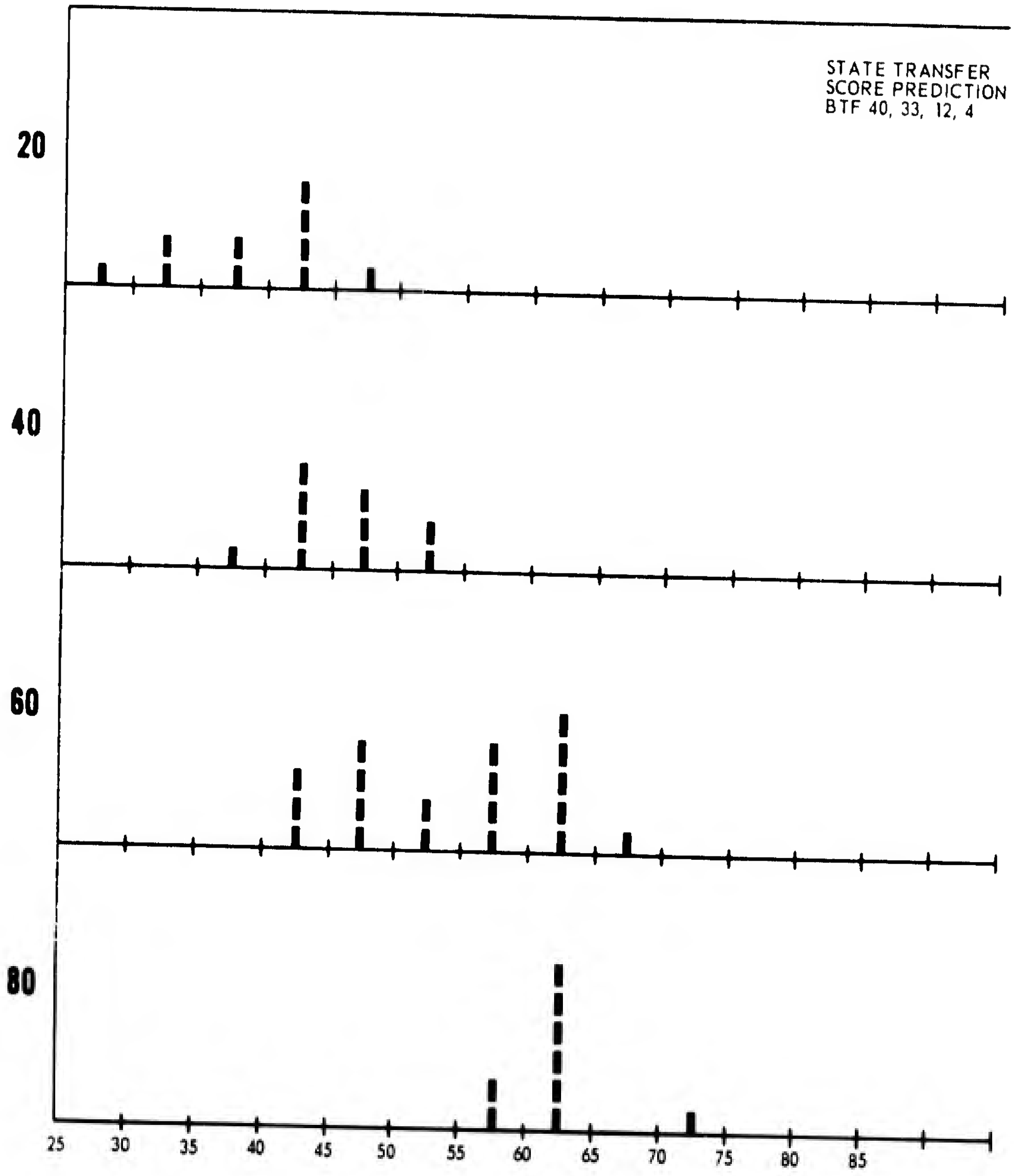

Figure 42. Histogram No. 15 Instructor Score versus Predicted Score

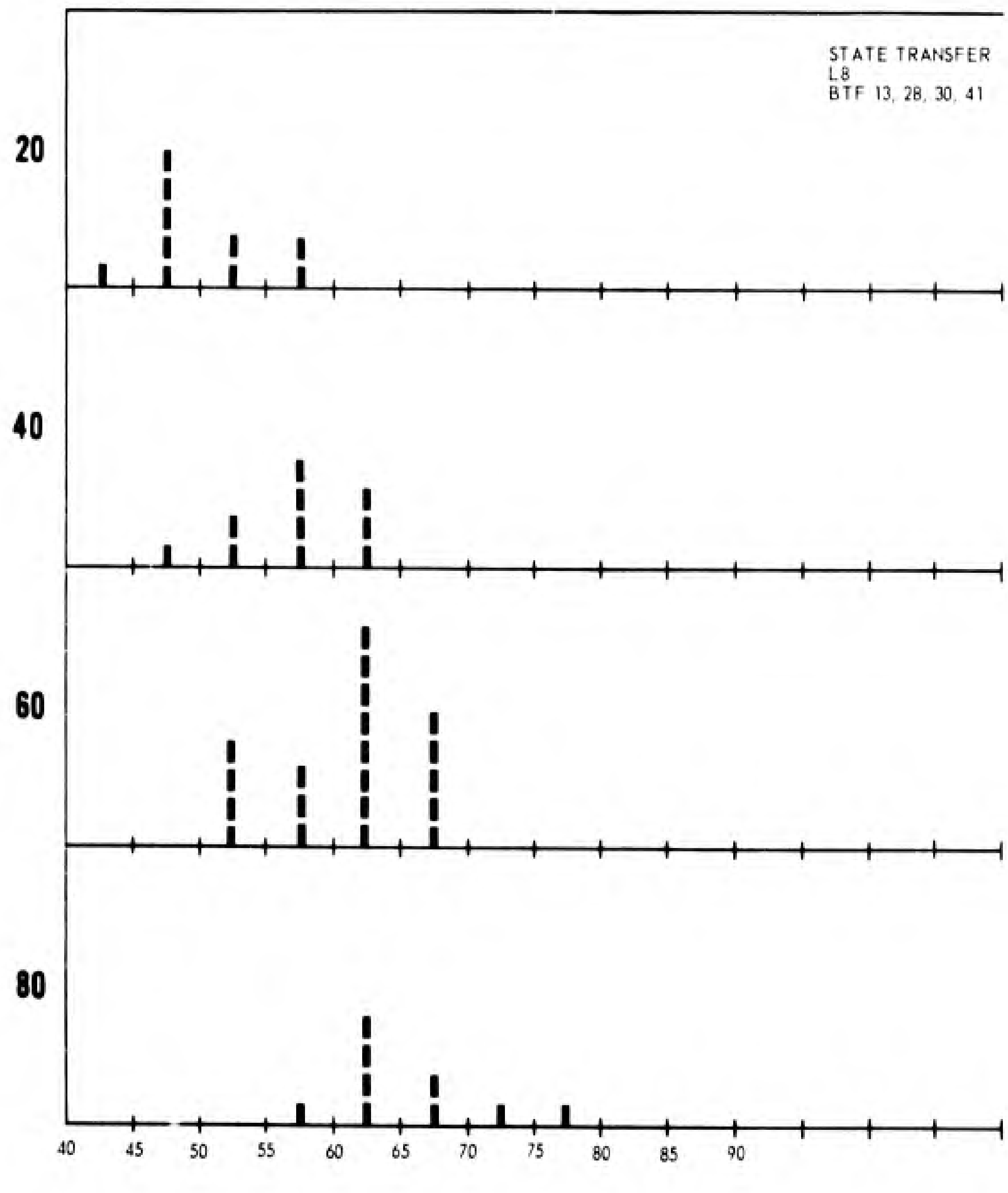

Figure 43. Histogram No. 16 Instructor Score versus Predicted Score

5.4 Summary and Recommendations

The objective of this study was to test and evaluate the potential of the math-model approach using real (T-37) data. Three models were employed, each of which seeks to derive performance measures of a different type: (1) Absolute, i.e., comparison of performance with an absolute standard; (2) Relative, i.e., investigating relations among performance variables, and (3) State transfer, i.e., examining performance trends by reference to changes in states of the pilot/aircraft system. Specifically, the goal was to demonstrate the capabilities of each model independently, extract the resulting performance information that appears most relevant to measurement, and attempt to illustrate face validity of derived measures through comparison of results with subjective performance ratings and through reference to accepted knowledge about the performance of the maneuvers.

Work on the absolute computation technique demonstrated the need for multivariable performance measures. Only when operations on several variables (BTS) were accomplished with a regression analysis, did good score prediction result. Also, the Boolean functions derived from criterion flight paths contained considerable performance information. This result is not surprising. The air-speed-versus-pitch and roll-versus-pitch functions generated as mean value of airspeed (roll) for each value of pitch for the flights rated excellent, provided Boolean functions of great value. The positive results suggest that this type of Boolean function should be tested in all performance measurement systems.

The relative computation provided a direct method of processing more than one BTS, as was found necessary with the absolute computation. This method allows tests to determine if functions of BTS are related to score. Such an approach showed promise in separating poor (unsatisfactory) and fair performance, which appears to be a difficult discrimination task. In addition, to direct automatic scoring of total flight performance, an interesting demonstration was presented of how separate portions of the maneuver can be scored. The benefit of using this capability is that difficult portions and/or critical portions (from an instructor's point of view) may be identified. From this, we may be able to learn how instructors score, as well as how to improve instruction methods by concentrating on the difficult portions of the maneuver.

Results of the state transition computation, which also treats operations on more than one BTS, indicate a moderate capability of score prediction. These results are simply not as convincing as those of the absolute and relative computation. The method tends to produce two prediction categories (poor, fair; good, excellent) instead of four and such a result is obtained by a visual examination of the associated histograms (13, 14, 15, 16). Allowing a little speculation, an application of the powerful regression on selected transition matrix incremental scores may have yielded better results. Put in a different way, the method of adjusting the incremental score was devised to extract score information, but, was not designed to provide a best fit to data partially related to score.

It is of interest to examine the score of each flight event that was predicted by the various computational methods applied to the data. We are first specifically looking for a consistently predicted flight score and subsequently examining to see whether or not the consistently predicted score is in agreement with the instructor's rating. In order to obtain numerical results, a number was assigned to each score category as follows,

Poor	20
Fair	40
Good	60
Excellent	80.

This assignment was quite arbitrary; however, with it we see that a prediction of the correct score ±10 units would represent an ideal prediction. Thus, poor can be considered as from 10 to 30, and fair from 30 to 50, etc. Examination of the predicted scores for each flight leads to the data summarized in table VII. Data for this table was taken from those histograms having good score prediction, as identified in the table.

As the data indicates, the predictions associated with some flights showed significant differences between instructor and predicted scores. The table provides a summary of these differences. Thus, for flight event 5 four (of the six predictions for the absolute mode) were greater than 10 units above the instructor's rating (60). Two of the A predictions, and all R and S predictions fell within the 10-unit tolerance suggested previously. Flights 64, 73, and 94 showed a significant deviation from the instructor's rating. One could ask: Are flights 64 and 73 really poor or should the correct rating be fair? Likewise: Is flight 94 really good or should it be rated excellent? Similar questions can be asked about flight maneuvers 20 and 84: Are these really good or should they be rated fair? (As shown earlier, there is some evidence that supports the models ordering of these maneuvers.) Data flight 6 is included to illustrate a situation where very good agreement with the instructor was obtained.

The data presented above illustrates that methods of instructor scoring may be reviewed to answer the questions posed. In addition, it suggests that a means is available to increase skill-level discrimination by ordering the flights within the overall rating categories.

While the evaluation of the math model is not complete, it is useful to consider what simplifications would be possible if the method were to be streamlined for an on-line application. The absolute computation can be simplified by selecting those Hadamard channels that contribute to the score prediction. The fast Hadamard transform is an efficient way of computing all coefficient values; but, calculation of only a few coefficient values can be efficiently determined by a correlation against appropriate MacDonald Codes. Likewise, the relative computation can be simplified by forming only those functional elements shown to be related to score. It may be that no functional form is required and that the proportion of the time a BTS is true, may be useful. Furthermore, such a measurement may not be required throughout the total maneuver. Instead it may be necessary to sample the maneuver only during the critical portions. Considerable simplification of the state transition computation is possible since most of the computation employed in this study is for initial training purposes. The score prediction mode is a relatively simple computation.

The development and evaluation of the score prediction processing described in this report cannot be considered complete. As indicated in the introduction, the work was limited to obtain only an initial indication of the value of the approach. A specific listing of the tasks required to complete the effort is:

a. Complete the analysis of the data processed.

b. Complete processing and analysis of data available.

c. Develop a statistical model of the process.

d. Obtain additional necessary data required to validate measures.

e. Validate measures.

f. Simplify computational procedures.

TABLE VII

TRENDS IN PREDICTION OF FLIGHT SCORES

Flight Event	Predicted Rating Minus Instructor Rating							
	<-15	-15+→-10	-10+→-5	-5+→0	0+→5	5+→10	10+→15	>15
5				A		A, 2R, 2S	4A	
63					A, R	2A, S	2A, R	A, S
64					R	R	S	6A, S
73						A, R	4A,	A, R, 2S
94		S			S, 2A, R	R	4A	
46					4A, R		S, 2A, R	S
6			A	4A	A, 2S, R		R	
16	S	3A, R	3A, S	R				
20		3A, S	3A, S, R		R			
21	2S, 2A, R	A, R	3A					
58	2A, A	2A, 2R	3A					

TABLE VII

TRENDS IN PREDICTION OF FLIGHT SCORES

	Predicted Rating Minus Instructor Rating							
Flight Event	<-15	-15+→-10	-10+→-5	-5+→0	0+→5	5+→10	10+→15	>15
74	2S,	A	R5A	R				
84	2A, R, S	3A	A	R, S				

Data taken from Histograms:

3, 4, 5, 6, 7, 8 Absolute Computation (A)

11, 12 Relative Computation (R)

15, 16 State Transition Computation (S)

Note that A represents a predicted score from the absolute computation, 2A indicates two scores from the absolute computation, etc.

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APPENDIX I

EVENT NUMBERS AND INSTRUCTOR RATINGS FOR LAZY 8 (L8) AND BARREL ROLL (BR) MANEUVER DATA

EVENT NUMBERS AND INSTRUCTOR RATINGS FOR LAZY 8 (L8) AND BARREL ROLL (BR) MANEUVER DATA

TAPE NO. T37 D16. T37 D17

	AF EVENT NO.	MELPAR EVENT NO.	RATING
L8	45	45	60
	46	46	40
	47	47	80
	48	48	80
	49	49	80
	50	50	60
	51	51	60
	54	54	60
	59	59	60
	62	62	80
	63	163	60
BR	55	1655	80
	56	1656	80
	57	1657	80

TAPE NO. T37 D10

	AF EVENT NO.	MELPAR EVENT NO.	RATING
L8	4	84	60
	5	85	60
	6	86	60
	7	87	80
	13	93	60
	14	94	60
BR	8	1008	80
	9	1009	80
	10	1010	40
	11	1011	40
	12	1012	60

EVENT NUMBERS AND INSTRUCTOR RATINGS FOR LAZY 8 (L8) AND BARREL ROLL (BR) MANEUVER DATA (Continued)

TAPE NO. T37 D28, T37 D32

	AF EVENT NO.	MELPAR EVENT NO.	RATING
L8	5	5	60
	6	6	60
	9	9	60
	12	12	60
	13	13	60
	15A	15	40
	15B	16	60
	20	20	60
	21	21	80
BR	3	2803	80
	4	2804	80
	7	2807	80
	8	2808	80
	10	2810	80
	11	2811	60
	14	2814	60
	16	3216	60
	17	3217	60
	18	3218	60
	19	3219	40

TAPE NO. T37 D52, T37 D35

	AF EVENT NO.	MELPAR EVENT NO.	RATING
L8	58	58	80
	63	63	40
	64	64	20
	65	65	40
	66	66	20
	67	67	80
	68	68	20
	70	70	20
	71	71	40
	72	72	40
	73	73	20
	74	74	80

EVENT NUMBERS AND INSTRUCTOR RATINGS FOR LAZY 8 (L8) AND BARREL ROLL (BR) MANEUVER DATA (Continued)

TAPE NO. T37 D52, T37 D35 (Continued)

	AF EVENT NO.	MELPAR EVENT NO.	RATING
BR	53	5253	80
	54	5254	60
	55	5255	20
	56	5256	40
	57	5257	20
	59	5259	40
	60	5260	20
	61	5261	20
	62	5262	20
	69	3569	20
	75	3575	80
	76	3576	20

TAPE NO. T37 D56, T37 D57

	AF EVENT NO.	MELPAR EVENT NO.	RATING
L8	26	26	40
	27	27	40
	28	28	40
	29	29	40
	30	30	20
	31A	31	20
	31B	32	20
	33	33	20
	34	34	20
	35	35	60

EVENT NUMBERS AND INSTRUCTOR RATINGS FOR LAZY 8 (L8)
AND BARREL ROLL (BR) MANEUVER DATA (Continued)

TAPE NO. T37 D56, T37 D57 (Continued)

	AF EVENT NO.	MELPAR EVENT NO.	RATING
BR	36	5736	40
	37	5737	40
	38	5738	40
	39	5739	20
	40	5740	40
	41	5741	20
	42	5742	20
	43	5743	60
	44	5744	40
	45	5745	80
	46	5746	20
	47	5747	40
	48	5748	40
	49	5749	40

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APPENDIX II

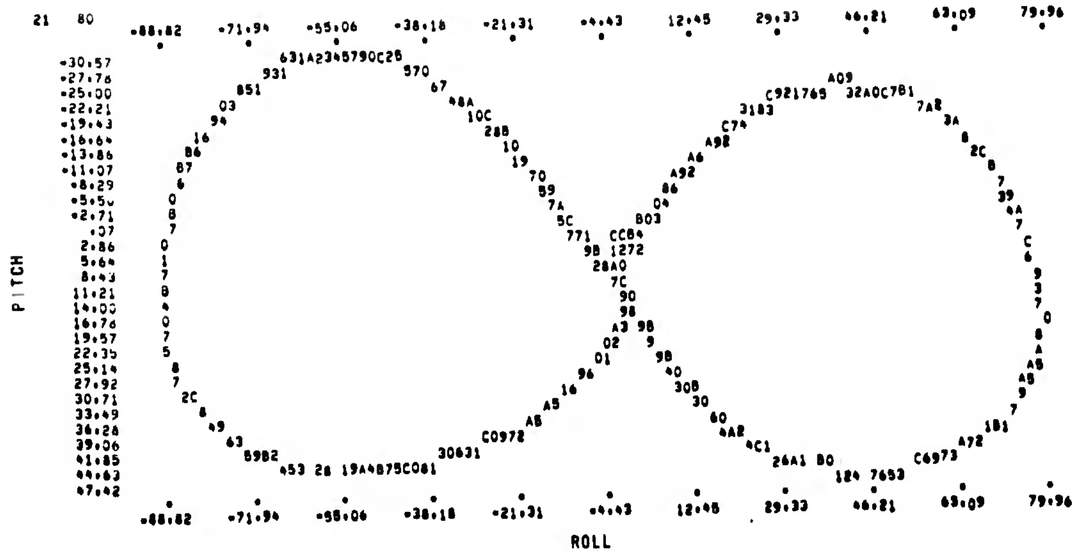
FLIGHT DATA

AIRCRAFT FLIGHT DATA

Figure 44 consists of computer-printed trajectories of the Lazy 8 maneuver. These printouts were generated from the smoothed data presented to the computational mechanisms. The plot is pitch angle versus roll angle with the scale printed along each axis. The two numbers in the upper-left portion of the printout just above the pitch angle scale are event number and instruction rating.

Figure 45 provides a computer plot of the smoothed data from the Barrel Roll maneuver. Table VIII is a list of the start and stop times for the Lazy 8 maneuver and table IX provides similar data for the Barrel Roll.

July 31, 1970-1
LAZY8
PLOT Pitch .VS. Roll
"DEGLITCHED" DATA



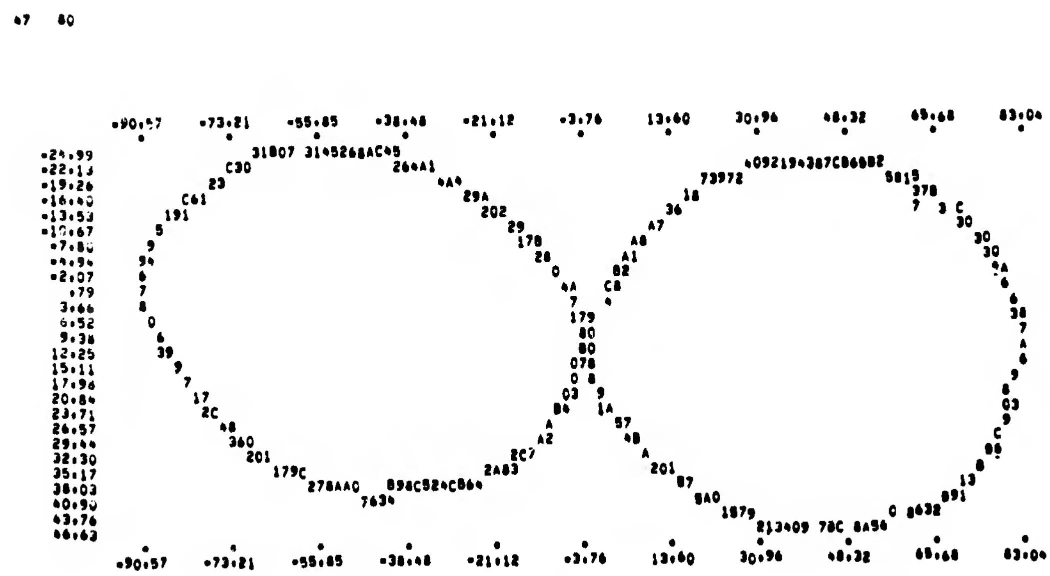
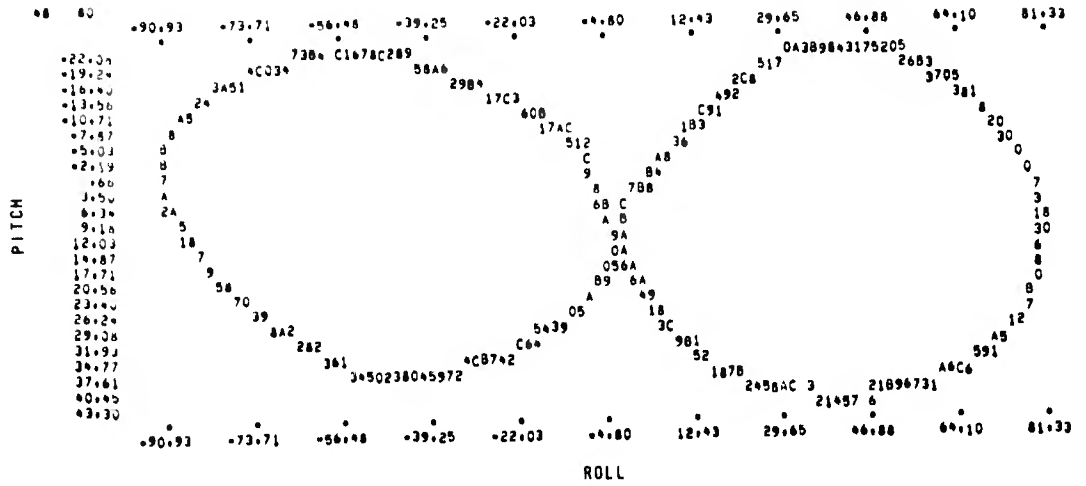
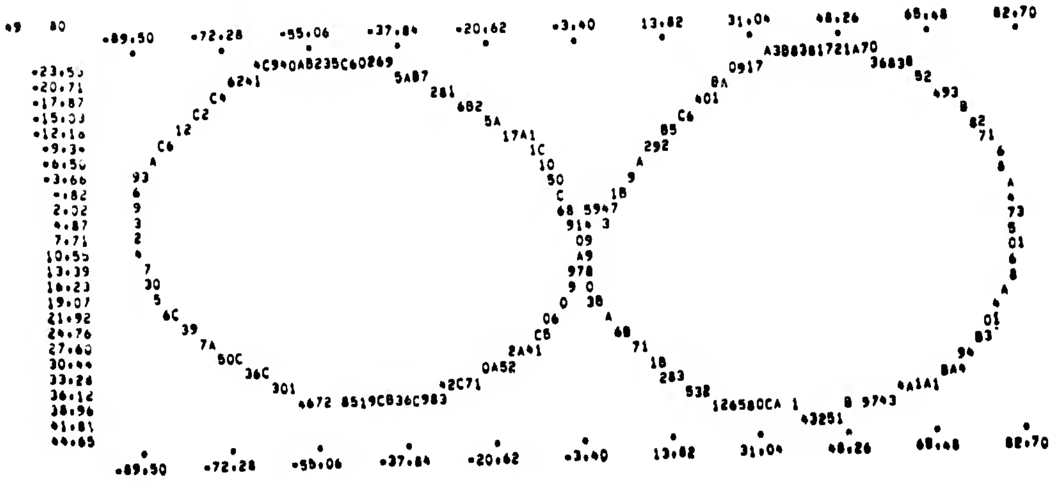


Figure 44. Trajectories of Lazy 8 Maneuver





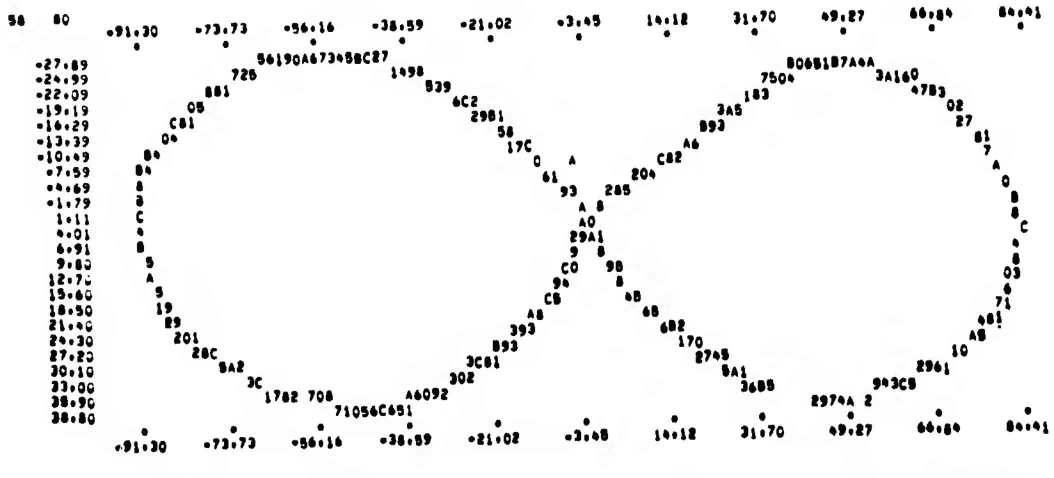
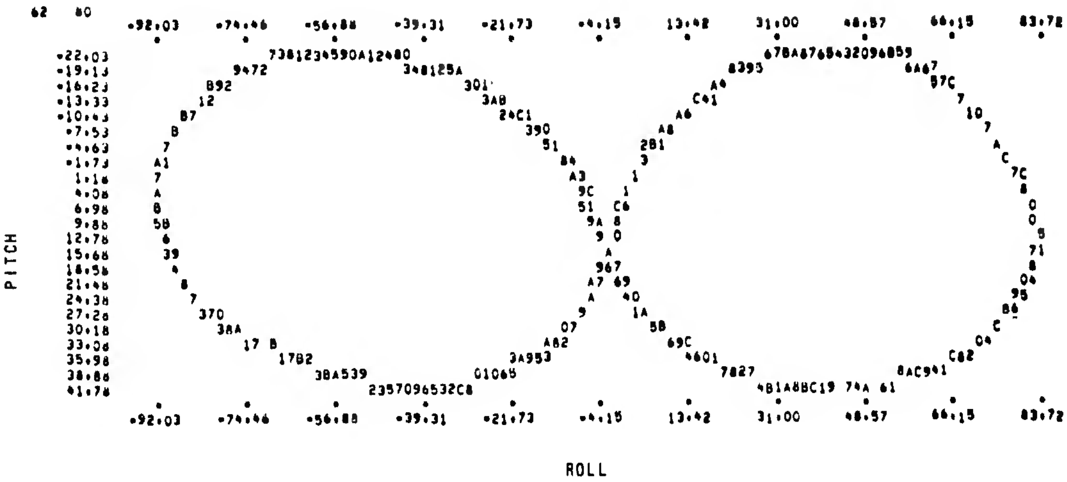
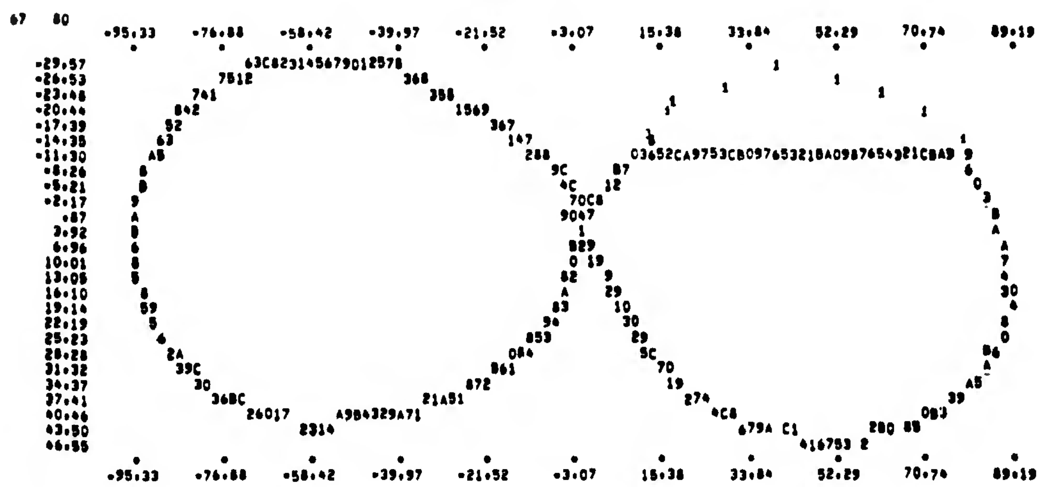


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)





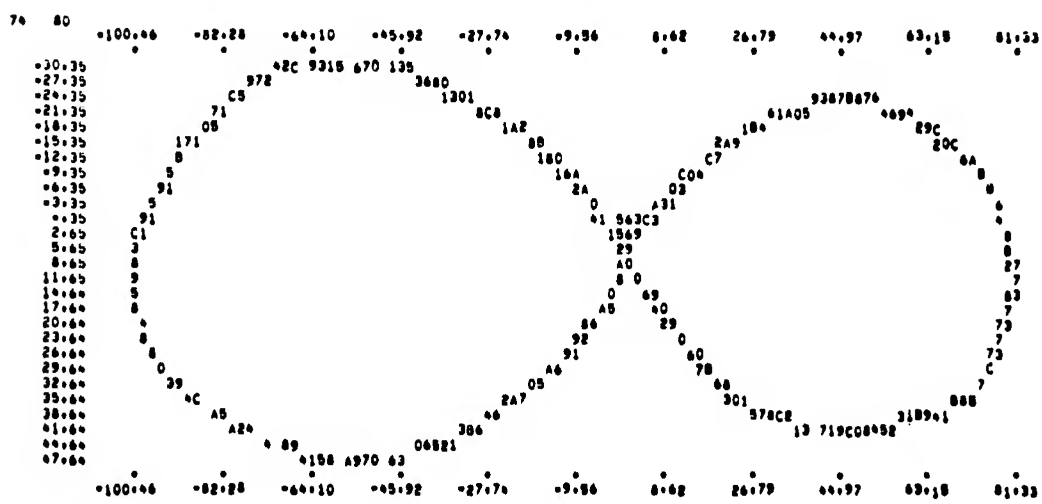


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)

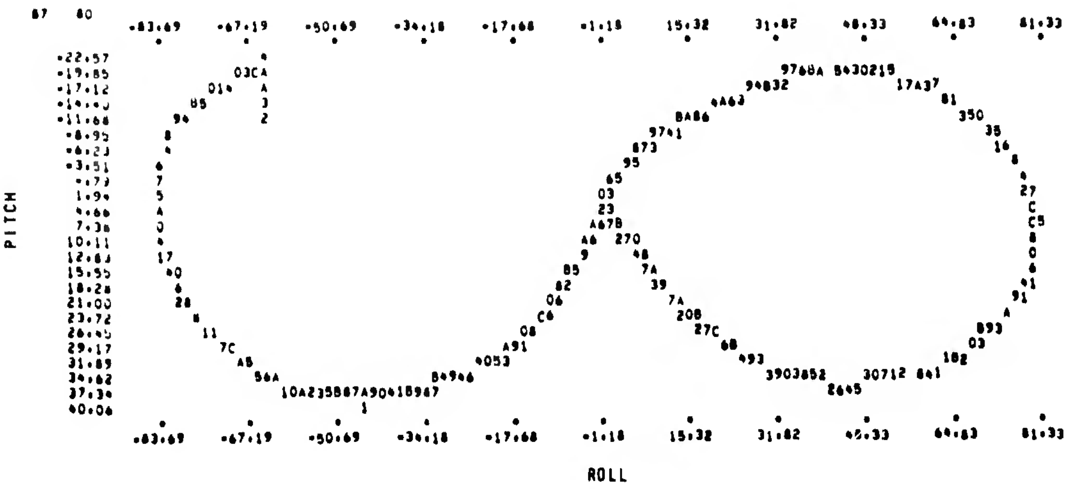
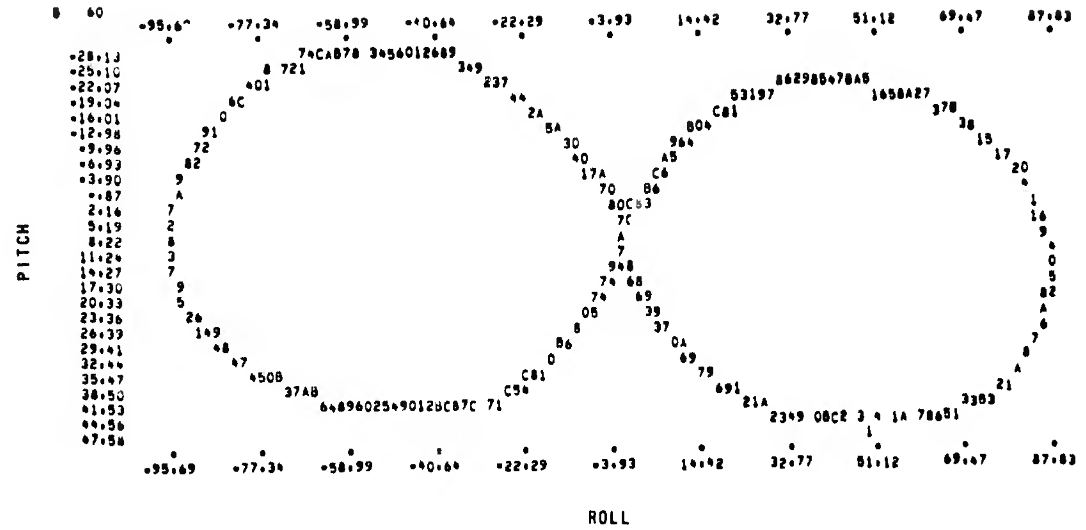
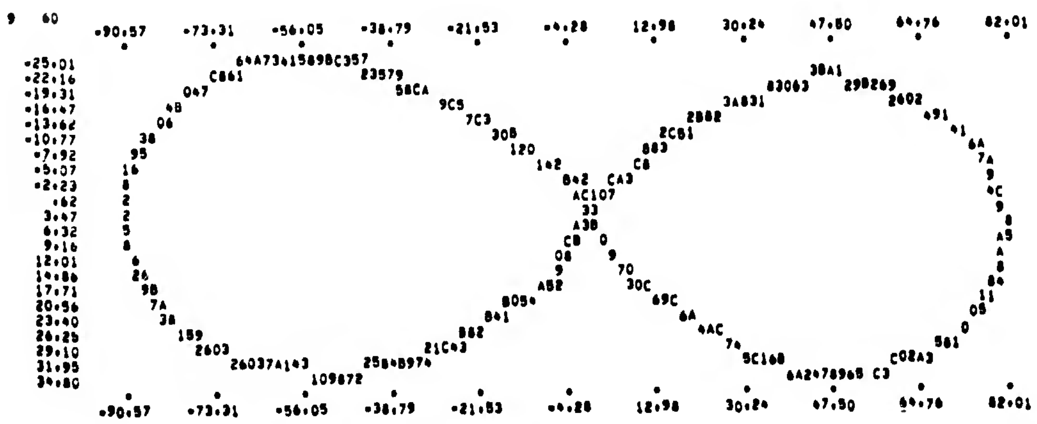


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)





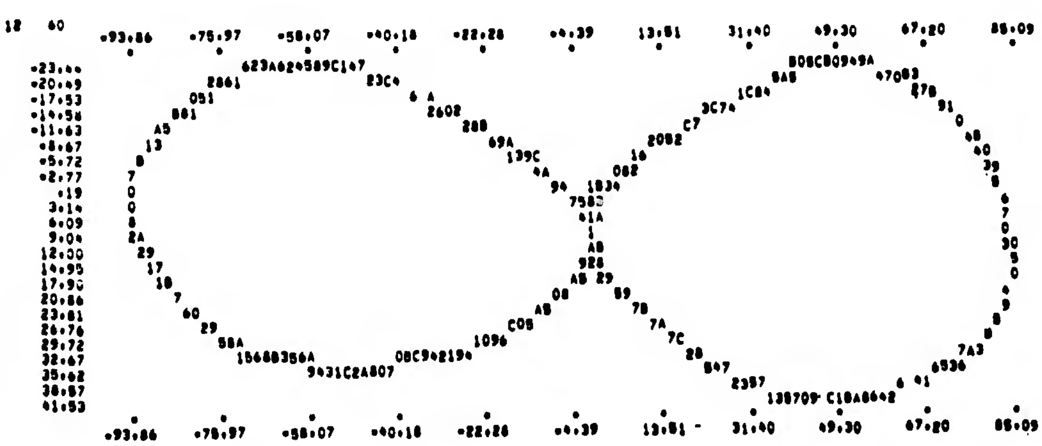


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)

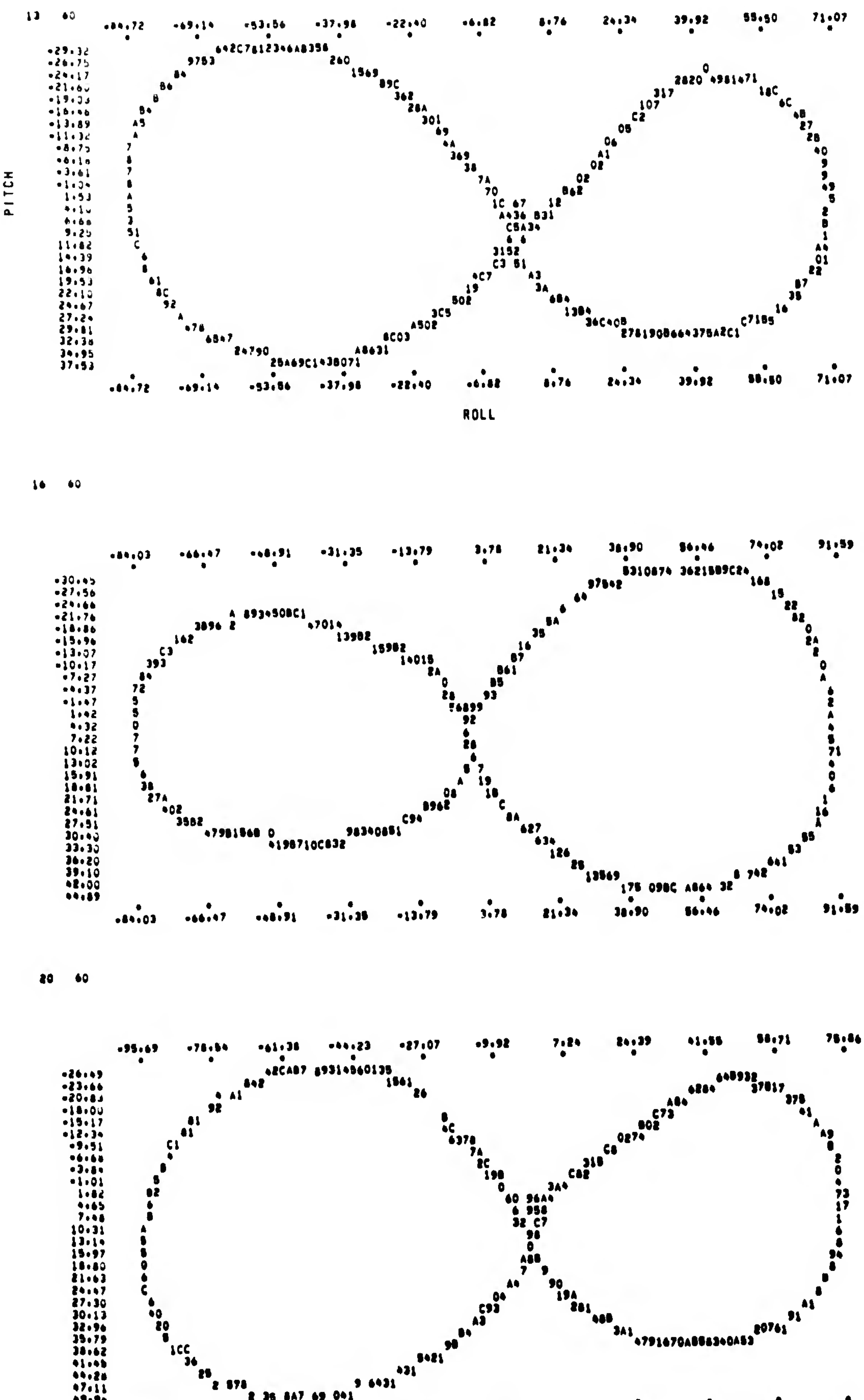
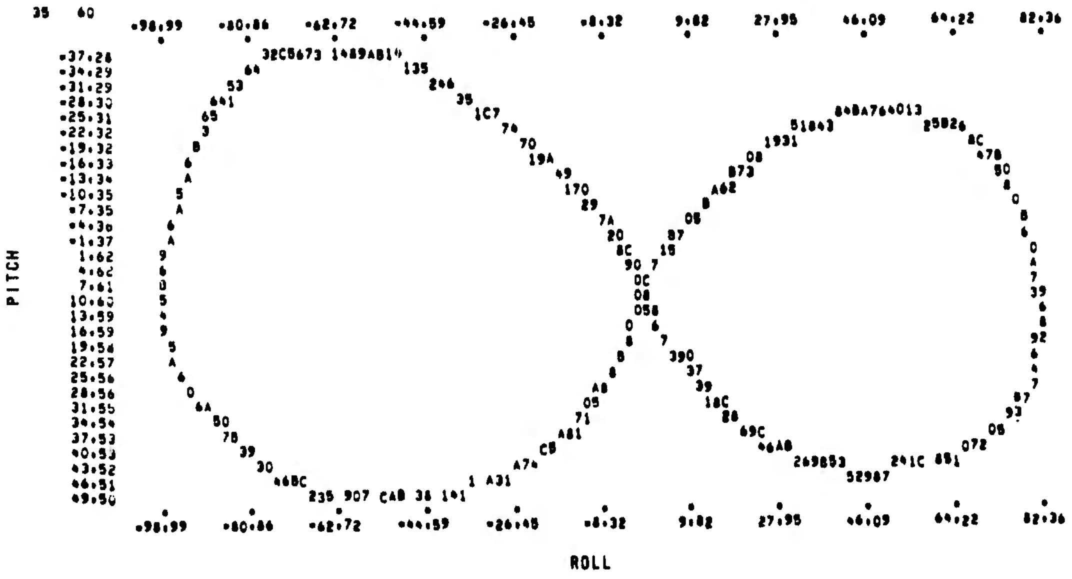
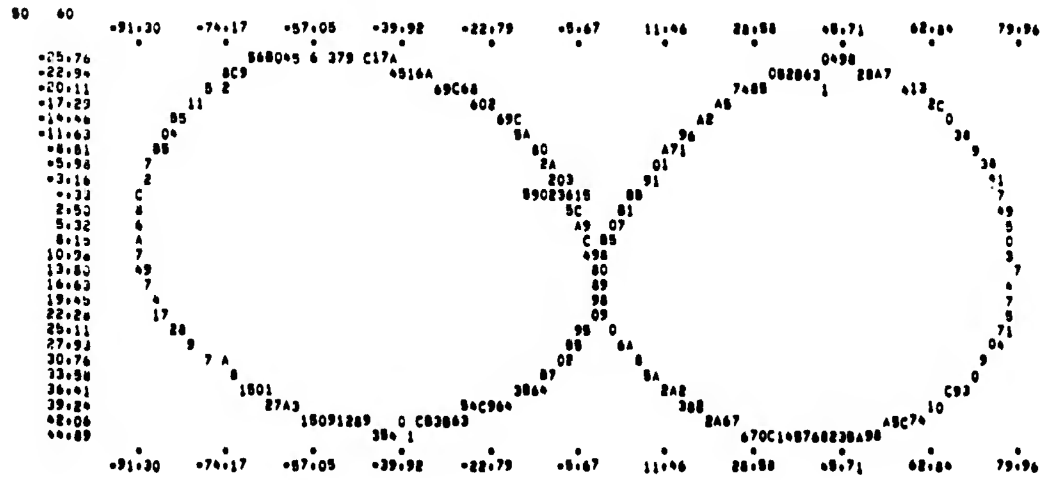


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)





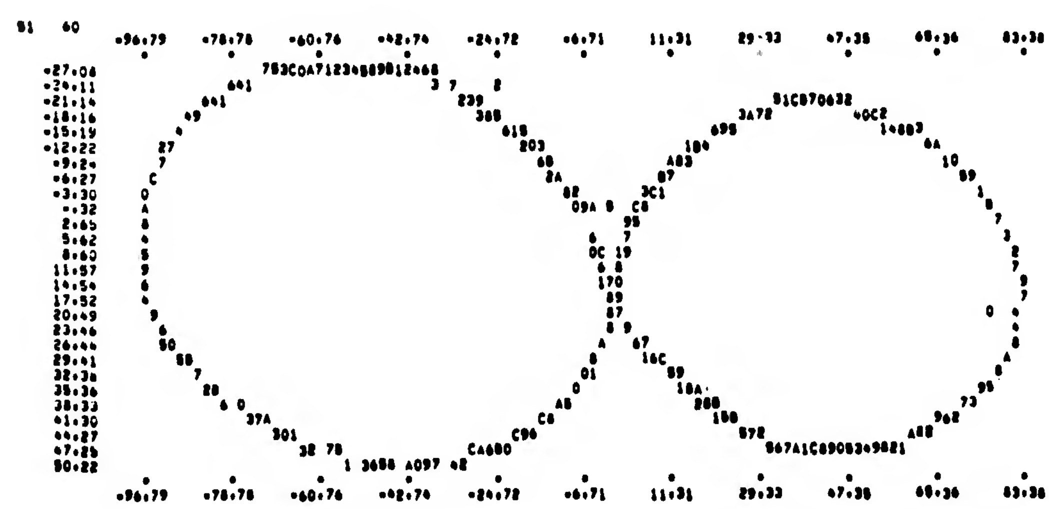


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)

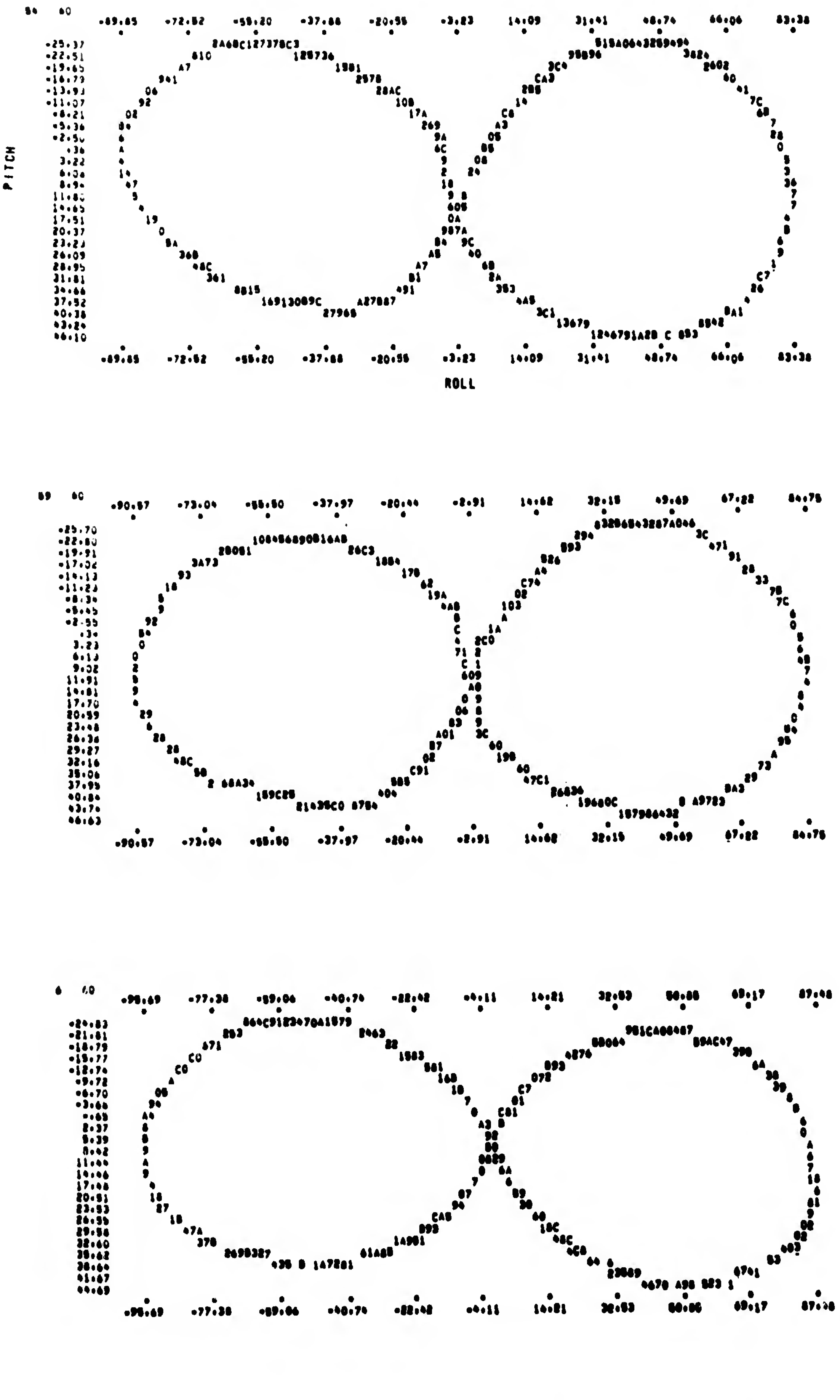
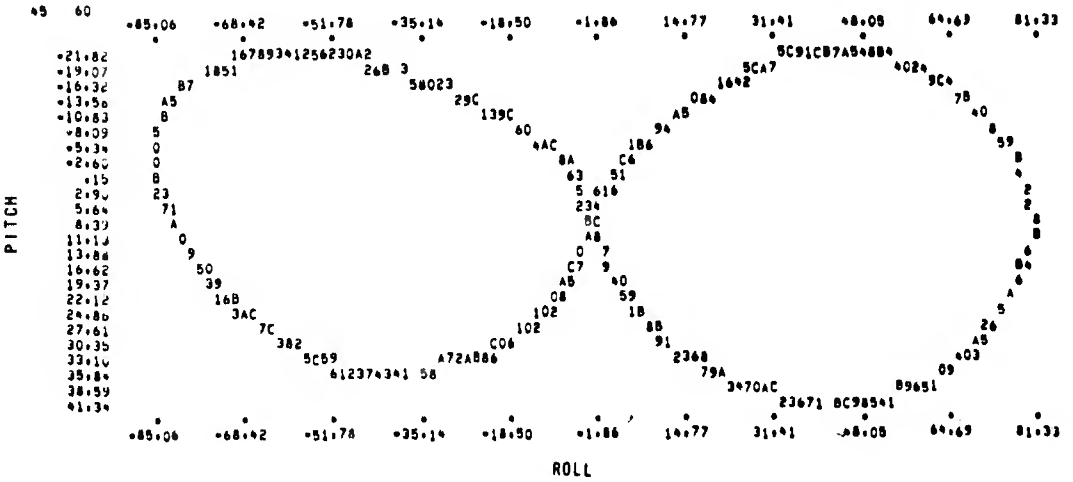


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)



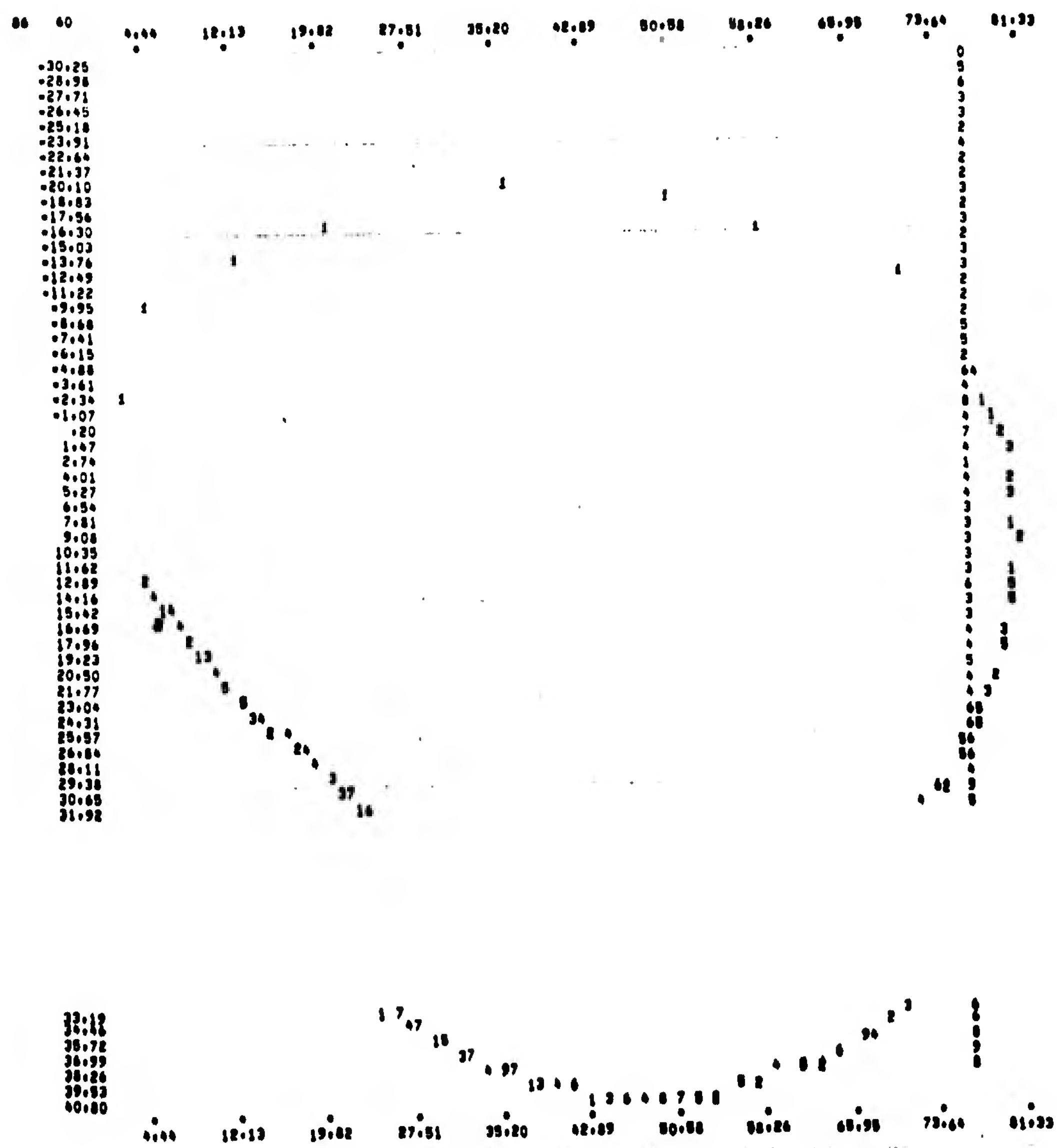


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)

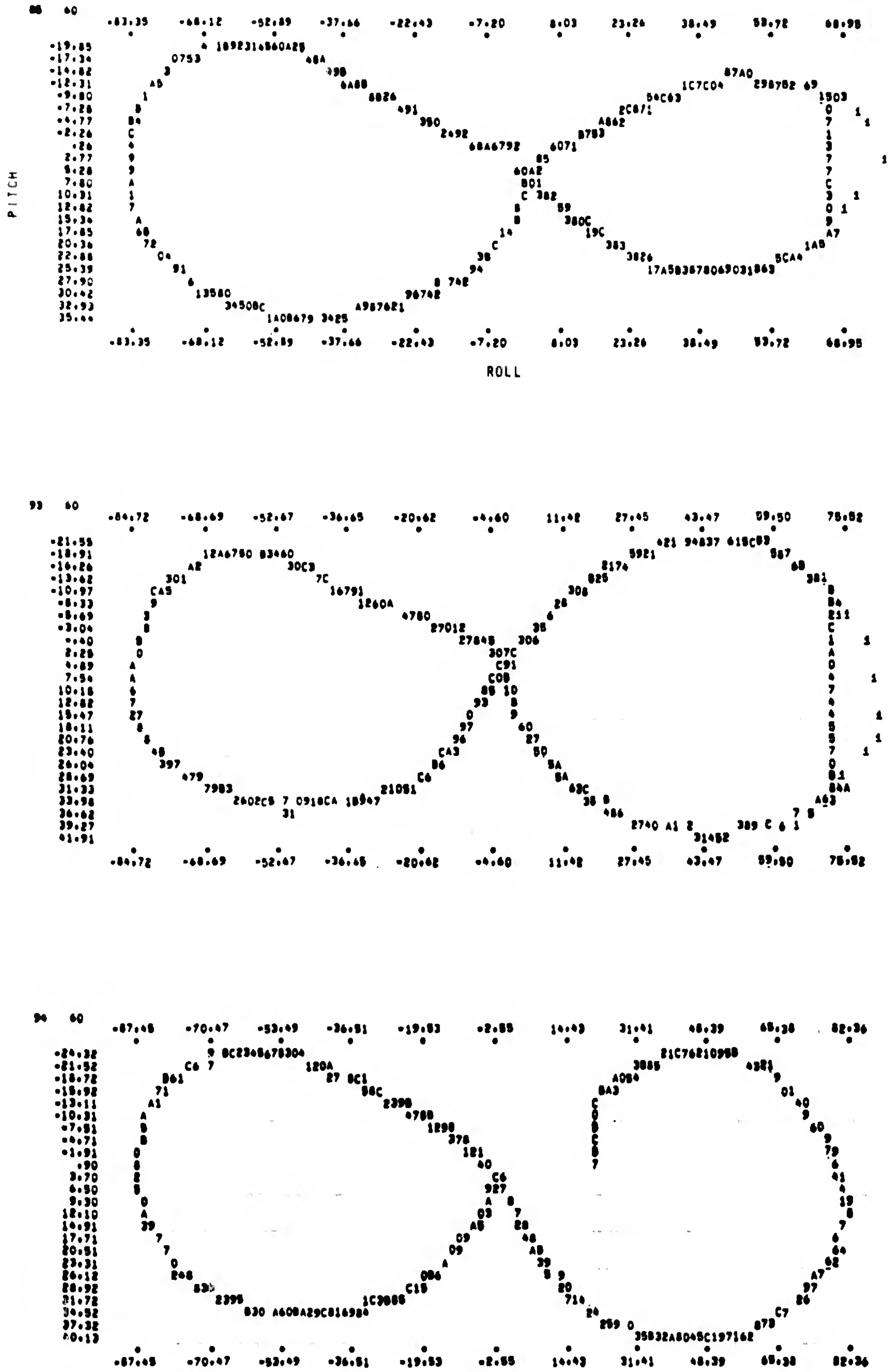
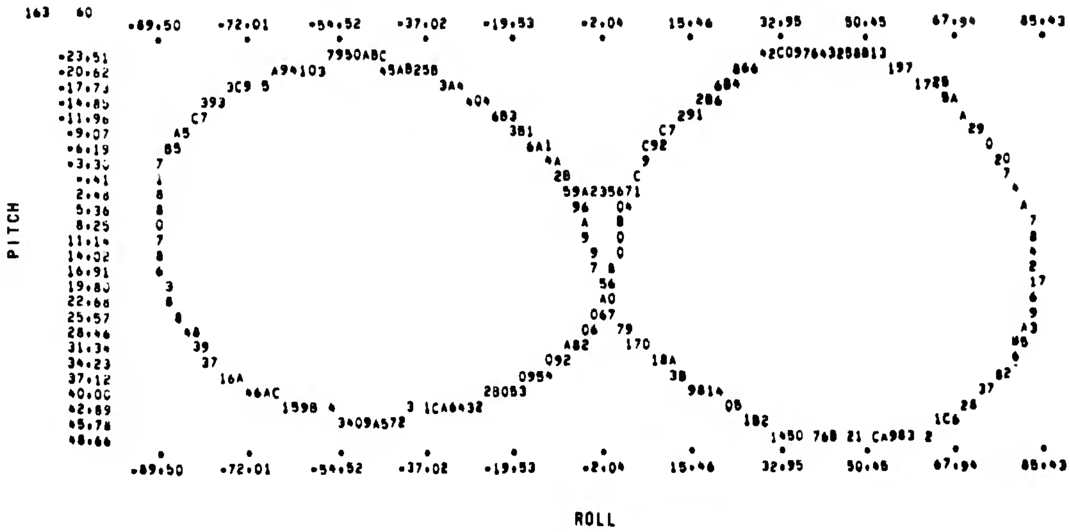


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)



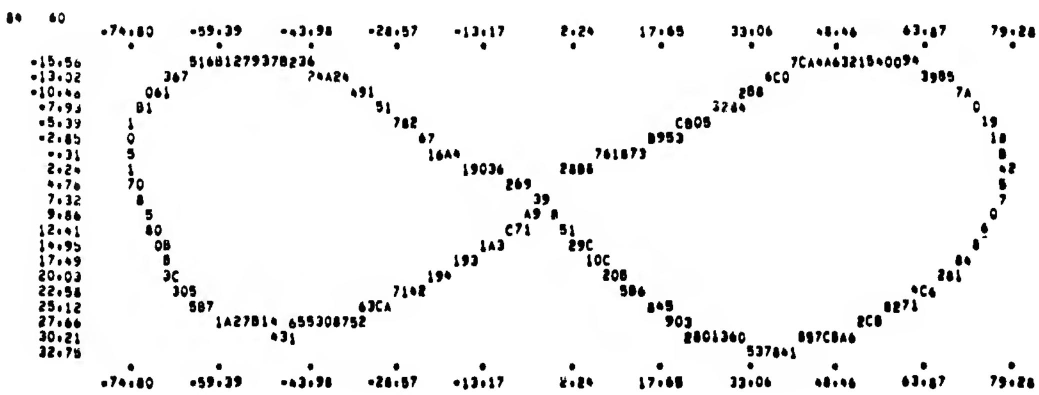
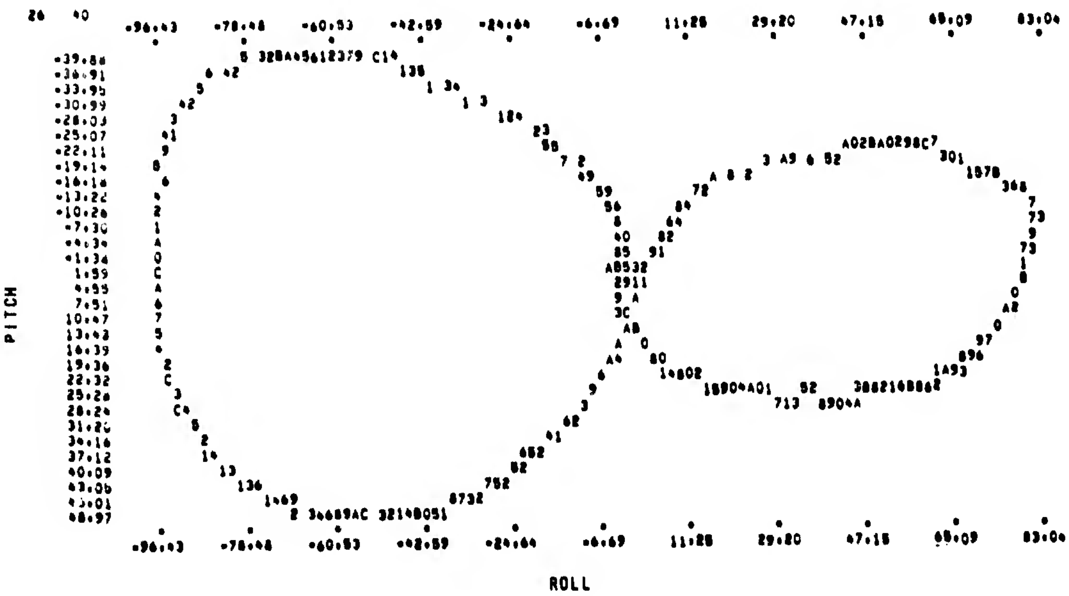
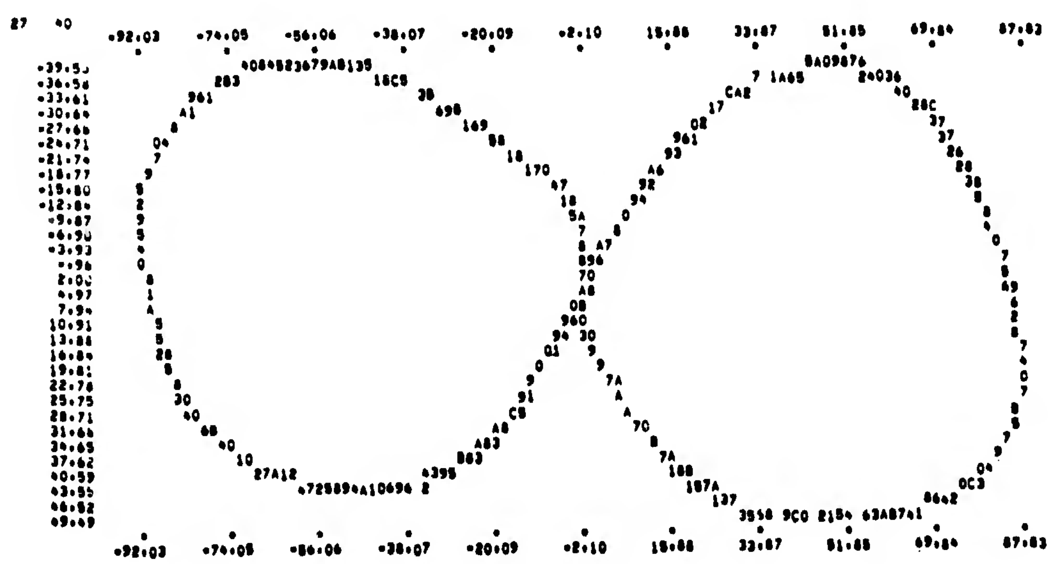


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)





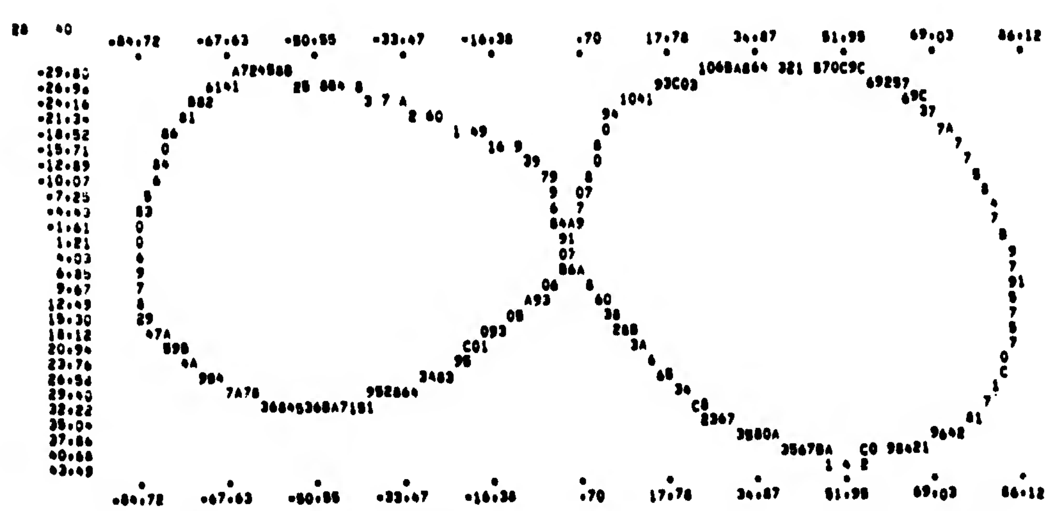
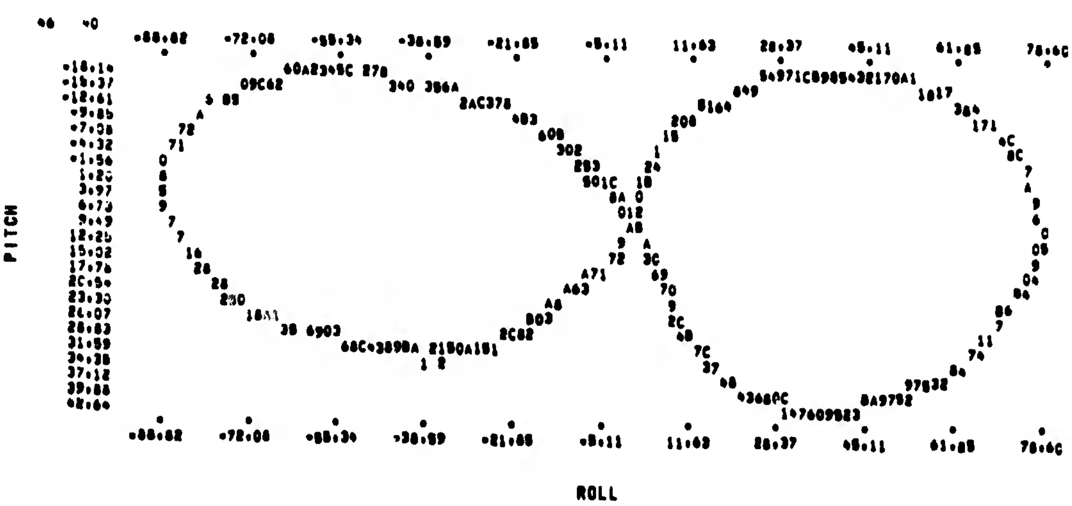


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)



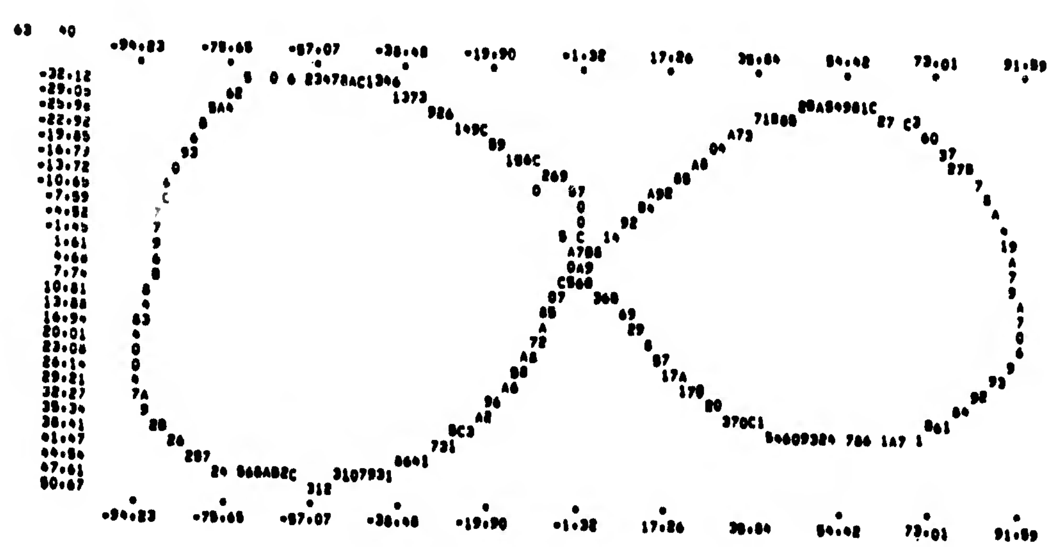
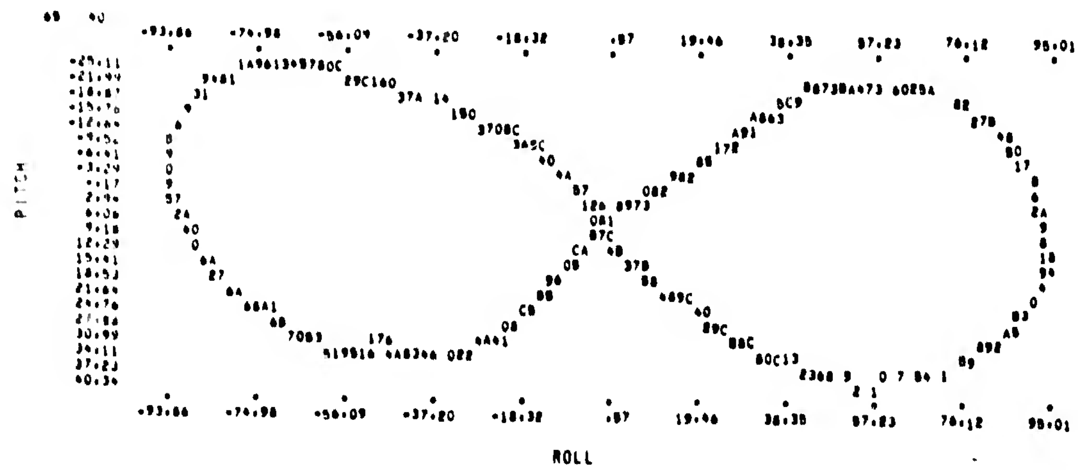


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)



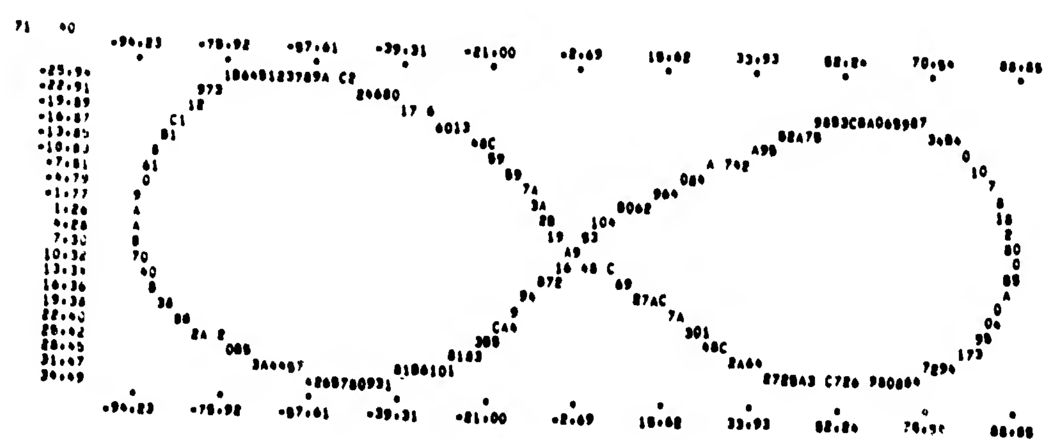
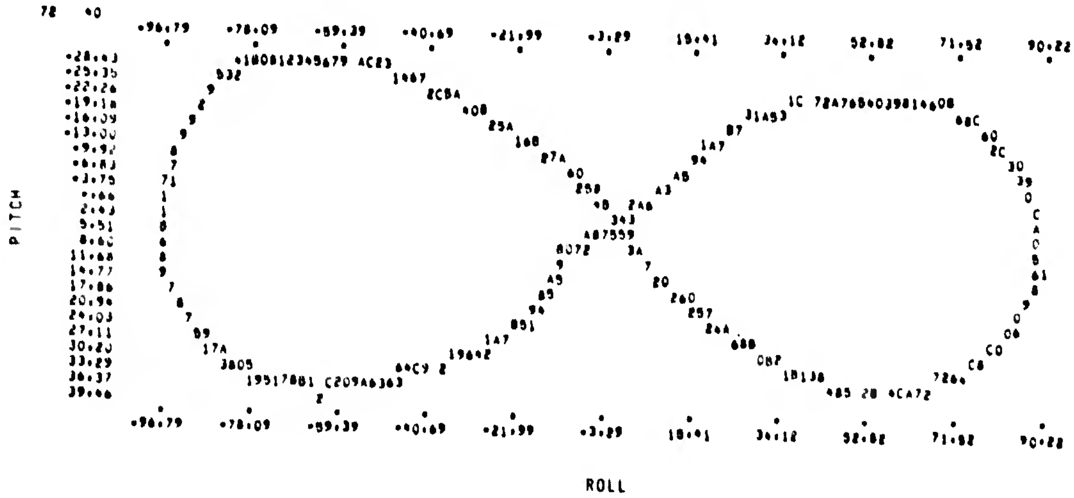
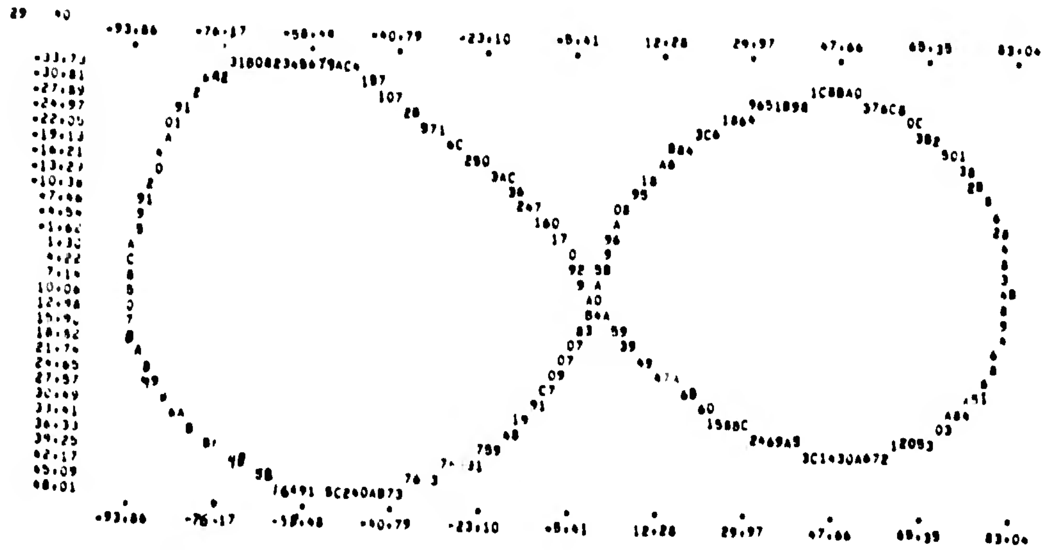


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)





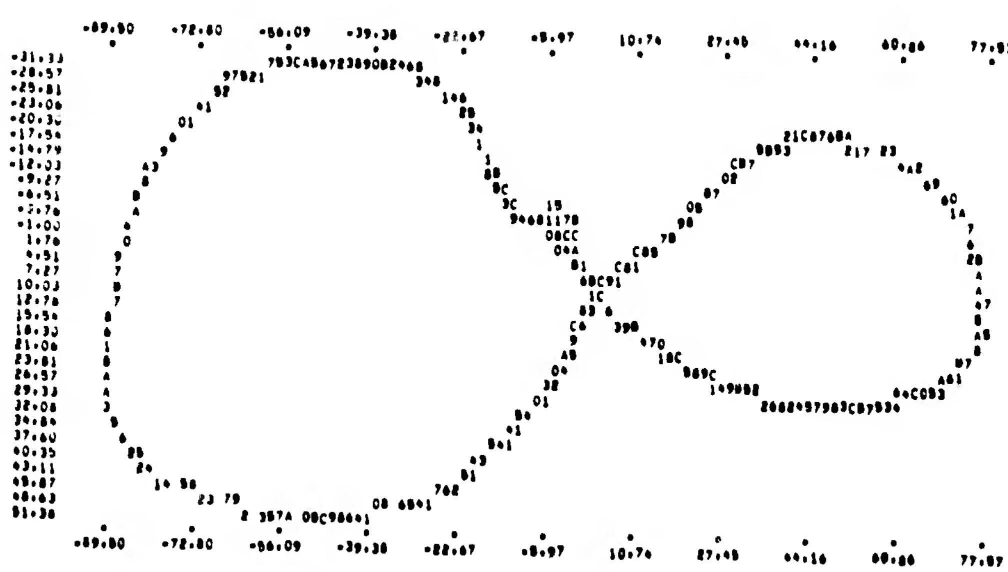
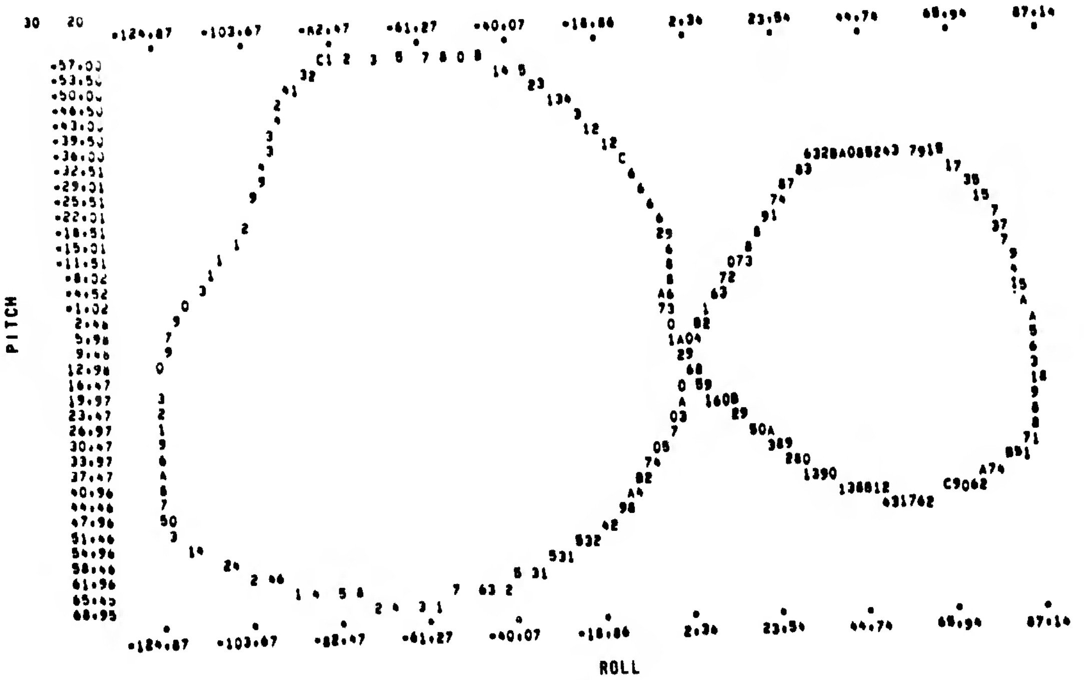
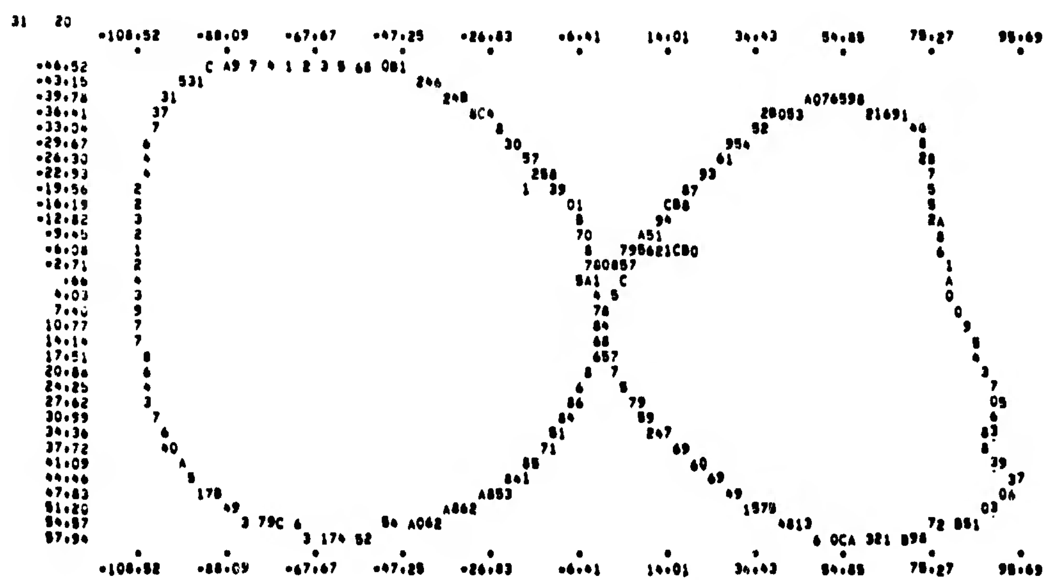


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)





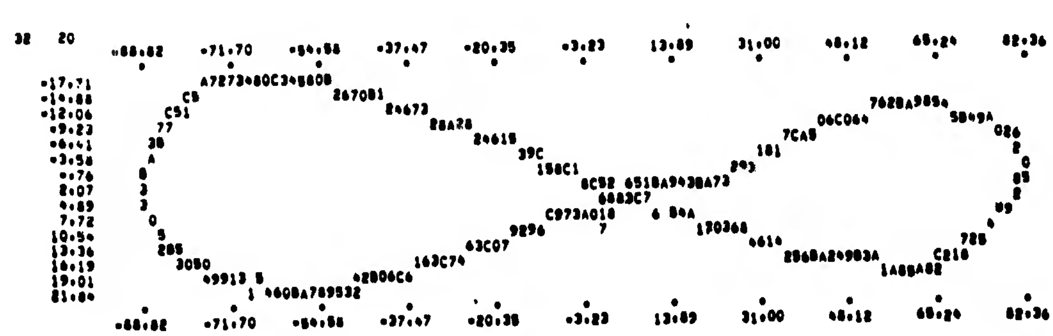


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)

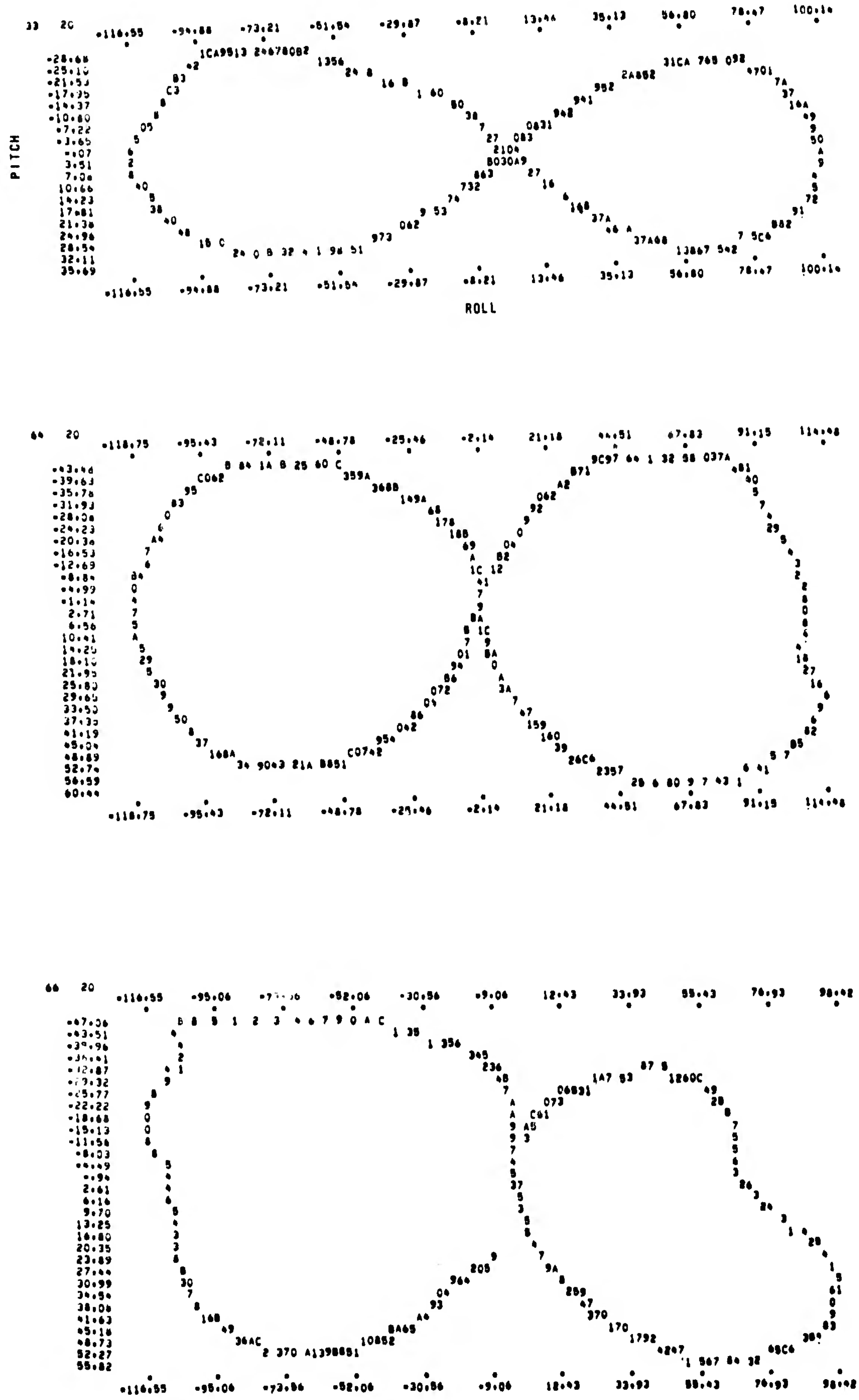
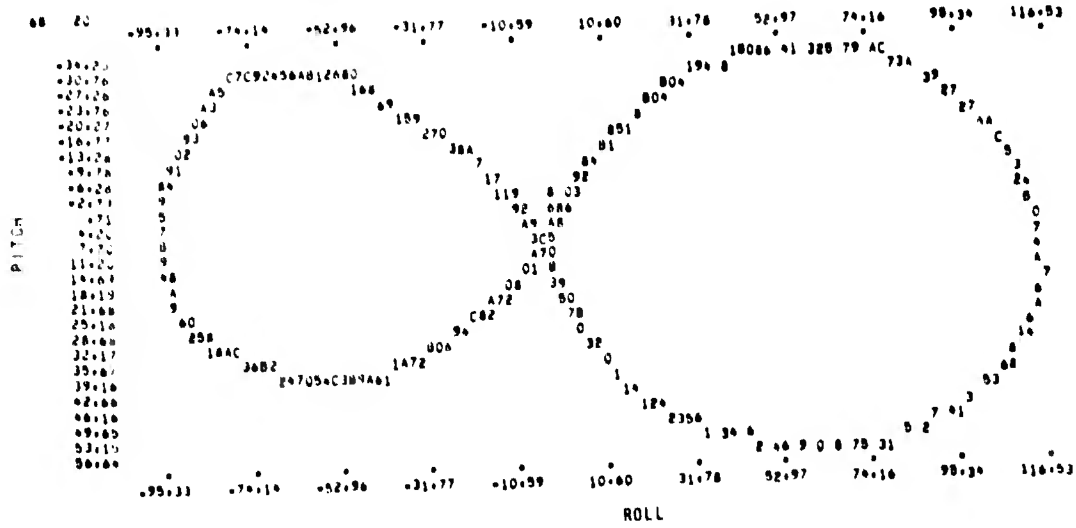
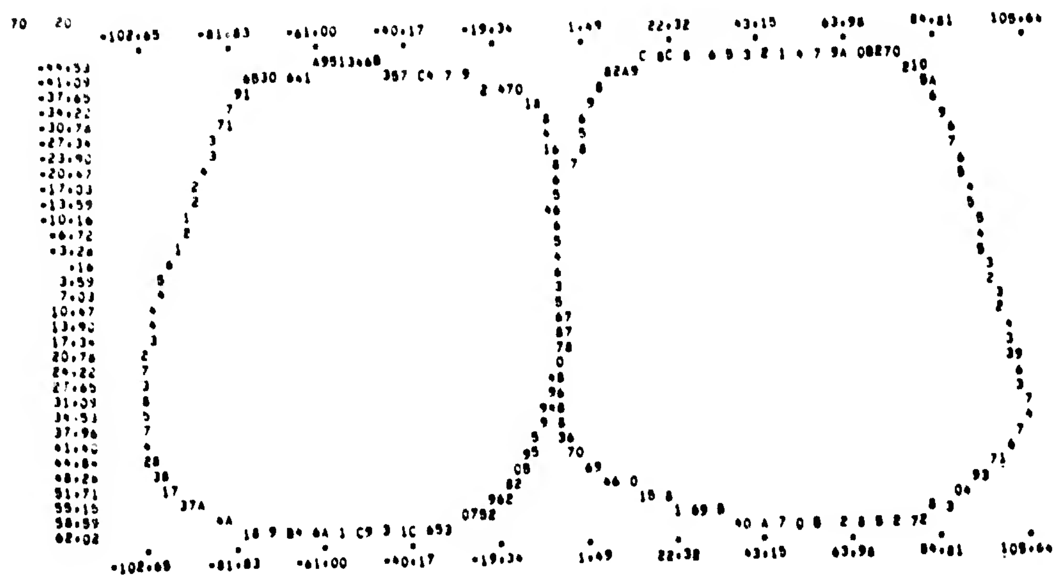


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)





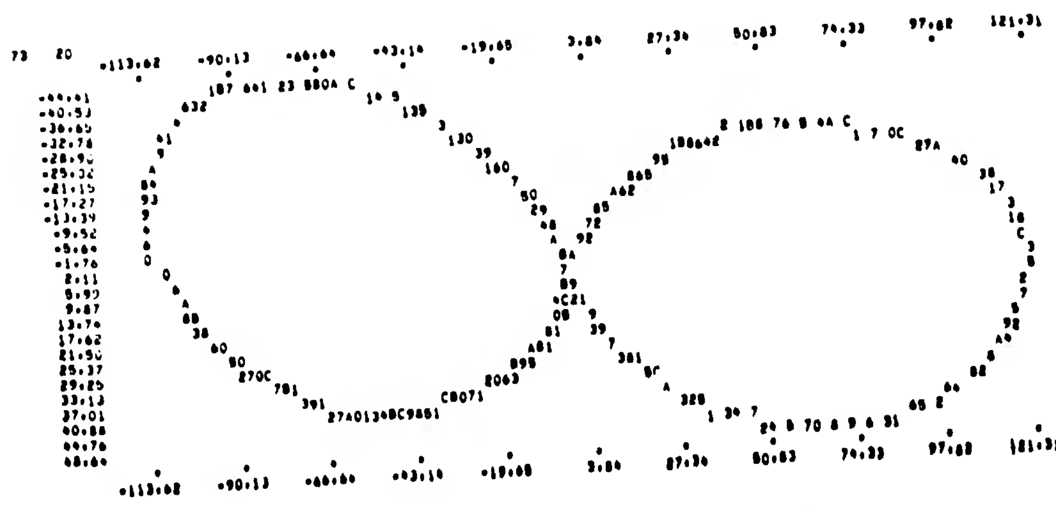


Figure 44. Trajectories of Lazy 8 Maneuver (Continued)

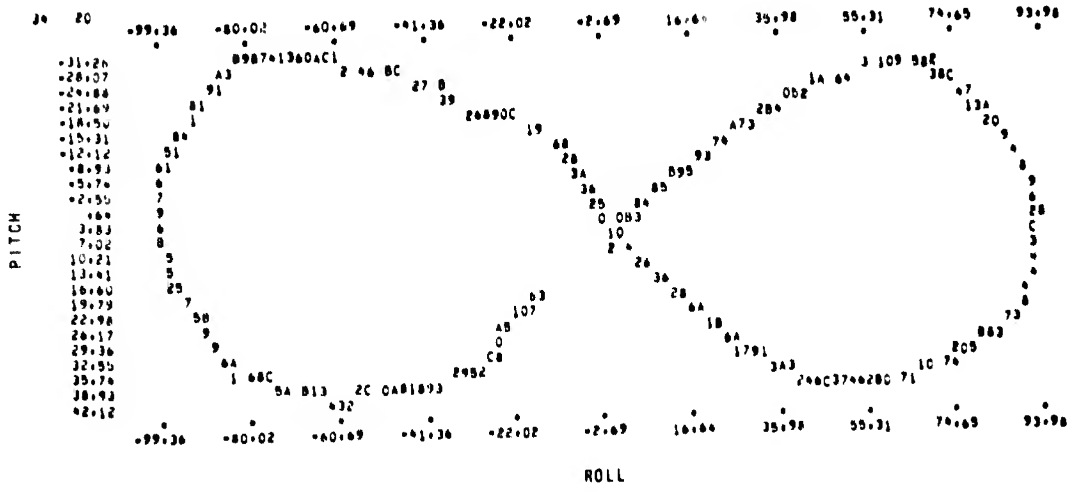


Figure 44. Trajectories of Lazy 8 Maneuver (Concluded)

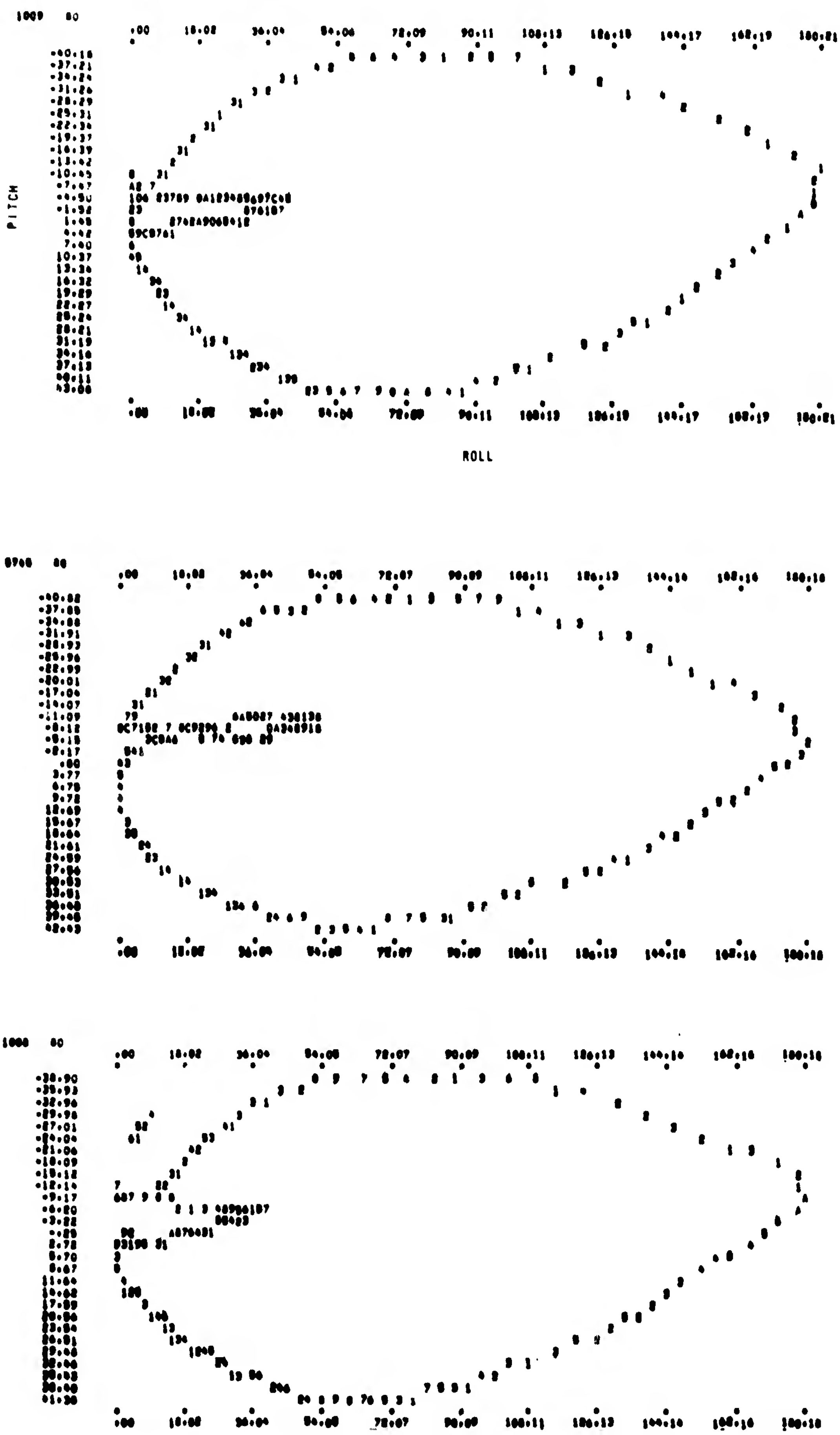


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver

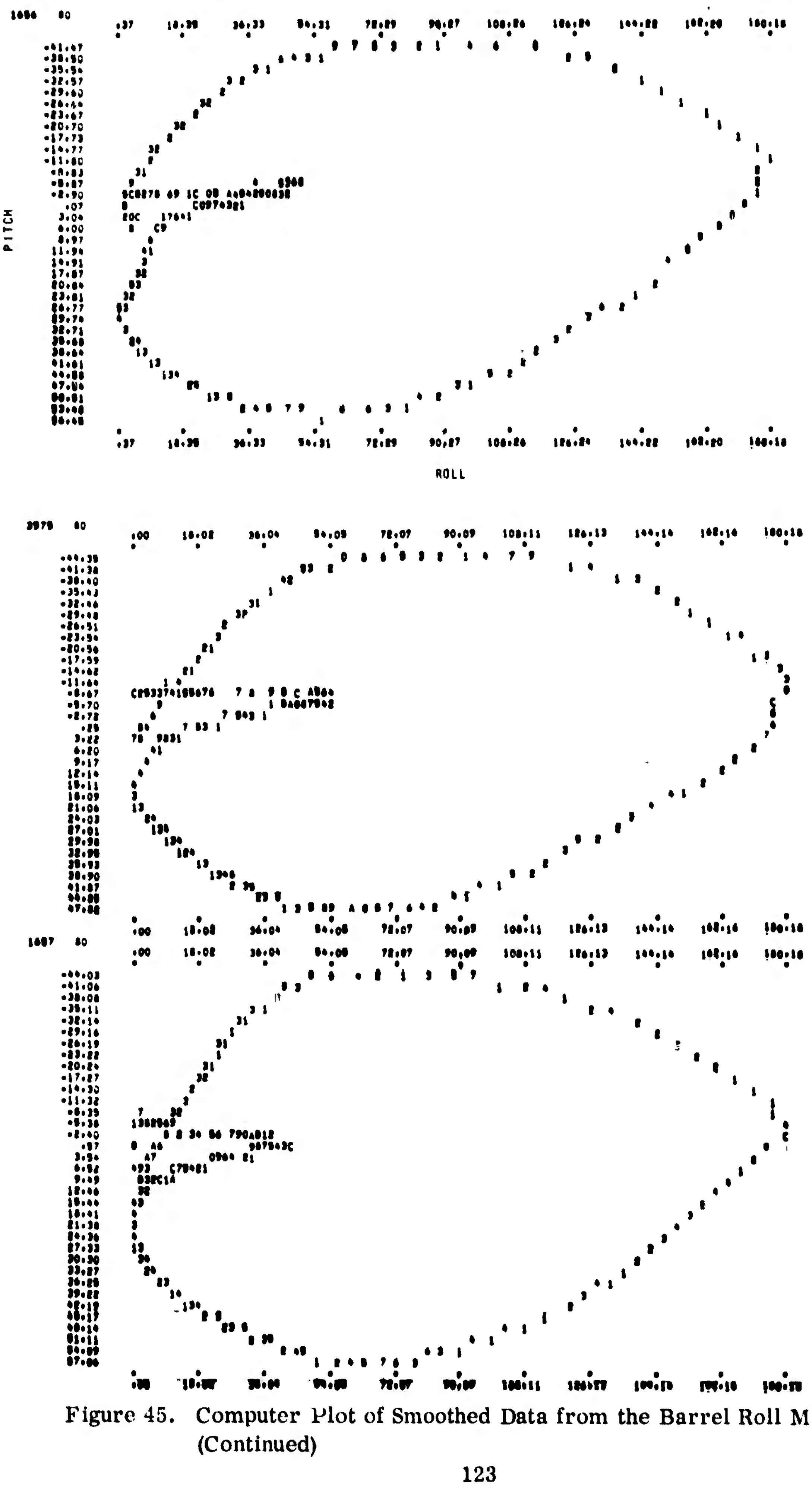


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

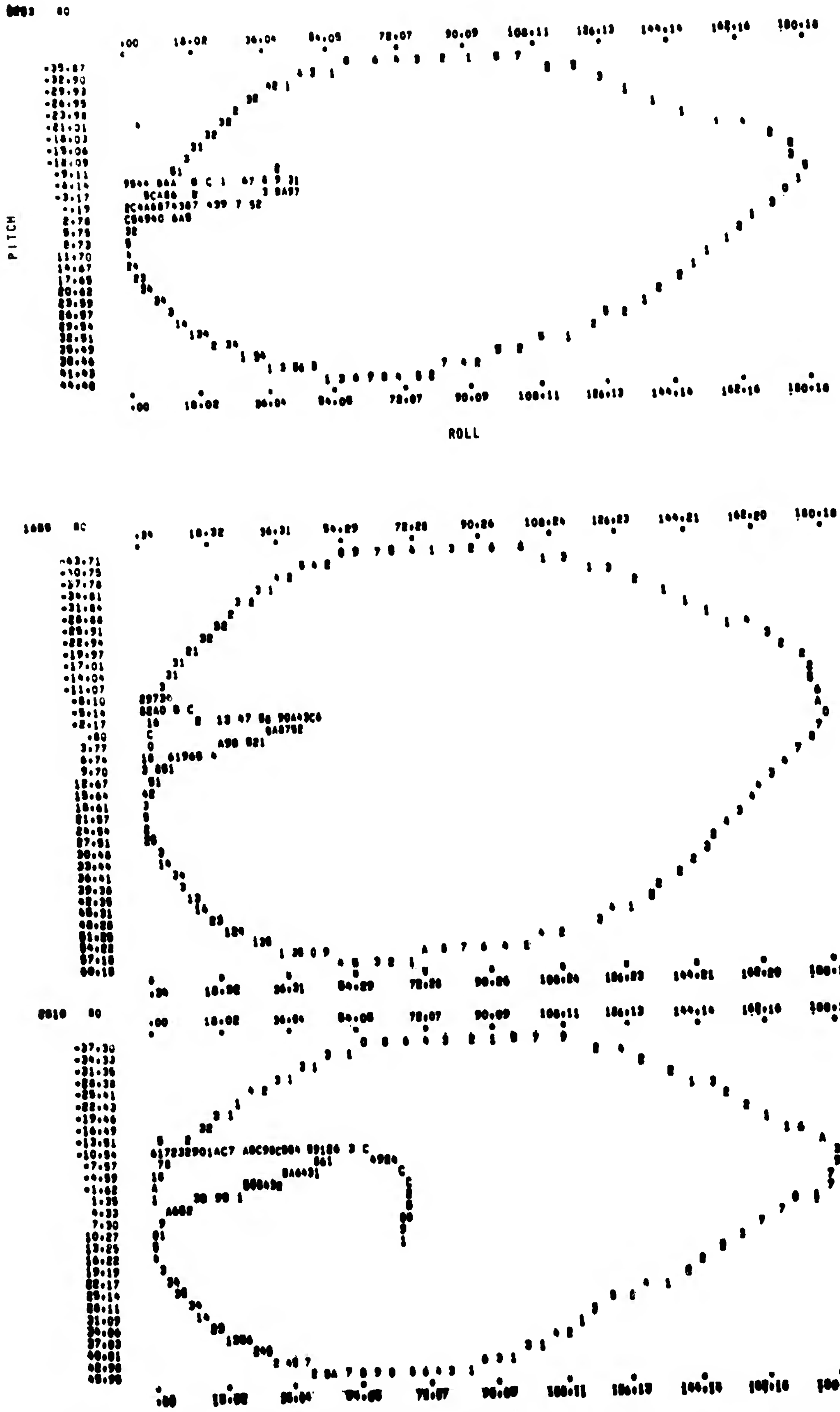


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

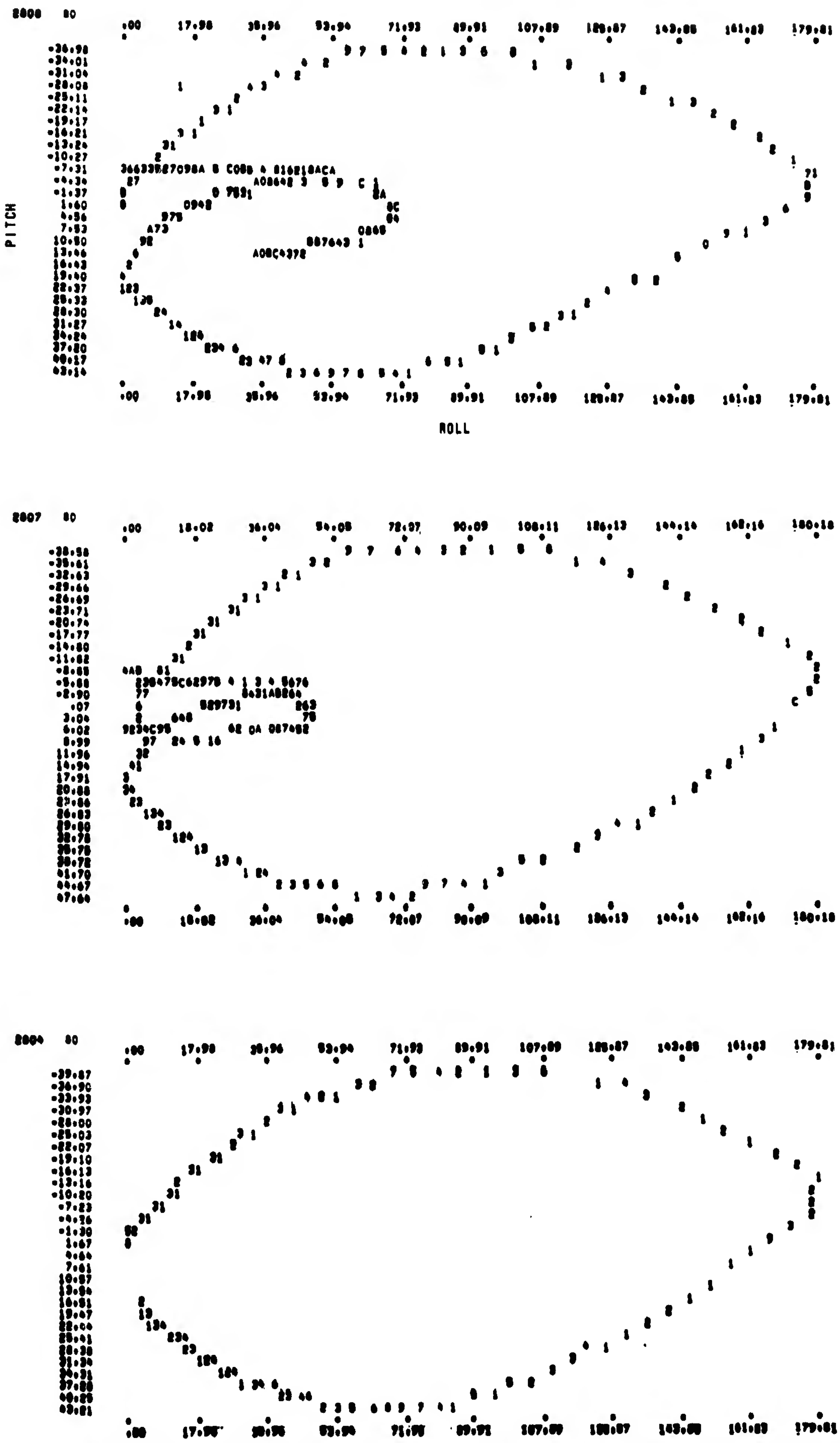


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

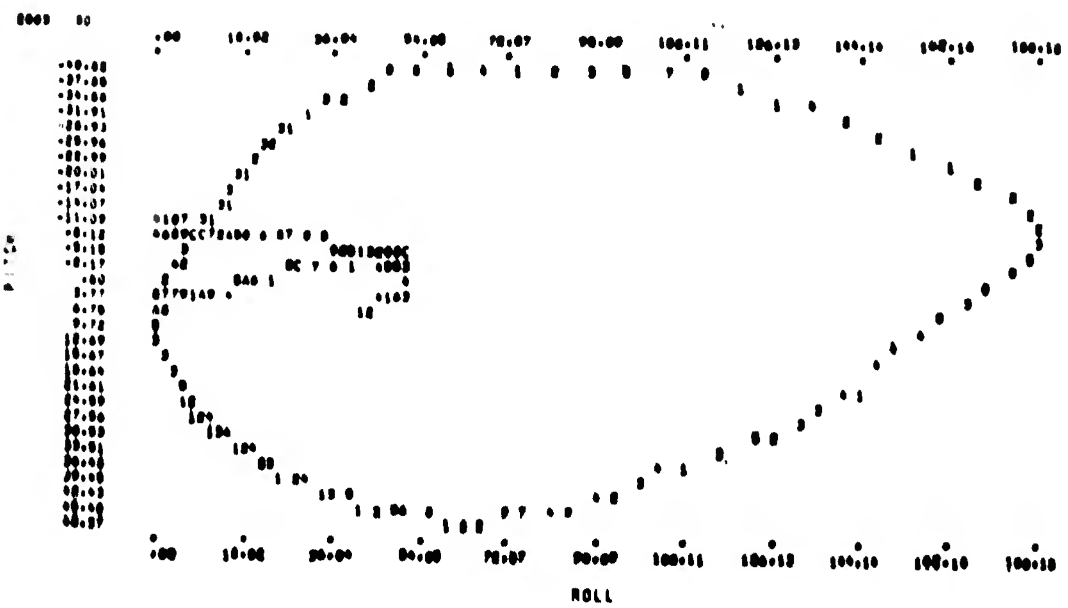


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

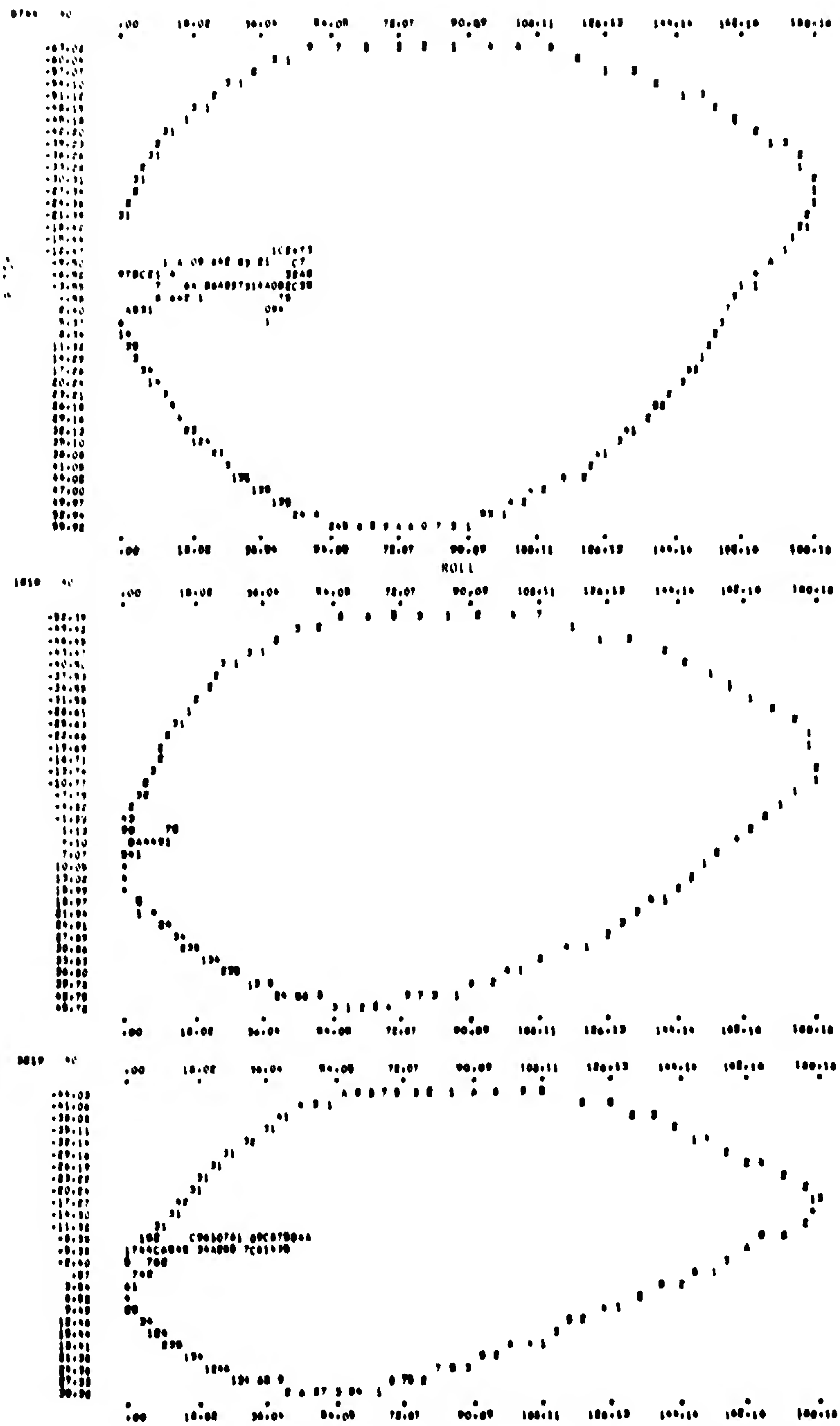


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

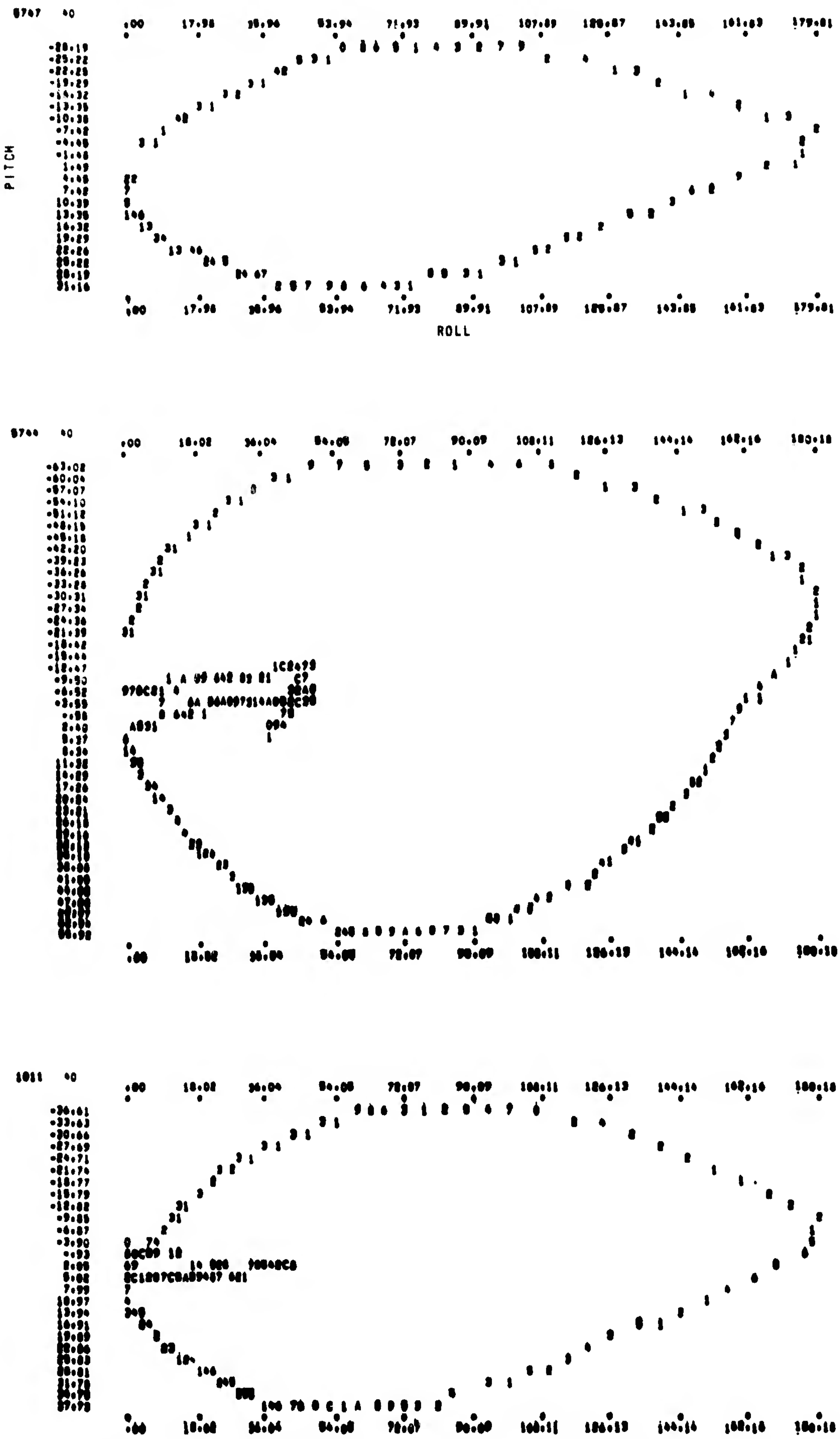


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

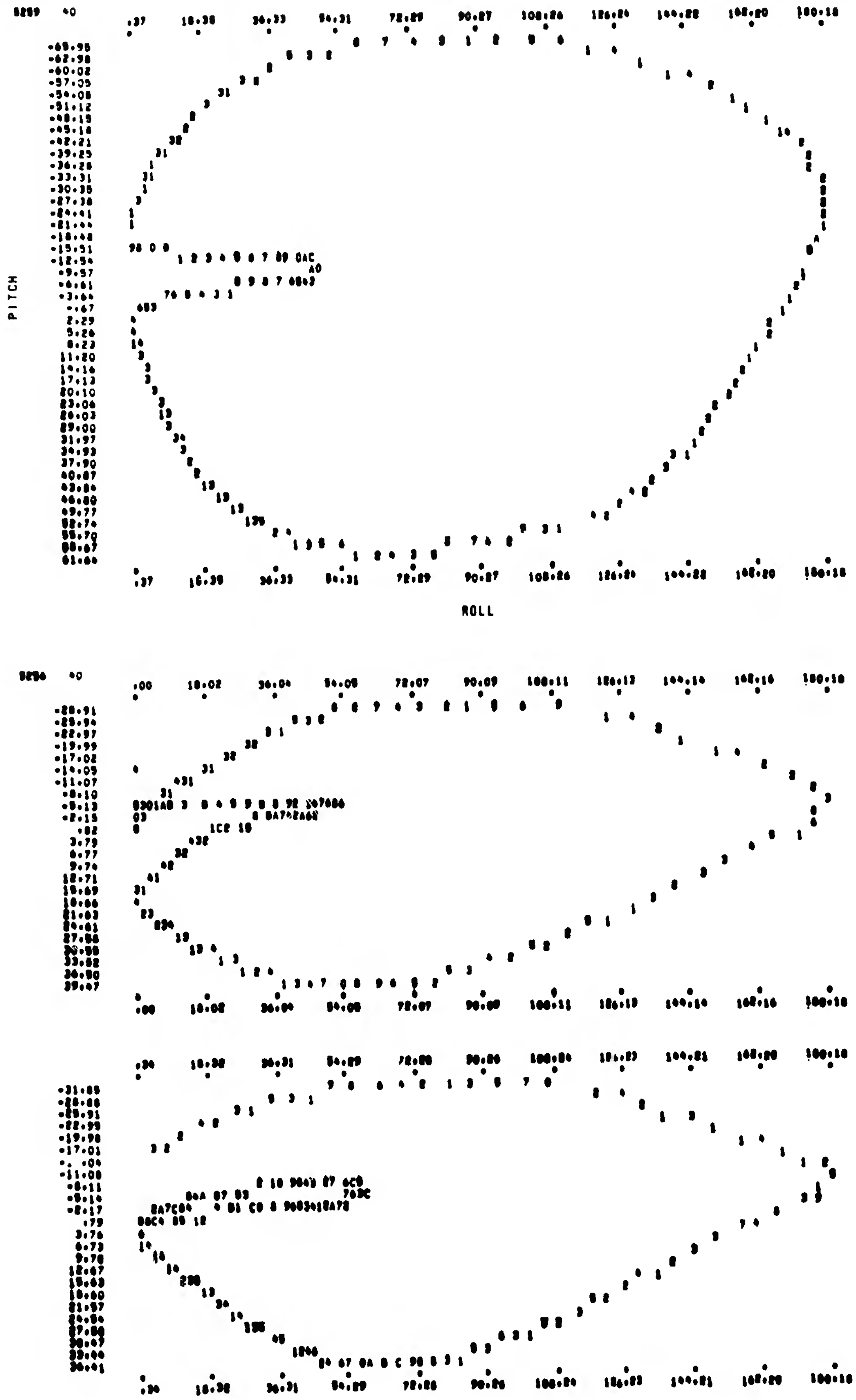


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

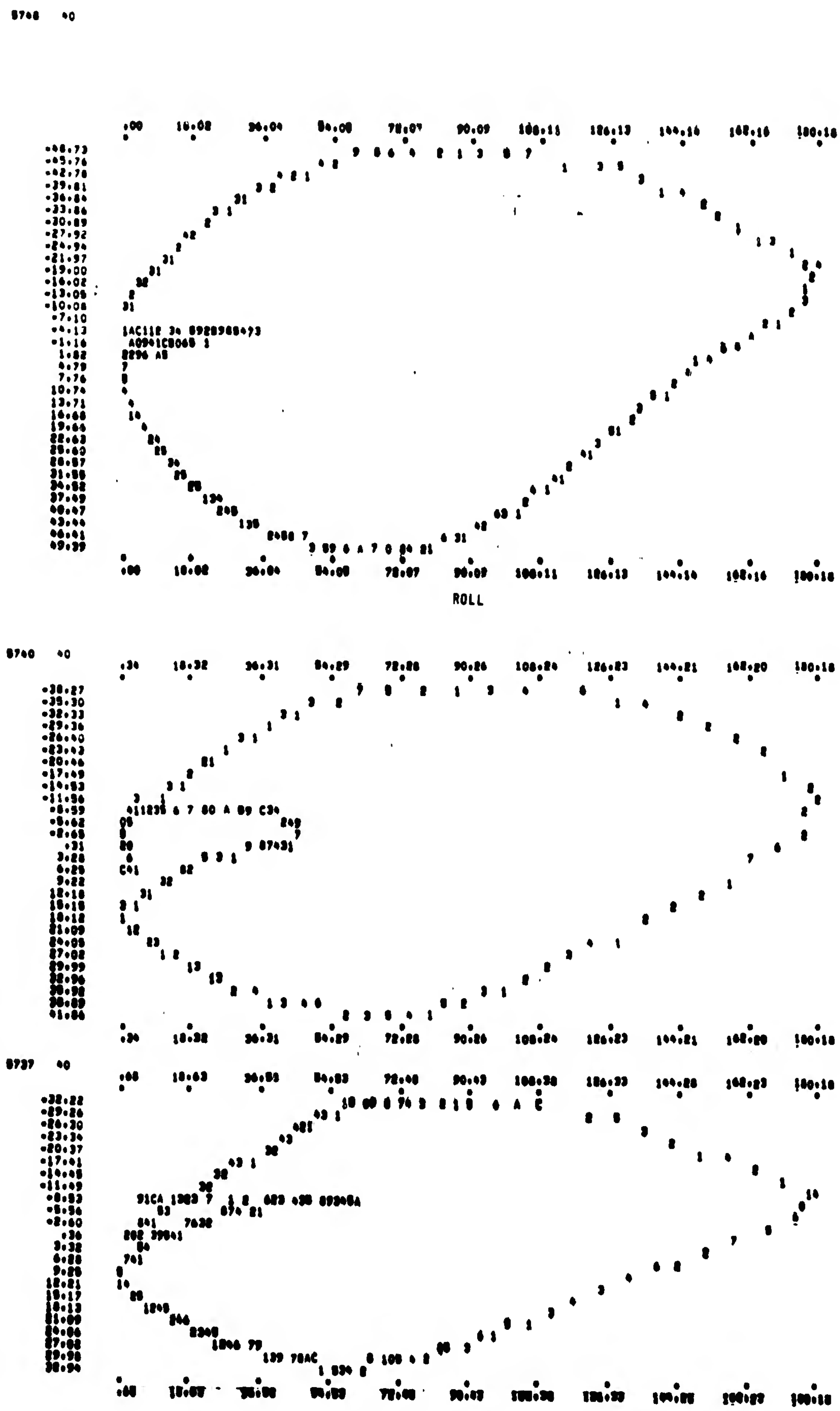


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

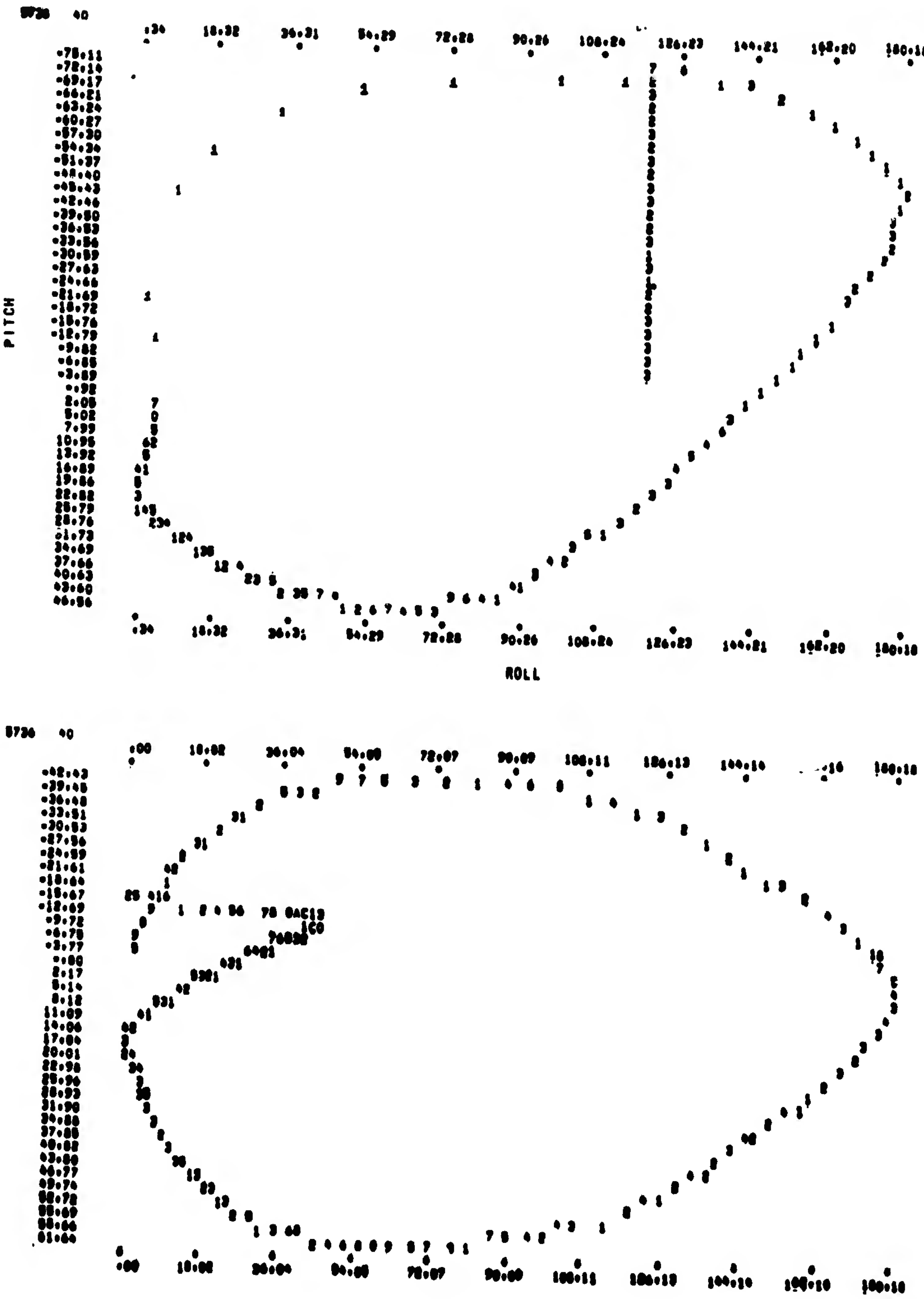


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

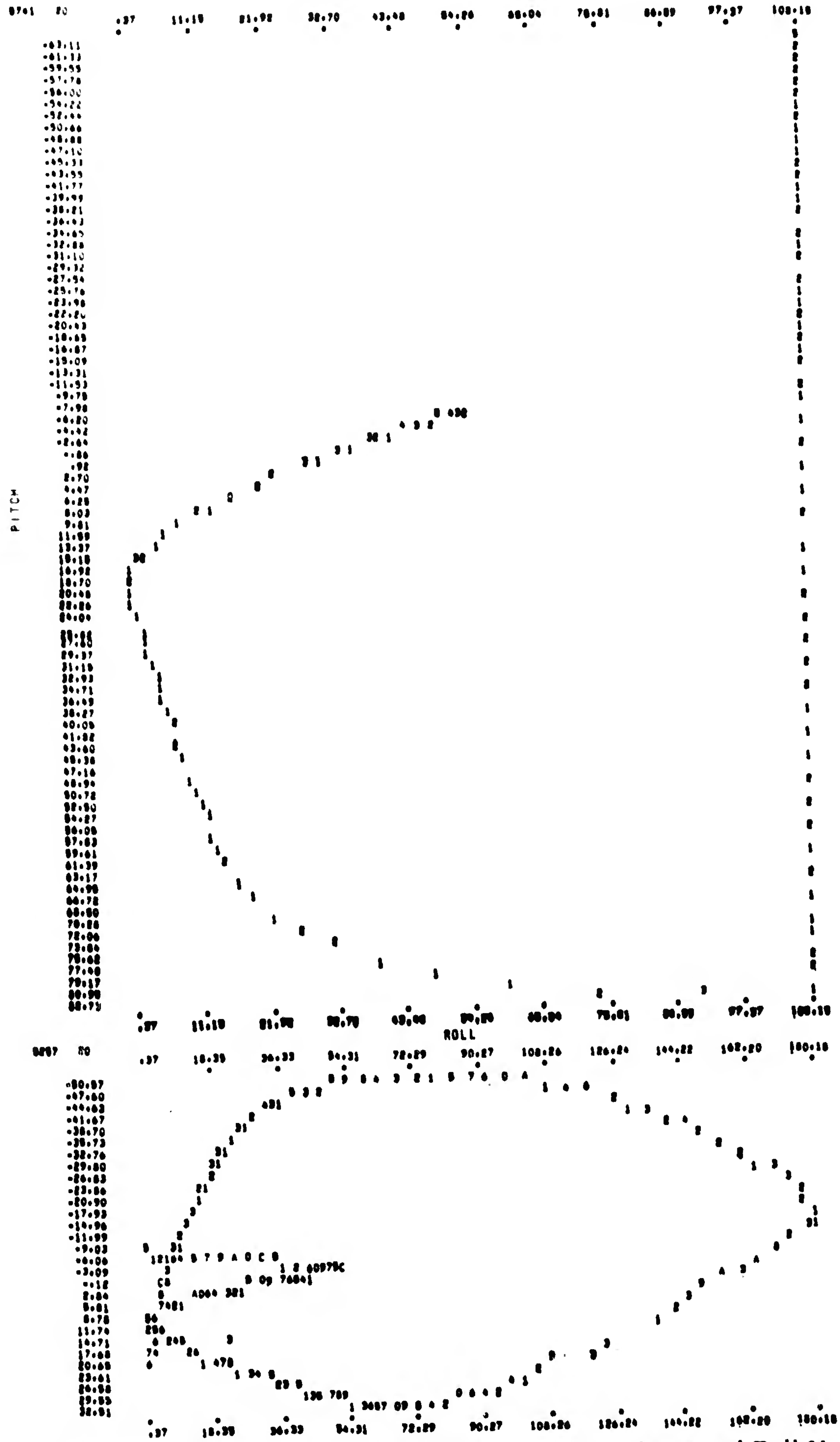


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

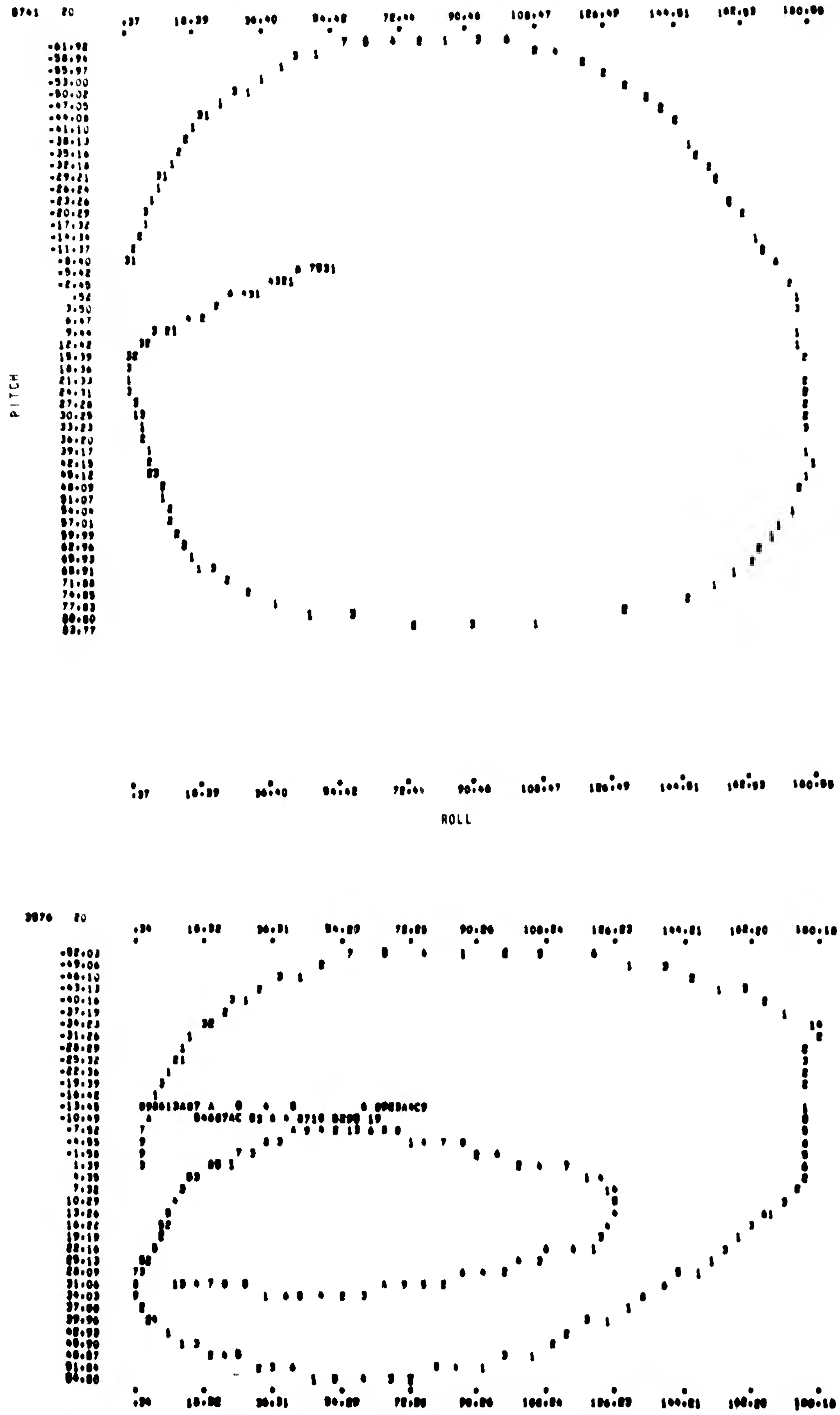
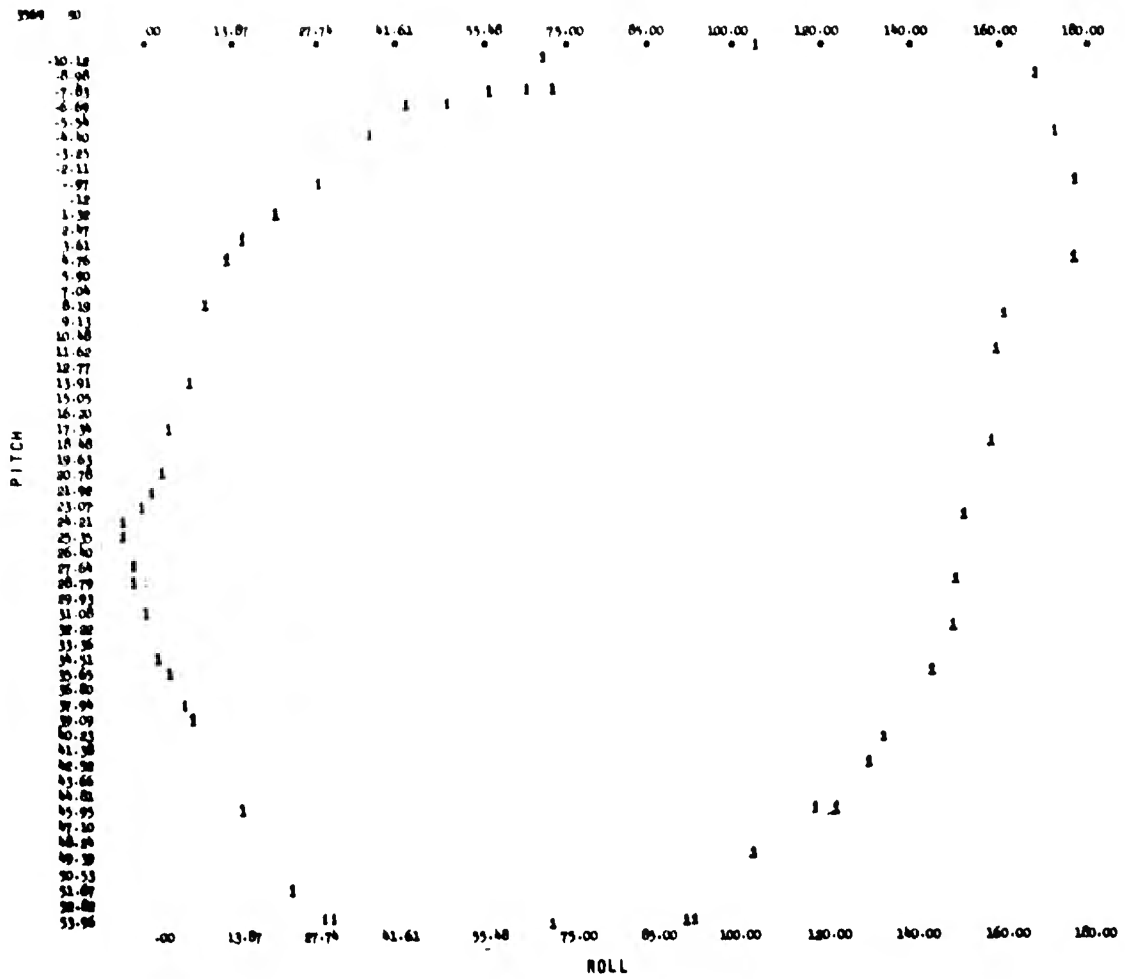


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)



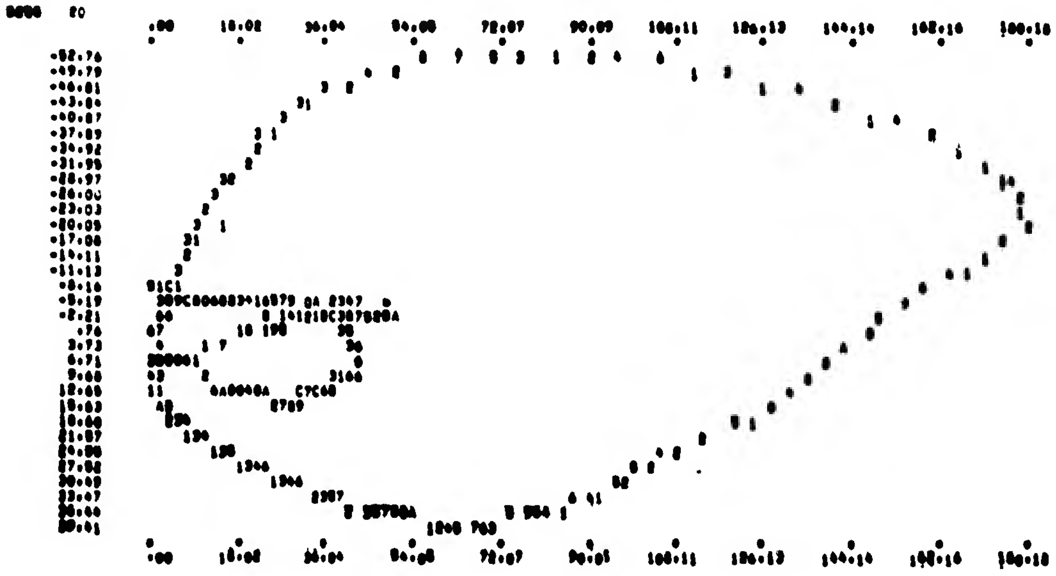


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

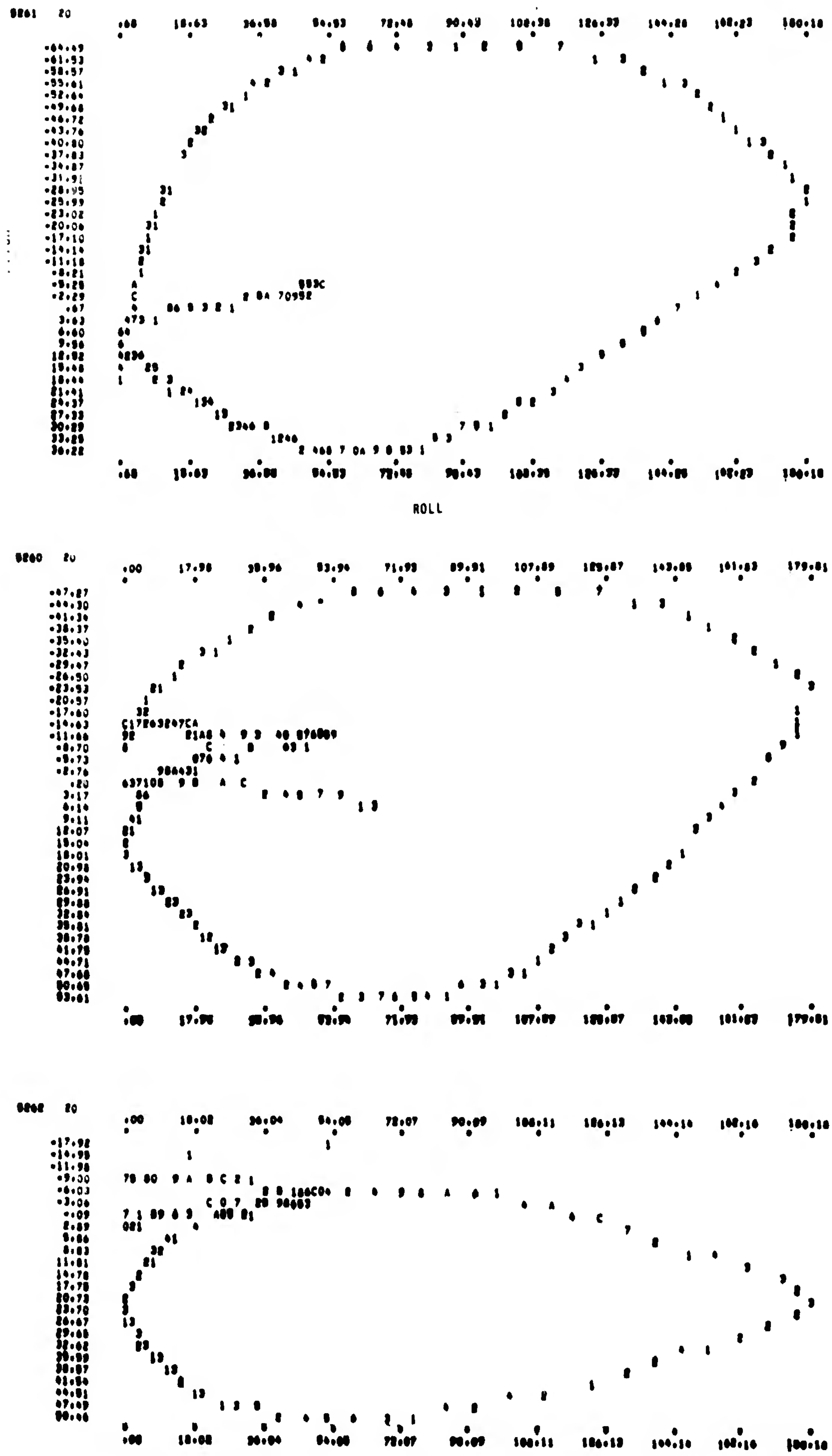


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

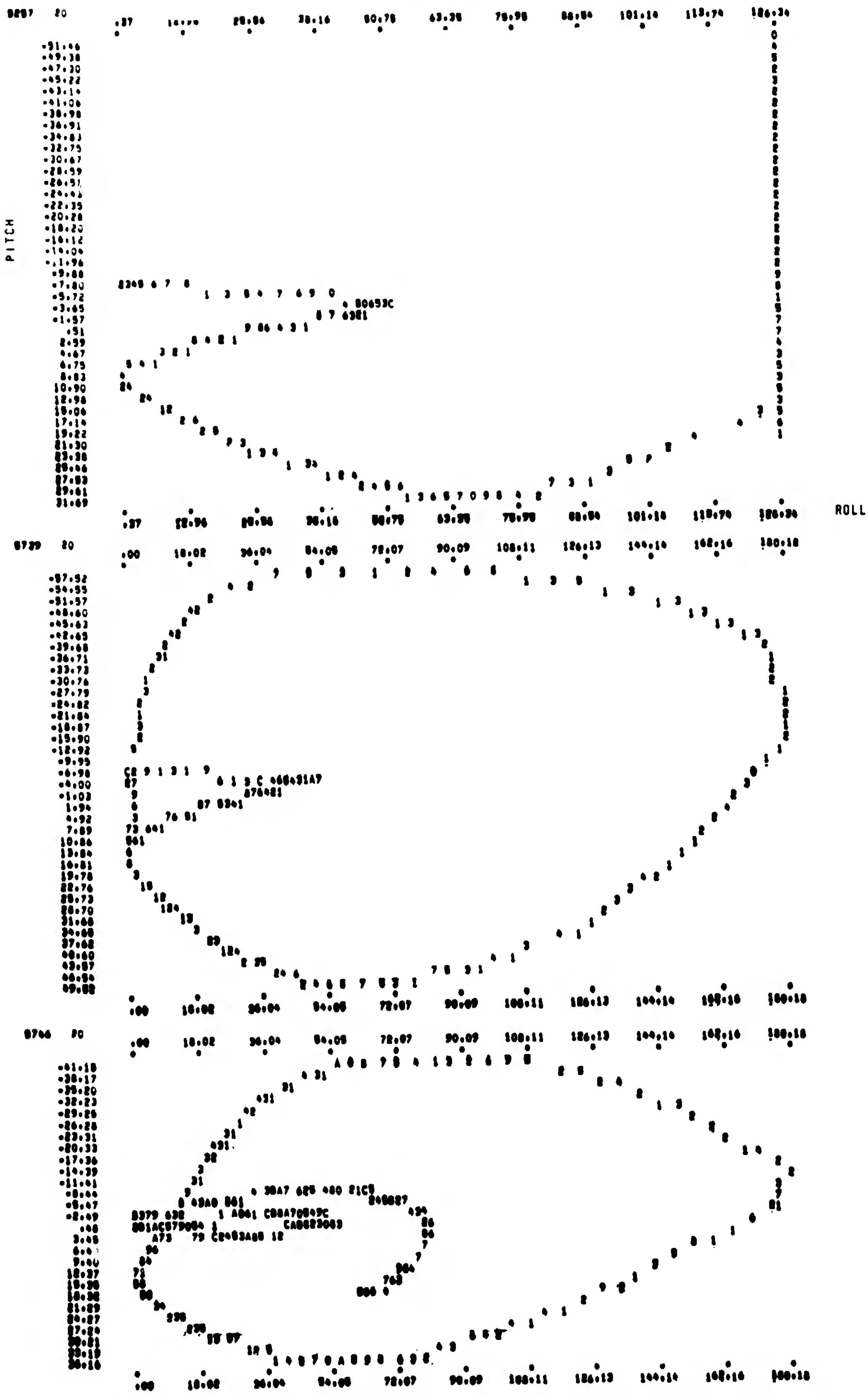


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

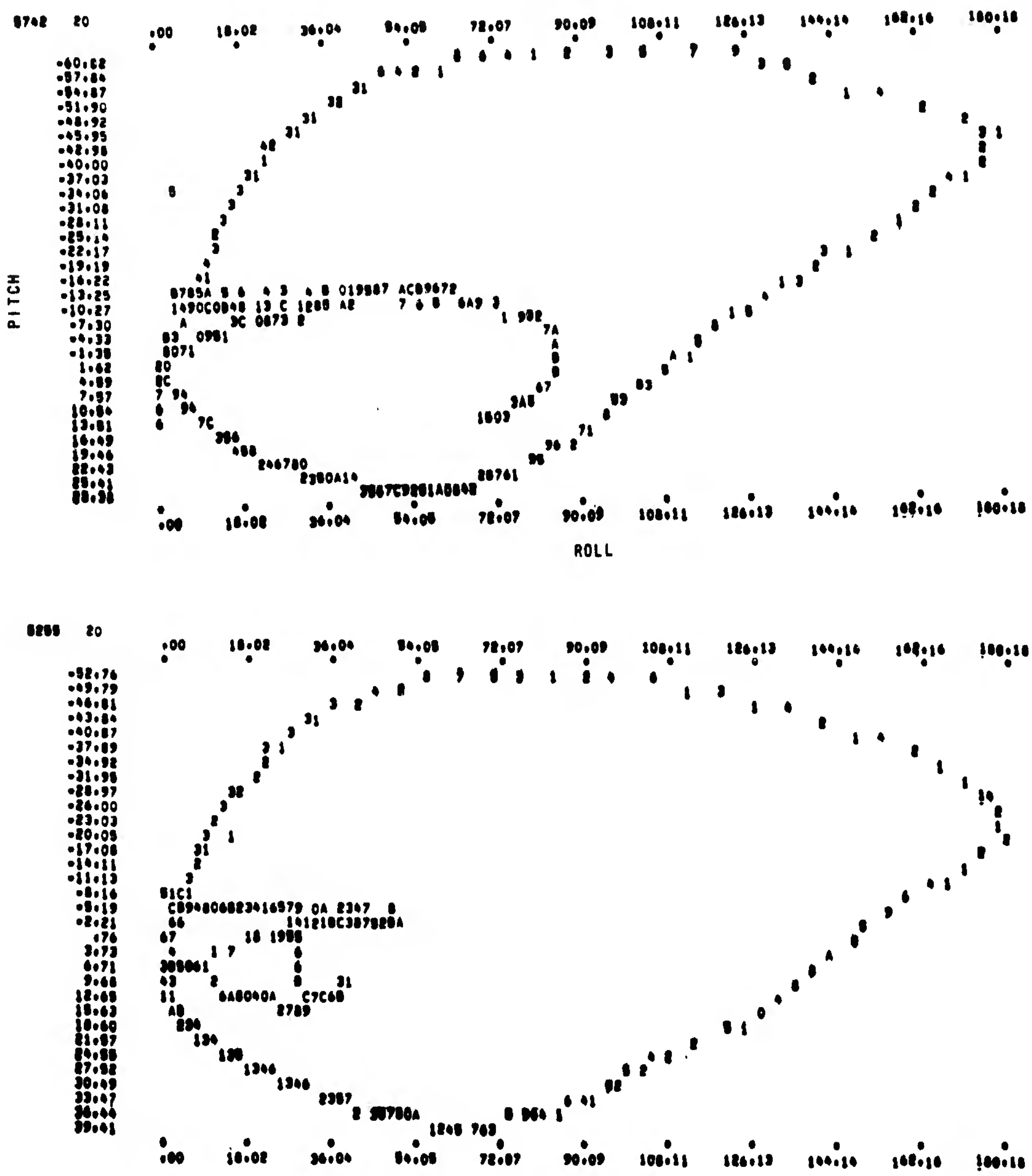


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

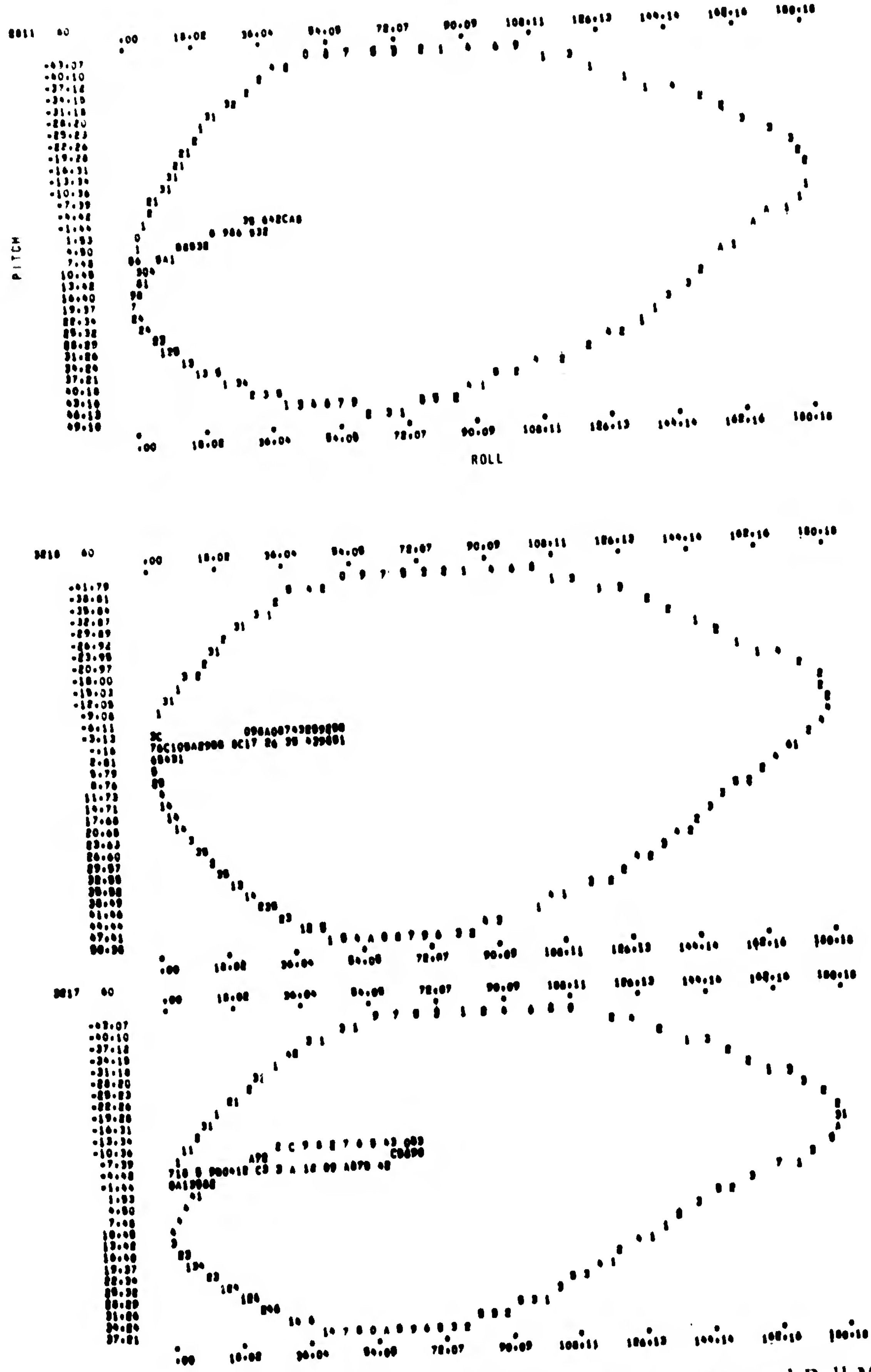


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)

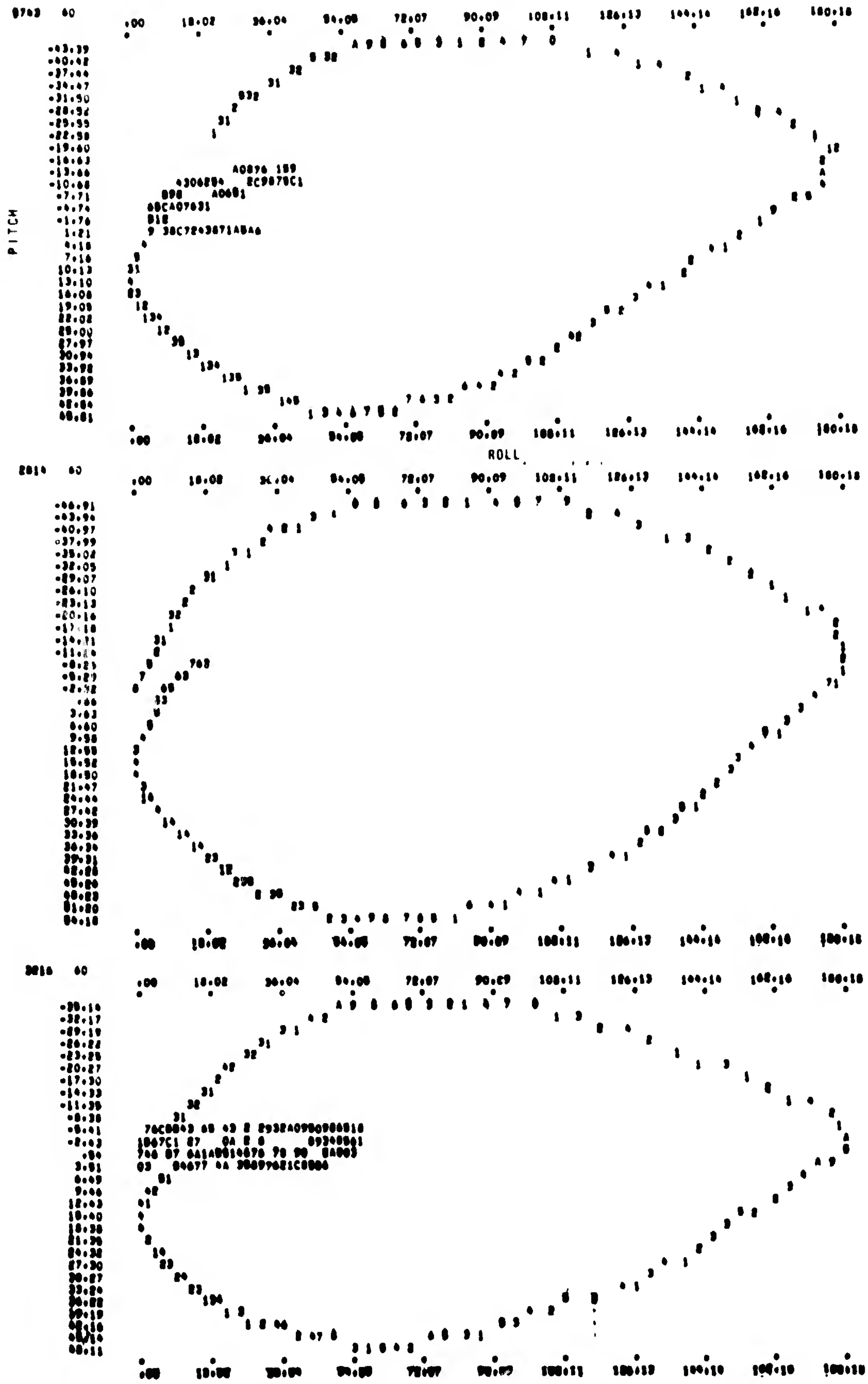
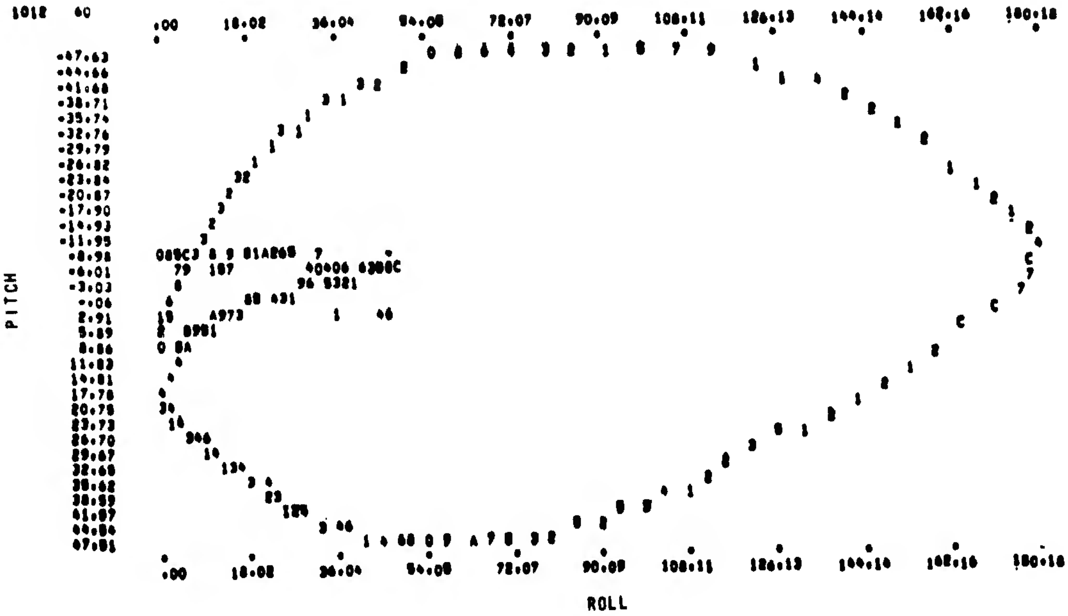


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Continued)



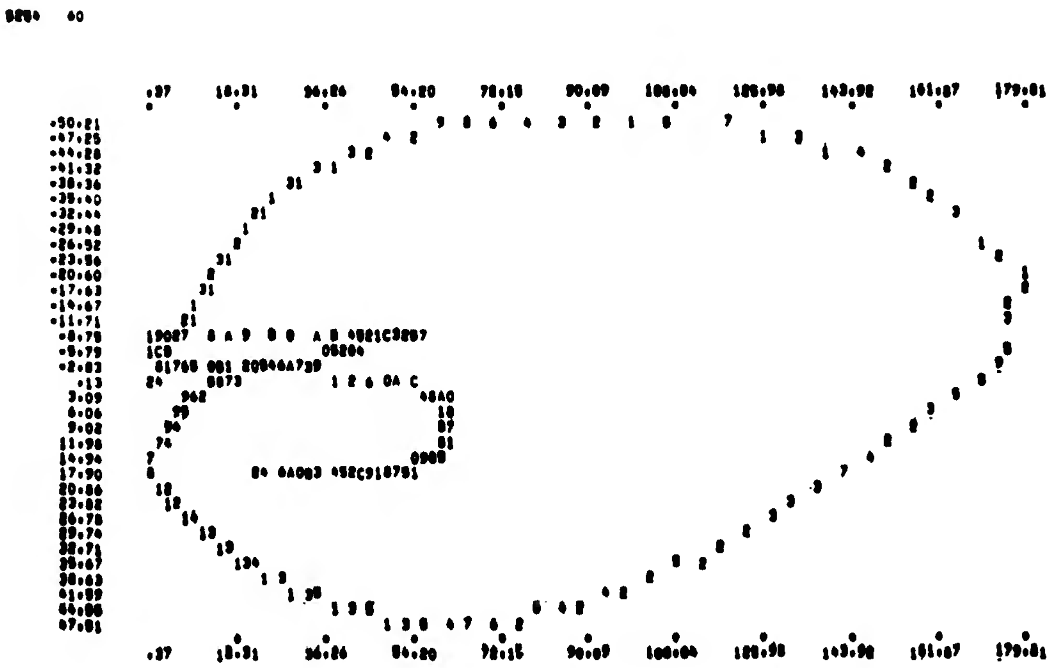


Figure 45. Computer Plot of Smoothed Data from the Barrel Roll Maneuver (Concluded)

TABLE VIII

LAZY 8 MANEUVER START AND STOP TIMES

EVENT NO.	SCORE	SAMPLES	START TIME	STOP TIME
29	40	1083	1468.90	1577.10
5	60	742	284.00	358.10
6	60	672	367.00	434.10
9	60	761	613.10	689.10
12	60	711	912.10	983.10
13	60	1131	1036.10	1149.10
16	60	681	1630.10	1698.10
20	60	951	2147.10	2242.10
21	80	881	2311.10	2399.10
62	80	901	1507.10	1597.10
163	60	841	1598.10	1682.10
58	80	748	616.40	691.10
63	40	861	1068.10	1154.10
64	20	661	1214.10	1280.10
65	40	671	1299.10	1366.10
66	20	561	1419.10	1475.10
48	80	792	320.00	399.10
67	80	881	1620.10	1708.10
68	20	851	1751.10	1836.10
71	40	611	2058.10	2119.10
72	40	681	2138.10	2206.10
73	20	551	2234.10	2289.10
74	80	791	2320.10	2399.10

TABLE VIII

LAZY 8 MANEUVER START AND STOP TIMES (Continued)

EVENT NO.	SCORE	SAMPLES	START TIME	STOP TIME
85	60	731	153.10	226.10
86	60	736	229.10	302.60
87	80	772	304.00	381.10
93	60	791	667.10	746.10
94	60	671	772.10	839.10
34	20	611	1136.10	1197.10
84	60	698	71.40	141.10
70	20	611	1977.10	2038.10
26	40	841	246.10	330.10
27	40	842	407.00	491.10
28	40	762	506.00	582.10
30	20	731	766.10	839.10
31	20	791	849.10	928.10
32	20	681	969.10	1037.10
33	20	591	1067.10	1126.10
35	60	731	1226.10	1299.10
59	60	821	1343.10	1425.10
45	60	851	14.10	99.10
46	40	771	105.10	182.10
47	80	711	230.10	301.10
49	80	912	415.00	506.10
50	60	961	550.10	646.10
51	60	789	647.30	726.10
54	60	771	833.10	910.10

TABLE IX

BARREL ROLL MANEUVER START AND STOP TIMES

EVENT NO.	SCORE	SAMPLES	START TIME	STOP TIME
1009	80	582	450.00	508.10
1010*	40	502	511.00	561.10
1011	40	428	564.40	607.10
1012	60	511	613.10	664.10
2803	80	551	93.10	148.10
2804	80	211	199.10	220.10
2807	80	472	452.00	499.10
2808	80	482	510.00	558.10
2810	80	529	700.30	753.10
2811	60	401	855.10	895.10
2814	60	311	1162.10	1193.10
1655	80	531	932.10	985.10
5736	40	390	1500.20	1539.10
5737	40	401	1559.10	1599.10
5738	40	321	1613.10	1645.10
5739	20	431	1677.10	1720.10
5740	40	281	1761.10	1789.10
5741*	20	271	1827.10	1854.10
5742	20	671	1872.10	1939.10
5743	60	460	2025.20	2071.10
5744	40	551	2095.10	2150.10
5745	80	391	2191.10	2230.10
5746	20	531	2248.10	2301.10

*Not used in model study

TABLE IX

BARREL ROLL MANEUVER START AND STOP TIMES (Continued)

EVENT NO.	SCORE	SAMPLES	START TIME	STOP TIME
5747	40	221	2371.10	2393.10
5748	40	521	2438.10	2490.10
5749	40	431	2530.10	2573.10
5253	80	570	68.20	125.10
5254	60	521	139.10	191.10
5255*	20	681	234.10	302.10
5256	40	412	329.00	370.10
5257*	20	382	432.00	470.10
5259	40	378	728.40	766.10
5260	20	479	795.30	843.10
5261	20	341	877.10	911.10
5262	20	301	988.10	1018.10
3575	80	481	2483.10	2531.10
3576	20	491	2548.10	2597.10
1657	80	571	1081.10	1138.10
1656	80	511	1006.10	1057.10
1008	80	521	392.00	444.00
3569	20	550	1848.20	1903.10
3216	60	611	1719.10	1780.10
3217	60	371	1811.10	1848.10
3218	60	391	1882.10	1921.10
3219	40	451	2038.10	2083.10
1010	40	317	529.50	561.10

*Not used in model study

TABLE IX

BARREL ROLL MANEUVER START AND STOP TIMES (Continued)

EVENT NO.	SCORE	SAMPLES	START TIME	STOP TIME
5741	20	271	1827.10	1854.10
5255	20	681	234.10	302.10
5257	20	382	432.00	470.10

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APPENDIX III

BINARY VALUED FUNCTIONS, TRANSFORMS, AND SEQUENCES

Discrete Walsh Transform

The Walsh functions are a complete orthogonal set of functions which have been employed by scientific investigators in recent years in speech recognition, signal classification and related areas. The prevalence and obvious importance of resonance, Doppler and other frequency-related phenomena have indicated the need for the Fourier transform in much of the research performed in signal analysis and processing. Moreover, the Fast Fourier transform, an innovation, has made a great impact on signal-analysis techniques by providing an efficient way of replacing time domain convolution with multiplication in the frequency domain. Utilization of this one property has altogether changed the costs and computing effort involved with performing autocorrelation, power spectrum, and digital filtering operations.

The impact of the Fast Fourier transform has resulted in an increased awareness on the part of investigators of the value of transform techniques in signal analysis and has led to the consideration of the possible utility of other transforms as well.

One of these transforms is the discrete Walsh transform which is the subject of this discussion.

Walsh Functions and the Discrete Walsh Transform

The Walsh functions have been defined (Reference 2) over the interval (0, 1) as the successive modulation, in various combinations, of a set of square waves $\Psi_p(t)$, $p = 2^n$, $n = 0, 1, 2, \ldots, r$, where p designates the number of periods in the interval. For $p = 0$, $\Psi_0(t) \triangleq 1$, for $0 < t < 1$ ($\triangleq$ means "defined as"). Replacing p by its equivalent "r" bit binary number, the waveform of a particular Walsh function is specified as the product of those Walsh functions represented by each "1" in its binary subscript. Letting r = 2, for example, $\Psi_{11} = (\Psi_{01})(\Psi_{10})$ is seen to be the modulation of Ψ_{01} by Ψ_{10} (see figure 46).

These functions form a complete orthogonal set which can be expressed as the kernel of an integral transform known as the Walsh transform:

$$w(p) = \int_0^T f(t)\, \Psi(p, t)\, dt.$$

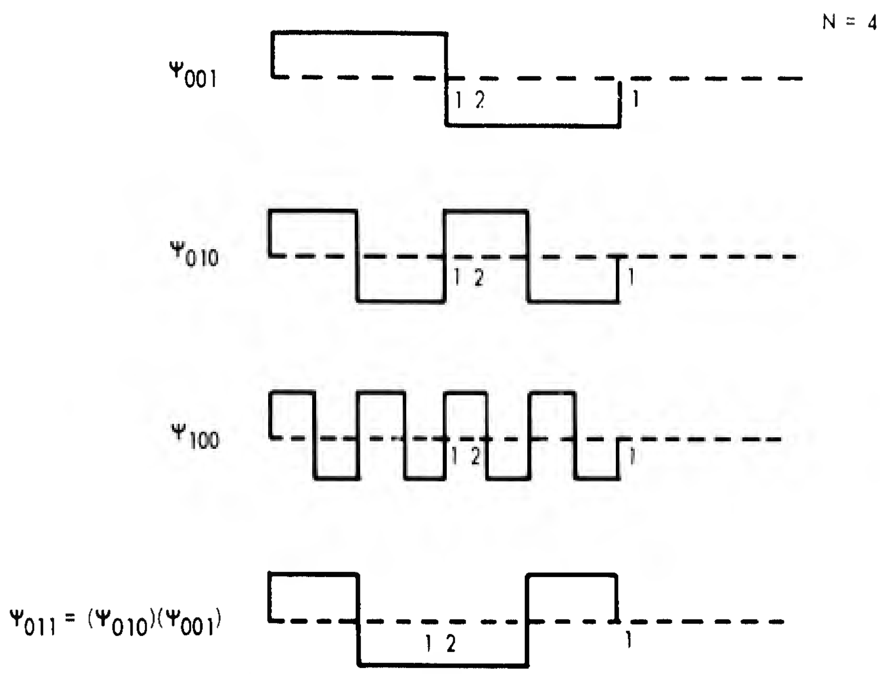

Figure 46. Walsh Functions

N= 8

Ψ_{000}	1	1	1	1	1	1	1	1
Ψ_{001}	1	1	1	1	-1	-1	-1	-1
Ψ_{010}	1	1	-1	-1	1	1	-1	-1
Ψ_{011}	1	1	-1	-1	-1	-1	1	1
Ψ_{100}	1	-1	1	-1	1	-1	1	-1
Ψ_{101}	1	-1	1	-1	-1	1	-1	1
Ψ_{110}	1	-1	-1	1	1	-1	-1	1
Ψ_{111}	1	-1	-1	1	-1	1	1	-1

Figure 47. Walsh Matrix N = 8

$$H_8 = \begin{pmatrix} H_4 & H_4 \\ H_4 & -H_4 \end{pmatrix} = \left(\begin{array}{cccc|cccc} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ \hline 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{array}\right)$$

Figure 48. Hadamard Matrix

Just as in the Fourier series representation of periodically extended signals, the dimensionality of the set of Walsh functions can be made finite for bandwidth-limited signals without loss of information. Due to the nature of their generation, the dimensionality is chosen as some power of $N = 2^n$, $n = 2, 3, \ldots$, with the set for $N = 8$ shown in figure 47.

We know from the sampling theorem that a signal, band limited to B cycles over the interval 0 to T, can be accurately represented by a 2TW-2TB dimensional signal vector $\vec{S}$. Unlike many orthogonal sets, the set of sampled Walsh functions becomes an orthogonal N-by-N matrix "W" in discrete time where $N = 2TB$. The matrix "W" is known as a Walsh matrix (figure 47), and all elements of W are +1's or -1's. As a point of interest, the sets of functions in the Fourier expansion (sines and cosines) also retain their orthogonality when sampled at equally spaced time intervals, resulting in a Fourier matrix or discrete Fourier transform.

The discrete time analogy of the integral transform then becomes:

$$\vec{W} = W\vec{S}, \quad \vec{S} \,\Delta\, \text{column vector.}$$

The sampled Walsh functions can be shown to be identical (Reference 3) to the rows of an N-by-N orthogonal matrix (known as a Hadamard matrix) except for ordering of the rows. The rows of the Hadamard matrix are related to those of the Walsh matrix by the binary bit reversal mapping which, illustrated for the case of N = 4, is:

WALSH		HADAMARD		
BASE 10		BASE 2		BASE 10
0		0 0 → 0 0		0
1	=	0 1 → 1 0	=	2
2		1 0 → 0 1		1
3		1 1 → 1 1		3

The Hadamard matrix provides for a different interpretation of Walsh functions as well as an efficient algorithm for computing the discrete Walsh transform via the discrete Hadamard transform.

Discrete Hadamard Transform

The Hadamard matrix, (Reference 4) is, generated recursively from successive Kronecker (direct) products, $H_N = H_2 \times H_{N/2}$ for N = 4, 8, 16, . . . , and where $H_2 = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$. For example,

$$H_4 = H_2 \times H_2$$

$$= \begin{pmatrix} H_2 & H_2 \\ H_2 & -H_2 \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{pmatrix}$$

and in general

$$H_{2N} = \begin{pmatrix} H_N & H_N \\ H_N & -H_N \end{pmatrix}$$

It is clear that both the orthogonal and symmetric properties of $\frac{1}{\sqrt{2}} H_2$ are preserved in each step of the recursion so that $\left(\frac{1}{\sqrt{N}}\right) H_N$ is both orthogonal and symmetric, $\left(\frac{1}{N}\right) HH = I$ and $H = H^T$.

The Hadamard matrix for N = 8 is shown in figure 48. The equivalence between it and the Walsh matrix (except for row ordering) is shown clearly in the figure.

Fast Hadamard Transform (FHT)

The innovation of the Fast Fourier transform in digital signal processing has reduced the requirement for computing the Fourier transform load by orders of magnitude from N^2 real products and adds to 2NlogN. A similar algorithm exists for the Hadamard transform, the nature of which we discuss next.

To develop the algorithm, we note, (Reference 3)

$$\text{Diag}\ (H_N, H_N) = I_2 \times H_N = \begin{pmatrix} H_N & 0 \\ 0 & H_N \end{pmatrix}$$

and note that

$$H_2 \times I_N = \begin{pmatrix} I_N & I_N \\ I_N & -I_N \end{pmatrix}$$

$I_N \triangleq$ N-by-N diagonal matrix. Then a recursion formula can be developed from the following property of direct products:

$$H_N = (I_2 \times H_{N/2})(H_2 \times I_{N/2})$$

thus,

$$H_4 = (I_2 \times H_2)(H_2 \times I_2)$$

$$= \begin{pmatrix} H_2 & 0 \\ 0 & H_2 \end{pmatrix} \begin{pmatrix} I_2 & I_2 \\ I_2 & -I_2 \end{pmatrix}$$

$$H_8 = (I_2 \times H_4)(H_2 \times I_4)$$

$$= (I_4 \times H_2)(I_2 \times H_2 \times I_2)(H_2 \times I_4)$$

$$= \begin{pmatrix} H_2 & & & 0 \\ & H_2 & & \\ & & H_2 & \\ 0 & & & H_2 \end{pmatrix} \begin{pmatrix} H_2 \times I_2 & 0 \\ 0 & H_2 \times I_2 \end{pmatrix} \begin{pmatrix} I_4 & I_4 \\ I_4 & -I_4 \end{pmatrix}$$

This algorithm provides for the rapid computation of the Walsh or Hadamard spectra for digital signal vectors such as the Boolean time sequences employed in this study.

Sequency Spectra

There is yet a third ordering of the Walsh spectra called the "sequency" ordering due to Harmuth (Reference 5) which was used in interpreting the spectral characteristics of Boolean time sequences. This ordering preserves a one-to-one relationship between the Walsh spectra and Fourier spectra based on an increasing number of zero crossings.

Because of this property, signals which have distinct characteristics in the frequency domain often retain much of the structure in the sequency domain as well. As an illustrative example, studies were performed by Robinson and Campanella (Reference 6) to determine the feasibility of detecting formant structure in the Walsh spectra of speech. (The term "formant" refers to each of a set of peaks usually observed in the frequency spectrum of the vowel portion of a speech waveform. The peaks arise from resonances set up by the human vocal tract in the voice generating process.)

In that study, analog speech was sampled at a 10-kHz rate and the frequency and sequency spectra were computed for time windows containing 64 samples (6.4 milliseconds).

Formants were observed in the frequency domain as typified by the vowel /u/ shown in figure 49. The 32 points in the abscissa are the power spectral coefficients computed from:

$$P_n = \frac{1}{2}\left[(a_n)^2 + (b_n)^2\right]$$

where

$$a_n = \frac{1}{N}\sum_{k=0}^{N-1} X(k) \cos \frac{2\pi(nk)}{N},$$

and b_n is the corresponding n^{th} sine coefficient, both computed using the Fast Fourier transform.

An analogous pairing was performed in the sequency domain by combining Walsh functions with even and odd numbered zero crossings as shown by the example for N = 8 in figure 50. This pairing does not become invariant to phase, however, as is the case with the power spectrum. The sequency spectrum is then obtained from:

$$S_n = \frac{1}{2}\left[a_n^2(\text{cal}) + a_n^2(\text{sal})\right].$$

The formant structure was found to be recognizable in the sequency domain although additional spurious peaks usually occur which can obscure the higher formants.

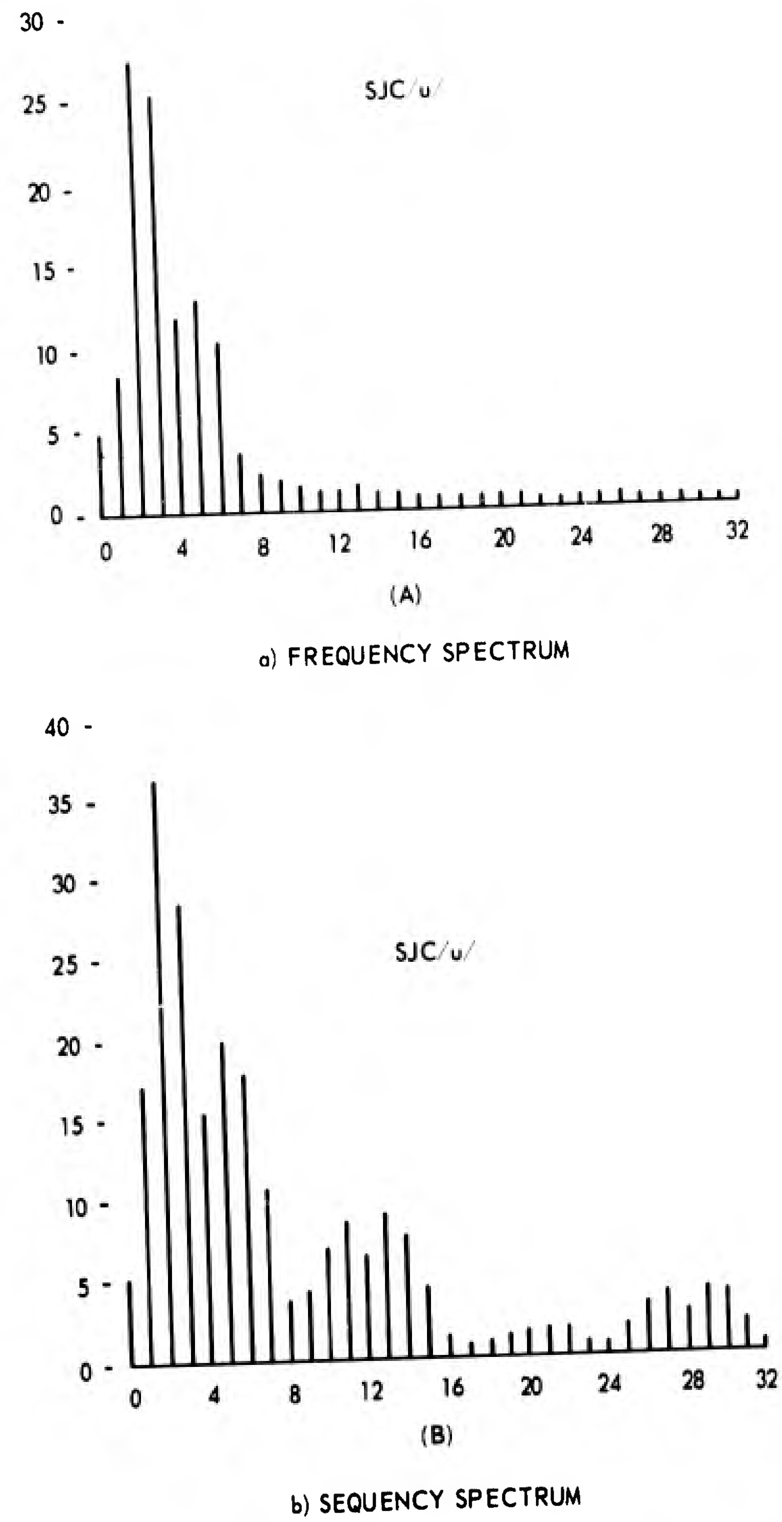

Figure 49. Spectra of the Vowel /u/

$$
W_8 = \begin{bmatrix}
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\
1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\
1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\
1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\
1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\
1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\
1 & -1 & 1 & -1 & 1 & -1 & 1 & -1
\end{bmatrix}
\begin{array}{l}
\mathrm{Wal}(0,\ x) \\
\mathrm{Wal}(1,\ x) \text{ or } \mathrm{Sal}(1,\ x) \\
\mathrm{Wal}(2,\ x) \text{ or } \mathrm{Cal}(1,\ x) \\
\mathrm{Wal}(3,\ x) \text{ or } \mathrm{Sal}\ (2,\ x) \\
\mathrm{Wal}(4,\ x) \text{ or } \mathrm{Cal}(2,\ x) \\
\mathrm{Wal}(5,\ x) \text{ or } \mathrm{Sal}(3,\ x) \\
\mathrm{Wal}(6, x) \text{ or } \mathrm{Cal}(3,\ x) \\
\mathrm{Wal}(7,\ x) \text{ or } \mathrm{Sal}(4,\ x)
\end{array}
$$

Figure 50. Walsh-Hadamard Combination

The value in the sequency ordering of Walsh spectra for Boolean time functions may lie in the combination of an efficient computation technique, with the retention of considerable information, related to the frequency response of the human operator, which may be contained in the BTS data.

The mapping or reordering which provides sequency spectra from the Walsh spectra is as follows: Let the r bit binary subscript which denotes p^{th} Walsh function be represented as the binary number $\vec{p} = (a_r, a_{r-1}, \ldots, a_1)$, $a_i = +1$ or -1. Its location in the sequency spectrum is determined from the relation:

$$b_{i-1} = a_i \oplus a_{i-1}$$

$$i = 2, \ldots, r$$

$$b_r = a_r ,$$

where $\oplus$ denotes modulo two addition where the vector $\vec{b} = (b_r, b_{r-1}, \ldots, b_1)$ is the binary number which denotes the location in the sequency domain of $\Psi_p(t)$. For example Ψ_{110}, the sixth coefficient in the Walsh spectrum which ranges from the 0^{th} to 7^{th} coefficients will be located in the sequency spectrum according to:

$$b_3 = a_3$$

$$b_2 = a_3 \oplus a_2$$

$$b_1 = a_2 \oplus a_1$$

therefore, $\vec{b} = (1, 0, 1)$.

The 5^{th} sequency function, denoted by Wal (5, X), is identical to the 6^{th} Walsh function in figure 47.

MacDonald Codes

A slightly different terminology describing Hadamard matrices has been employed in error-correction coding investigations. An often-used set of error-correcting codes known as the Reed-Muller codes has been shown (Reference 7) to be identical in construction to the rows of a Hadamard matrix with the exception of a one-to-one mapping which relates the individual elements of one system to the elements of the other. This mapping is an isomorphism, Φ, of the multiplicative group of two elements (-1, 1) onto the additive group of two elements (0, 1) as given by:

$$\Phi(1, -1) \rightarrow (0, 1).$$

One, therefore, replaces each "1" in the Hadamard matrix with a "0" and each -1 with a 1 to obtain the Reed-Muller codes. MacDonald has shown (Reference 8) that the individual rows can be generated with term-by-term addition modulo 2 of the elements of the codes R_{001}, R_{010}, etc., corresponding to the Walsh functions Ψ_{001}, Ψ_{010} described earlier, the correspondence being the isomorphism just mentioned. The generation of the MacDonald Codes is identical to the generation of the Walsh set except for the replacement of multiplication by addition modulo 2. An example of the MacDonald Codes for N = 4 is shown below:

$$\begin{matrix} R_{00} \\ R_{01} \\ R_{10} \\ R_{11} \end{matrix} \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{pmatrix}$$

where $\vec{R}_{11} = \vec{R}_{01} \oplus \vec{R}_{10}$.

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APPENDIX IV

HADAMARD COEFFICIENT DISTRIBUTION VARIANCES
FOR THE LAZY 8 (BTS 40)

INPUT SEQ. 40, 48 EVENTS

SCORE 20
MAC CODES VARIANCES=10

1	359.1	401.7	949.9	366.1	864.2	343.9	494.8	361.3	832.8	708.4
2	3.4	.1	4.1	4.1	4.3	.0	1.8	.9	6.2	8.3
3	2.7	.3	3.8	2.6	2.2	.0	2.1	1.8	10.0	2.0
4	2.4	.2	3.3	2.5	1.8	.0	1.9	1.7	9.3	1.4
5	3.7	.7	5.9	5.3	4.1	.0	4.7	5.1	7.5	5.7
6	2.4	.3	5.6	3.3	3.2	.0	5.9	2.0	5.0	2.9
7	2.8	.3	4.4	4.5	2.5	.0	3.8	4.6	5.1	3.8
8	2.4	.3	5.5	3.3	3.1	.0	5.3	2.1	5.2	2.9

SCORE 40
MAC CODES VARIANCES=10

1	940.2	588.6	630.6	960.9	703.5	827.4	453.2	1078.3	1148.6	349.9
2	3.8	1.6	3.9	3.0	3.6	14.5	6.0	5.2	5.3	1.8
3	4.1	2.5	5.3	6.7	4.1	14.8	2.8	5.8	14.8	3.9
4	3.4	2.0	4.8	6.1	3.3	14.1	2.4	5.3	14.3	3.7
5	10.4	4.4	7.7	10.4	7.2	11.1	4.4	7.9	18.1	5.0
6	3.3	2.4	3.6	9.3	4.0	12.0	2.1	4.8	15.0	2.0
7	8.5	2.5	5.7	8.0	4.9	7.4	2.6	4.9	16.6	4.1
8	3.3	2.4	3.7	9.7	3.9	12.4	2.1	4.9	14.9	2.0

SCORE 60
MAC CODES VARIANCES=19

1	546.7	439.1	1056.3	796.4	568.5	344.3	1112.7	1211.6	1083.7	1140.1	1319.3	1529.3	1128.3	948.9	885.5	737.2	541.6	377.1	699.9
2	9.3	5.8	7.9	8.5	4.4	3.7	7.5	11.0	3.7	10.3	64.6	4.6	3.1	7.3	10.6	5.2	1.1	7.2	4.4
3	14.0	14.6	4.8	10.0	5.0	3.7	15.0	10.8	14.5	17.5	22.7	14.5	13.7	10.0	8.0	6.3	3.8	1.2	7.2
4	13.0	14.2	4.1	9.6	4.5	3.4	13.8	10.3	13.5	16.3	22.0	13.5	12.7	9.3	7.5	5.4	3.2	.9	6.9
5	12.3	6.1	8.3	12.3	12.7	3.3	12.7	9.1	9.0	22.6	27.6	39.7	10.2	9.7	15.7	9.7	10.1	2.9	5.5
6	5.9	2.2	5.3	15.9	8.2	1.8	20.1	4.9	8.2	18.2	20.0	17.8	4.6	4.6	14.8	9.6	2.9	1.4	3.7
7	9.2	5.3	5.6	9.5	10.6	2.2	9.2	6.1	5.3	19.9	24.7	40.6	7.8	7.9	13.9	6.8	8.0	1.9	3.9
8	6.2	2.3	5.3	14.7	8.1	1.8	20.4	4.7	8.1	18.6	20.5	18.5	4.8	4.7	14.6	9.7	3.1	1.4	3.7

SCORE 80
MAC CODES VARIANCES= 9

1	553.7	887.4	1230.8	1125.3	938.0	1576.0	519.8	829.6	528.5
2	35.7	19.3	16.2	20.1	11.1	7.7	4.2	10.8	15.1
3	26.1	16.8	11.8	17.7	17.1	14.8	12.7	21.6	10.6
4	24.9	15.6	10.7	16.7	15.9	14.1	11.9	20.7	9.7
5	37.6	24.5	19.0	26.8	19.5	18.4	13.4	17.8	18.8
6	19.7	19.7	12.1	18.4	11.8	16.5	9.5	15.9	8.9
7	32.8	20.0	14.8	22.6	15.2	16.6	11.2	13.2	16.6
8	19.0	20.1	12.0	18.5	11.6	17.2	9.5	15.7	9.0

INPUT SEQ. 40, 48 EVENTS

SCORE 20
MAC CODES VARIANCES=10

9	15.6	2.4	20.4	7.6	19.4	.C	16.8	13.0	28.2	20.0
10	1.7	.2	3.5	4.0	4.9	.C	2.9	1.0	3.8	4.2
11	2.8	.4	4.0	3.8	7.1	.C	3.4	4.2	9.0	4.4
12	1.2	.3	2.0	3.3	4.2	.0	1.7	2.3	5.9	3.2
13	10.6	.7	13.1	5.4	13.0	.C	14.6	11.9	17.1	10.1
14	1.6	.3	3.1	3.9	4.8	.0	3.3	1.1	3.7	4.2
15	2.5	.3	4.2	3.7	6.6	.0	3.6	4.4	8.7	4.2
16	1.2	.4	2.5	3.1	4.1	.0	1.8	2.3	5.8	3.0

SCORE 40
MAC CODES VARIANCES=10

9	17.1	24.3	21.9	19.9	26.0	36.3	22.6	19.4	35.9	16.2
10	5.8	2.9	2.3	10.2	4.0	8.3	4.4	5.0	12.0	2.3
11	7.8	7.6	5.8	9.5	9.7	10.4	4.1	8.2	12.5	4.4
12	7.7	5.7	3.2	8.8	5.5	6.8	2.9	8.5	10.9	2.6
13	7.2	16.4	14.9	11.1	16.2	21.6	15.7	7.4	25.8	12.2
14	6.1	2.9	2.4	10.8	4.5	8.7	4.5	4.9	12.6	2.2
15	7.9	7.8	5.8	9.6	9.7	10.3	4.3	7.6	12.8	4.3
16	7.7	6.0	3.0	9.2	5.5	7.0	3.1	7.9	11.4	2.5

SCORE 60
MAC CODES VARIANCES=19

9	32.1	11.7	24.4	23.3	28.2	10.1	31.8	28.9	21.3	26.6	32.8	35.2	20.C	29.7	20.7
	21.0	19.1	15.7	17.3											
10	9.1	2.8	6.0	8.4	6.5	1.3	8.2	6.6	6.2	11.7	12.8	8.1	4.3	4.7	13.2
	10.3	4.3	3.5	4.8											
11	11.8	6.7	7.8	8.9	8.1	2.7	10.3	15.1	5.0	13.7	16.1	12.2	5.8	9.1	12.3
	7.1	10.8	4.7	5.5											
12	10.3	5.0	5.2	10.3	7.0	1.8	8.2	14.4	4.4	13.4	16.6	12.0	4.6	5.8	12.1
	6.8	6.4	3.2	5.3											
13	16.5	7.4	11.6	12.1	19.8	5.7	15.8	18.4	7.0	12.3	23.8	28.2	8.7	19.C	13.1
	9.6	8.7	11.0	12.8											
14	9.8	3.0	6.8	9.8	6.8	1.4	8.9	6.6	6.2	12.0	12.7	7.9	4.1	4.9	14.0
	9.9	4.1	3.2	4.8											
15	11.2	6.0	8.C	9.0	7.8	2.6	10.0	14.5	5.2	13.4	14.5	13.3	5.7	10.3	12.8
	7.5	10.9	4.9	5.9											
16	9.6	4.4	5.6	10.7	6.4	1.8	8.3	13.8	4.6	13.9	15.1	12.2	4.4	6.3	12.5
	6.9	6.5	3.4	5.5											

SCORE 80
MAC CODES VARIANCES= 9

9	44.1	40.9	40.5	49.2	62.3	31.8	24.4	46.3	44.9
10	25.4	20.1	10.9	22.7	18.4	12.C	8.3	9.1	16.6
11	27.4	15.8	12.9	21.4	22.7	19.0	9.1	14.5	18.4
12	22.8	17.6	11.1	22.3	15.6	20.7	7.0	10.7	12.1
13	30.9	22.4	23.5	32.3	45.C	20.3	14.8	24.9	34.8
14	24.5	20.0	10.6	21.1	17.4	12.3	8.7	8.9	18.0
15	26.9	16.3	12.3	21.5	22.6	17.9	9.1	13.9	19.3
16	21.9	17.3	10.2	21.5	15.0	19.2	7.0	10.3	13.0

INPUT SEG. 40, 46 EVENTS

SCORE 20
MAC CODES VARIANCES=10

MAC CODES										
17	42.8	16.2	46.1	29.4	71.3	.0	17.9	18.1	95.4	86.2
18	2.3	.3	5.1	2.5	12.0	.0	2.9	.9	5.8	6.8
19	3.6	.7	3.9	4.0	7.0	.0	4.9	2.9	10.2	7.1
20	2.1	.3	2.4	3.6	5.5	.0	5.2	2.0	7.6	4.5
21	7.7	2.2	14.4	5.9	9.8	.0	6.2	8.0	14.6	16.9
22	2.5	.1	5.4	3.8	7.2	.0	4.6	1.6	6.0	6.0
23	2.7	.4	8.6	4.1	3.3	.0	3.9	4.5	7.1	6.5
24	2.4	.2	5.1	4.0	4.9	.0	3.6	2.2	6.8	4.9

SCORE 40
MAC CODES VARIANCES=10

MAC CODES										
17	79.6	54.9	68.2	67.2	76.4	127.3	61.3	107.6	79.7	47.8
18	6.7	3.1	3.0	13.5	4.4	9.3	6.0	5.5	13.9	3.1
19	5.8	4.3	7.6	6.9	6.8	11.8	3.8	8.6	13.4	4.1
20	4.4	3.0	5.2	6.3	4.3	9.5	2.9	7.3	11.7	3.2
21	15.1	10.7	14.2	10.2	12.0	22.2	8.8	14.9	20.6	9.8
22	8.4	2.7	3.4	10.7	3.6	8.1	5.2	5.1	14.9	2.7
23	9.4	5.8	6.8	6.4	5.4	10.2	3.6	6.1	14.3	3.6
24	8.6	3.9	4.0	7.3	3.7	9.0	4.1	6.6	12.9	2.8

SCORE 60
MAC CODES VARIANCES=19

MAC CODES															
17	124.3	26.9	95.5	107.5	60.5	55.0	97.6	102.6	91.7	112.2	72.9	94.9	82.8	93.1	81.8
	77.1	90.0	45.6	32.4											
18	9.3	2.4	4.9	10.1	4.6	2.4	11.7	9.4	9.0	13.2	23.2	26.6	8.7	6.5	18.2
	12.0	6.0	4.1	4.0											
19	19.4	4.1	9.9	13.6	12.7	3.8	7.[illegible]	8.9	6.1	20.3	24.2	18.5	9.2	10.6	16.0
	7.0	6.5	2.9	6.7											
20	15.9	3.7	9.6	13.2	11.2	2.7	6.3	7.9	5.2	17.8	22.5	15.2	7.5	8.6	15.0
	5.7	4.4	1.9	6.3											
21	22.0	3.6	12.3	20.4	11.3	8.9	16.9	14.7	8.9	22.9	19.2	27.9	17.1	24.0	22.6
	13.6	12.4	6.8	9.3											
22	8.2	2.3	7.3	13.8	9.0	3.4	8.3	11.9	4.8	15.4	16.2	14.3	5.8	8.7	19.1
	8.7	4.4	2.1	4.6											
23	13.1	3.1	7.4	9.6	9.0	2.8	12.9	7.2	4.8	17.3	17.0	18.1	14.7	20.1	17.0
	9.2	5.2	3.1	7.0											
24	10.3	3.3	8.2	13.0	7.5	3.4	7.5	8.6	4.4	17.5	16.8	13.1	6.9	11.1	18.9
	7.5	5.0	2.4	5.9											

SCORE 80
MAC CODES VARIANCES= 9

MAC CODES									
17	154.9	171.3	110.8	131.6	147.3	88.2	73.0	140.6	97.6
18	32.3	24.8	10.1	20.6	15.6	10.2	6.8	15.7	11.6
19	27.1	20.9	11.3	19.5	20.2	16.4	13.9	15.4	10.4
20	25.6	18.7	9.8	17.8	15.8	14.0	11.5	15.0	8.3
21	62.2	38.1	18.2	28.5	26.7	26.9	17.3	21.8	23.7
22	41.6	22.4	11.6	14.4	16.8	14.1	8.5	13.9	13.2
23	38.8	22.7	11.5	19.5	16.8	22.7	12.1	11.6	15.9
24	35.8	19.4	10.8	15.3	17.5	19.0	9.3	13.4	12.1

INPUT SEQ. 40, 48 EVENTS

SCORE 20
MAC CODES VARIANCES=10

25	31.9	9.7	27.2	16.3	42.7	.0	12.1	16.9	56.6	63.1
26	2.0	.2	5.1	2.5	8.4	.0	2.7	1.0	5.7	5.8
27	3.2	1.0	3.9	4.1	6.2	.0	4.2	3.2	9.4	8.6
28	1.7	.5	2.0	3.8	4.8	.0	4.4	2.0	6.9	5.3
29	8.4	2.4	14.6	5.1	10.5	.0	7.9	9.0	14.9	18.3
30	2.3	.2	4.4	4.1	7.0	.0	5.8	1.5	5.6	6.6
31	2.5	.9	9.2	3.6	3.9	.0	4.1	4.5	7.2	6.4
32	2.1	.3	4.1	4.0	5.2	.0	3.6	2.2	6.8	5.5

SCORE 40
MAC CODES VARIANCES=10

25	41.5	29.0	35.8	27.8	42.2	68.7	28.9	52.7	53.0	39.0
26	5.6	2.6	2.9	11.7	4.7	8.2	5.2	6.4	15.8	3.2
27	5.9	5.3	7.6	6.3	8.0	10.7	3.6	8.2	14.5	4.1
28	4.4	3.6	4.9	5.5	5.1	7.7	2.9	7.4	13.1	3.1
29	14.6	11.8	14.0	9.4	13.0	21.7	8.5	13.1	22.4	10.8
30	7.5	2.7	3.5	9.2	3.7	7.7	5.3	5.1	16.4	2.7
31	8.5	6.2	6.5	6.6	6.3	10.7	3.4	5.9	13.9	3.6
32	7.6	4.4	4.0	6.5	4.4	8.5	3.9	6.7	14.3	2.9

SCORE 60
MAC CODES VARIANCES=19

25	67.6	12.2	41.7	55.2	26.6	38.1	34.7	46.5	26.1	50.9	43.5	62.0	40.2	58.8	57.6
	23.4	51.9	29.3	11.9											
26	8.2	2.0	5.4	8.9	4.8	2.1	12.5	9.8	8.0	10.2	25.1	26.0	8.7	6.0	18.2
	14.1	6.5	3.6	4.2											
27	17.5	3.8	9.3	12.8	13.3	3.7	9.0	8.4	5.6	17.9	24.9	19.6	8.5	11.8	14.7
	6.3	7.3	3.2	6.8											
28	14.2	3.3	9.3	12.6	11.8	2.6	7.6	7.6	4.9	15.5	23.4	14.8	6.7	9.6	13.9
	5.6	5.0	2.0	6.7											
29	22.4	4.1	11.9	17.5	12.2	9.1	15.5	13.0	7.6	21.0	20.0	29.9	15.7	29.2	23.8
	12.4	12.2	7.3	11.1											
30	8.3	2.4	8.2	10.3	9.2	3.3	9.2	10.4	4.6	14.6	17.4	12.6	5.4	8.7	19.1
	9.4	4.5	2.3	5.2											
31	14.3	3.4	8.2	8.7	9.0	2.8	11.4	7.7	4.4	17.8	16.9	17.2	13.2	17.7	18.4
	9.2	5.4	3.5	8.2											
32	11.1	3.6	8.6	10.3	7.6	3.2	7.7	8.0	4.2	17.1	18.2	12.0	6.5	11.2	20.0
	7.2	4.9	2.6	7.0											

SCORE 80
MAC CODES VARIANCES= 9

25	69.1	77.7	38.9	74.3	81.8	48.2	39.0	66.7	58.2
26	33.1	29.2	11.8	20.0	16.7	11.6	6.6	14.9	12.7
27	28.6	20.3	11.5	18.6	23.6	17.0	14.2	14.4	11.0
28	26.9	19.2	10.2	17.5	18.5	14.4	11.1	13.9	9.2
29	69.2	35.9	17.6	27.9	29.0	26.1	18.4	21.9	23.1
30	40.5	22.6	11.4	13.7	16.3	13.3	7.7	12.7	13.5
31	40.4	22.6	11.3	17.4	19.6	21.6	12.8	11.6	15.1
32	33.6	18.6	10.4	15.4	17.2	19.0	8.8	12.7	12.9

INPUT SEG. 40, 48 EVENTS

SCORE 20
MAC CODES VARIANCES=10

33	55.7	40.6	148.9	78.6	117.8	.0	93.1	20.7	223.6	221.4
34	1.6	.1	4.1	2.5	4.8	.0	2.4	.9	4.4	8.9
35	3.0	.3	3.3	4.4	2.9	.0	4.2	2.2	6.8	2.8
36	2.0	.2	2.4	4.1	2.6	.0	3.5	1.8	5.7	1.8
37	5.4	.7	7.8	6.5	5.0	.0	6.7	6.1	10.7	10.7
38	1.6	.3	5.6	3.7	6.9	.0	6.8	1.9	7.0	3.3
39	2.4	.3	4.2	4.2	3.3	.0	4.1	4.6	5.4	5.6
40	1.6	.3	5.2	3.7	6.1	.0	5.2	2.1	7.5	3.2

SCORE 40
MAC CODES VARIANCES=10

33	244.4	137.8	210.1	249.8	246.9	352.7	214.7	287.8	289.3	67.6
34	7.4	4.4	2.9	3.2	8.9	15.4	6.7	5.5	6.5	2.2
35	4.5	3.6	7.1	9.3	8.2	14.2	3.3	7.3	13.6	3.9
36	3.3	2.7	5.7	8.3	6.6	12.6	2.1	6.5	12.1	3.6
37	13.6	6.7	11.4	12.8	11.0	16.5	8.8	11.7	20.0	6.6
38	6.1	2.9	3.5	8.7	4.3	11.5	3.2	6.5	14.8	2.2
39	12.0	3.6	6.2	9.7	4.2	9.1	3.4	5.9	14.4	3.9
40	6.6	3.2	3.9	9.0	4.6	12.5	2.9	6.3	15.2	2.3

SCORE 60
MAC CODES VARIANCES=19

33	486.9	122.2	320.1	270.4	212.9	80.8	389.4	297.2	362.7	335.7	328.8	231.7	290.7	291.2	308.3
	335.2	281.7	113.8	241.2											
34	10.3	5.7	4.4	9.4	4.1	3.6	9.8	6.1	4.2	20.1	24.6	10.4	6.2	13.0	15.6
	6.6	2.0	4.0	5.9											
35	20.5	7.8	6.9	12.5	9.0	3.5	10.0	11.5	9.8	17.8	24.1	12.8	9.1	13.1	12.9
	8.3	4.8	2.3	5.4											
36	18.9	7.2	5.4	12.9	8.2	2.9	9.1	10.4	8.6	16.3	22.2	11.4	7.1	12.4	10.9
	6.7	3.3	1.7	3.9											
37	19.5	4.9	10.9	16.0	11.6	5.7	15.0	12.0	10.1	26.8	30.0	37.4	16.1	19.6	24.0
	14.2	12.3	4.7	12.0											
38	8.6	2.2	5.1	24.3	9.4	2.6	14.3	6.1	8.7	15.3	13.0	14.6	6.5	6.9	14.8
	7.6	4.8	1.3	3.5											
39	9.4	2.8	5.1	11.2	8.2	3.0	10.2	6.8	6.4	20.7	20.7	36.9	11.4	16.3	18.3
	9.0	6.4	2.2	5.3											
40	9.2	2.4	5.0	20.8	9.2	2.7	13.1	5.7	8.2	15.8	13.5	16.9	6.9	7.4	14.0
	8.6	5.2	1.3	3.0											

SCORE 80
MAC CODES VARIANCES= 9

33	542.3	519.4	424.8	387.9	425.5	336.9	285.0	494.9	354.6
34	39.8	18.3	8.3	16.6	13.6	8.1	5.9	11.9	11.7
35	30.8	19.1	12.2	19.9	20.8	18.5	12.3	20.1	13.4
36	27.1	16.4	11.1	17.9	18.3	17.3	9.3	18.3	10.9
37	48.2	29.8	16.1	29.0	24.7	32.1	15.3	20.7	21.8
38	28.9	19.9	12.2	16.2	12.8	11.8	8.1	15.5	10.4
39	35.4	18.2	11.4	21.2	15.9	22.7	9.1	12.1	13.0
40	28.6	19.8	12.2	16.6	12.3	12.6	8.6	15.2	9.3

INPUT SEQ. 40, 48 EVENTS

SCORE 20
MAC CODES VARIANCES=10

41	22.2	2.4	26.4	11.4	14.5	.0	18.2	14.3	35.6	28.4
42	1.9	.2	3.9	2.9	4.5	.0	6.9	1.0	4.4	4.6
43	3.7	.4	5.3	4.5	4.3	.0	3.4	3.9	7.7	4.8
44	2.0	.3	2.6	3.9	3.9	.0	2.8	2.2	5.3	3.6
45	9.3	.7	15.4	4.3	7.3	.0	10.8	10.9	12.2	10.4
46	2.1	.3	3.3	3.1	5.4	.0	9.0	1.2	5.7	4.4
47	3.6	.3	6.7	4.0	4.8	.0	3.8	4.4	6.2	4.2
48	2.2	.4	3.8	3.6	5.1	.0	3.5	2.3	4.9	3.6

SCORE 40
MAC CODES VARIANCES=10

41	22.8	23.4	29.5	20.0	43.1	47.8	34.5	30.3	49.1	23.8
42	6.1	3.4	2.3	5.5	4.7	8.3	4.2	5.2	10.3	2.6
43	6.4	6.9	6.2	6.6	8.0	12.7	3.8	7.8	13.3	4.3
44	5.6	4.7	3.8	5.6	5.4	9.9	2.7	8.6	13.8	2.7
45	8.0	13.7	13.4	6.6	16.0	20.8	12.1	10.9	21.3	11.7
46	6.7	3.3	2.6	6.2	4.8	8.9	4.9	4.7	13.3	2.3
47	7.5	7.6	6.0	6.9	6.8	13.5	3.9	6.6	13.1	4.1
48	6.1	4.7	3.2	6.1	4.9	11.0	3.4	6.9	15.2	2.7

SCORE 60
MAC CODES VARIANCES=19

41	66.8	17.7	39.8	31.1	26.3	20.1	33.6	31.2	23.9	43.2	61.3	45.4	39.0	41.1	50.8
	32.2	37.3	16.9	32.7											
42	7.5	3.1	6.3	12.3	5.2	1.9	8.5	11.3	6.2	14.7	20.9	9.0	4.9	9.9	14.8
	7.6	4.8	3.4	6.6											
43	15.2	6.5	7.2	9.7	8.2	3.1	11.6	11.5	7.0	14.1	23.8	14.7	7.6	12.3	12.5
	7.9	7.1	3.5	6.1											
44	14.5	6.1	5.7	11.8	7.1	2.1	9.3	9.2	6.7	13.1	23.5	14.0	5.7	9.7	11.0
	7.6	5.0	3.0	5.7											
45	19.4	7.4	14.8	12.3	13.7	7.6	14.3	12.9	7.5	17.6	32.8	27.8	12.0	20.0	18.6
	11.5	9.0	6.0	9.4											
46	9.7	3.4	8.3	15.9	6.8	2.5	10.5	9.2	7.3	12.0	23.0	9.0	4.2	11.5	14.9
	7.5	4.5	2.9	6.3											
47	12.6	5.3	7.7	9.3	7.3	2.9	11.0	10.6	5.9	14.3	21.7	16.6	7.6	14.4	13.6
	9.6	6.9	4.1	5.8											
48	12.5	4.7	6.3	13.2	5.8	2.3	9.9	8.5	6.4	13.5	22.2	13.5	5.6	11.5	11.8
	9.0	5.0	3.4	5.4											

SCORE 80
MAC CODES VARIANCES= 9

41	85.6	83.2	37.6	60.5	76.0	58.7	52.6	61.8	60.8
42	27.6	25.5	13.7	17.7	25.0	11.0	6.5	13.1	14.2
43	34.6	20.8	14.4	18.0	25.2	18.5	14.6	14.0	16.8
44	30.1	18.2	14.0	16.3	19.1	14.8	9.8	13.0	12.5
45	37.3	39.4	15.0	35.2	37.5	31.7	21.2	24.5	26.5
46	26.9	22.2	12.3	17.1	21.7	11.2	6.8	12.6	14.7
47	27.8	22.7	13.9	20.8	22.1	17.6	14.1	12.8	19.9
48	24.9	17.3	13.5	17.4	16.6	12.9	8.8	11.8	14.9

INPUT SEQ. 40, 48 EVENTS

SCORE 20
MAC CODES VARIANCES=10

49	86.9	16.2	49.4	53.3	52.9	.0	46.9	19.4	135.8	94.6
50	2.0	.3	6.9	2.7	9.9	.0	2.7	.9	4.7	6.6
51	4.9	.7	3.4	4.0	5.4	.0	5.5	2.5	8.1	4.4
52	2.8	.3	2.6	3.6	4.9	.0	4.9	1.9	6.0	2.7
53	9.9	2.2	9.4	6.6	7.0	.0	6.9	7.0	13.1	13.2
54	2.2	.1	5.2	4.2	7.3	.0	5.1	1.8	5.8	3.9
55	3.3	.4	4.9	4.0	3.2	.0	4.4	4.5	4.7	5.5
56	2.3	.2	5.0	4.1	5.9	.0	4.1	2.2	6.2	3.5

SCORE 40
MAC CODES VARIANCES=10

49	86.9	71.6	103.9	75.7	157.5	174.7	135.8	124.1	181.3	57.7
50	8.5	4.2	3.2	5.5	6.8	15.2	7.5	5.7	6.5	2.7
51	4.8	4.4	7.3	8.1	7.2	13.4	3.8	8.7	14.2	4.0
52	3.7	2.9	5.5	7.3	5.0	11.3	2.4	7.8	12.9	3.4
53	13.5	9.6	12.2	10.4	13.0	19.4	10.8	14.5	19.4	8.2
54	8.2	3.2	3.5	8.5	3.7	10.3	3.9	7.0	12.9	2.4
55	11.8	4.6	6.4	8.5	4.3	9.5	4.2	6.8	12.2	3.8
56	8.8	3.7	4.2	8.3	4.2	11.5	3.4	6.7	13.7	2.6

SCORE 60
MAC CODES VARIANCES=19

49	242.1	54.3	155.2	113.5	81.6	72.0	120.7	134.6	87.1	160.4	228.6	149.8	158.4	132.0	182.8
	135.5	156.0	64.3	127.7											
50	7.6	3.6	4.7	11.6	4.7	3.1	10.2	6.8	6.9	21.9	15.3	12.0	8.3	11.4	19.9
	8.9	3.7	3.4	5.8											
51	24.4	5.5	8.2	11.5	9.0	3.7	9.1	10.0	8.7	18.3	26.2	14.2	9.2	12.4	14.6
	7.5	5.2	2.8	5.9											
52	22.9	5.0	6.9	12.1	8.7	2.6	8.1	9.2	8.0	16.2	24.3	12.6	6.5	10.9	12.4
	6.0	3.5	2.0	4.7											
53	20.3	4.6	11.6	16.6	10.9	8.0	14.9	13.6	8.3	25.2	28.6	26.9	17.8	22.6	23.5
	14.1	12.6	5.5	12.3											
54	8.8	2.3	5.5	21.7	8.8	2.5	10.0	8.8	8.0	13.8	13.8	11.4	6.1	7.7	17.0
	7.9	5.1	1.6	4.2											
55	10.1	2.7	5.1	10.2	7.5	3.0	10.8	7.1	6.3	16.7	18.4	19.9	11.5	19.8	18.1
	9.0	5.3	2.6	6.2											
56	10.4	2.8	5.9	18.3	8.6	2.4	8.8	7.8	7.2	13.4	14.9	13.5	6.4	8.6	15.4
	8.8	5.6	1.8	3.7											

SCORE 80
MAC CODES VARIANCES= 9

49	300.4	327.1	135.7	172.5	178.6	179.4	154.3	185.6	207.6
50	39.5	19.2	8.8	20.4	15.3	8.2	7.3	12.9	15.1
51	33.6	20.7	11.0	21.9	18.8	20.4	14.3	15.2	10.4
52	29.8	16.4	9.9	20.2	16.3	18.7	11.8	14.4	9.2
53	51.1	39.8	17.0	31.2	23.8	33.4	17.9	21.2	25.4
54	37.3	18.8	12.6	19.0	13.9	13.5	9.2	13.9	12.4
55	34.5	20.2	11.5	22.9	14.6	22.6	11.2	13.2	15.7
56	33.2	17.0	12.4	19.5	13.1	15.4	10.1	13.8	11.2

INPUT SEQ. 40, 48 EVENTS

SCORE 20

MAC CODES	VARIANCES=10									
57	42.5	9.7	25.4	14.3	24.4	.0	16.3	15.6	54.8	44.5
58	2.0	.2	5.7	2.9	6.8	.0	5.7	1.0	4.6	4.5
59	5.0	1.0	3.9	4.3	5.0	.0	3.8	3.5	9.3	6.9
60	2.5	.5	1.9	3.9	4.6	.0	3.3	2.1	6.9	4.2
61	12.3	2.4	13.9	4.5	9.3	.0	9.5	9.9	14.5	16.0
62	2.2	.2	3.6	3.3	6.1	.0	8.7	1.4	5.3	4.6
63	4.3	.9	6.0	3.8	4.8	.0	4.3	4.5	6.0	5.3
64	2.6	.3	3.3	3.4	5.7	.0	3.6	2.2	5.5	4.2

SCORE 40

MAC CODES	VARIANCES=10									
57	26.7	33.6	31.3	16.4	54.2	60.5	37.2	36.5	52.4	31.4
58	5.7	3.9	2.6	5.6	4.8	7.6	4.6	7.2	9.4	2.9
59	5.6	6.4	6.9	5.1	8.9	13.3	3.5	7.8	14.2	4.2
60	4.3	4.1	4.4	4.6	6.9	10.5	2.6	7.7	14.8	2.9
61	10.1	14.1	13.4	6.1	15.7	23.4	9.6	12.5	20.2	11.3
62	6.7	3.1	2.9	6.0	4.0	7.8	5.0	5.6	13.2	2.5
63	8.0	6.7	6.6	5.9	6.5	13.8	3.6	6.3	13.2	3.9
64	6.1	4.2	3.6	5.4	5.9	11.3	3.4	6.0	15.5	2.8

SCORE 60

MAC CODES	VARIANCES=19														
57	71.1	17.3	42.5	37.7	23.7	30.6	33.0	37.7	17.3	53.2	75.5	56.1	48.4	46.0	46.0
	30.9	46.6	20.0	29.9											
58	6.5	2.3	6.1	12.2	4.7	1.9	9.5	12.2	7.2	14.3	19.8	8.8	6.5	8.0	16.6
	9.5	5.5	3.0	6.5											
59	15.7	5.3	7.0	10.1	9.6	3.3	9.9	12.0	5.9	15.8	26.8	15.9	9.3	12.7	13.4
	7.5	6.4	3.1	7.7											
60	14.0	4.9	6.5	11.7	9.7	2.0	8.3	10.2	5.8	12.8	26.0	13.7	6.4	10.2	11.6
	6.9	4.7	2.6	7.2											
61	20.7	6.3	12.6	14.0	11.9	9.1	15.0	11.4	7.0	19.2	35.1	26.3	14.7	19.4	20.2
	12.7	10.7	5.3	11.7											
62	8.9	2.6	9.1	16.0	7.4	2.5	10.7	10.1	6.4	11.1	23.4	8.3	5.0	9.8	14.8
	8.2	4.9	2.5	6.1											
63	12.7	4.1	7.4	8.9	7.5	3.1	10.6	9.2	4.8	13.9	22.3	16.3	9.8	15.0	16.7
	10.5	5.3	3.7	8.2											
64	11.7	4.1	7.7	13.0	6.9	2.3	8.7	8.6	5.4	11.2	22.3	11.6	6.3	10.9	14.3
	9.4	4.7	3.0	5.8											

SCORE 80

MAC CODES	VARIANCES= 9								
57	87.5	116.0	39.3	68.6	74.9	58.5	54.7	56.0	63.4
58	32.1	27.8	14.6	19.2	21.2	9.9	7.1	13.0	15.1
59	39.6	21.0	12.0	19.2	22.2	17.0	16.5	13.2	12.2
60	35.6	17.6	11.7	16.6	18.0	14.4	12.0	13.2	10.7
61	51.5	44.6	14.2	34.7	33.3	29.0	22.1	21.4	23.0
62	33.1	22.5	13.1	18.2	19.0	11.3	8.0	12.3	14.9
63	34.7	24.4	12.3	21.1	18.4	17.8	15.4	11.5	15.7
64	30.1	17.5	12.9	18.1	15.0	14.5	10.5	12.2	14.5

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APPENDIX V

HADAMARD COEFFICIENT DISTRIBUTION VARIANCES
FOR THE LAZY 8 (BTS 33)

INPUT SEQ. 33, 48 EVENTS

SCORE 20
MAC CODES VARIANCES=10

MAC CODES										
1	2151.2	1755.9	1908.5	1216.0	2240.1	2354.3	2461.4	1865.7	1434.5	1459.8
2	.6	1.1	1.9	.9	1.3	1.3	1.5	1.2	1.2	1.0
3	1.7	3.0	2.2	2.3	3.2	4.3	3.7	3.8	4.0	2.6
4	.6	1.1	1.2	.9	1.3	3.1	2.1	1.5	2.5	1.0
5	6.2	10.5	7.0	7.5	10.2	8.3	9.8	13.5	12.1	10.1
6	.6	1.1	2.5	.9	1.0	2.7	1.9	1.4	2.1	1.2
7	1.7	3.0	3.3	2.3	2.9	3.5	3.2	4.3	6.3	3.3
8	.6	1.1	2.5	.9	1.0	2.8	1.9	1.4	2.2	1.2

SCORE 40
MAC CODES VARIANCES=10

MAC CODES										
1	504.3	1794.4	1167.6	1131.5	1526.9	1336.8	2041.0	2487.5	1669.9	624.2
2	1.0	2.1	4.4	2.0	2.4	2.3	1.5	1.0	.6	.7
3	3.9	2.5	2.2	2.2	3.1	4.0	3.6	2.5	3.5	2.6
4	3.4	.9	1.2	1.0	1.4	2.2	2.0	1.0	2.4	2.0
5	8.3	8.7	8.3	8.5	11.0	13.9	9.7	8.2	8.0	3.7
6	2.8	1.1	1.4	1.9	1.9	2.3	2.0	1.1	2.8	.7
7	5.8	2.3	4.2	3.7	3.9	6.4	3.5	2.7	3.5	1.4
8	2.8	1.1	1.5	2.0	1.8	2.3	2.0	1.1	2.8	.7

SCORE 60
MAC CODES VARIANCES=19

MAC CODES															
1	318.2	346.3	834.2	328.0	1468.5	1790.5	813.1	420.9	2149.8	2267.3	1578.9	1055.6	403.0	1238.6	279.6
	348.2	1256.9	301.6	288.1											
2	.0	.0	1.7	.0	.4	.7	2.2	1.9	.8	1.3	.3	1.0	.5	.7	.3
	.1	.6	1.0	.3											
3	.0	.8	1.7	.7	1.3	1.8	2.8	1.3	3.9	3.0	1.0	2.5	.7	1.9	.3
	.3	1.3	1.0	.4											
4	.0	.7	1.1	.7	.4	.7	2.0	1.0	2.3	1.3	.3	1.6	.5	.7	.3
	.1	.6	1.0	.3											
5	.0	1.5	4.3	1.1	4.7	7.0	5.7	3.3	11.2	9.9	3.8	5.1	1.4	7.0	.3
	1.1	3.9	2.4	1.6											
6	.0	.4	1.8	.3	.4	.7	1.6	.7	1.5	1.0	.3	1.3	.5	.7	.3
	.1	.6	1.0	.3											
7	.0	1.2	1.8	1.1	1.3	2.6	2.1	2.3	4.6	3.0	1.0	1.6	.7	2.3	.3
	.3	1.3	2.3	1.5											
8	.0	.4	1.7	.4	.4	.7	1.6	.6	1.6	1.0	.3	1.3	.5	.7	.3
	.1	.6	1.0	.3											

SCORE 80
MAC CODES VARIANCES= 9

MAC CODES									
1	537.8	272.0	266.4	315.7	300.0	1077.7	330.8	299.9	263.4
2	.2	.0	.0	.1	.1	.2	.0	.0	.0
3	1.2	.0	.0	.1	.1	.5	.0	.0	.0
4	.9	.0	.0	.1	.1	.2	.0	.0	.0
5	3.5	.0	.0	.1	.1	1.7	.0	.0	.0
6	.7	.0	.0	.1	.1	.2	.0	.0	.0
7	1.9	.0	.0	.1	.1	.5	.0	.0	.0
8	.6	.0	.0	.1	.1	.2	.0	.0	.0

INPUT SEQ. 33, 48 EVENTS

SCORE 20
MAC CODES VARIANCES-10

MAC CODES										
9	24.4	43.7	27.6	34.8	40.5	36.3	39.4	52.0	48.6	37.4
10	.6	1.3	2.8	.9	1.1	1.9	1.9	1.4	2.0	1.1
11	1.7	3.7	3.5	3.3	3.0	5.5	3.7	4.1	6.5	3.0
12	.6	1.3	2.2	.9	1.1	1.8	1.7	1.3	1.9	1.1
13	6.4	13.1	11.4	12.8	11.1	18.3	13.9	15.8	24.4	10.7
14	.6	1.3	2.8	.9	1.2	1.8	2.0	1.5	2.1	1.1
15	1.7	3.7	3.3	3.3	3.1	5.5	3.7	4.3	6.8	3.0
16	.6	1.3	2.3	.9	1.2	1.8	1.7	1.3	2.1	1.1

SCORE 40
MAC CODES VARIANCES-10

MAC CODES										
9	29.8	34.6	25.5	39.2	45.9	43.6	35.1	30.2	33.4	17.7
10	1.9	1.0	1.4	1.8	2.4	1.9	1.6	1.1	2.1	.7
11	6.2	3.4	3.7	5.1	4.2	4.7	3.9	2.6	5.0	3.4
12	2.7	1.6	2.8	1.9	1.8	2.4	2.1	1.1	2.2	1.4
13	18.4	8.8	8.8	20.1	17.0	14.1	10.4	8.4	14.0	8.2
14	1.9	1.0	1.3	1.7	2.4	1.8	1.7	1.0	2.1	.7
15	5.8	3.4	3.8	4.9	4.2	4.8	3.9	2.6	5.2	3.3
16	2.5	1.6	2.7	1.9	1.8	2.5	2.2	1.0	2.2	1.3

SCORE 60
MAC CODES VARIANCES-19

MAC CODES															
9	.0	7.5	18.1	1.3	18.9	25.4	25.4	7.3	39.0	38.6	15.0	23.2	4.4	27.5	.3
	8.0	14.3	3.0	2.2											
10	.0	.5	5.8	.2	.5	.7	2.0	1.9	1.3	1.2	.3	1.1	.5	.7	.3
	.4	.6	1.0	.3											
11	.0	1.3	6.3	.9	1.4	2.3	5.6	2.3	4.5	3.4	1.0	2.9	.7	2.1	.3
	1.3	1.3	1.6	.9											
12	.0	.2	4.3	.6	.5	.7	2.3	1.4	2.0	1.2	.3	1.5	.5	.7	.3
	.4	.6	1.0	.3											
13	.0	6.7	8.0	1.2	5.3	7.5	10.8	3.6	12.6	11.4	3.8	8.7	1.5	8.3	.3
	4.8	3.9	2.9	2.1											
14	.0	.6	5.9	.2	.5	.7	2.1	1.7	1.3	1.3	.3	1.1	.5	.7	.3
	.4	.6	1.C	.3											
15	.0	1.3	6.1	.9	1.4	2.2	5.5	2.3	4.6	3.5	1.0	2.8	.7	2.1	.3
	1.3	1.3	1.7	1.0											
16	.0	.2	4.1	.5	.5	.7	2.4	1.3	2.0	1.3	.3	1.4	.5	.7	.3
	.4	.6	1.0	.3											

SCORE 80
MAC CODES VARIANCES- 9

MAC CODES									
9	10.9	.0	.C	.1	.1	6.7	.0	.0	.0
10	.5	.0	.0	.1	.1	.2	.0	.0	.0
11	1.6	.0	.C	.1	.1	.5	.0	.0	.0
12	.6	.0	.C	.1	.1	.2	.0	.0	.0
13	5.5	.0	.C	.1	.1	1.8	.0	.0	.0
14	.5	.C	.C	.1	.1	.2	.0	.0	.0
15	1.7	.0	.C	.1	.1	.5	.0	.0	.0
16	.7	.0	.0	.1	.1	.2	.0	.0	.0

INPUT SEQ. 33, 48 EVENTS

SCORE 20
MAC CODES VARIANCES=10

17	96.9	188.4	111.7	131.1	156.7	138.5	154.1	208.6	174.7	169.3
18	.6	1.8	2.2	.9	1.1	2.3	1.9	1.3	2.0	1.5
19	1.7	5.5	3.2	2.9	3.0	4.5	4.1	4.2	5.6	4.7
20	.6	1.8	1.3	.9	1.1	1.6	1.8	1.5	1.7	1.5
21	6.4	20.4	10.9	10.7	10.1	17.4	12.8	15.3	23.1	18.7
22	.6	1.8	2.7	.9	1.2	2.2	1.8	1.4	2.3	1.9
23	1.7	5.5	2.9	2.9	3.1	5.1	3.0	4.0	7.0	5.9
24	.6	1.8	2.7	.9	1.2	2.0	1.8	1.3	2.1	1.9

SCORE 40
MAC CODES VARIANCES=10

17	81.9	136.7	113.8	134.9	196.9	189.1	142.5	126.8	107.1	66.2
18	1.7	1.6	2.5	2.1	2.6	2.5	1.8	1.1	1.0	.7
19	4.8	2.8	4.5	3.8	4.7	4.9	3.5	2.7	4.0	3.0
20	3.0	1.3	2.8	1.5	1.5	1.8	1.6	1.1	2.5	1.7
21	11.3	8.7	12.7	14.5	16.3	18.7	11.7	9.1	11.7	6.2
22	1.9	1.1	1.3	1.9	2.2	2.2	1.9	1.0	1.7	.7
23	3.8	2.9	3.5	4.3	3.7	5.5	3.3	2.5	4.2	2.3
24	2.4	1.2	1.5	1.9	2.0	2.2	1.8	1.0	1.9	1.0

SCORE 60
MAC CODES VARIANCES=19

17	.0	10.8	65.3	1.4	76.8	97.8	90.1	26.2	146.4	172.5	59.5	87.4	16.1	103.9	.3
	27.8	55.8	3.4	2.5											
18	.0	.3	2.5	.1	.5	.7	1.6	1.9	1.1	1.2	.3	1.0	.5	.7	.3
	.3	.6	1.0	.3											
19	.0	1.0	4.1	.8	1.4	2.1	3.1	1.8	4.3	3.5	1.0	2.8	.7	2.1	.3
	.9	1.3	1.3	.6											
20	.0	.5	3.6	.6	.5	.7	1.8	1.2	2.2	1.2	.3	1.5	.5	.7	.3
	.3	.6	1.0	.3											
21	.0	3.7	5.8	1.2	5.3	7.3	9.4	3.6	12.4	13.0	3.8	7.3	1.5	7.6	.3
	3.3	3.9	2.6	1.8											
22	.0	.5	1.9	.3	.5	.7	2.6	1.1	1.5	1.3	.3	1.2	.5	.7	.3
	.3	.6	1.0	.3											
23	.0	1.2	2.4	1.0	1.4	2.4	3.2	2.2	4.8	3.3	1.0	2.2	.7	2.1	.3
	.9	1.3	2.0	1.3											
24	.0	.3	2.5	.4	.5	.7	2.2	.9	1.8	1.3	.3	1.4	.5	.7	.3
	3	.6	1.0	.3											

SCORE 80
MAC CODES VARIANCES= 9

17	54.6	.0	.0	.1	.1	26.6	.0	.0	.0
18	.7	.0	.0	.1	.1	.2	.0	.0	.0
19	2.0	.0	.C	.1	.1	.5	.0	.0	.0
20	.5	.0	.0	.1	.1	.2	.0	.0	.0
21	8.0	.0	.C	.1	.1	1.8	.C	.0	.0
22	.6	.0	.C	.1	.1	.2	.0	.0	.0
23	1.7	.0	.C	.1	.1	.5	.0	.0	.0
24	.4	.0	.C	.1	.1	.2	.0	.0	.0

INPUT SEQ. 33, 48 EVENTS

SCORE 20

MAC CODES	VARIANCES=10									
25	25.0	83.1	47.7	39.4	39.3	60.6	54.6	59.7	81.9	67.3
26	.6	2.0	2.3	.9	1.1	2.3	1.9	1.4	2.2	1.6
27	1.7	6.2	3.2	2.7	2.9	4.6	3.9	4.2	5.9	5.0
28	.6	2.0	1.4	.9	1.1	1.6	1.9	1.4	1.8	1.6
29	6.4	22.9	10.9	9.6	10.4	18.2	11.9	16.0	23.5	19.2
30	.6	2.0	2.8	.9	1.3	2.1	1.8	1.4	2.2	1.8
31	1.7	6.2	3.1	2.7	3.1	5.7	3.2	4.1	6.4	5.6
32	.6	2.0	2.8	.9	1.3	1.8	1.8	1.3	1.9	1.8

SCORE 40

MAC CODES	VARIANCES=10									
25	45.7	33.0	52.9	51.0	70.5	69.4	47.0	35.7	37.3	25.5
26	1.9	1.4	2.3	1.8	2.3	2.5	1.8	1.0	1.1	.7
27	5.2	2.9	4.9	3.5	4.0	5.0	3.7	2.6	4.0	2.9
28	3.3	1.4	2.9	1.5	1.5	2.0	1.6	1.0	2.5	1.6
29	12.2	8.7	13.4	12.7	13.1	18.5	12.1	9.0	11.9	5.7
30	2.0	1.1	1.4	1.8	2.0	2.2	1.8	1.1	1.6	.7
31	4.1	3.0	3.6	4.3	3.1	5.6	3.4	2.6	4.3	2.4
32	2.7	1.3	1.8	1.9	1.7	2.3	1.9	1.1	2.0	1.0

SCORE 60

MAC CODES	VARIANCES=19														
25	.0 12.2	10.0 14.3	19.7 3.3	1.3 2.5	20.1	25.7	34.1	9.0	41.0	48.7	15.0	26.4	4.5	32.0	.3
26	.0 .2	.3 .6	2.5 1.0	.1 .3	.4	.7	1.5	1.8	1.0	1.1	.3	1.1	.5	.7	.3
27	.0 .7	1.1 1.3	4.5 1.4	.8 .7	1.3	2.0	3.3	1.8	4.1	3.0	1.0	2.6	.7	2.2	.3
28	.0 .2	.4 .6	4.1 1.0	.6 .3	.4	.7	1.7	1.2	2.1	1.1	.3	1.5	.5	.7	.3
29	.0 2.6	4.5 3.9	5.1 2.7	1.2 1.9	4.7	7.2	9.4	3.3	11.4	10.9	3.8	6.4	1.5	8.0	.3
30	.0 .2	.5 .6	2.2 1.0	.3 .3	.4	.7	2.5	1.3	1.3	1.2	.3	1.2	.5	.7	.3
31	.0 .7	1.2 1.3	2.8 2.0	1.0 1.2	1.3	2.5	3.4	2.4	4.4	3.0	1.0	2.1	.7	2.0	.3
32	.0 .2	.3 .6	2.8 1.0	.5 .3	.4	.7	2.2	1.0	1.8	1.2	.3	1.4	.5	.7	.3

SCORE 80

MAC CODES	VARIANCES= 9								
25	33.2	.0	.0	.1	.1	7.1	.0	.0	.0
26	.8	.0	.0	.1	.1	.2	.0	.0	.0
27	2.0	.0	.0	.1	.1	.5	.0	.0	.0
28	.4	.0	.0	.1	.1	.2	.0	.0	.0
29	8.4	.0	.0	.1	.1	1.8	.0	.0	.0
30	.7	.0	.0	.1	.1	.2	.0	.0	.0
31	1.8	.0	.0	.1	.1	.5	.0	.0	.0
32	.5	.0	.0	.1	.1	.2	.0	.0	.0

INPUT SEQ. 33, 48 EVENTS

SCORE 20
MAC CODES VARIANCES=10

33	387.2	687.6	371.2	489.7	631.8	499.2	552.2	884.3	795.8	699.1
34	.6	1.1	2.5	.9	1.0	1.9	1.7	1.5	2.3	1.4
35	1.7	3.4	3.5	2.9	2.9	4.9	3.8	4.4	7.1	4.3
36	.6	1.1	1.7	.9	1.0	2.4	1.9	1.2	2.1	1.4
37	6.4	12.8	10.5	10.7	10.7	15.1	11.7	16.9	25.3	15.6
38	.6	1.1	2.7	.9	1.3	2.2	2.0	1.4	1.8	1.2
39	1.7	3.4	2.8	2.9	3.2	4.3	3.3	4.0	5.3	3.7
40	.6	1.1	2.6	.9	1.3	2.3	1.8	1.4	1.9	1.2

SCORE 40
MAC CODES VARIANCES=10

33	284.4	553.2	403.4	470.1	790.0	776.9	600.7	567.9	471.6	301.9
34	1.3	1.9	2.6	2.8	2.7	2.3	1.8	1.4	1.0	.7
35	4.6	2.6	3.0	3.7	4.8	5.1	4.5	3.6	4.3	3.5
36	2.5	1.0	1.4	1.1	1.5	2.0	2.0	1.4	2.5	1.9
37	13.0	8.7	9.6	14.5	17.1	17.6	13.3	12.5	10.8	8.9
38	2.2	1.1	1.4	1.7	2.1	2.2	1.7	1.3	2.3	.7
39	4.5	2.5	2.8	4.1	3.6	5.2	2.8	3.4	3.7	2.4
40	2.3	1.1	1.6	1.7	2.0	2.2	1.6	1.3	2.7	.8

SCORE 60
MAC CODES VARIANCES=19

33	.0	12.5	262.8	1.4	308.6	429.7	415.3	127.8	575.8	701.1	237.6	343.6	76.6	462.2	.3
	96.0	221.9	3.5	2.7											
34	.0	.1	2.7	.0	.5	.7	1.8	2.7	1.0	1.3	.3	1.0	.5	.7	.3
	.3	.6	1.0	.3											
35	.0	.9	2.7	.8	1.4	2.5	3.3	2.3	4.2	3.6	1.0	2.9	.7	2.3	.3
	.9	1.3	1.1	.4											
36	.0	.7	1.8	.7	.5	.7	1.4	1.4	2.3	1.3	.3	1.6	.5	.7	.3
	.3	.6	1.0	.3											
37	.0	2.2	5.7	1.1	5.3	9.2	10.4	5.6	12.2	12.4	3.8	7.4	1.4	8.5	.3
	3.3	3.9	2.4	1.7											
38	.0	.4	2.1	.3	.5	.7	2.0	.9	1.6	1.2	.3	1.3	.5	.7	.3
	.3	.6	1.0	.3											
39	.0	1.2	2.1	1.0	1.4	2.0	3.2	2.4	4.9	3.3	1.0	2.1	.7	1.9	.3
	.9	1.3	2.2	1.4											
40	.0	.3	2.0	.4	.5	.7	1.9	.8	1.7	1.2	.3	1.3	.5	.7	.3
	.3	.6	1.0	.3											

SCORE 80
MAC CODES VARIANCES= 9

33	213.9	.0	.0	.1	.1	106.2	.0	.0	.0
34	.7	.0	.0	.1	.1	.2	.0	.0	.0
35	1.9	.0	.0	.1	.1	.5	.0	.0	.0
36	.6	.0	.0	.1	.1	.2	.0	.0	.0
37	6.9	.0	.0	.1	.1	1.8	.0	.0	.0
38	.5	.0	.0	.1	.1	.2	.0	.0	.0
39	1.6	.0	.0	.1	.1	.5	.0	.0	.0
40	.5	.0	.0	.1	.1	.2	.0	.0	.0

INPUT SEQ. 33, 48 EVENTS

SCORE 20
MAC CODES VARIANCES-10

41	25.0	58.6	49.2	42.6	39.9	55.5	42.0	67.2	105.2	62.0
42	.6	1.8	3.3	.9	1.2	1.7	1.8	1.3	1.9	1.3
43	1.7	5.5	4.2	2.7	3.1	4.5	3.6	4.1	6.0	4.0
44	.6	1.8	2.1	.9	1.2	1.8	1.9	1.4	2.2	1.3
45	6.4	20.4	15.7	9.6	9.9	13.9	12.0	14.6	20.8	15.1
46	.6	1.8	3.3	.9	1.1	1.6	2.C	1.3	1.9	1.3
47	1.7	5.5	3.5	2.7	3.0	4.7	3.6	4.0	5.7	4.0
48	.6	1.8	2.4	.9	1.1	1.9	1.8	1.5	2.1	1.3

SCORE 40
MAC CODES VARIANCES-10

41	57.1	34.2	38.5	58.2	66.5	64.9	54.9	48.8	49.0	31.5
42	2.3	1.1	1.8	2.0	2.2	2.2	1.9	1.3	1.8	.7
43	6.6	3.3	4.2	4.4	3.5	5.0	3.5	3.5	5.1	2.4
44	3.2	1.5	3.0	1.6	1.5	2.3	1.6	1.3	2.5	1.5
45	17.9	8.8	10.1	15.7	11.8	14.5	11.9	12.3	16.1	5.7
46	2.3	1.0	1.8	1.7	2.1	2.0	1.8	1.4	1.7	.7
47	5.3	3.3	4.1	4.2	3.6	5.0	3.1	3.5	4.8	2.2
48	2.8	1.5	3.1	1.6	1.6	2.5	1.7	1.4	2.5	1.2

SCORE 60
MAC CODES VARIANCES-19

41	.0	8.3	21.7	1.3	20.1	38.9	37.7	16.3	40.7	47.6	15.0	29.1	4.4	32.8	.3
	12.2	14.3	3.1	2.3											
42	.0	.5	4.0	.1	.4	.7	1.5	2.5	1.1	1.2	.3	1.1	.5	.7	.3
	.2	.6	1.0	.3											
43	.0	1.2	5.5	.9	1.3	2.4	3.9	2.7	4.2	3.1	1.0	2.4	.7	2.1	.3
	.7	1.3	1.5	.8											
44	.0	.3	4.3	.6	.4	.7	1.8	1.5	2.0	1.2	.3	1.5	.5	.7	.3
	.2	.6	1.0	.3											
45	.0	5.9	6.2	1.2	4.7	9.1	8.1	5.2	11.5	10.6	3.8	6.3	1.5	7.1	.3
	2.6	3.9	2.9	2.1											
46	.0	.5	4.3	.2	.4	.7	1.8	1.9	1.3	1.1	.3	1.2	.5	.7	.3
	.2	.6	1.0	.3											
47	.0	1.3	4.8	.9	1.3	2.1	3.7	2.7	4.3	2.9	1.0	2.3	.7	2.1	.3
	.7	1.3	1.8	1.1											
48	.0	.2	3.7	.5	.4	.7	1.7	1.4	1.9	1.1	.3	1.4	.5	.7	.3
	.2	.6	1.0	.3											

SCORE 80
MAC CODES VARIANCES- 9

41	27.6	.0	.C	.1	.1	7.1	.0	.0	.0
42	.5	.0	.0	.1	.1	.2	.0	.0	.0
43	1.7	.0	.0	.1	.1	.5	.0	.0	.0
44	.7	.0	.C	.1	.1	.2	.0	.0	.0
45	5.2	.0	.C	.1	.1	1.8	.C	.0	.0
46	.4	.0	.C	.1	.1	.2	.0	.0	.0
47	1.6	.0	.C	.1	.1	.5	.C	.0	.0
48	.7	.0	.0	.1	.1	.2	.0	.0	.0

INPUT SEG. 33, 46 EVENTS

SCORE 20
MAC CODES VARIANCES=10

49	99.3	178.3	174.8	166.7	161.6	250.4	181.8	270.6	497.2	260.1
50	.6	1.3	2.7	.9	1.2	2.9	1.8	1.5	2.6	1.7
51	1.7	3.7	3.9	3.1	3.1	5.7	4.1	4.1	7.5	4.9
52	.6	1.3	1.7	.9	1.2	2.6	2.0	1.3	1.8	1.7
53	6.4	13.1	12.5	11.7	10.8	17.7	12.2	15.1	28.8	16.4
54	.6	1.3	2.8	.9	1.1	1.9	1.8	1.3	1.9	1.3
55	1.7	3.7	2.8	3.1	3.0	4.2	3.0	4.2	5.7	3.6
56	.6	1.3	2.6	.9	1.1	1.9	1.7	1.4	1.9	1.3

SCORE 40
MAC CODES VARIANCES=10

49	192.4	136.9	149.1	237.9	277.2	260.3	234.0	185.8	142.7	151.7
50	1.6	1.7	2.1	2.6	2.3	2.5	2.1	1.3	1.0	.7
51	4.9	2.7	3.7	4.1	3.7	4.9	4.7	3.4	3.6	3.4
52	2.4	1.1	2.1	1.3	1.4	2.0	1.9	1.3	2.0	1.8
53	13.9	8.7	10.7	16.0	13.2	17.7	15.7	11.5	10.6	9.0
54	1.9	1.1	1.4	1.6	2.0	2.3	1.9	1.4	1.9	.7
55	3.9	2.7	2.9	4.0	3.4	5.6	3.4	3.6	3.6	2.5
56	2.1	1.2	1.6	1.5	1.8	2.3	1.7	1.4	2.3	.9

SCORE 60
MAC CODES VARIANCES=19

49	.0	11.6	80.0	1.4	78.0	159.0	160.2	68.8	147.7	178.2	59.5	130.2	16.2	135.9	.3				
	60.5	55.8	3.4	2.6															
50	.0	.2	2.7	.1	.4	.7	1.5	2.7	.9	1.0	.3	1.0	.5	.7	.3				
	.4	.6	1.0	.3															
51	.0	.9	3.2	.8	1.3	2.5	3.2	2.5	4.0	2.7	1.0	3.0	.7	2.1	.3				
	1.1	1.3	1.2	.5															
52	.0	.6	2.7	.7	.4	.7	1.7	1.4	2.2	1.0	.3	1.6	.5	.7	.3				
	.4	.6	1.0	.3															
53	.0	3.0	5.2	1.1	4.7	9.3	9.1	5.7	11.3	9.9	3.8	8.2	1.5	7.8	.3				
	4.0	3.9	2.5	1.8															
54	.0	.4	2.1	.3	.4	.7	2.2	1.1	1.4	1.3	.3	1.2	.5	.7	.3				
	.4	.6	1.0	.3															
55	.0	1.2	2.2	1.0	1.3	1.9	3.2	2.3	4.5	3.2	1.0	2.3	.7	2.1	.3				
	1.1	1.3	2.1	1.4															
56	.0	.3	2.1	.4	.4	.7	2.0	.9	1.7	1.3	.3	1.3	.5	.7	.3				
	.4	.6	1.0	.3															

SCORE 80
MAC CODES VARIANCES= 9

49	109.1	.0	.0	.1	.1	28.4	.0	.0	.0
50	.6	.0	.0	.1	.1	.2	.0	.0	.0
51	1.7	.0	.0	.1	.1	.5	.0	.0	.0
52	.4	.0	.0	.1	.1	.2	.0	.0	.0
53	7.0	.0	.0	.1	.1	1.8	.0	.0	.0
54	.7	.0	.0	.1	.1	.2	.0	.0	.0
55	1.9	.0	.0	.1	.1	.5	.0	.0	.0
56	.6	.0	.0	.1	.1	.2	.0	.0	.0

INPUT SEG. 33, 48 EVENTS

SCORE 20   *

MAC CODES	VARIANCES=10									
57	25.0	58.9	56.8	44.2	41.1	70.3	49.4	59.8	116.2	68.5
58	.6	2.0	3.C	.9	1.3	2.4	1.8	1.4	2.0	1.6
59	1.7	5.7	4.C	2.5	3.1	4.8	3.8	4.1	6.0	4.5
60	.6	2.0	1.9	.9	1.3	1.7	1.9	1.4	2.2	1.6
61	6.4	20.6	14.7	8.6	10.5	17.9	12.4	14.5	20.6	15.9
62	.6	2.0	3.2	.9	1.1	2.C	1.9	1.3	1.9	1.4
63	1.7	5.7	3.4	2.5	2.9	5.5	3.4	4.1	5.4	3.9
64	.6	2.0	2.6	.9	1.1	2.C	1.8	1.4	2.0	1.4

SCORE 40

MAC CODES	VARIANCES=1C									
57	62.3	33.6	46.3	62.8	52.7	67.3	66.8	43.3	44.2	33.0
58	2.3	1.3	2.0	2.3	2.5	2.3	2.1	1.4	1.7	.7
59	6.3	3.1	4.7	3.9	4.1	5.1	4.3	3.5	4.3	2.5
60	3.3	1.5	2.9	1.5	1.7	2.1	1.8	1.4	1.9	1.5
61	16.0	8.8	12.C	15.7	15.2	17.C	15.2	11.7	14.1	5=6
62	2.4	1.0	1.8	1.9	2.3	2.C	1.9	1.3	1.6	.7
63	4.7	3.2	3.8	4.2	4.3	5.C	3.5	3.5	4.4	2.1
64	2.9	1.4	2.7	1.7	1.8	2.3	1.8	1.3	2.0	1.1

SCORE 60

MAC CODES	VARIANCES=19																		
57	.0	9.1	18.7	1.3	13.6	14.3	3.2	2.4	18.9	39.C	30.C	16.9	39.1	39.1	15.0	30.2	4.5	28.4	.3
58	.0	.4	3.0	.1	.2	.6	1.0	.3	.5	.7	1.3	2.4	1.2	1.3	.3	1.1	.5	.7	.3
59	.0	1.2	5.1	.8	.5	1.3	1.5	.7	1.4	2.3	3.3	2.6	4.4	3.4	1.0	2.3	.7	2.0	.3
60	.0	.4	4.3	.6	.2	.6	1.0	.3	.5	.7	1.8	1.5	2.1	1.3	.3	1.5	.5	.7	.3
61	.0	5.2	6.1	1.2	1.8	3.9	2.8	2.0	5.3	9.0	6.6	5.1	12.5	12.2	3.8	5.6	1.5	7.4	.3
62	.0	.5	3.3	.2	.2	.6	1.0	.3	.5	.7	1.8	1.8	1.4	1.2	.3	1.2	.5	.7	.3
63	.0	1.3	3.9	1.0	.5	1.3	1.9	1.1	1.4	2.2	3.1	2.7	4.7	3.4	1.0	2.C	.7	2.2	.3
64	.0	.3	3.3	.5	.2	.6	1.0	.3	.5	.7	1.7	1.3	1.9	1.2	.3	1.4	.5	.7	.3

SCORE 80

MAC CODES	VARIANCES= 9								
57	28.2	.0	.C	.1	.1	7.1	.0	.0	.0
58	.7	.0	.0	.1	.1	.2	.0	.0	.0
59	1.8	.0	.0	.1	.1	.5	.C	.0	.0
60	.5	.0	.C	.1	.1	.2	.0	.0	.0
61	6.6	.0	.C	.1	.1	1.8	.0	.0	.C
62	.5	.0	.C	.1	.1	.2	.0	.0	.0
63	1.7	.0	.C	.1	.1	.5	.0	.0	.0
64	.7	.0	.C	.1	.1	.2	.0	.0	.0

APPENDIX VI

RESULTS OF REGRESSION ANALYSIS ON ABSOLUTE DATA

INPUT SEQ. = 33,

EVENT NO.	TRUE SCORE	PREDICTED SCORE	ERROR
67	80	58.15	-21.85
29	40	25.84	-14.16
5	60	65.24	5.24
6	60	58.58	-1.42
9	60	17.89	-42.11
12	60	56.89	-3.11
13	60	58.98	-1.02
15	40	48.63	8.63
16	60	55.61	-4.39
20	60	47.03	-17.97
21	80	65.24	-14.76
62	80	65.24	-14.76
163	60	49.64	-10.36
58	80	63.43	-16.57
63	40	28.84	-11.16
64	20	57.68	37.68
65	40	46.31	6.31
66	20	42.41	22.41
68	20	47.99	27.99
70	20	53.14	33.14
71	40	45.13	5.13
72	40	41.39	1.39
73	20	50.31	30.31
74	80	64.39	-15.61
84	60	36.37	-23.63
85	60	49.50	-10.50
86	60	60.71	.71
87	80	63.08	-16.92
93	60	45.10	-14.90
94	60	58.96	-1.04
26	40	45.06	5.06
27	40	51.14	11.14
28	40	32.72	-7.28
30	20	44.09	24.09
31	20	41.28	21.28
32	20	46.20	26.20
33	20	43.04	23.04
34	20	45.90	25.90
35	60	56.11	-3.89
45	60	61.33	1.33
46	40	43.09	3.09
47	80	65.24	-14.76
48	80	65.24	-14.76
49	80	65.24	-14.76
50	60	61.34	1.34
51	60	56.80	-3.20
54	60	52.28	-7.72
59	60	61.18	1.18

Results of Regression No. 1

EVENT NO.	TRUE SCORE	PREDICTED SCORE	ERROR
67	80	50.96	-29.04
23	40	40.59	.59
5	60	71.25	11.25
6	60	61.60	1.60
7	60	53.78	-6.22
10	60	67.80	7.80
13	60	57.79	-2.21
15	40	48.66	8.66
16	60	52.59	-7.41
20	60	46.43	-13.57
21	80	71.25	-8.75
62	80	71.25	-8.75
63	60	61.32	1.32
58	80	70.78	-9.22
61	40	37.54	-2.46
64	20	54.97	34.97
65	40	34.25	-5.75
66	20	19.43	-.57
68	20	43.15	23.15
70	20	44.03	24.03
71	40	29.69	-10.31
72	40	23.50	-16.50
73	20	45.19	25.19
74	80	71.03	-8.97
84	60	38.78	-21.22
85	60	38.15	-21.85
86	60	61.50	1.50
87	80	66.60	-13.40
91	60	51.84	-8.16
94	60	67.22	7.22
26	40	40.94	.94
27	40	47.74	7.74
28	40	40.30	.30
30	20	26.76	6.76
31	20	38.11	18.11
32	20	32.15	12.15
33	20	12.69	-7.31
34	20	23.82	3.82
35	60	51.92	-8.08
45	60	70.24	10.24
46	40	54.39	14.39
47	80	71.25	-8.75
48	80	71.25	-8.75
49	80	71.25	-8.75
50	60	62.85	2.85
51	60	61.07	1.07
54	60	63.92	3.92
89	60	66.45	6.45

INPUT SEQ. # 33,

Results of Regression No. 2

INPUT SEQ. = 33.

EVENT NO.	TRUE SCORE	PREDICTED SCORE	ERROR
67	60	69.76	-10.24
29	40	47.08	6.08
5	60	74.04	14.04
6	60	55.38	-4.62
9	60	63.09	3.09
12	60	73.94	13.94
11	60	58.33	-1.67
1[illegible]	40	42.25	2.25
1[illegible]	60	51.80	-8.20
20	60	53.52	-6.48
21	80	74.04	-5.96
62	80	74.04	-5.96
163	60	53.02	-6.98
58	80	72.24	-7.76
63	40	43.51	3.51
64	20	50.77	30.77
65	40	30.97	-9.03
66	20	15.73	-4.27
68	20	31.53	11.53
70	20	41.18	21.18
71	40	26.30	-13.70
72	40	42.25	2.25
73	20	28.49	8.49
74	80	73.19	-6.81
84	60	39.85	-20.15
85	60	50.42	-9.58
86	60	59.77	-.23
87	80	67.65	-12.35
93	60	45.26	-14.74
94	60	64.05	4.05
26	40	38.14	-1.86
27	40	44.42	4.42
28	40	31.22	-8.78
30	20	25.67	5.67
31	20	22.53	2.53
32	20	27.03	7.03
33	20	21.72	1.72
34	20	27.94	7.94
35	60	43.53	-16.47
45	60	70.16	10.16
46	40	53.43	13.43
47	80	74.04	-5.96
48	80	74.04	-5.96
49	80	74.04	-5.96
50	60	70.81	10.81
51	60	56.54	-3.46
54	60	61.76	1.76
59	60	70.55	10.55

Results of Regression No. 3

INPUT SEQ. = 33, 40,

EVENT NO.	TRUE SCORE	PREDICTED SCORE	ERROR
67	80	[illegible]	[illegible]
68	20	[illegible]	[illegible]
70	20	[illegible]	[illegible]
71	40	[illegible]	[illegible]
72	40	[illegible]	[illegible]
73	[illegible]	[illegible]	[illegible]
74	80	[illegible]	[illegible]
84	60	[illegible]	[illegible]
85	60	[illegible]	[illegible]
86	60	[illegible]	[illegible]
87	80	[illegible]	[illegible]
93	60	[illegible]	[illegible]
94	60	72.66	12.66
26	40	53.44	13.44
27	40	39.99	-.01
28	40	32.44	-7.56
30	20	18.90	-1.10
31	20	29.04	9.04
32	20	31.39	11.39
33	20	26.41	6.41
34	20	15.86	-4.14
35	60	55.76	-4.24
45	60	61.80	1.80
46	40	45.00	5.00
47	80	87.75	7.75
48	80	78.54	-1.46
49	80	68.04	-11.96
50	60	55.30	-4.70
51	60	59.44	-.56
54	60	43.91	-16.09
59	60	49.31	-10.69
29	40	29.24	-10.76
5	60	72.34	12.34
6	60	56.60	-3.40
9	60	56.71	-3.29
12	60	59.40	-.60
13	60	56.30	-3.70
15	40	50.74	10.74
16	60	49.44	-10.56
20	60	47.33	-12.67
21	80	63.80	-16.20
62	80	75.30	-4.70
163	60	50.20	-9.80
58	80	70.60	-9.40
63	40	47.96	7.96
64	20	54.41	34.41
65	40	35.52	-4.48
66	20	22.78	2.78

Results of Regression No. 4

EVENT NO.	TRUE SCORE	PREDICTED SCORE	ERROR
67	80	79.44	-.56
68	20	34.60	14.60
70	20	27.42	7.42
71	40	35.94	-4.06
72	40	34.58	-5.42
73	20	32.84	12.84
74	80	74.75	-5.25
84	60	49.83	-10.17
85	60	59.39	-.61
86	60	60.05	.05
87	80	80.99	.99
93	60	59.49	-.51
94	60	64.14	4.14
26	40	41.44	1.44
27	40	33.40	-6.60
28	40	33.86	-6.14
30	20	22.71	2.71
31	20	33.05	13.05
32	20	29.69	9.69
33	20	29.48	9.48
34	20	33.54	13.54
35	60	51.96	-8.04
45	60	66.51	6.51
46	40	53.72	13.72
47	80	91.98	11.98
48	80	73.01	-6.99
49	80	74.91	-5.09
50	60	55.60	-4.40
51	60	60.46	.46
54	60	55.74	-4.26
59	60	43.30	-16.70
29	40	20.01	-19.99
5	60	71.50	11.50
6	60	55.73	-4.[illegible]
9	60	50.95	-9.05
12	60	57.90	-2.10
13	60	53.56	-6.44
15	40	47.21	7.21
16	60	44.51	-15.49
20	60	47.45	-12.55
21	80	61.51	-18.49
62	80	77.36	-2.64
163	60	65.60	5.60
58	80	77.07	-2.93
63	40	55.94	15.94
64	20	43.79	23.79
65	40	27.33	-12.67
66	20	24.79	4.79

INPUT SEQ. = 30, 40, 33,

Results of Regression No. 5

INPUT SEQ. = 40, 33, 31, 43,

EVENT NO.	TRUE SCORE	PREDICTED SCORE	ERROR
67	80	80.03	.03
68	20	20.05	.05
70	20	32.60	12.60
71	40	37.21	-2.79
72	40	32.31	-7.69
73	20	33.26	13.26
74	80	70.71	-9.29
84	60	50.09	-9.91
85	60	56.61	-3.39
86	60	50.66	-9.34
87	80	89.32	9.32
93	60	63.13	3.13
94	60	70.40	10.40
26	40	48.47	8.47
27	40	37.86	-2.14
28	40	43.08	3.08
30	20	16.62	-3.38
31	20	22.42	2.42
32	20	22.97	2.97
33	20	24.54	4.54
34	20	21.64	1.64
35	60	74.17	14.17
45	60	64.78	4.78
46	40	43.99	3.99
47	80	78.07	-1.93
48	80	66.73	-13.27
49	80	83.50	3.50
50	60	58.55	-1.45
51	60	63.40	3.40
54	60	56.27	-3.73
59	60	53.36	-6.64
29	40	30.92	-9.08
5	60	59.77	-.23
6	60	59.07	-.93
9	60	53.62	-6.38
12	60	55.86	-4.14
13	60	47.33	-12.67
15	40	47.52	7.52
16	60	47.82	-12.18
20	60	54.44	-5.56
21	80	72.09	-7.91
62	80	83.52	3.52
163	60	57.41	-2.59
58	80	77.12	-2.88
63	40	50.15	10.15
64	20	38.21	18.21
65	40	34.04	-5.96
66	20	24.33	4.33

Results of Regression No. 6

INPUT SEG. = 30, 31, 33, 40,

EVENT NO.	TRUE SCORE	PREDICTED SCORE	ERROR
67	80	78.13	-1.87
68	20	20.89	.89
70	20	31.12	11.12
71	40	41.73	1.73
72	40	32.42	-7.58
73	20	30.37	10.37
74	80	74.80	-5.20
84	60	43.92	-16.08
85	60	58.57	-1.43
86	60	49.20	-10.80
87	80	84.55	4.55
93	60	64.36	4.36
94	60	73.59	13.59
26	40	49.51	9.51
27	40	39.95	-.05
28	40	40.24	.24
30	20	16.32	-3.68
31	20	33.25	13.25
32	20	25.41	5.41
33	20	31.65	11.65
34	20	22.38	2.38
35	60	62.00	2.00
45	60	62.41	2.41
46	40	41.58	1.58
47	80	79.35	-.65
48	80	75.40	-4.60
49	80	88.79	8.79
50	60	55.28	-4.72
51	60	59.07	-.93
54	60	53.17	-6.83
59	60	64.11	4.11
29	40	23.91	-16.09
5	60	71.00	11.00
6	60	56.22	-3.78
9	60	52.46	-7.54
12	60	57.03	-2.97
13	60	49.23	-10.77
15	40	53.14	13.14
16	60	52.01	-7.99
20	60	49.76	-10.24
21	80	69.82	-10.18
62	80	70.64	-9.36
163	60	60.07	.07
58	80	67.66	-12.34
63	40	52.53	12.53
64	20	35.17	15.17
65	40	30.06	-9.94
66	20	24.92	4.92

Results of Regression No. 7

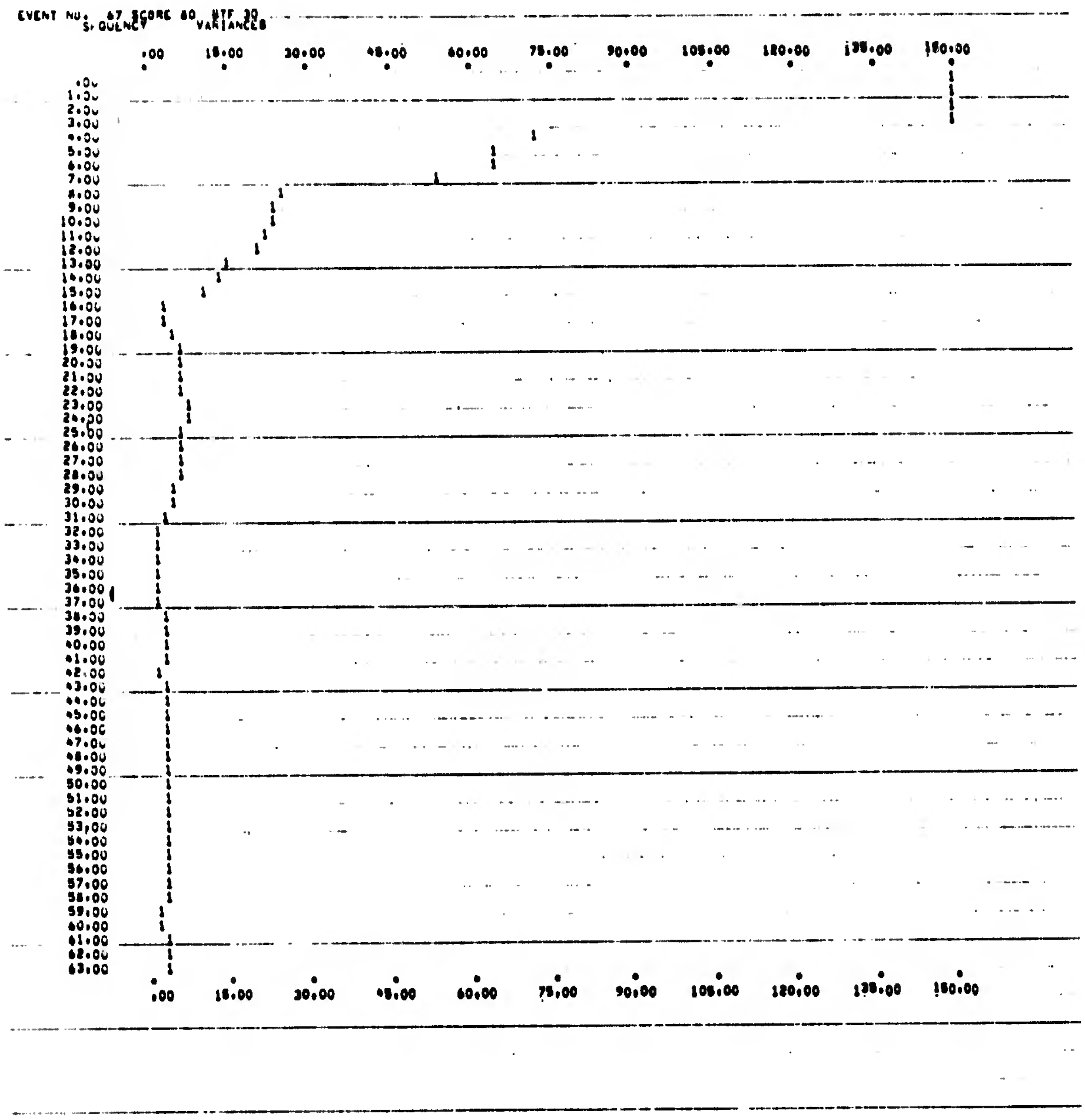
INPUT SEQ. = 30, 31, 33, 40, 43,

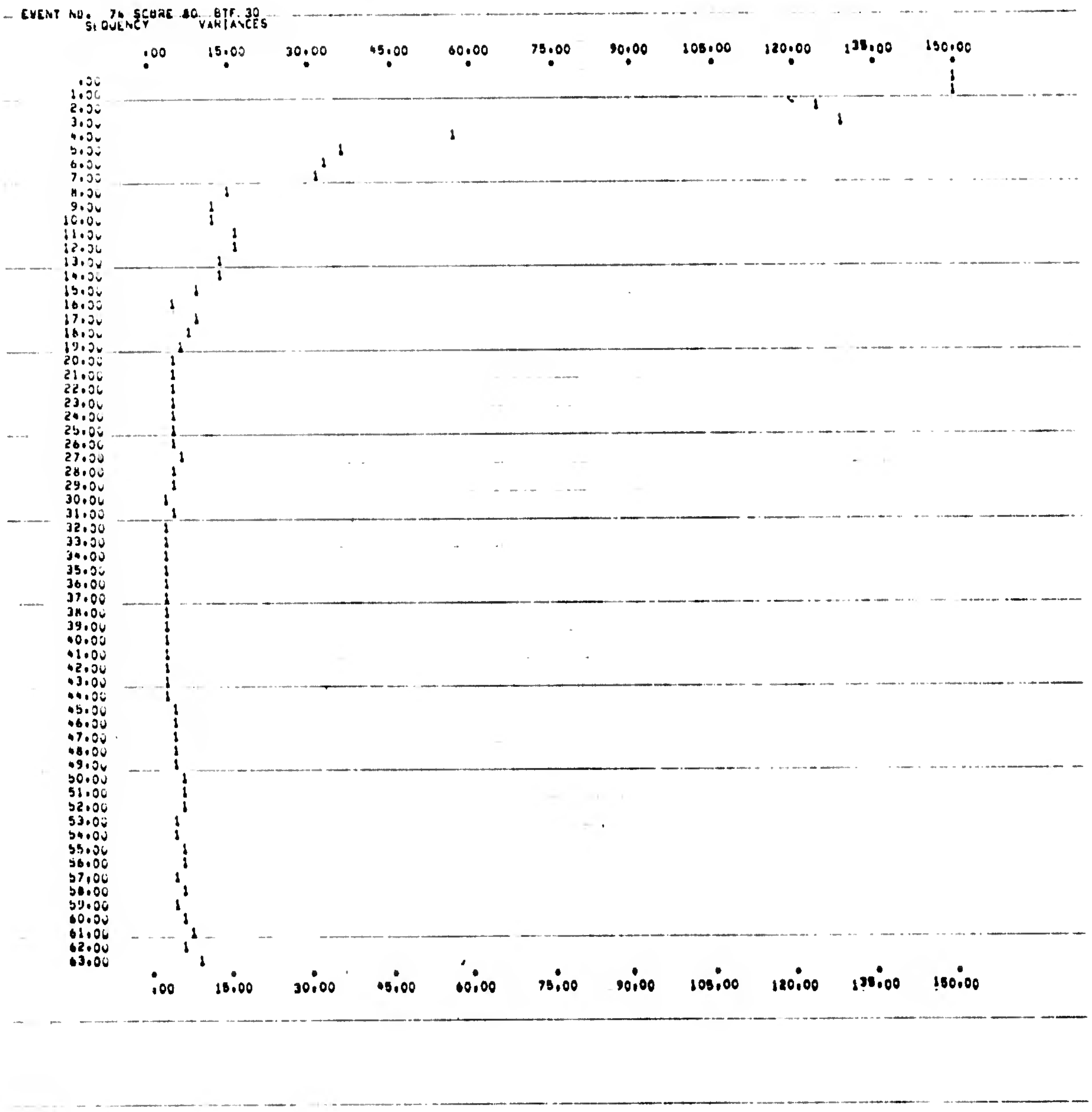
EVENT NO.	TRUE SCORE	PREDICTED SCORE	ERROR
67	80	84.37	4.37
68	20	18.99	-1.01
70	20	28.45	8.45
71	40	42.18	2.18
72	40	28.89	-11.11
73	20	31.47	11.47
74	80	69.53	-10.47
84	60	49.02	-10.98
85	60	56.28	-3.72
86	60	47.24	-12.76
87	80	88.22	8.22
93	60	57.35	-2.65
94	60	70.56	10.56
26	40	45.82	5.82
27	40	31.45	-8.55
28	40	41.45	1.45
30	20	19.05	-.95
31	20	28.51	8.51
32	20	19.92	-.08
33	20	27.45	7.45
34	20	24.78	4.78
35	60	69.02	9.02
45	60	67.51	7.51
46	40	40.74	.74
47	80	77.51	-2.49
48	80	69.34	-10.66
49	80	78.65	-1.35
50	60	57.91	-2.09
51	60	64.53	4.53
54	60	56.85	-3.15
59	60	58.39	-1.61
29	40	31.72	-8.28
5	60	67.98	7.98
6	60	63.71	3.71
9	60	56.13	-3.87
12	60	59.35	-.65
13	60	47.74	-12.26
15	40	45.10	5.10
16	60	49.55	-10.45
20	60	54.74	-5.26
21	80	74.11	-5.89
62	80	79.42	-.58
163	60	60.51	.51
58	80	75.35	-4.65
63	40	49.79	9.79
64	20	34.92	14.92
65	40	36.24	-3.76
66	20	22.21	2.21

Results of Regression No. 8

APPENDIX VII

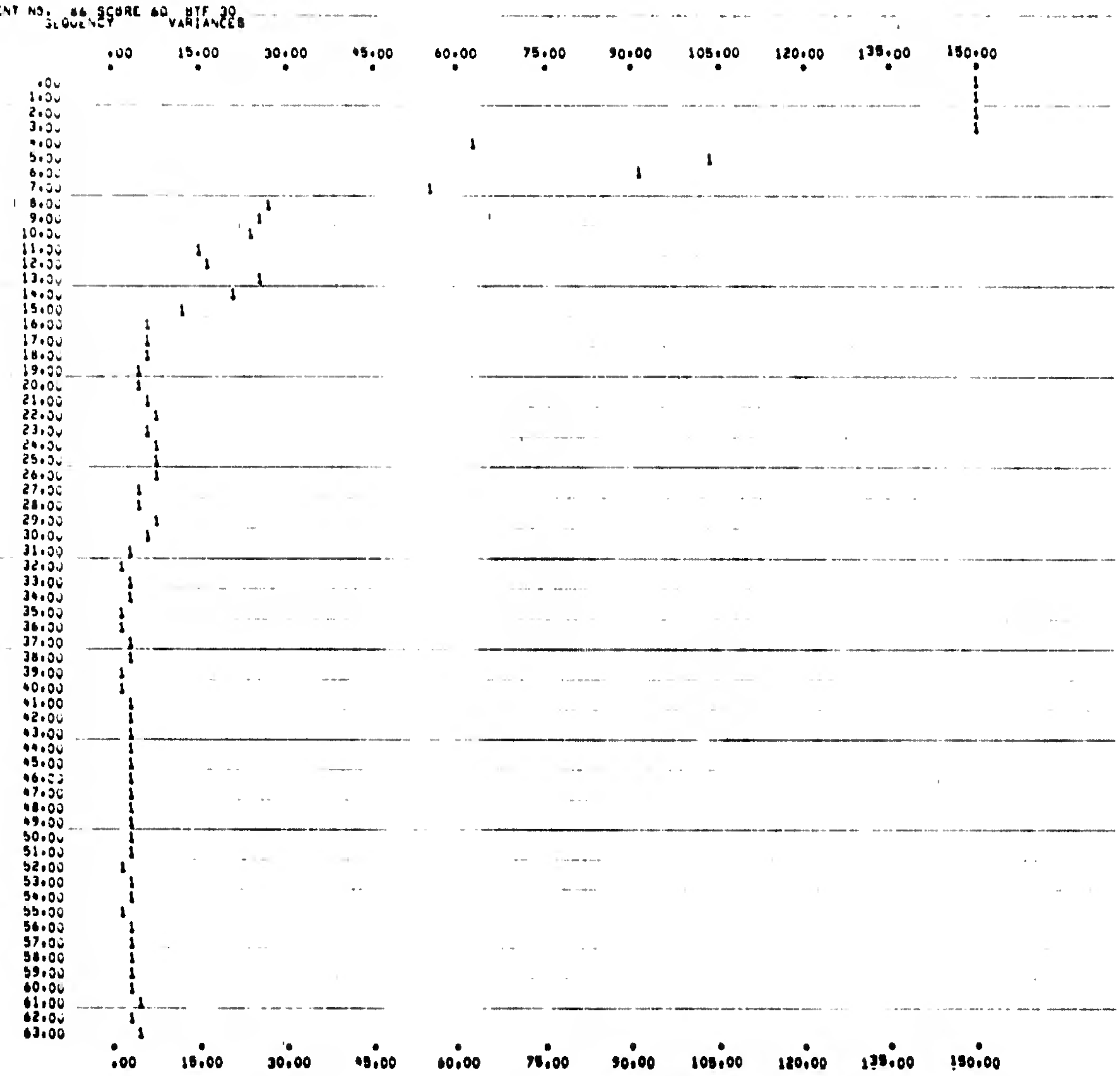
VARIANCE VERSUS SEQUENCY PLOTS (BTS 30 AND 40)

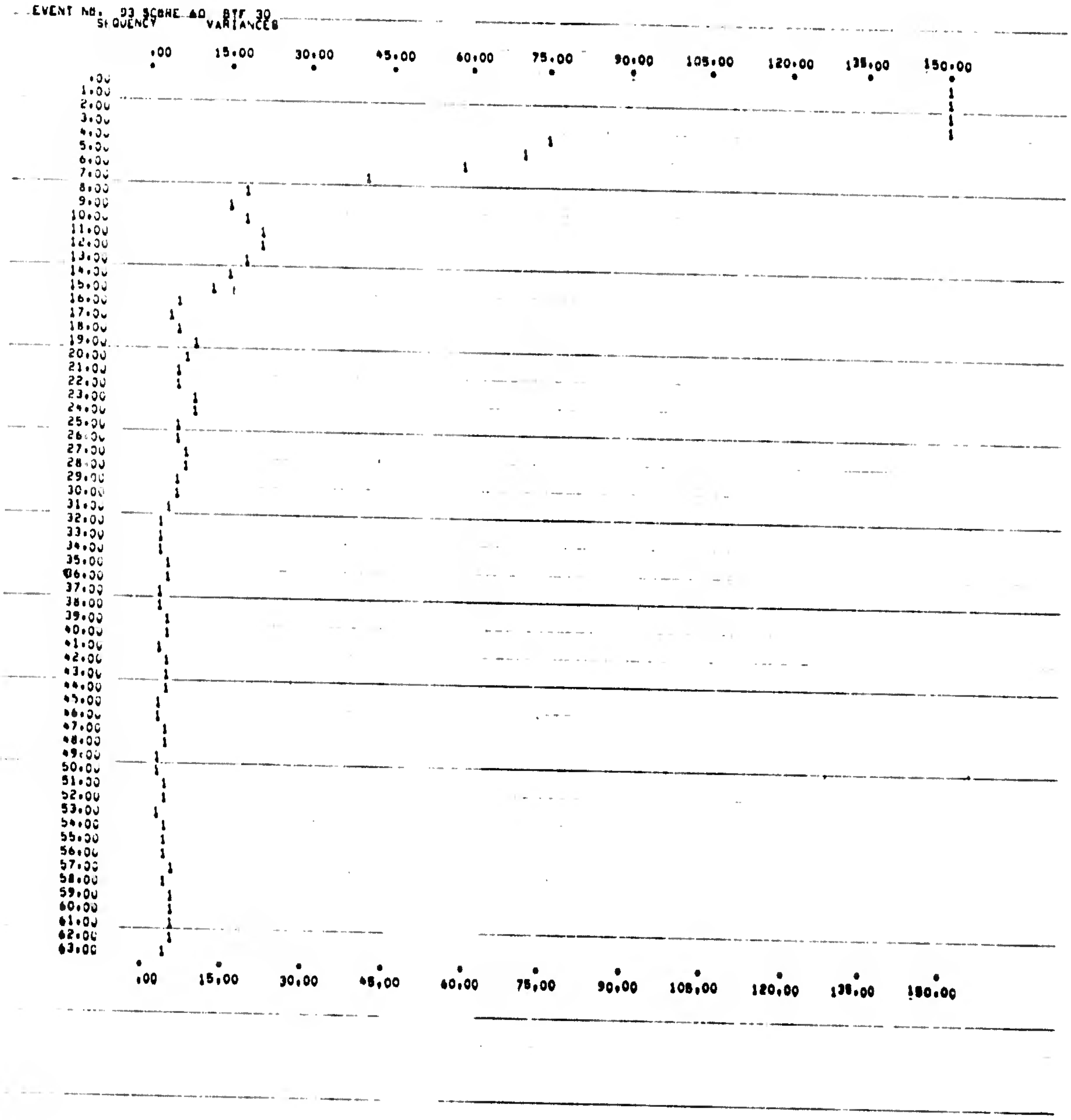

EVENT NO. 67 SCORE 80 BTF 30
SEQUENCY VARIANCES

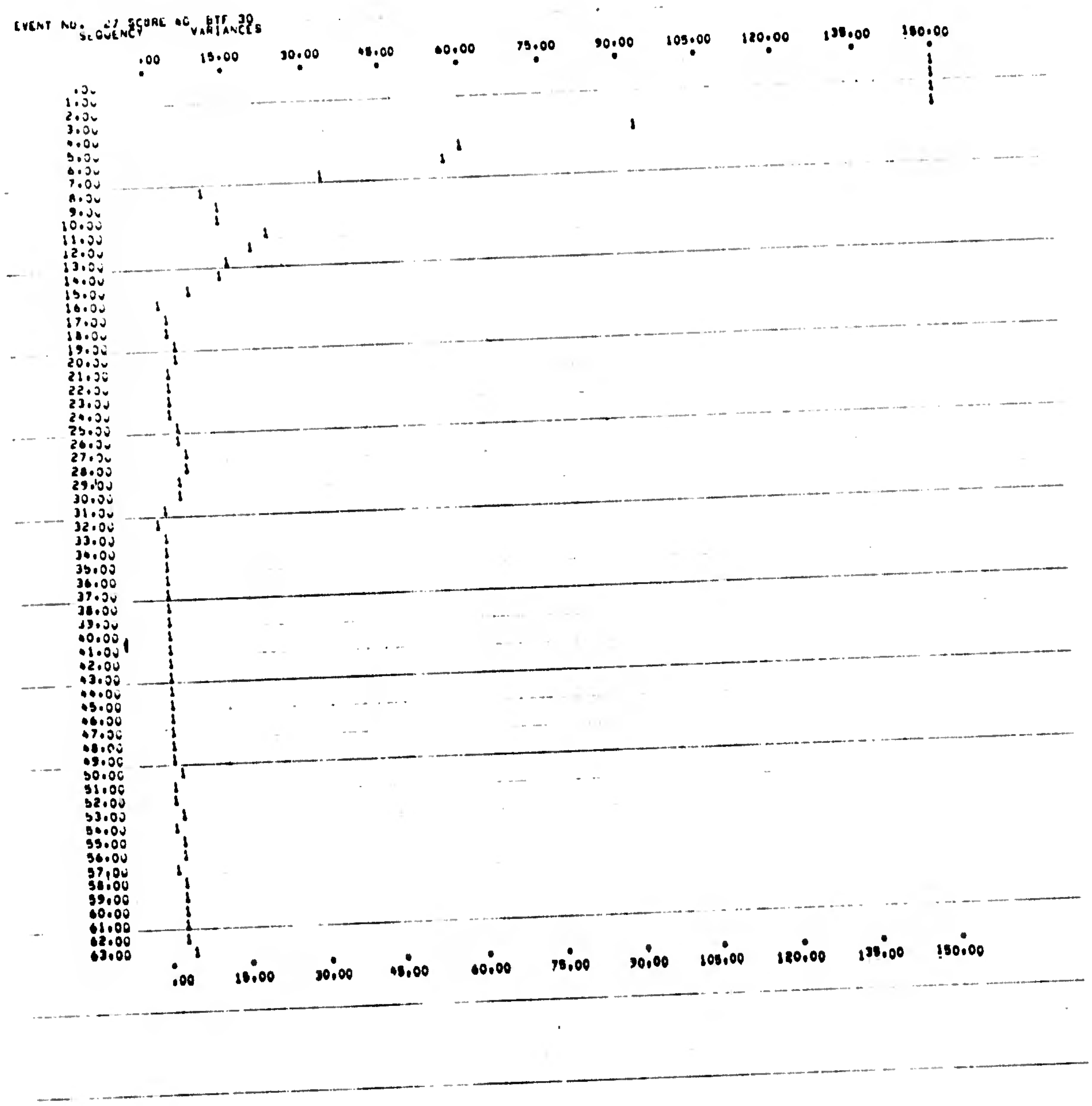


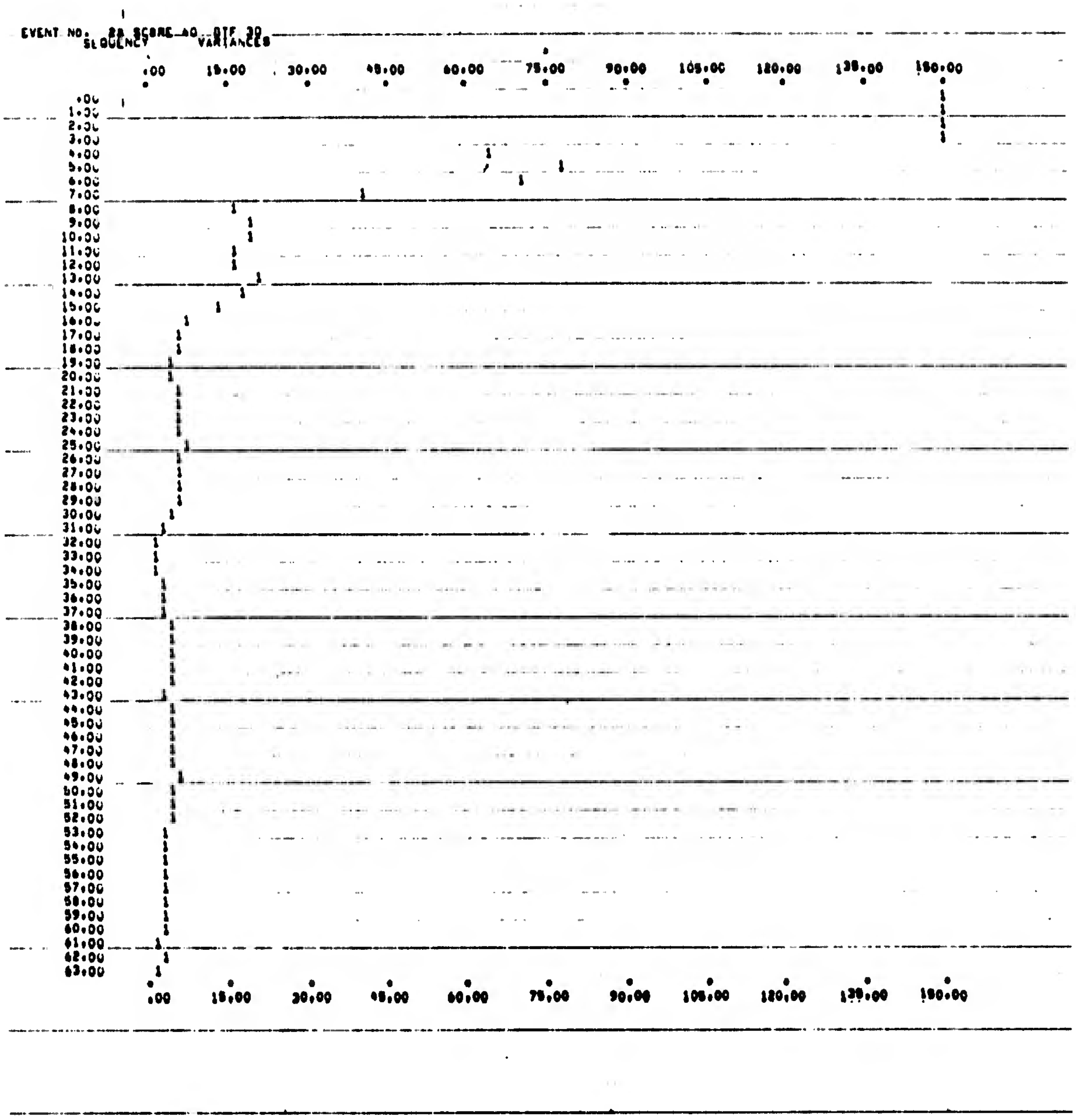
SCORE 80 BTF 30
SEQUENCY
VARIANCES
.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
135.00
150.00

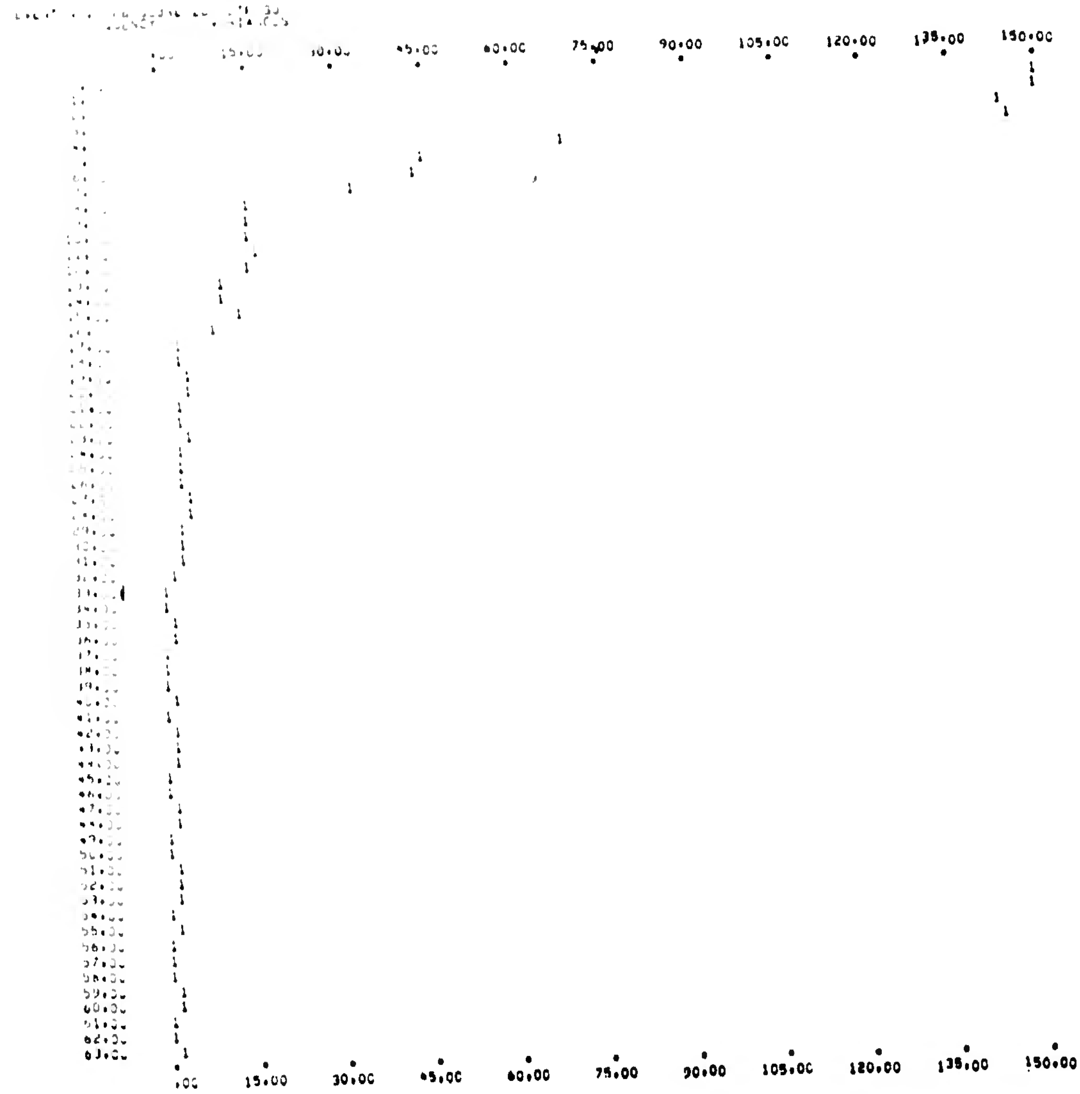
EVENT NO. 86 SCORE 60 HTF 30




EVENT NO. 93 SCORE 60 BTF 30
SEQUENCY VARIANCES

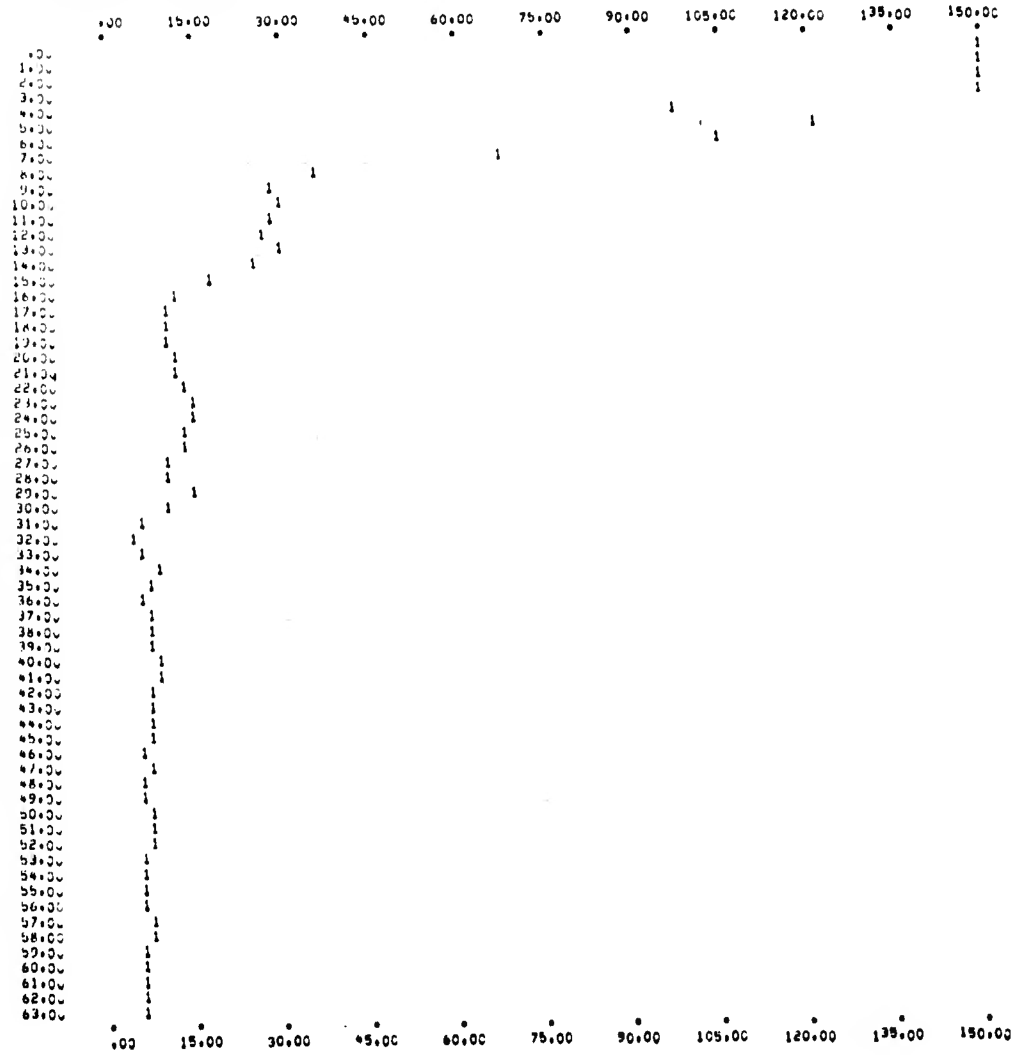

EVENT NO. 27 SCORE 40 BTF 30
SEQUENCY VARIANCES
.00 15.00 30.00 45.00 60.00 75.00 90.00 105.00 120.00 135.00 150.00

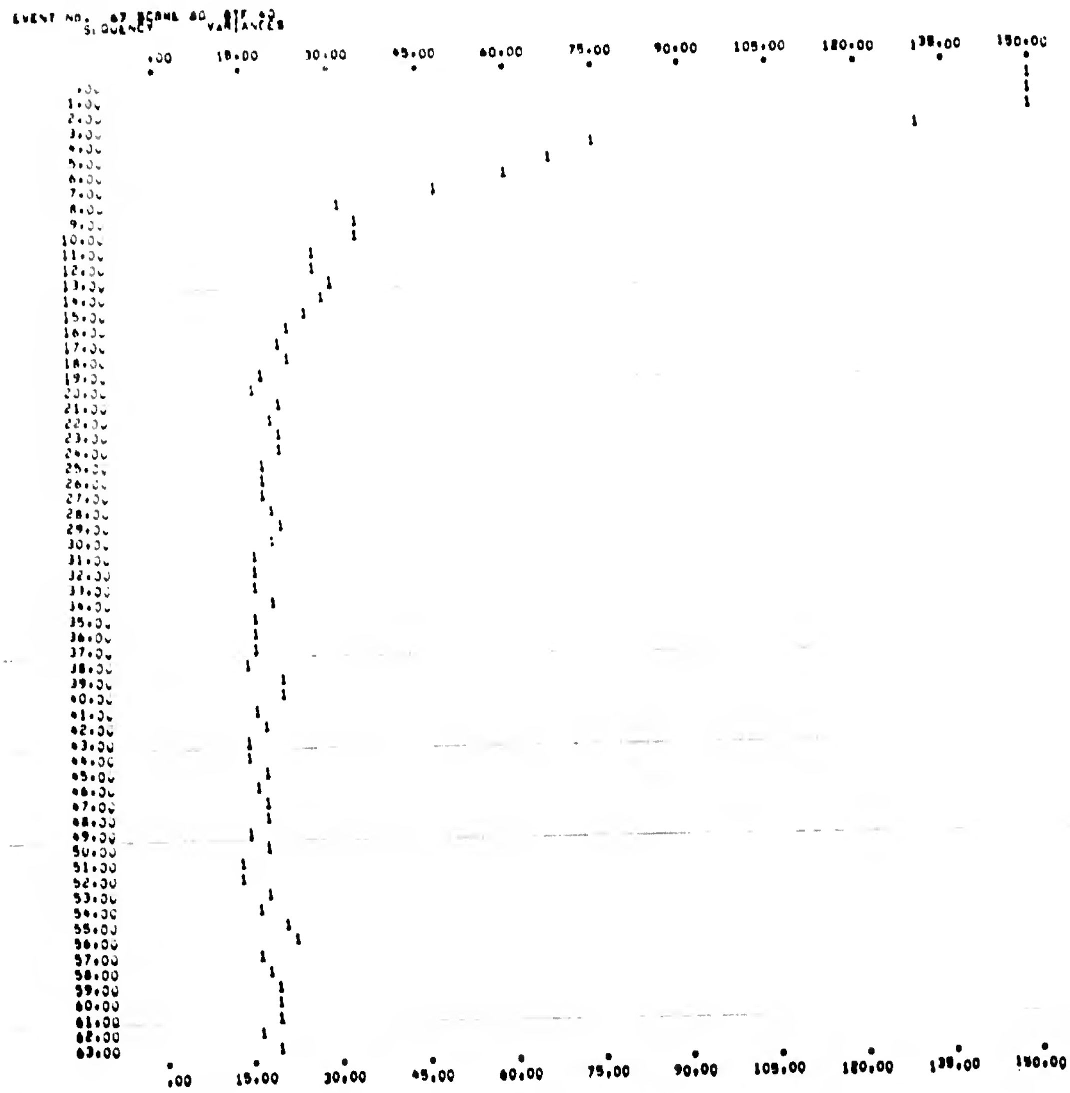

EVENT NO. 28 SCORE AO DTF 30
SEQUENCY
VARIANCES
.00 15.00 30.00 45.00 60.00 75.00 90.00 105.00 120.00 135.00 150.00



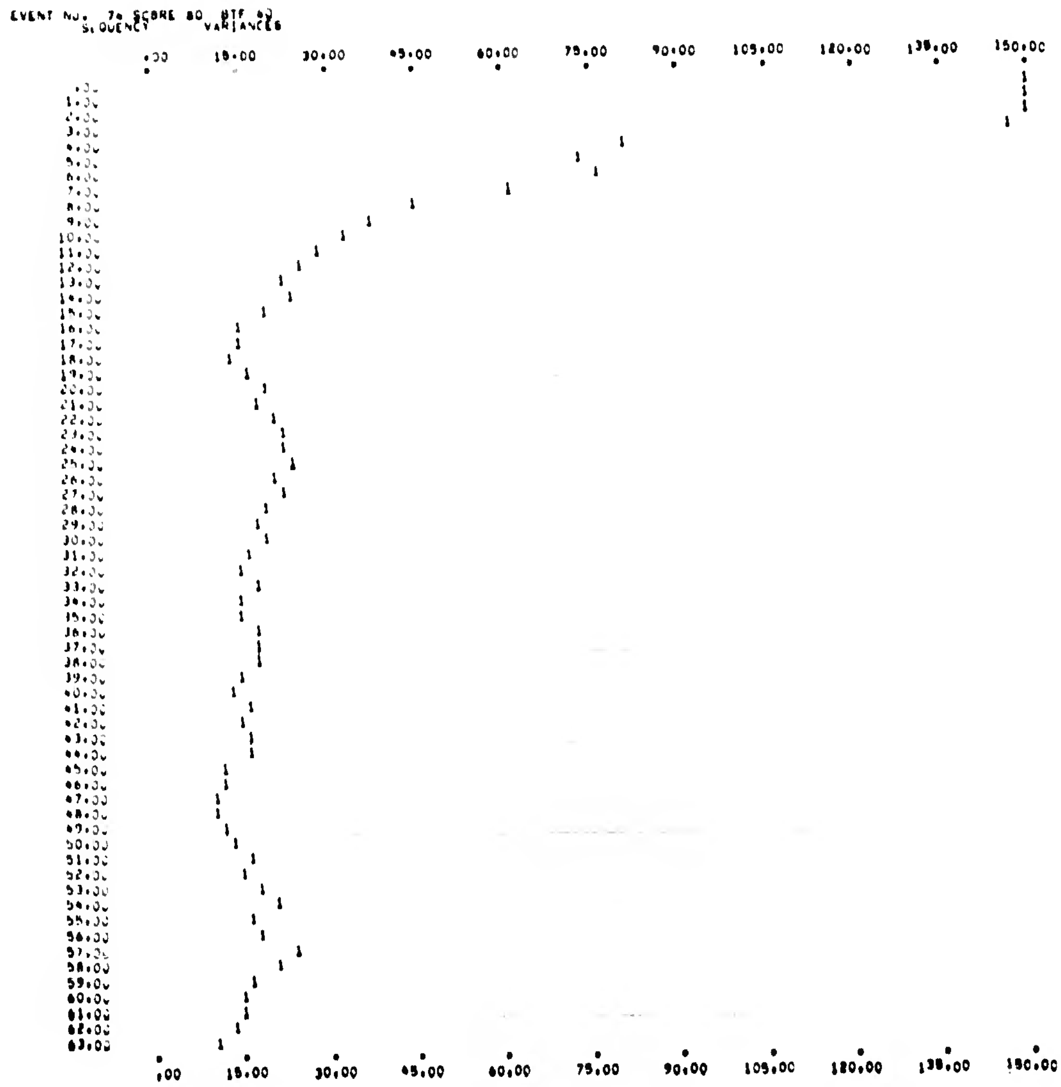
NOT REPRODUCIBLE

EVENT NO. 34 SCORE 20 BTF 30
FREQUENCY VARIANCES



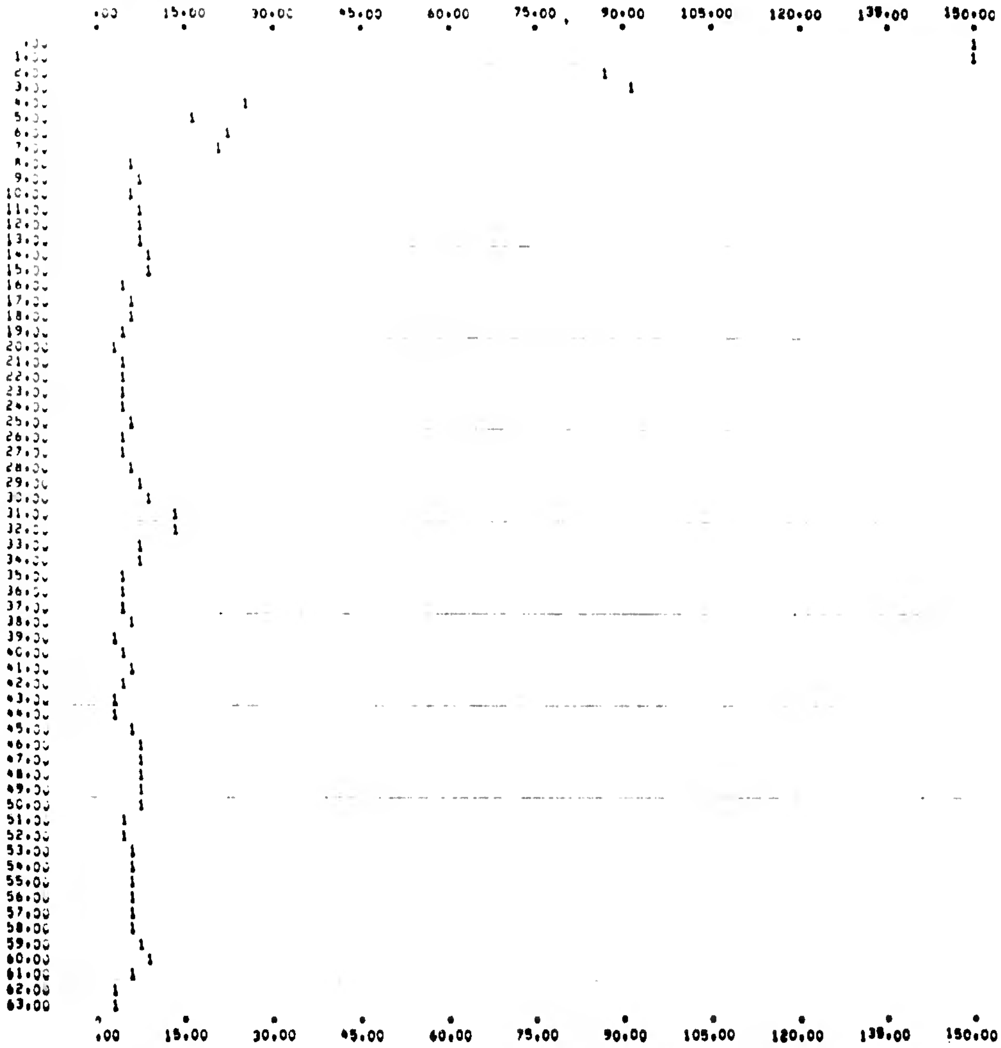


SEQUENCY
VARIANCES
.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
135.00
150.00

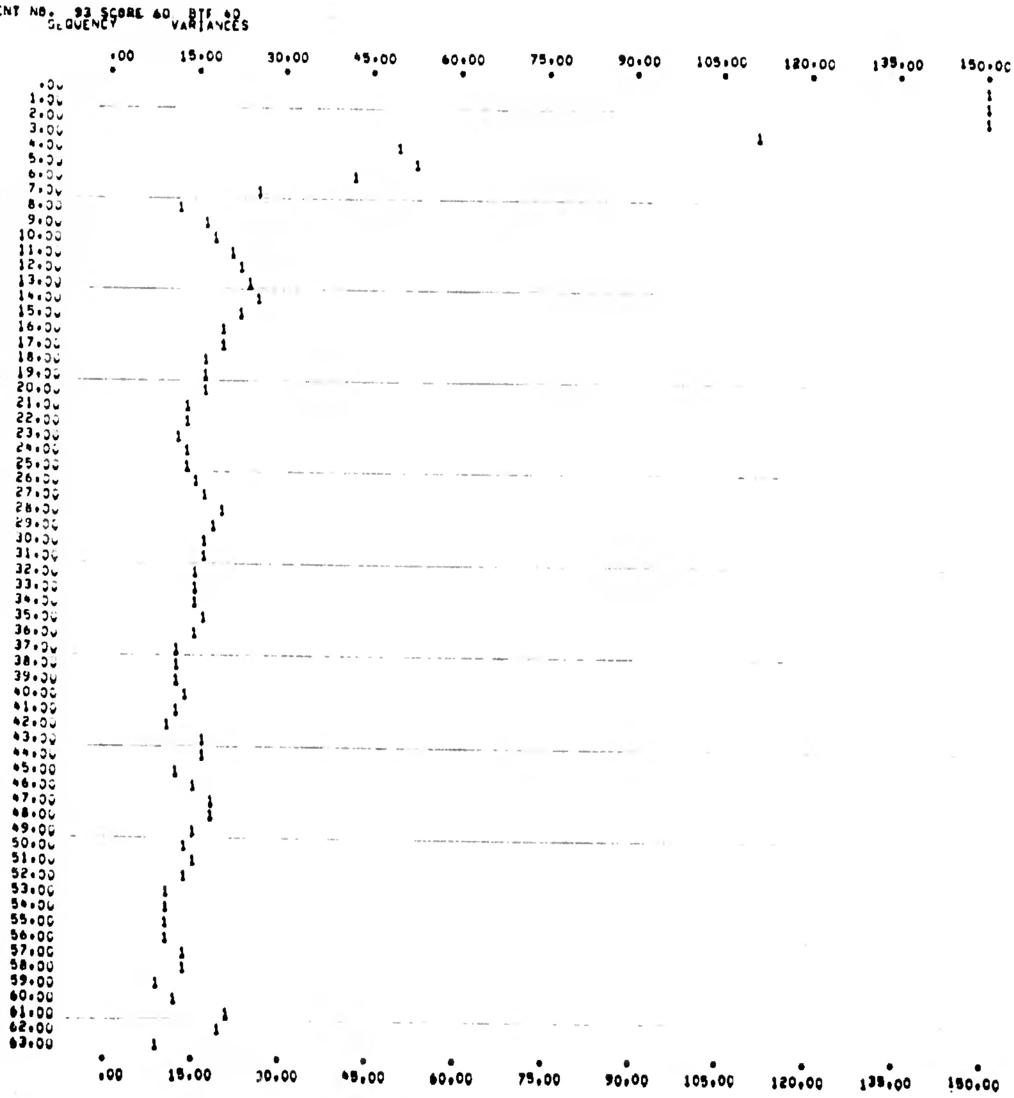


EVENT NO. 7a SCORE 80 BTF 6J
SEQUENCY
VARIANCES
.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
135.00
150.00

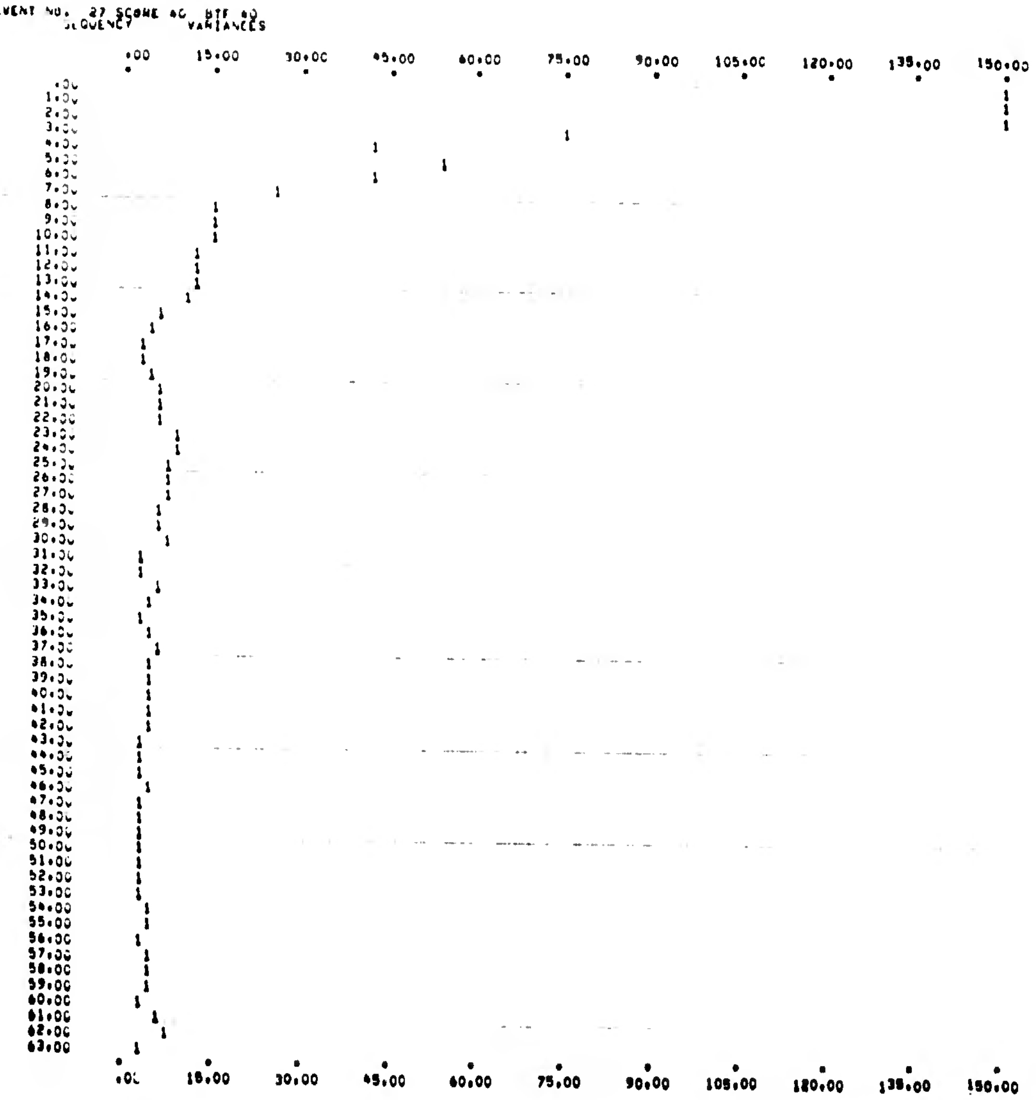
EVENT NO. 86 SCORE 60 BTF 63
FREQUENCY VARIANCES



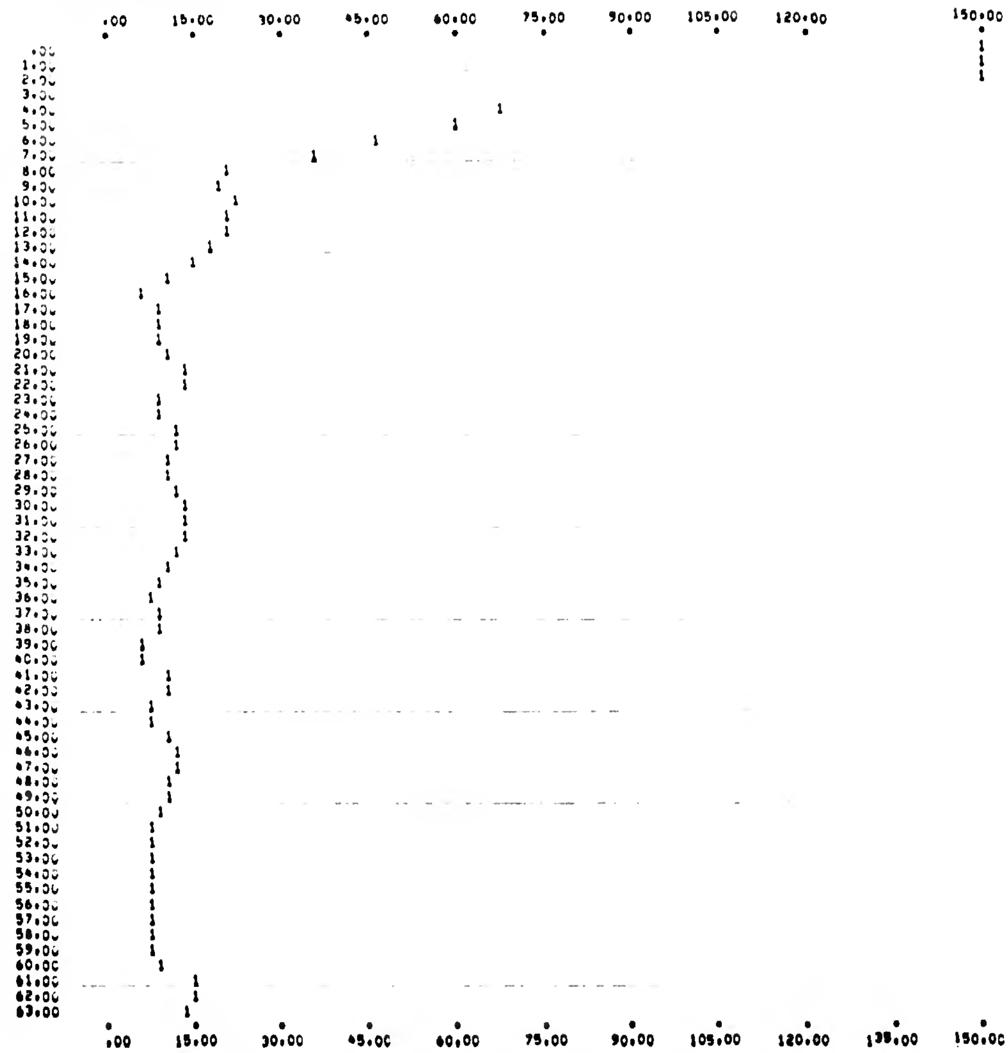
EVENT NO. 93 SCORE 60 BTF 60



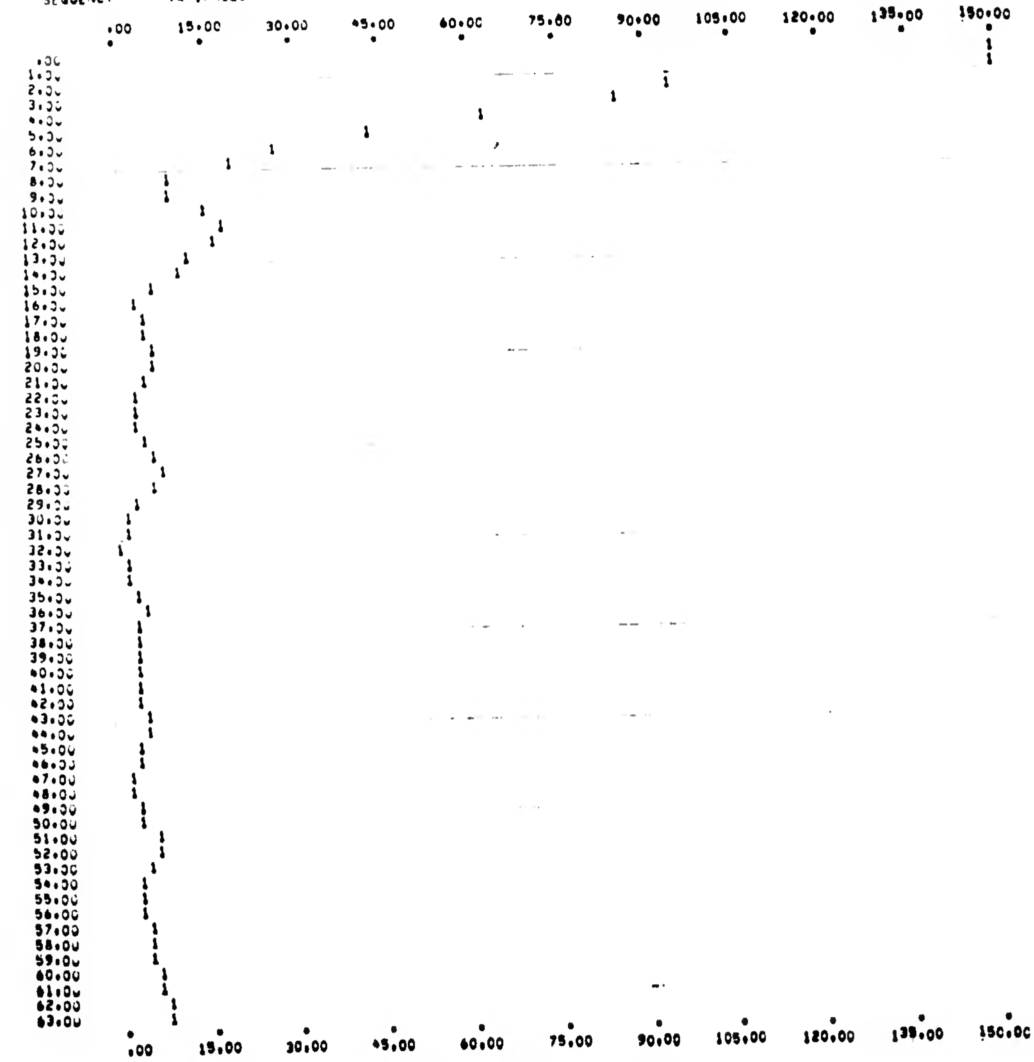
EVENT NO. 27 SCORE 40 BTF 40

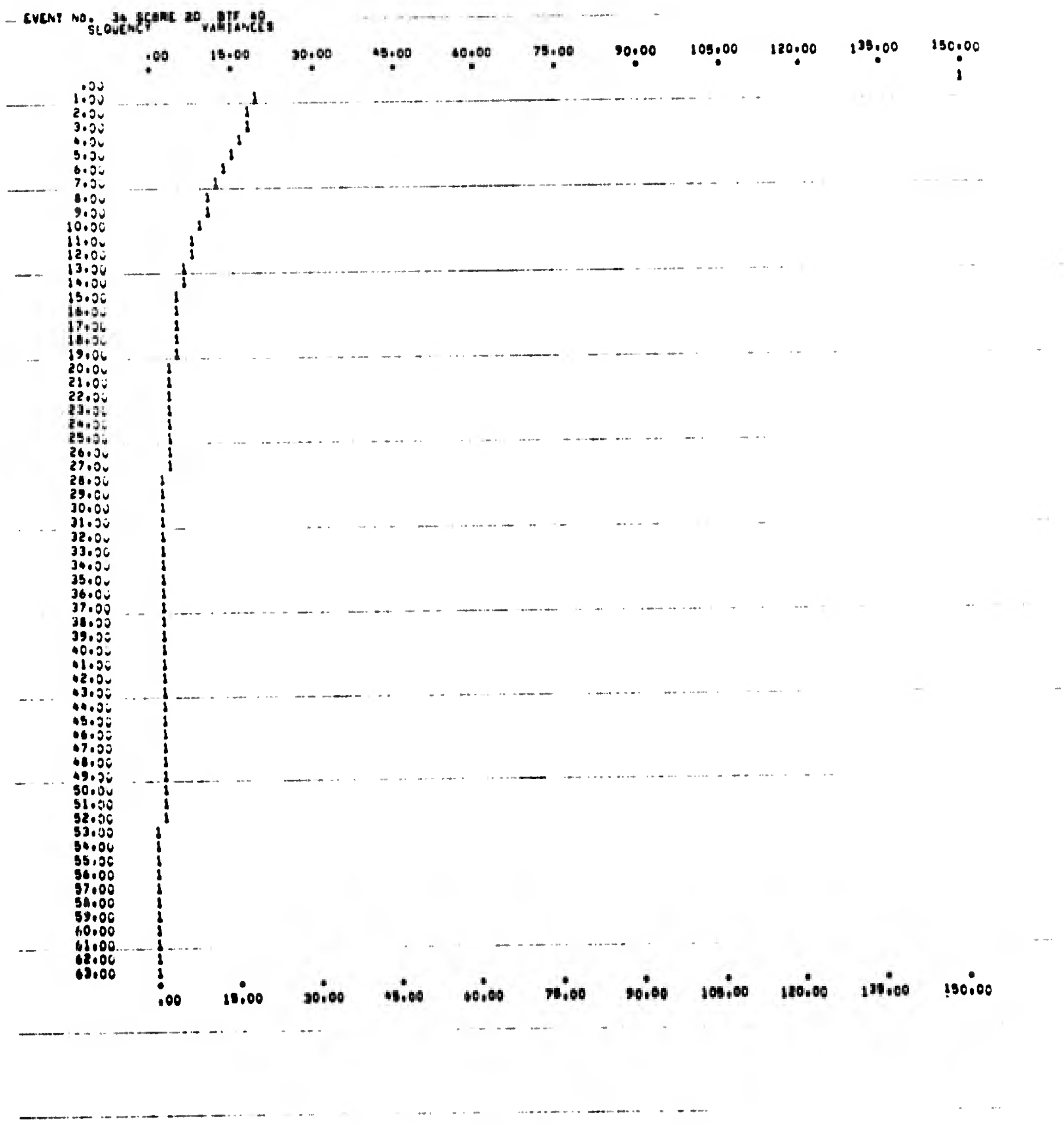


EVENT NO. 28 SCORE 40 BTF 40
SEQUENCY VARIANCES



EVENT NO. 66 SCORE 20 BIF 40
SEQUENCY VARIANCES




EVENT NO. 36 SCORE 20 BTF 40
SEQUENCY
VARIANCES
.00 15.00 30.00 45.00 60.00 75.00 90.00 105.00 120.00 135.00 150.00

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APPENDIX VIII

RESULTS OF REGRESSION ANALYSIS ON RELATIVE DATA
(BTS 8, 9, 13, 15, 28)

EVENT NO.	TRUE SCORE	PREDICTED SCORE	ERROR
67	80	58.64	-21.36
68	20	36.44	16.44
70	20	42.55	22.55
71	40	40.06	.06
72	40	55.36	15.36
73	20	24.80	4.80
74	80	72.53	-7.47
84	60	63.15	3.15
85	60	63.57	3.57
86	60	54.03	-5.97
87	80	102.12	22.12
93	60	57.63	-2.37
94	60	61.33	1.33

Results of Regression No. 9 BTS 8, 9, 13, 15, 28

26	40	37.79	-2.21
27	40	31.24	-8.76
28	40	49.70	9.70
30	20	34.19	14.19
31	20	41.63	21.63
32	20	25.80	5.80
33	20	28.34	8.34
34	20	33.78	13.78
35	60	43.35	-16.65
45	60	59.90	-.10
46	40	49.67	9.67
47	80	62.19	-17.81
48	80	66.08	-13.92

49	80	54.02	-25.98
50	60	62.27	2.27
51	60	56.44	-3.56
54	60	55.85	-4.15
59	60	55.10	-4.90
29	40	38.60	-1.40
5	60	62.49	2.49
6	60	68.06	8.06
9	60	69.52	9.52
12	60	66.30	6.30
13	60	43.08	-16.92
15	40	37.45	-2.55
16	60	24.47	-35.53
20	60	42.97	-17.03

21	80	57.47	-22.53
62	80	54.77	-25.23
163	60	54.45	-5.55
58	80	6C.36	-19.64
63	40	45.37	5.37
64	20	46.77	26.77
65	40	5C.08	10.08
66	20	44.14	24.14

EVENT NO.	TRUE SCORE	PREDICTED SCORE	ERROR
67	80	48.03	-31.97
68	20	39.13	19.13
70	20	44.01	24.01
71	40	40.54	.54
72	40	41.14	1.14
73	20	48.58	28.58
74	80	53.04	-26.96
84	60	72.74	12.74
85	60	70.16	10.16
86	60	55.65	-4.35
87	80	94.43	14.43
93	60	52.45	-7.55
94	60	64.10	4.10

Results of Regression No. 10 BTS 8, 9, 12, 15, 28

26	40	50.19	10.19
27	40	32.05	-7.95
28	40	51.98	11.98
30	20	41.59	21.59
31	20	45.98	25.98
32	20	29.60	9.60
33	20	28.79	8.79
34	20	39.25	19.25
35	60	50.63	-9.37
45	60	57.35	-2.65
46	40	68.87	28.87
47	80	66.00	-14.00
48	80	57.41	-22.59

49	80	51.70	-28.30
50	60	58.66	-1.34
51	60	59.86	-.14
54	60	66.43	6.43
59	60	52.89	-7.11
29	40	45.61	5.61
5	60	57.90	-2.10
6	60	57.67	-2.33
9	60	68.71	8.71
12	60	58.51	-1.49
13	60	50.81	-9.19
15	40	32.25	-7.75
16	60	49.43	-10.57
20	60	41.48	-18.52

21	80	38.50	-41.50
62	80	67.02	-12.98
163	60	52.75	-7.25
58	80	52.26	-27.74
63	40	34.85	-5.15
64	20	42.47	22.47
65	40	41.26	1.26
66	20	50.08	30.08

EVENT NO.	TRUE SCORE	PREDICTED SCORE	ERROR
67	80	69.41	-10.59
68	20	38.49	18.49
70	20	14.03	-5.97
71	40	35.62	-4.38
72	40	38.40	-1.60
73	20	33.18	13.18
74	80	73.76	-6.24
84	60	57.26	-2.74
85	60	52.86	-7.14
86	60	46.51	-13.49
87	80	70.40	-9.60
93	60	54.70	-5.30
94	60	68.45	8.45

Results of Regression No. 11 BTS 7, 12, 33, 40, 28

26	40	39.66	-.34
27	40	36.94	-3.06
28	40	50.25	10.25
30	20	22.21	2.21
31	20	17.77	-2.23
32	20	30.89	10.89
33	20	11.21	-8.79
34	20	34.99	14.99
35	60	51.10	-8.90
45	60	54.98	-5.02
46	40	47.72	7.72
47	80	76.60	-3.40
48	80	81.88	1.88

49	80	84.48	4.48
50	60	62.75	2.75
51	60	53.19	-6.81
54	60	56.77	-3.23
59	60	50.96	-9.04
29	40	49.11	9.11
5	60	64.83	4.83
6	60	60.22	.22
9	60	64.88	4.88
12	60	70.48	10.48
13	60	77.23	17.23
15	40	48.07	8.07
16	60	58.66	-1.34
20	60	51.97	-8.03

21	80	57.75	-22.25
62	80	76.87	-3.13
163	60	59.85	-.15
58	80	73.91	-6.09
63	40	42.87	2.87
64	20	21.85	1.85
65	40	35.10	-4.90
66	20	15.59	-4.41

EVENT NO.	TRUE SCORE	PREDICTED SCORE	ERROR
67	80	71.33	-8.67
68	20	36.03	16.03
70	20	15.14	-4.86
71	40	32.63	-7.37
72	40	43.79	3.79
73	20	29.10	9.10
74	80	75.62	-4.38
84	60	36.61	-23.39
85	60	40.45	-19.55
86	60	53.95	-6.05
87	80	80.91	.91
93	60	58.24	-1.76
94	60	64.62	4.62

Results of Regression No. 12 BTS 9, 11, 15, 40, 33

26	40	40.10	.10
27	40	29.26	-10.74
28	40	55.82	15.82
30	20	30.52	10.52
31	20	23.62	3.62
32	20	39.98	19.98
33	20	25.17	5.17
34	20	18.79	-1.21
35	60	51.18	-8.82
45	60	58.89	-1.11
46	40	53.98	13.98
47	80	94.36	14.36
48	80	76.21	-3.79

49	80	75.56	-4.44
50	60	56.50	-3.50
51	60	50.75	-9.25
54	60	59.47	-.53
59	60	55.51	-4.49
29	40	49.29	9.29
5	60	66.55	6.55
6	60	71.11	11.11
9	60	67.30	7.30
12	60	60.44	.44
13	60	56.62	-3.38
15	40	38.46	-1.54
16	60	45.44	-14.56
20	60	61.24	1.24

21	80	65.73	-14.27
62	80	68.27	-11.73
163	60	58.94	-1.06
58	80	71.54	-8.46
63	40	51.76	11.76
64	20	25.24	5.24
65	40	40.42	.42
66	20	36.53	16.53

APPENDIX IX

INSTRUCTOR AND PREDICTED SCORE DATA FOR STATE TRANSITION COMPUTATIONS

UPDATED SUMMARY

EVENT NO.	SCORES TRUE	PREDICTED **** 5
26	40	42
27	40	42
28	40	38
31	20	46
33	20	49
29	40	49
30	20	46
32	20	50
35	60	48
70	20	39
34	20	46
67	80	50
68	20	49
71	40	48
72	40	48
73	20	47
74	80	49
84	60	47
85	60	51
86	60	44
87	80	48
93	60	41
94	60	38
45	60	46
46	40	58
49	80	49
50	60	51
51	60	50
54	60	47
47	80	48
59	60	46
48	80	49
5	60	52
9	60	51
12	60	48
13	60	49
20	60	39
6	60	50
16	60	45
21	80	49
15	40	48
64	20	40
66	20	44
62	80	53
163	60	49
58	80	49
63	40	40
65	40	39

ICON= 1 10 13 24

Instructor and Predicted Score Data for Histogram No. 13

	SCORES	
EVENT NO.	TRUE	PREDICTED ****
67	80	31
68	20	30
70	20	19
71	40	32
72	40	38
73	20	32
74	80	38
84	60	33
85	60	29
86	60	38
87	80	39
93	60	34
94	60	37
26	40	26
27	40	35
28	40	31
30	20	18
31	20	19
32	20	22
33	20	26
34	20	27
35	60	37
45	60	39
46	40	33
47	80	49
48	80	41
49	80	43
50	60	40
51	60	41
54	60	42
59	60	40
29	40	34
5	60	34
6	60	45
9	60	46
12	60	40
13	60	37
15	40	21
16	60	35
20	60	40
21	80	39
62	80	43
163	60	31
58	80	49
63	40	25
64	20	18
65	40	32
66	20	24

Instructor and Predicted Score Data for Histogram No. 14

UPDATED SUMMARY

	SCORES	
EVENT NO.	TRUE	PREDICTED ****
29	40	57
5	60	66
6	60	64
9	60	63
12	60	65
13	60	61
15	40	60
16	60	52
20	60	54
21	80	63
62	80	67
163	60	54
58	80	62
63	40	55
64	20	49
65	40	49
66	20	55
67	80	61
68	20	47
70	20	47
71	40	52
72	40	57
73	20	58
74	80	65
84	60	58
85	60	57
86	60	62
87	80	58
93	60	53
94	60	65
26	40	56
27	40	60
28	40	53
30	20	52
31	20	53
32	20	47
33	20	48
34	20	43
35	60	60
45	60	66
46	40	61
47	80	75
48	80	72
49	80	64
50	60	66
51	60	61
54	60	61
59	60	59

ICON= 13

Instructor and Predicted Score Data for Histogram No. 15

UPDATED SUMMARY

	SCORES	
EVENT NO.	TRUE	PREDICTED ****
		3
29	40	50
5	60	66
6	60	62
9	60	53
12	60	60
13	60	44
15	40	39
16	60	43
20	60	49
21	80	60
62	80	62
163	60	58
58	80	60
63	40	48
64	20	34
65	40	46
66	20	35
67	80	55
68	20	41
70	20	25
71	40	43
72	40	43
73	20	48
74	80	64
84	60	40
85	60	45
86	60	47
87	80	59
93	60	56
94	60	59
26	40	46
27	40	41
28	40	40
30	20	42
31	20	40
32	20	41
33	20	34
34	20	37
35	60	46
45	60	63
46	40	53
47	80	71
48	80	64
49	80	63
50	60	60
51	60	52
54	60	60
59	60	60

ICON= 40 4

Instructor and Predicted Score Data for Histogram No. 16