AD-786 492

MACHINE RECOGNITION OF HAND-SENT MORSE CODE USING THE PDP-12 COMPUTER

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Air Force Institute of Technology
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December 1973

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THESIS

GE/EE/73A-9

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ib

Unclassified
Security Classification

AD786492

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Institute of Technology (AFIT-EN) Wright-Patterson AFB, Ohio 45433	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Machine Recognition of Hand-Sent Morse Code using the PDP-12 Computer

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

AFIT Thesis

5. AUTHOR(S) (First name, middle initial, last name)

Joel A. Guenther
Captain USAF

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1973	153	8

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	GE/EE/73A-9
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Approved for public release; IAW AFR 190-17. JERRY C. HIX, Captain, USAF Director of Information	6570th AMRL Wright-Patterson AFB, OH

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DD FORM 1 NOV 65 1473

Unclassified
Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Morse Code Recognition						
Computer Recognition Program						
Hand-Sent Morse Code						
Machine Recognition						

Unclassified
Security Classification

MACHINE RECOGNITION OF HAND-SENT MORSE CODE USING THE PDP-12 COMPUTER

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

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Captain USAF

Graduate Electrical Engineering

December 1973

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Preface

This thesis is the result of an effort to provide real-time machine recognition of hand-sent Morse code through the use of a minicomputer. While the capability to recognize hand-sent Morse code messages by machine has been demonstrated before on large scale special purpose computers, the main contribution of this study was to do it with a relatively inexpensive general purpose minicomputer.

I wish to express my gratitude to my advisor, Lt. Col. Tom Purnhagen, for his assistance and guidance throughout the development of this study. I wish also to express my thanks to Captain Joseph Carl, of the Aerospace Medical Research Laboratory, for his appreciated support of this project as my laboratory sponsor, and to the Dayton Amateur Radio Association for their assistance in obtaining Morse code transmissions for use in this project. Special thanks are reserved for my wife and family for their sacrifices and patience while I spent my evenings conversing with the computer.

Joel A. Guenther

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Abstract

The purpose of this investigation is to determine an optimum decision algorithm for use in machine recognition of hand-sent Morse code. An extensive analysis of hand-sent Morse code data is presented together with a discussion on the relative merits of several recognition algorithms. A recognition program is developed for use on the PDP-12 digital computer to test these algorithms. Test results are presented for a time duration averaging algorithm which achieves less than a one per cent recognition error rate for noise-free Morse code signals.

MACHINE RECOGNITION OF HAND-SENT MORSE CODE USING THE PDP-12 COMPUTER

I. Introduction

The idea of machine recognition of Morse code is not a new one. Much work has been done to develop equipment for the automatic reception of Morse code signals in the last two decades. The first notable effort was undertaken by Lincoln Laboratories at the Massachusetts Institute of Technology in the late 1950s (Ref 4). The machine which resulted from this project was actually a special purpose digital computer, called MAUDE (Morse AUtomatic DEcoder). The recognition algorithm used in MAUDE was based on its "knowledge" of Morse code linguistic properties and of the relative time durations of marks (referred to as pulses throughout this report) and spaces. MAUDE demonstrated a 90 to 95 per cent correct decoding rate, although this rate was later improved by the addition of an output error detection and correction scheme. The main disadvantage of MAUDE, however, was its physical size and complexity.

The development of small, low-cost integrated circuits led to the design and fabrication of several Morse-to-teletype converters. Generally speaking, much simpler code recognition algorithms, as compared to those used in MAUDE, were used in these converters to identify pulses and spaces. One such converter, designed at the Naval Postgraduate School in 1968 (Ref 6), uses the time duration of the most recently received short pulse (DOT) as a reference unit for pulse and space identification. Multiples of this reference unit are used as decision thresholds to identify succeeding pulses and spaces, and to eliminate signal noise. Another example of this type of converter, called the Morse-A-Verter, uses a variation of the previous recognition algorithm to make pulse-space decisions (Ref 5). The time duration of the most recently processed pulse, short or long, is used to determine the classification of the succeeding pulse. Spaces are identified by comparison with the time duration of the most recent long pulse (DASH).

Morse code recognition machines perform five basic functions. First, the pulse-modulated audio Morse signal is converted into a form usable by the machine, usually dc pulses, while discriminating against noise. Second, the time duration and identification of each pulse and space is determined. Third, pulses and spaces are classified into one of two pulse or three space categories according to their relative time duration. Fourth, the categorized pulses and spaces are combined to form Morse code characters. Finally, a signal representing the identified Morse code character is transmitted to an output device.

The third function, that of categorizing pulses and spaces, is the most difficult to perform. This difficulty is mainly due to the inherently non-uniform pulse and space time durations of hand-sent code. Since these time durations form the basis for the recognition process, a rigid set of decision algorithms, such as those used in commercial Morse telegraphy equipment, cannot be used. Instead, algorithms based on traits common to all variations of hand-sent Morse code must be used to achieve the highest possible degree of machine recognition accuracy.

The objective of this study is two fold: first, to conduct a thorough examination of hand-sent Morse code data and identify common traits which may be used in a machine recognition process, and second, to develop a Morse code recognition program, for use on the PDP-12 digital computer, to test and refine decision algorithms based on these common traits. Thus, the main concern here is optimization of the third function performed by Morse code recognition machines, as previously defined. Of course, all five functions must be considered in the development of the PDP-12 computer program. The remaining four functions, however, are of secondary concern to this project.

A discussion on the properties of hand-sent Morse code, and on the primary factors responsible for the variations present in hand-sent Morse code, is presented in Chapter II. Chapter III describes the procedure used to obtain and analyze Morse code data, and the common traits discovered during and the decision algorithms derived from this analysis procedure. A complete description of the resulting computer recognition program is presented in Chapter IV, as well as a brief description of the PDP-12 computer and peripheral devices used in this project. The operational procedure used with the recognition program is described in Chapter V. Chapter VI presents an analysis of the results obtained during the testing procedure. Conclusions and recommendations are contained in Chapter VII.

II. Properties of Hand-Sent Morse Code

This chapter presents a discussion on the characteristic properties of hand-sent Morse code. This discussion includes a definition of international Morse code, a description of common mechanical devices used to transmit Morse code, and the problems associated with machine recognition of hand-sent Morse code.

International Morse Code

Morse code is a rudimentary one-dimensional binary encoding scheme for language in which each character is represented by a unique sequence of pulses and spaces. These characters represent letters, numbers, punctuation signs, and special symbols. The international Morse code alphabet is given in Appendix C.

Two types of pulses and three types of spaces, distinguished by their relative time durations, are used to define Morse code characters. In terms of time units, the accepted standard definitions for these pulses and spaces are: pulses- DOT = 1 and DASH = 3; spaces- SYMBOL = 1, CHARACTER = 3, and WORD = 5 to 7. Characters are defined by a sequence of pulses separated by spaces. SYMBOL spaces separate pulses within a character, CHARACTER spaces separate characters within words, and WORD spaces separate words.

Morse code transmission speed is measured in terms of words per minute (wpm), with an average of 5 characters per word assumed as standard. Transmission rates for hand-sent Morse code are normally in the 10 to 40 wpm range, although rates as high as 60 wpm are not uncommon. Morse code machines are capable of operating at much faster rates, but generally do not unless another machine is used to receive the transmitted message.

Code Sending Instruments

Morse code is transmitted by keying an oscillator tuned to the desired transmission frequency or subharmonic of this frequency. The four standard instruments (keys) used to generate Morse code are, in ascending order of sophistication: 1) the simple hand key, 2) the semi-automatic key, or "bug", 3) the electronic keyer, and 4) the fully automatic Morse machine. A brief description of each instrument is presented in the following paragraphs.

The hand key, because of its simplicity and low cost, is most often used. Pulses are transmitted by depressing a paddle key; spaces are produced by lifting the key. The relative time duration in either position determines the type of pulse or space transmitted. The durations of all pulses and spaces are controlled directly by the sender.

The semiautomatic key, or "bug", is more difficult to operate and is generally used by the more experienced operator. Two paddle keys are used, one for DOTs and one for DASHes. The DOT key is used to produce a machinelike sequence of alternating DOTs and SYMBOL spaces for as long as the key is depressed. The DASH key produces DASHes in the same manual fashion as is done on the hand key.

The electronic keyer produces regulated DOTs, DASHes, and SYMBOL spaces. Two paddle keys are again used, one for DOTs and one for DASHes. Either key generates a sequence of pulses and SYMBOL spaces for as long as it is depressed. CHARACTER and WORD spaces, however, are still controlled manually. The time durations of automatically generated pulses and spaces can be adjusted to match the sending rate of the particular transmission.

Fully automatic Morse machines regulate the time durations of all pulses and spaces. Messages are prepared ahead of time on paper tape or stored in a memory device for transmission by the machine. The transmission and reception of completely automatic Morse code is not of concern in this project.

Characteristics of Hand-Sent Morse Code

The time duration standards for Morse code pulse and space relationships presented earlier are not always realized in hand-sent transmissions. Commonly encountered distortions include fluctuating pulse and space time duration ratios and variations in sending speed. In hand-sent Morse code, the time durations of pulse and space elements vary substantially from their prescribed values, and recognition must be based on the proportions of the time durations of these elements. These proportions generally vary non-trivially.

In a 1968 report on Morse code teaching methods (Ref 8), it was noted that the chief type of code reception error arises from the tendency to hear code signals shorter than they really are. For example, five DOTs are heard as four, four DOTs as three, etc. The tendency toward "signal shrinkage" mainly involves the last element of a code character. The report further states that this tendency to hear signals shorter than they are may be responsible for the general tendency for all operators to lengthen terminal DASHes. Also noted was the tendency of operators at all levels of skill to make pulse and space time duration ratios larger than the theoretical 1:3:7 ratios. However, a better set of ratios could not be recommended since actual ratios varied widely between individual operators.

Transmission rates generally tend to decrease over an extended period of time. This is mainly due to physical as well as mental fatigue.

Pulse and space ratios also tend to change as the transmission rate decreases. The amount of ratio change varies from sender to sender, and is partly a function of the type of sending unit being used. When hand keys are used, slower transmission rates generally result in longer pulses and spaces, with spaces tending to lengthen proportionately more than pulses. The use of semiautomatic keys prevents the automatically generated pulses and spaces from being affected by speed variations. Only those output functions controlled by the operator are subject to change. Thus, the degree of ratio change due to speed change may be significantly different when semiautomatic keys are used than when hand keys are used.

The recognition algorithms used in the machines discussed earlier may not be optimal. The prospects for the useful application of linguistic techniques directly to binarised hand-sent Morse code do not appear to be good because of the non-trivial variation of element proportions (Ref 7:254). Decisions made strictly on an element-to-element basis may not be flexible enough to cope with the widely varying proportions found in hand-sent transmissions.

These variations in hand-sent Morse code transmissions are the crux of the machine recognition problem. Code recognition machine performance ultimately depends on the algorithms used to identify individual pulse and space characters. Many algorithms that work well with certain Morse signals perform miserably with others. An algorithm is needed that can correctly identify pulse and space characters for all possible hand-sent Morse code variations.

III. Data Analysis Procedure

Many possible decision algorithms may be used to recognize hand-sent Morse code by machine. Indeed, each of the three recognition machines discussed in Chapter I employs a different method to perform the recognition process. Since there was no intuitively "best" method to use in performing this process, a thorough data analysis procedure was undertaken in search for an "optimal" decision algorithm, i.e., one that would yield the smallest percentage of recognition errors for all types of Morse code transmissions. The procedures used to obtain and analyze hand-sent Morse code data and the decision algorithms derived from this analysis are presented in the following paragraphs.

Data Gathering

Three samples of Morse code transmissions were recorded for analysis. These samples differ from each other in two ways: 1) the type of sending unit used, and 2) the degree of operator proficiency. The first sample, Recording Session 1, was transmitted with a "bug" at a rate of approximately 15 words per minute. Recording Session 2 was transmitted with a hand key at a rate of approximately 10-12 words per minute. Recording Session 3 was transmitted with a "bug" at a rate of approximately 18-20 words per minute. The three recording sessions were transmitted by separate individuals at their normal speed. None of these individuals were, at the time of the recordings, actively involved in cw (continuous wave) transmissions as a hobby, although they were at some time in their past. Thus, the recordings, are biased towards a low-proficiency level. As pointed out in the next section, this resulted in a slightly erratic sending rate and a wide spread of pulse and space time durations over a given time period.

The recording sessions were conducted in the following manner. A 500-word text, taken from The Radio Amateur's Handbook (Ref 1:7), was prepared for use as the message to be transmitted. A copy of this message, listed in Appendix D, was given to each of three individuals. While one individual transmitted the message, the other two annotated observed sending errors on their copy of the text. The Morse code transmission was recorded for use in the data analysis process. Only one recording session was held at a time to prevent mental fatigue from adversely affecting both the sender and the receivers. Recording sessions were held every other day until complete. The annotated copies of the transmitted Morse code messages were saved for use in evaluating recognition program performance, as explained in Chapter VI.

Data Categorizing

The recorded hand-sent Morse code transmissions were examined in a three step process. First, the time durations of pulses and spaces were obtained and stored on magnetic computer tape. Second, each pulse and space was identified as belonging to one of twenty different categories and again stored on magnetic tape. Finally, the categorized pulses and spaces were plotted for visual examination. Each of these three steps will now be discussed.

Analog-to-Digital Conversion. The time duration for each transmitted pulse and space was obtained and stored through the use of the PDP-12 computer in the following manner. The recorded Morse code transmission was connected to an A-D Converter external input channel and sampled periodically. When a change was detected, i.e., pulse-to-space or space-to-pulse, the time duration indicated on a real-time clock was recorded and stored. The clock was then reset and the process repeated.

Approximately the first 200 words of each 500-word Morse code transmission were processed in this manner. Upon completion of this process, the stored time durations were visually examined and categorized, as explained next.

Manual Identification. Pulses and spaces were classified into 10 separate categories each. Space categories were chosen to permit investigation of the pulse vs. following space interrelations known to exist in hand-sent Morse code. For example, the time duration of a space, when preceded by a DASH, is generally less than it is when preceded by a DOT. Thus, space categories correspond directly to the category of the preceding pulse. Pulses were separated into five DOT and five DASH categories according to their relative position within a Morse code character. In this way, time duration vs. position interrelationships, if any, would be disclosed. The 20 pulse and space categories are listed in Table I.

TABLE I

Pulse and Space Categories

1.	DOT (Only)	11.	DASH (Only)
2.	Space following 1.	12.	Space following 11.
3.	DOT (First)	13.	DASH (First)
4.	Space following 3.	14.	Space following 13.
5.	DOT (Intermediate)	15.	DASH (Intermediate)
6.	Space following 5.	16.	Space following 15.
7.	DOT (Last Character)	17.	DASH (Last Character)
8.	Space following 7.	18.	Space following 17.
9.	DOT (Last Word)	19.	DASH (Last Word)
10.	Space following 9.	20.	Space following 19.

The Only category identifies a DOT or DASH that by itself signifies a Morse code character (the characters E and T respectively). A pulse is First if it is the first pulse of at least two pulses comprising a character. Likewise, a pulse is Last if it appears as the last pulse in the character. The Last Character and Last Word categories are determined by the type of space following the pulse, i.e., CHARACTER space or WORD space. An Intermediate pulse is one which is neither first nor last in a multi-pulse string. Only category pulses which also appear as the last pulse in a word are categorized as Last Word.

The visual identification process was performed in the following manner. Stored pulse and space time durations were displayed on the PDP-12 CRT Display screen as a series of lines, proportionate in length to the time duration represented, as depicted in Fig. 3-1. A cursor was also displayed to indicate the particular pulse to be categorized. Note that it is only necessary to identify pulses, since spaces are categorized by the type of preceeding pulse. The pulse was then visually identified by noting its relative length and position with respect to surrounding pulses and spaces. The pulse and following space time durations were then stored according to their respective categories by depressing one

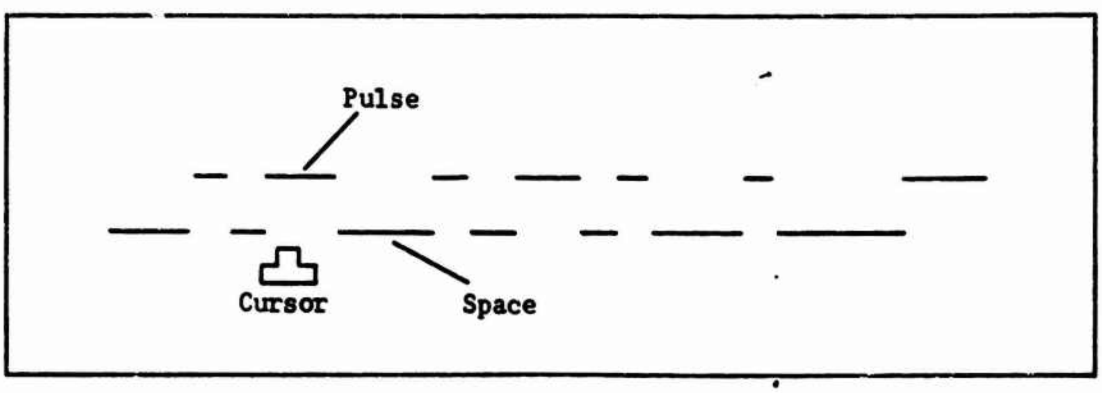

Fig. 3-1. CRT Morse Code Display

of 10 keys on a teletypewriter. Depression of the teletype key also advanced the display to the next pulse to be identified. The process was continued in this manner until all pulses and spaces were categorized and stored.

Distribution Plots. Cluster-type distribution plots of the categorized pulses and spaces were obtained by plotting pulse time duration versus following space time duration for the 10 categories. Plots were made of each individual category as well as all categories combined for the three recording sessions. The individual category plots for Recording Session 1 and combined plots for all recording sessions are contained in Appendix B, Figures B-1 through B-13.

Data Analysis

The individual and combined distribution cluster plots for the three recording sessions were examined to identify any possible relationships that might be used in the recognition program. Several such relationships were found.

It was immediately obvious that some of the pulse and following space categories are essentially identical and can be combined into one unique category. The First and Intermediate categories for both DOTs and DASHes are identical, as are the Only and Last Character categories. Thus, the 10 original categories can be reduced to 6 categories, 3 for each type of pulse. These three categories correspond to the type of following space, i.e., SYMBOL, CHARACTER, and WORD.

Another obvious trait disclosed by the data plots was the large variance of CHARACTER and WORD space time durations. Since the plots represent data obtained over an extended period of time (approximately

10-15 minutes) it was thought possible that the large variance was due to a gradual change in transmission speed during the time interval. To investigate this possibility, plots of pulse and space durations versus their sending sequence in time were made for the DASH Intermediate, Last Character, and Last Word categories. These plots, two of which are included in Appendix B (Figures B-14 and B-15), indicate that the large variance is not a function of a general speeding-up or slowing-down trend, but is, in fact, a characteristic of hand-sent Morse code.

Examination of the data plots for all categories combined indicates that a large overlap exists between CHARACTER space and WORD space time durations. The existance of this overlap prohibits correct identification of CHARACTER spaces versus WORD spaces on a time duration threshold basis. However, this distinction is not a critically important one, since both types of spaces signify the end of a Morse code character. The combined category data plots do, however, indicate a wide gap between SYMBOL space and non-SYMBOL space clusters. These gaps lend themselves to the formation of linear decision boundaries in two-dimensional pattern space quite easily.

Another obvious condition revealed by the combined data plots is the wide gap between DOT and DASH time durations. This again is conducive to a linear decision technique.

The combined data plots reveal two distinct correlations between DASH time durations and the type of following space. The first, and most obvious of the two is that DASH time durations are generally longer when followed by a CHARACTER or WORD space than they are when followed by a SYMBOL space. The second correlation is that SYMBOL space durations tend to decrease as the time duration of the preceding DASH increases, and vice versa. Neither of these pulse-space correlations are evident in the DOT-space categories.

As discussed earlier in Chapters I and III, several different types of decision algorithms have been successfully used to recognize hand-sent Morse code. Most notable among these are the use of a unique set of linguistic rules and the comparison of the time duration of the previous pulse with that of the next space and pulse on a threshold decision basis. A different approach to the recognition problem was looked for in this project; one that might prove more successful than those methods previously tried.

Evaluation of all the observations made from the data distribution plots led to the derivation of pulse and space linear decision algorithms, based on time duration averages, for use in the recognition program. These algorithms are discussed in the following paragraphs.

Pulse Algorithms. Due to the wide separation between DOT and DASH time durations, and the small variance of these durations, a linear decision boundary can easily be established as a function of DOT and DASH averages. However, to allow for slowly changing transmission rates, and to suppress temporarily large excursions from the mean, individual DOT and DASH averages must be calculated on a floating basis. That is, the averages must be computed for the last N DOTs and DASHes received, rather than on all received since the start of Morse code processing. The optimum size of N is that which both suppresses large excursions and permits the average to follow slowly varying changes. A value of eight achieves these goals and, as discussed below, permits easy average computation on the PDP-12 computer.

The DOT average is computed by the following equation:

$$\text{DOT AVG.} = \text{DOT AVG.} + \frac{\text{NEW DOT}}{8} - \frac{\text{DOT AVG.}}{8} \qquad (3.1)$$

When a newly received pulse is identified as a DOT, the DOT average is recomputed to include the new time duration information. The division process is performed by shifting the 12-bit register, containing the quantity to be divided, three places to the right. This is the equivalent of dividing the quantity by 2^3 or 8. The use of this process eliminates the time consuming task of adding 8 registers together and then dividing by 8. The DASH average is computed in the same manner as the DOT average.

The pulse average is computed after each recomputation of either the DOT average or the DASH average by the following equation:

$$\text{PULSE AVG.} = \frac{\text{DOT AVG.}}{4} + \frac{\text{DASH AVG.}}{2} \qquad (3.2)$$

The pulse average is used as the pulse time duration linear decision boundary. Note that the pulse average is not the mean of the DOT and DASH averages, but is instead, slightly closer to the DOT average. This adjustment compensates for the difference between DOT and DASH time duration variances. The resulting pulse decision boundary lies nearly in the center of the gap between DOT and DASH time duration clusters. If a new pulse has a time duration greater than the pulse average, it is considered to be a DASH; otherwise it is a DOT. Recomputation of the pulse average after receipt of each DOT and DASH permits the threshold to adjust to slowly varying changes as they occur.

The DOT and DASH averages are influenced most by the DOT-SYMBOL and DASH-SYMBOL clusters shown on the data distribution plots. This is due to the fact that there are proportionately more pulses followed by SYMBOL spaces than followed by CHARACTER or WORD spaces. Since the DOT and DASH time duration variance is smaller in these clusters, especially in the DASH-SYMBOL cluster, the resulting pulse average, as determined by equation (3.2), lies more near the center of the gap between the two clusters, thereby providing a better linear decision boundary.

Space Algorithms. The wide variance of CHARACTER and WORD space time durations prohibits use of the averaging technique used for the pulse algorithms. The technique was tried, however, with less than desirable results. A threshold was established as the mid-point between the CHARACTER space average and the WORD space average. New spaces were classified as CHARACTER spaces if their time duration was less than the threshold, and as WORD spaces if their time duration was greater than the threshold. Respective space averages were then computed in a manner similar to that used in the pulse algorithm. In test runs of the recognition program, the threshold point was consistently smaller than the optimum value, resulting in many CHARACTER spaces being classified as WORD spaces.

This lower than desired threshold is due to two contributing factors. The first, and most important, is the large overlap of the CHARACTER and WORD space variances. The second factor is the difference in frequency of occurrence of the two types of spaces. CHARACTER spaces, for English language text, occur approximately 4 times as often as WORD spaces. Those CHARACTER space time durations which are slightly greater than the threshold value force the WORD space average to be lower than it actually is. This, in turn, lowers the threshold value, which is defined as the mid-point of the CHARACTER and WORD space averages. The lower threshold causes more CHARACTER spaces to be defined as WORD spaces, thus lowering the WORD space average even more and compounding the problem. The threshold value settles near the true CHARACTER space average, much lower than desired.

The space algorithm finally arrived at for use in the recognition program is based on the average of all non-SYMBOL spaces which follow a DOT. The CHARACTER-WORD space average is calculated as follows:

$$\text{C-W SPACE AVG.} = \text{C-W SPACE AVG.} - \frac{\text{C-W SPACE AVG.}}{8} + \frac{\text{SPACE TIME}}{8} \quad (3.3)$$

Figures 3-2, 3-3, and 3-4 illustrate the linear decision boundaries, as determined by the pulse and space algorithms, for Recording Sessions 1, 2, and 3, respectively. Individual pulse-space clusters have been circled on these figures to indicate the size and shape of each cluster and the overlap regions between clusters. Table II lists the type of cluster identified by the letters shown on the three figures.

TABLE II

Cluster Identification for Figures 3-2, 3-3, and 3-4

Area	Cluster Type
A	DOT-WORD
B	DOT-CHARACTER
C	DOT-SYMBOL
D	DASH-WORD
E	DASH-CHARACTER
F	DASH-SYMBOL

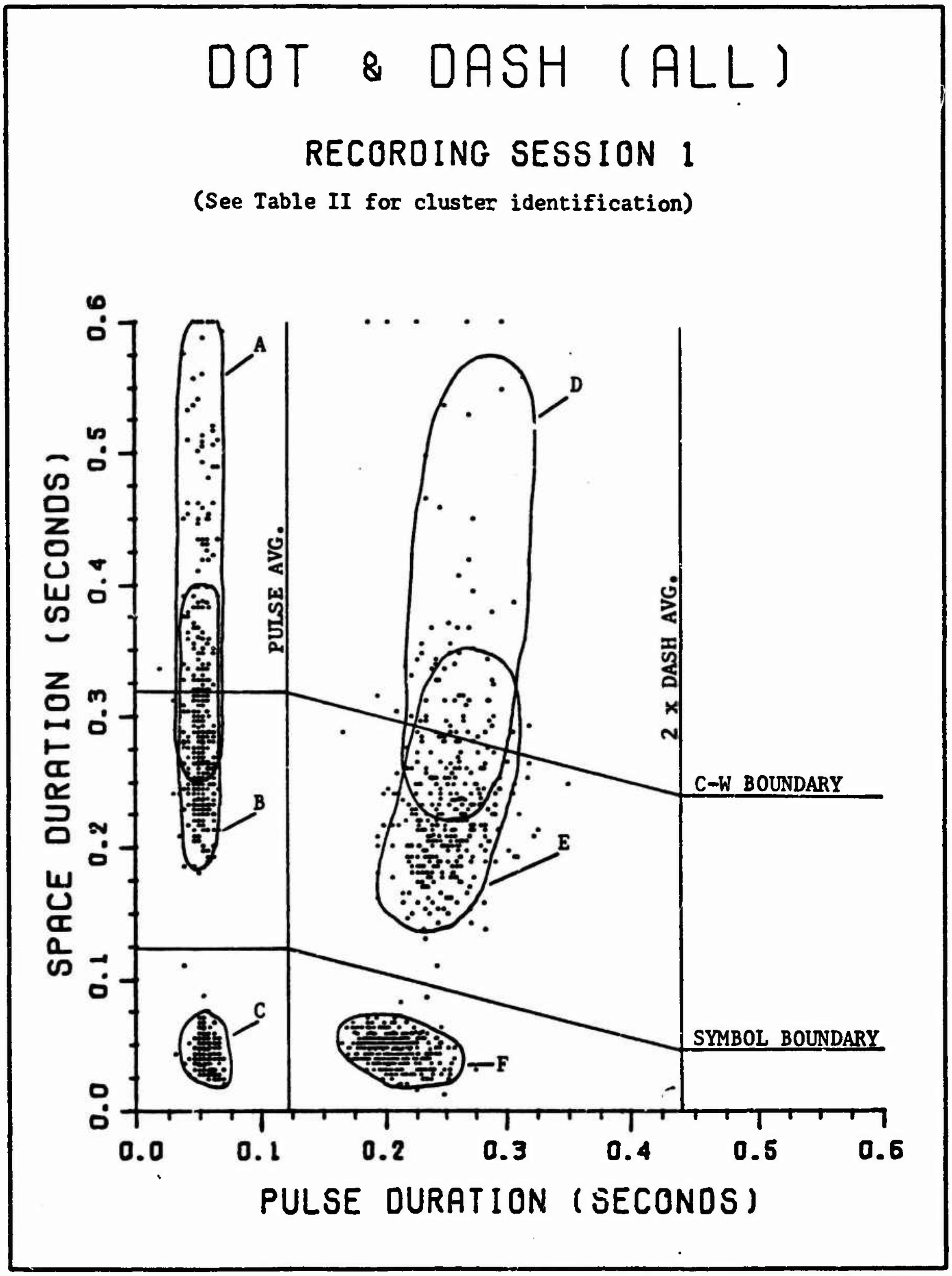

Fig. 3-2. Linear Decision Boundaries for Recording Session 1.

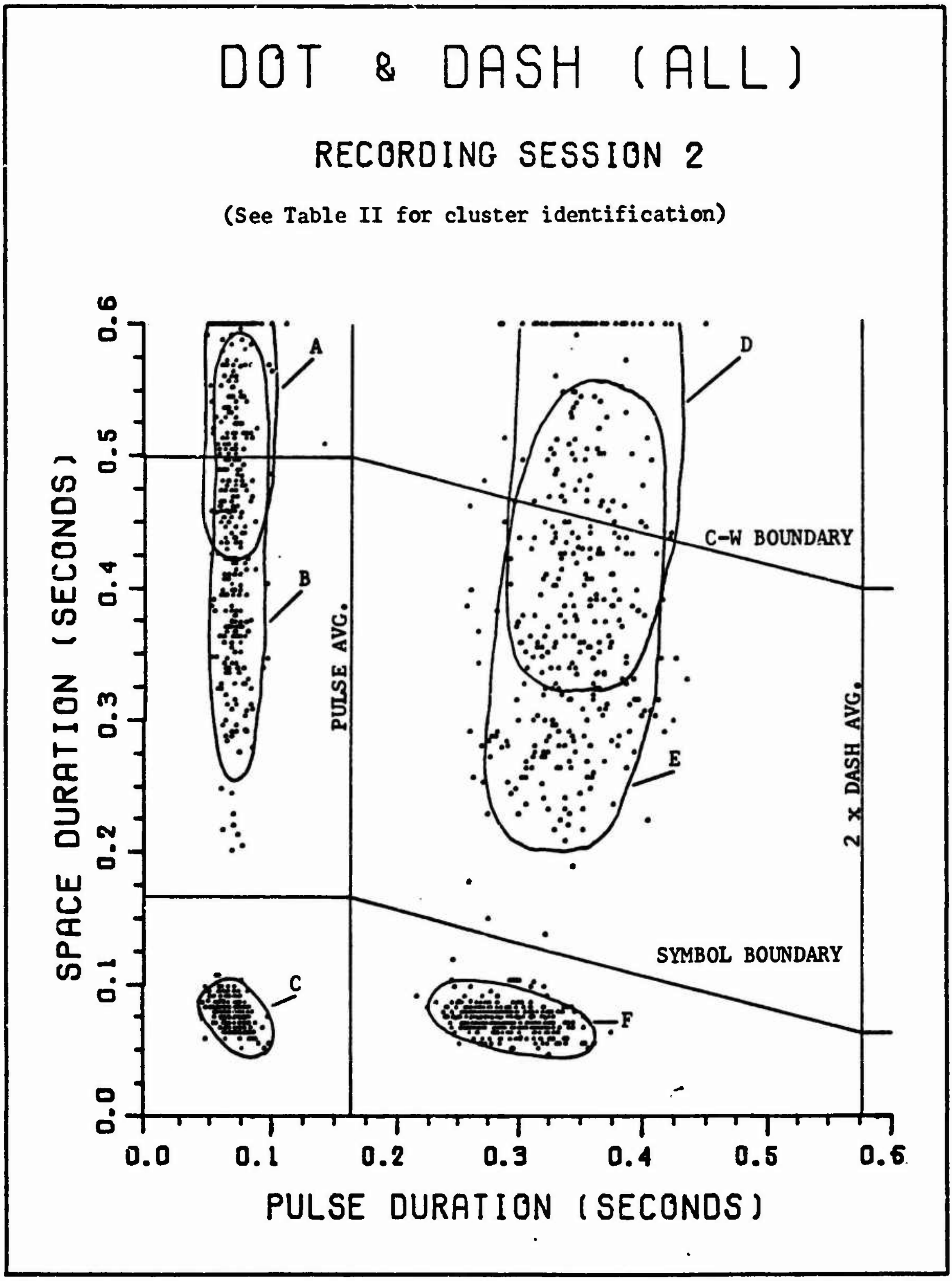

Fig. 3-3. Linear Decision Boundaries for Recording Session 2.

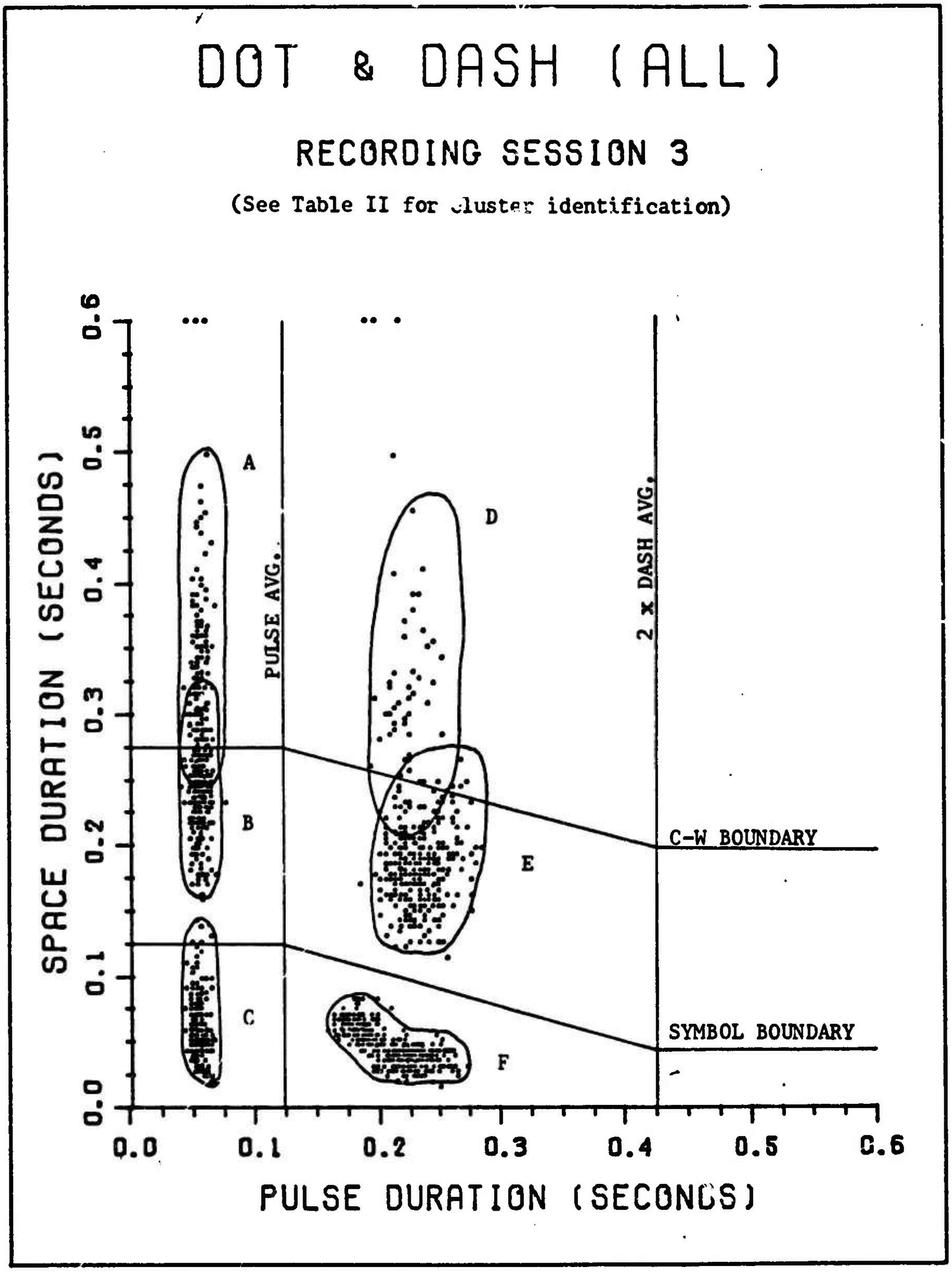

Fig. 3-4. Linear Decision Boundaries for Recording Session 3.

The pulse average lies in the gap between the DOT and DASH clusters on all three figures. This average value also lies in the gap between the DOT-SYMBOL cluster and the DOT-CHARACTER cluster for Recording Sessions 1 and 2, but not for Recording Session 3. Notice that the DOT-SYMBOL cluster in Fig. 3-4 has a much larger SYMBOL space variance than is indicated on similar clusters shown in Figures 3-2 and 3-3. This large variance is due to a faulty DOT-SYMBOL space generator on the "bug" used to transmit Recording Session 3. Therefore, it is assumed that the pulse average value also lies in the correct location for Recording Session 3. The pulse average is therefore used as the linear decision boundary for SYMBOL versus non-SYMBOL space decisions, when the space is preceded by a DOT. Also notice that the CHARACTER-WORD average, computed by equation (3.3), lies in the DOT-CHARACTER and DOT-WORD cluster overlap region.

CHARACTER and WORD spaces, when preceded by a DASH, have shorter time durations than those preceded by a DOT. Therefore, an adjusted boundary value must be used when a space is preceded by a DASH. The adjusted SYMBOL space boundary value is computed as a function of the time duration of the preceding DASH as follows:

$$\text{SYMBOL BOUNDARY} = \text{PULSE AVG.} - \frac{(\text{DASH TIME} - \text{PULSE AVG.})}{4} \qquad (3.4)$$

The adjusted CHARACTER-WORD space boundary value is computed in a similar manner as follows:

$$\text{C-W BOUNDARY} = \text{C-W SPACE AVG.} - \frac{(\text{DASH TIME} - \text{C-W SPACE AVG.})}{4} \qquad (3.5)$$

The resulting linear decision boundaries are negatively sloping lines, as shown on the accompanying figures. A maximum DASH time duration is established as twice the current DASH average for use in the boundary computations, thereby setting a lower limit to the threshold value.

To permit real-time adjustment of the C-W Boundary, a positive or negative adjustment value, X, is added to the threshold as follows:

$$\text{ADJUSTED C-W BOUNDARY} = \text{C-W BOUNDARY} \pm X \tag{3.6}$$

By adding the appropriate adjustment value to suit a particular Morse code transmission, the operator can optimize the readability of the printed output.

IV. The Computer Recognition Program

This Chapter describes the operation of the computer recognition program. The program consists of two distinct but interdependent parts: 1) the Signal Processor section, and 2) the Code Translation section. Discussion of the routines contained within each section is presented in an order indicative of the overall organization of the recognition program and the sequence in which the routines are executed. General flow charts are included for each routine to supplement the associated text.

A discussion of the programming constraints due to the physical limitations of the PDP-12 computer and the self-imposed operational goals is presented at the beginning of this chapter. It is hoped that knowledge of these limitations will enable the reader to better understand the rationale behind various operations performed within the program. A complete program listing with comments is provided in Appendix A.

Program Constraints

Before ideas can be constructively transformed into computer programs, the operational characteristics of the particular computer system to be used must be defined. A list of operational goals and performance objectives must also be defined to optimize the programming process.

PDP-12 Description. A brief overview of the characteristics of the DEC (Digital Equipment Corporation) PDP-12 (Programmed Data Processor-12) computer is provided in this section. A more complete description of the PDP-12 may be obtained in the PDP-12 System Reference Manual (Ref 2).

The PDP-12 is a versatile digital computer which contains two distinct operating modes within its central processor, each with its own instruction set. The central processor logic is fully parallel, using a basic word length of 12 bits. The processor cycle time is 1.6 microseconds ±20%. Most instructions require from 1 to 3 cycles for execution. The PDP-12 operates in one mode as a LINC (Laboratory Instrument Computer) and in the other mode as a PDP-8 computer. The computer may be stopped and started in either mode. Both operating modes have equal priority and programs may be switched from one to the other at will. Computations in one mode are immediately available to programs operating in the other mode because only one set of processing registers is involved.

The principal unit of core memory is a module of 4096 (4K) 12-bit words. Up to seven additional modules may be added, providing a total of 32,768 words. The logical organization within each module depends on the operating mode. In LINC mode, each 4K module is divided into four 1024-word segments. Only two of these segments are active at any given time: 1) the Instruction Field, which contains the executable program and directly addressed data, and 2) the Data Field, which contains only indirectly accessed data. In 8 mode, each 4K module (memory field) is divided into thirty-two 128-word pages. Data may be directly addressed to the current page or to page 0 only. Indirect addressing, through page 0, must be used to address data between pages. Special instructions must be used to change Instruction Field or Data Field segments in LINC mode and to change memory fields in 8 mode.

Many of the peripheral devices available with the PDP-12 are controllable only in LINC mode. Of these, the A-D Converter and the CRT Display are used in the recognition program listed in Appendix A. The CRT Display, however, is not essential to the program and its use will not be described in this report. The other peripheral devices used in the program, the Programmable Real-Time Clock and the Teletype device, may be controlled in either mode. A brief description of these devices and their use in the recognition program is given in the following paragraphs.

The A-D Converter consists of eight external input channels and eight internal input channels. The external input channels have an acceptable input voltage range of ± 1v, corresponding to a sample value range of $\pm 777_8$. The internal input channels (control knobs) also have a sample value range of $\pm 777_8$. One external input channel is used in the recognition program to sample the voltage level of the Morse code signal. Three internal input channels are used to set the input signal threshold level, the number of samples to be averaged, and the CHARACTER-WORD boundary adjustment value.

The Programmable Real-Time Clock consists of a 400 kHz crystal clock, a 12-bit counter register, and an overflow bit. The clock may be used to synchronize the central processor to external events, count external events, measure intervals of time between events, or provide program interrupts at intervals from 2.5 microseconds to over 40 seconds. The 400 kHz crystal clock may be used to provide pulses to the counter register at 100 Hz, 1 kHz, 10 kHz, 100 kHz, or 400 kHz rates; or an external source may be used to drive the counter. The clock is used in the recognition program to measure the time durations of pulses and spaces. An external source is used to permit variable counter rates in the 1 kHz to 10 kHz range.

The Teletype device is used to type in or print out information at a rate of up to ten characters per second. Similar devices, such as the

DECWRITER, operate at much faster rates. A DECWRITER was used during this project to print the test messages shown in Appendix D.

Certain distinguishing features of the two operating modes must be considered when changing modes within a program. One of these is the addressing scheme. In LINC mode, Instruction Fields and Data Fields consist of 1024-word segments. The addresses within each field range from 0000_8 to 1777_8, regardless of the physical location in core memory. Thus, location 0100_8 in Data Field 3 corresponds to physical location 6100_8 in core memory. In 8 mode, address locations correspond exactly to physical locations.

Another distinguishing feature between the two modes concerns arithmetic operations. LINC mode uses 1's complement addition for most operations, whereas 2's complement addition is used in 8 mode. As an example, 7777_8 is interpreted in LINC mode as -0 and in 8 mode as -1. Also, $7777_8 + 0001_8$ yields 0001_8 in LINC mode and 0000_8 in 8 mode.

Operational Goals. It goes without saying that the overall operational goal is accuracy. The output of the computer recognition program should exactly reproduce the hand-sent Morse code transmission. But by what measure should the accuracy of the program be evaluated? Should the program output be compared with that which a human would interpret as the transmitted message? Or should it be based strictly on the quality of the received code, as compared to the standards for Morse code language? Both evaluation criteria merit consideration. Further discussion of this topic is presented in Chapter VI.

Three operational goals are specified for the computer recognition program. These are:

1. The program must be able to process the received Morse code transmission in real-time.
2. The final program must occupy less than 4K of memory space.
3. The program should be designed to lend itself to construction of a small, low-cost hardware realization. i.e., a special purpose minicomputer.

These goals are somewhat interrelated. If the recognition program cannot process the received Morse code in real-time, a memory storage unit is required to save the received signal until it can be processed, thus requiring additional core space. In this case, the size of the memory will determine the maximum length message that could be processed at any one time. The real-time constraint eliminates this problem.

The 4K memory limitation was chosen to permit implementation of the program within one basic unit of memory. Thus, the recognition program can be implemented on the basic PDP-12 or similar minicomputer.

Construction of a hardware realization of the recognition program is of particular interest at the Air Force Institute of Technology. Aside from obvious educational benefits, construction of a low cost, portable Morse code recognition machine has many military and civilian applications. Proper choice of computer instructions, along with compliance to the aforementioned goals, will result in a minimum number of components necessary to construct a hardware realization.

Program Description

The recognition program is segmented into two major parts: the Signal Processing section (Fig. 4-1), and the Code Translation section

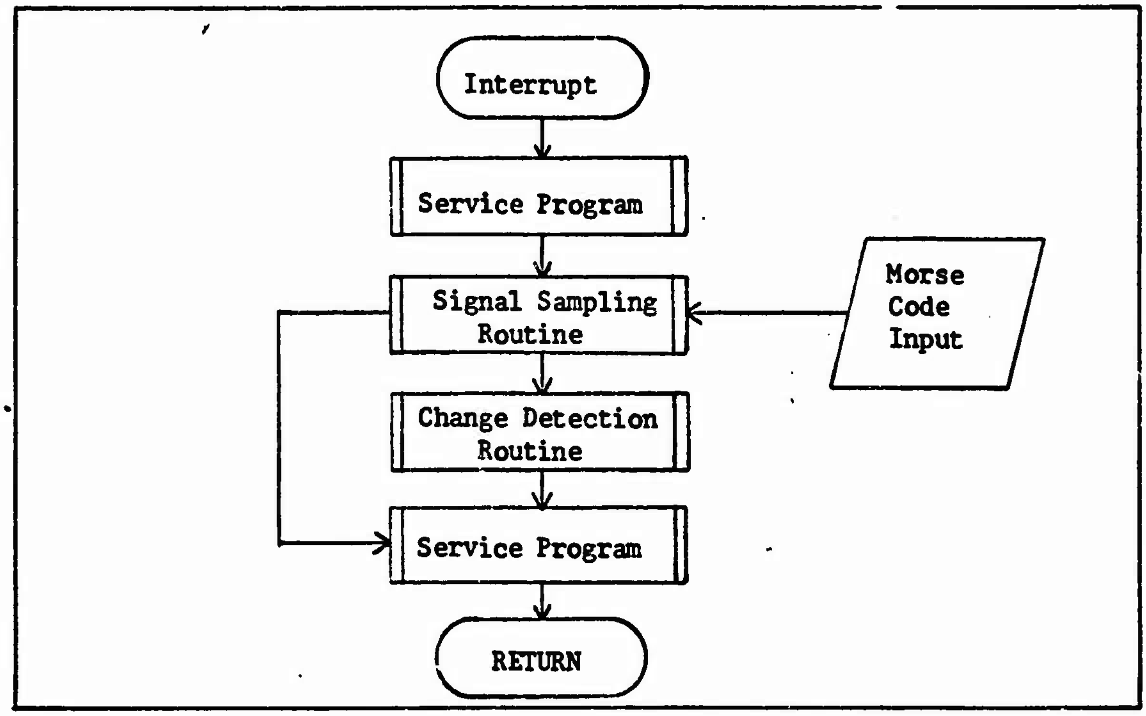

Fig. 4-1. Signal Processing Section Organization.

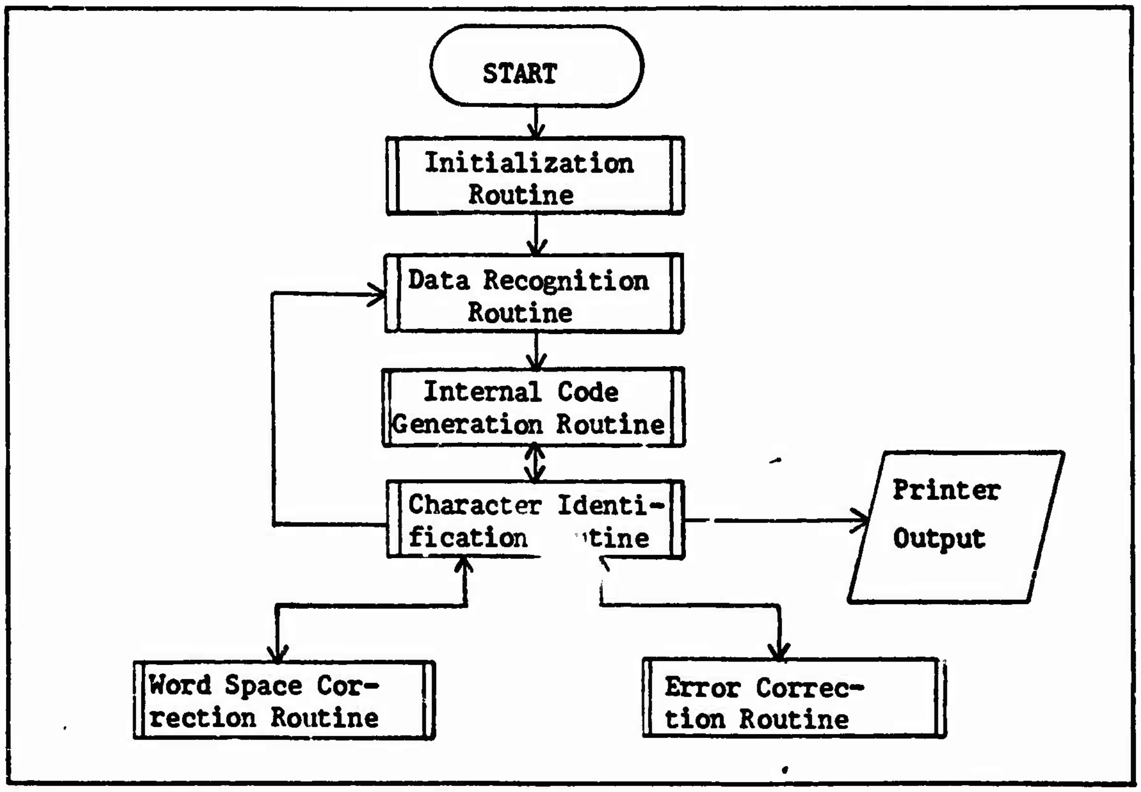

Fig. 4-2. Code Translation Section Organization.

(Fig. 4-2). The Signal Processing section serves to transform the received Morse code analog signal into pulse and space time duration information for use in the Code Translation section. The Code Translation section then uses these time durations to identify transmitted Morse code characters and print out the message. Detailed discussion of these two sections and their associated routines is presented in subsequent paragraphs.

Program operation in either section is controlled by an external program interrupt. Acknowledgement of a program interrupt is controlled by the status of an interrupt bus. If the bus is enabled, a program interrupt will halt current computer execution and transfer operation to absolute memory location 0001_8 in 8 mode or 0040_8 in LINC mode. If the interrupt bus is disabled, a program interrupt has no effect on execution. When a program interrupt is recognized and operation is transferred to the appropriate location, the interrupt bus is automatically disabled. The interrupt bus can only be enabled again by specific program instruction.

The interrupt bus is enabled during operation in the Code Translation section only. When an interrupt occurs, execution in that section is halted and the Service program (Fig. 4-3) is entered through location 0001_8 or 0040_8, depending on the computer mode at the time of interrupt. In either case, the current accumulator, link, and program counter register values are saved for use in returning to interrupted program. Signal Processing section operation then begins and continues until complete, at which time the Service program is reentered. Appropriate register values are restored, the interrupt bus is turned on, and operation again resumes in the Code Translation section at the point of interruption. Operation continues in this section until the occurrence of another inter-

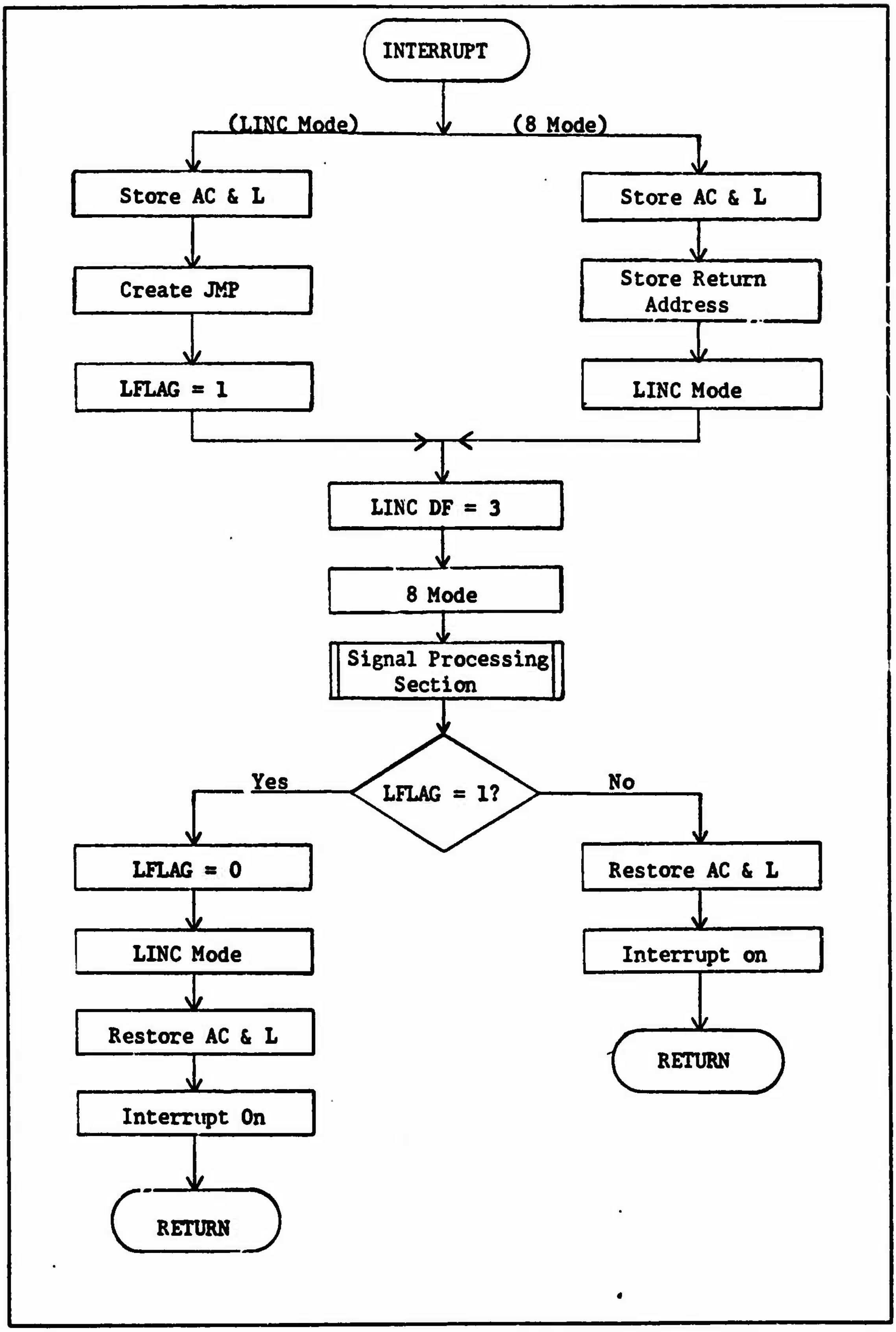

Fig. 4-3. Service Program Flowchart.

rupt, at which time the process is repeated.

Signal Processing Section

The Signal Processing section, as previously mentioned, serves to transform the received analog Morse code signal into pulse and space time duration information for use in the Code Translation section. If the received signal were completely clean and interference free, this transformation would be relatively easy. However, the transformation becomes rather difficult when the effects of noise and signal fading are considered. The main purpose, then, of the Signal Processing section is to recognize the Morse code transmission under realistic conditions of signal fading and distinguish it from pulse interference and "white" noise. The methods used to achieve these tasks will now be discussed.

The incoming pulse-modulated signal is first converted into dc pulses, corresponding to the Morse code being received, by a full-wave bridge rectifier and RC filter. The input signal voltage level is sampled periodically (approximately once every 200 microseconds) and compared to a threshold voltage level. If the input signal is less than the threshold level, a -1 is stored; if the input signal is greater than the threshold level, a +1 is stored. The effects of signal fading may be reduced by proper settings of the input signal voltage and threshold level.

A low pass digital filter technique is employed to limit the effects of noise on the input signal. Rather than base the pulse-space decision on whether the input signal level is above or below the threshold level for any one particular sample, the average of several of the samples must be above or below the threshold before a pulse-to-space or space-to-pulse change is detected.

When an input signal level change is detected, it is checked again to determine if the change is permanent. The checking process is similar to the change detection process, except that twice as many samples are averaged. If the checking process result confirms the input signal change, then the signal is considered to have changed permanently. The time duration of the just-ended pulse or space is then obtained from the real-time clock counter and the clock is reset to begin timing the next pulse or space. If the result of the checking process conflicts with the change detection process, then the input signal change was due to interference rather than a valid Morse code input. In this case, the change detection process is repeated, again looking for an input signal level change.

When a valid input signal change is detected, the pulse or space time duration is stored in a 200_8-word memory buffer. Previously stored time durations are retrieved from the buffer as needed by the Code Translation section for processing. The 200_8-word buffer permits the Code Translation section to temporarily lag behind the Signal Processing section without loss of Morse code signal information.

This method of storage and retrieval of Morse code time durations presents an operational limit to the overall recognition program in that it is possible to over-write previously stored time durations before the Code Translation section processes them. If the interrupts occur too frequently, not enough time will be available for the Code Translation section to keep up with the storage of new time durations, a function of the Morse code transmission speed. Thus, the interrupt frequency upper limit is determined by the execution time of the Code Translation section. Fortunately, this presents no real problem to the overall recognition program, since the upper limit is well above the minimum input signal sample frequency needed to ensure proper detection of Morse code signal changes.

The Signal Processing section is divided into two separate routines: 1) the Signal Sampling routine (Fig. 4-4), and 2) the Change Detection routine (Fig. 4-5). The particular function of these routines is discussed in the following paragraphs.

Signal Sampling Routine. The Signal Sampling routine performs the actual sampling of the Morse code input signal. If the sampled input voltage is greater than the threshold level, a +1 is stored. If the sampled input voltage is less than the threshold level, a -1 is stored. If N' samples have not been taken yet, program operation is returned to the Code Translation section through the Service program. When the N'th sample is taken, program operation continues in the Change Detection routine.

Change Detection Routine. The Change Detection routine performs the change detection and checking processes. After the N'th signal sample has been taken, the N' ±1s are added together to yield a positive or negative result. A +1 is assigned for a positive result and a -1 is assigned for a negative result. This value is then compared with the + or - 1 representing the current input signal level. If the comparison indicates that a change has occurred, the checking process is initiated to confirm or deny the change. If the comparison indicates that no change has occurred, program operation is returned to the Code Translation section through the Service program and the N' sampling process is started again.

As an example, assume that a Morse code pulse is being received.

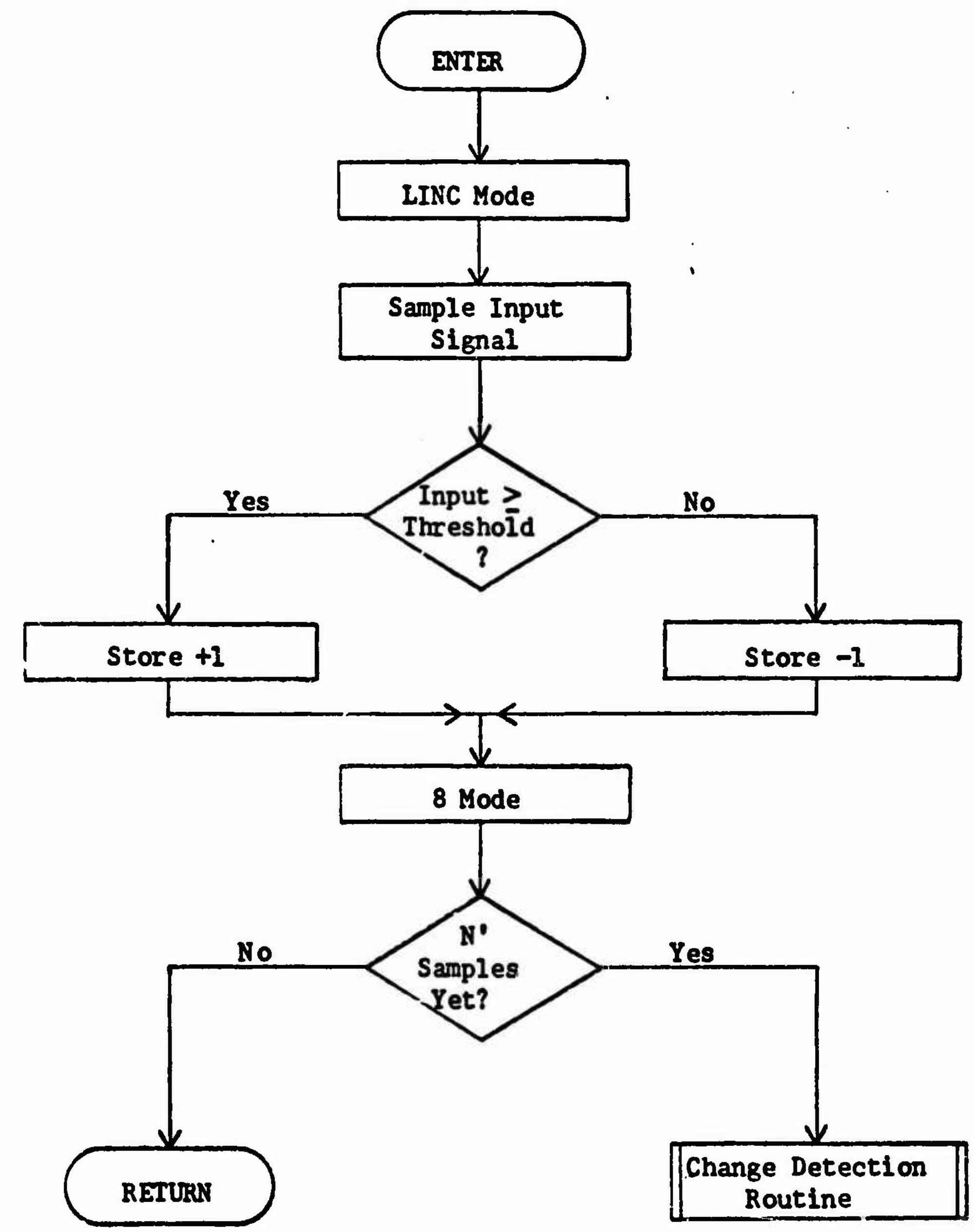

Fig. 4-4. Signal Sampling Routine Flowchart.

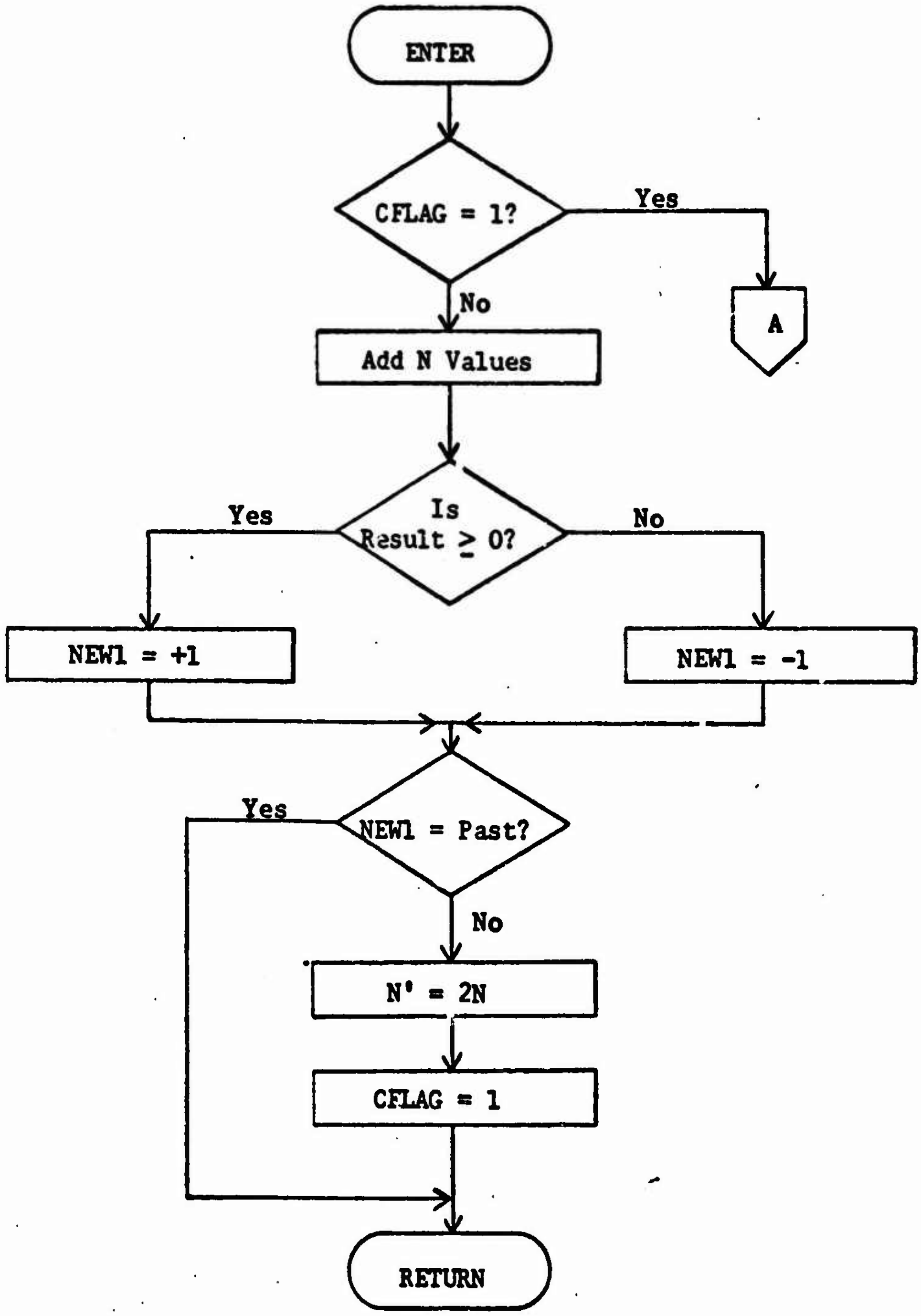

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Fig. 4-5. Change Detection Routine Flowchart

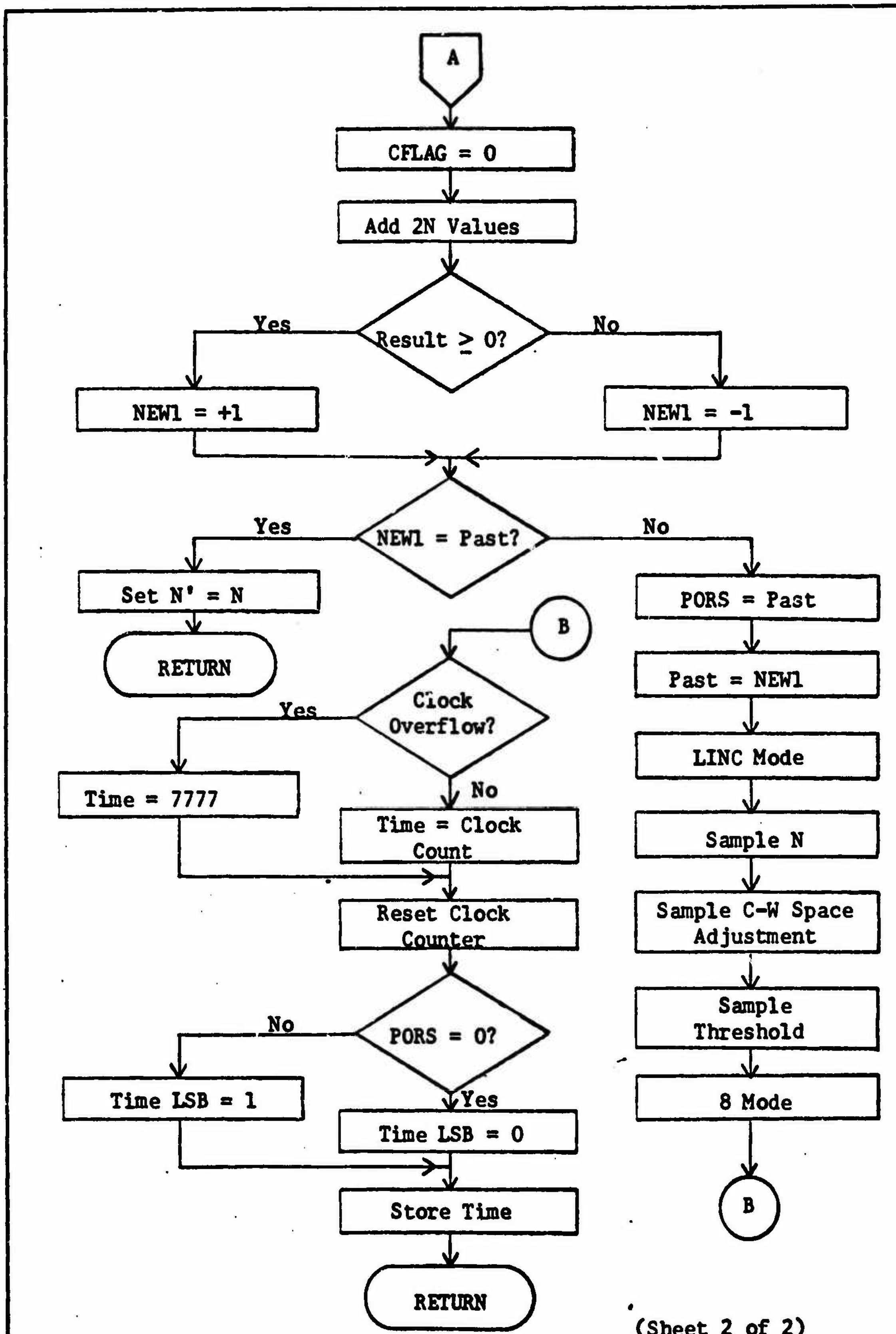


Fig. 4-5. Change Detection Routine Flowchart.

When the input signal changed from the previous space to the current pulse, the time duration of the space was recorded and stored, and a +1 was stored to indicate that a pulse is currently being received. After every N' samples are averaged, the ± 1 is compared with the stored +1 value. A change is indicated when the N' sample average is -1. The checking process then begins. If the result of the checking process also indicates a -1, then the input signal is considered to have permanently changed to the succeeding space and the time duration of the just completed pulse is read from the real-time clock and stored. This time duration is then marked as a pulse by setting the least significant bit (LSB) of the time duration to a 1. Likewise, the LSB is set to a 0 for a space. In this way, the Code Translation section can correctly identify pulses and spaces.

The real-time clock counter has a range of 0000_8 to 7777_8. If a space or a pulse is long enough, the counter will count past 7777_8 and restart at 0000_8. When this occurs, an overflow bit is set. Subsequent overflows will not reset the overflow bit. When a permanent change is detected the overflow bit is checked first before the clock counter is read. If an overflow has occurred, a clock value of 7777_8 is automatically assumed. The actual clock counter value is read only if an overflow has not occurred, thereby preventing erroneous time durations from being used in the program.

The actual time duration of a pulse or space is determined by the real-time clock frequency. This frequency is set to permit counter readings for the longest pulse or space to be below the overflow condition. Thus, overflows will normally only occur when there is a long pause between Morse code transmissions.

Code Translation Section

The Code Translation section converts the stored pulse and space time duration information produced by the Signal Processing section into a printed copy of the received Morse code message. This section is composed of six routines: 1) the Initialization routine, 2) the Data Recognition routine, 3) the Internal Code Generation routine, 4) the Character Identification routine, 5) the Word Space Correction routine, and 6) the Error Correction routine.

Recognition program operation begins in the Code Translation section. Pulses and spaces are identified by comparing the time duration of a particular pulse or space to the average of past pulses and spaces. Before any decisions can be made in this manner, some *a priori* knowledge of the particular averages must be obtained. The Initialization routine provides this knowledge by examining the first 49 pulses received, in a two-step process. The acquired knowledge is then used to start the recognition process, commencing with the first pulse or space received. As subsequent pulses and spaces are processed, the averaging information is constantly updated to adjust to changes in Morse code sending rates.

Pulses retrieved from the 200_8-word memory buffer are compared with the pulse average. If the time duration of the new pulse is greater than this average, it is classified as a DASH, otherwise it is a DOT. The receipt of a DASH is noted by storing a 1 in a word register. A 0 is stored in the word register to indicate the receipt of a DOT. The number of pulses received is recorded by incrementing a number register.

Spaces are classified in a two-step process. First, the time duration of the space in question is compared with the SYMBOL space boundary value. If the time duration is less than this boundary value, the new space is classified as a SYMBOL space. If the time duration is greater than the boundary value, the new space is either a CHARACTER or a WORD space. The second step of the space classification process is then used to make this distinction. The time duration of the new space is compared with the CHARACTER-WORD space boundary value. If the time duration is less than this value, the new space is classified as a CHARACTER space; otherwise it is classified as a WORD space.

When either a CHARACTER space or a WORD space is identified, the contents of the word and number registers are combined to yield a unique internal code word representing the received Morse code character. This internal code word is then compared with a list of internal code words stored in memory. The corresponding ASCII Teletype code is identified and used to print the character. A list of internal code words is presented in Appendix C.

When the internal code word cannot be identified as a valid code word, an error correction process is initiated. This process, when possible, corrects two types of errors: 1) the inclusion of an extra pulse in the code word due to noise in the received Morse code signal, and 2) the joining of two Morse code characters caused by too small a space separating the characters. In the first case, pulses having a time duration less than one-half of the current DOT average are eliminated. The internal code word is then recomputed and the valid character is identified. If no pulses can be eliminated in this process, the second case is considered. The largest SYMBOL space in the invalid code word is reclassified as a CHARACTER space. Two new internal code words are generated from the invalid code word and reprocessed. If either of the corrected internal code words is still invalid, a special error symbol is printed to indicate receipt of an unidentifiable Morse code character.

Recognition of a WORD space causes the Teletypewriter to skip a space, thereby forming words rather than an endless string of transmitted characters. However, the overlap of CHARACTER and WORD space time durations, as shown in Chapter III, causes some CHARACTER spaces to be erroneously classified as WORD spaces. In order to limit the number of erroneous classifications, a separate routine is used to re-evaluate WORD spaces following the letters I, J, Q, U, V, and Z. The occurrence of these letters as the last letter of an English language word is highly unlikely, although not impossible. This routine compares the time duration of the space in question with a slightly larger boundary value. If the time duration is greater than this new boundary value, the space is classified as a CHARACTER space. The readability of the printed message is greatly improved through the use of this technique.

Discussion of the particular functions performed by each of the six routines contained in the Code Translation section is now presented in the following paragraphs.

Initialization Routine. The Initialization routine (Fig. 4-6) is entered from the Data Recognition routine. Operation begins by enabling the interrupt bus. Then the first 49 pulses (98 stored pulse and space time durations) are examined to establish initial average information. This process is accomplished in two steps. First, the time durations of the first 16 pulses are averaged to establish approximate DOT, DASH, and pulse averages according to the following set of equations:

$$\text{DOT AVG.} = \frac{\text{DOT AVG.}}{2} + \frac{\text{NEW DOT}}{2} \qquad (4.1)$$

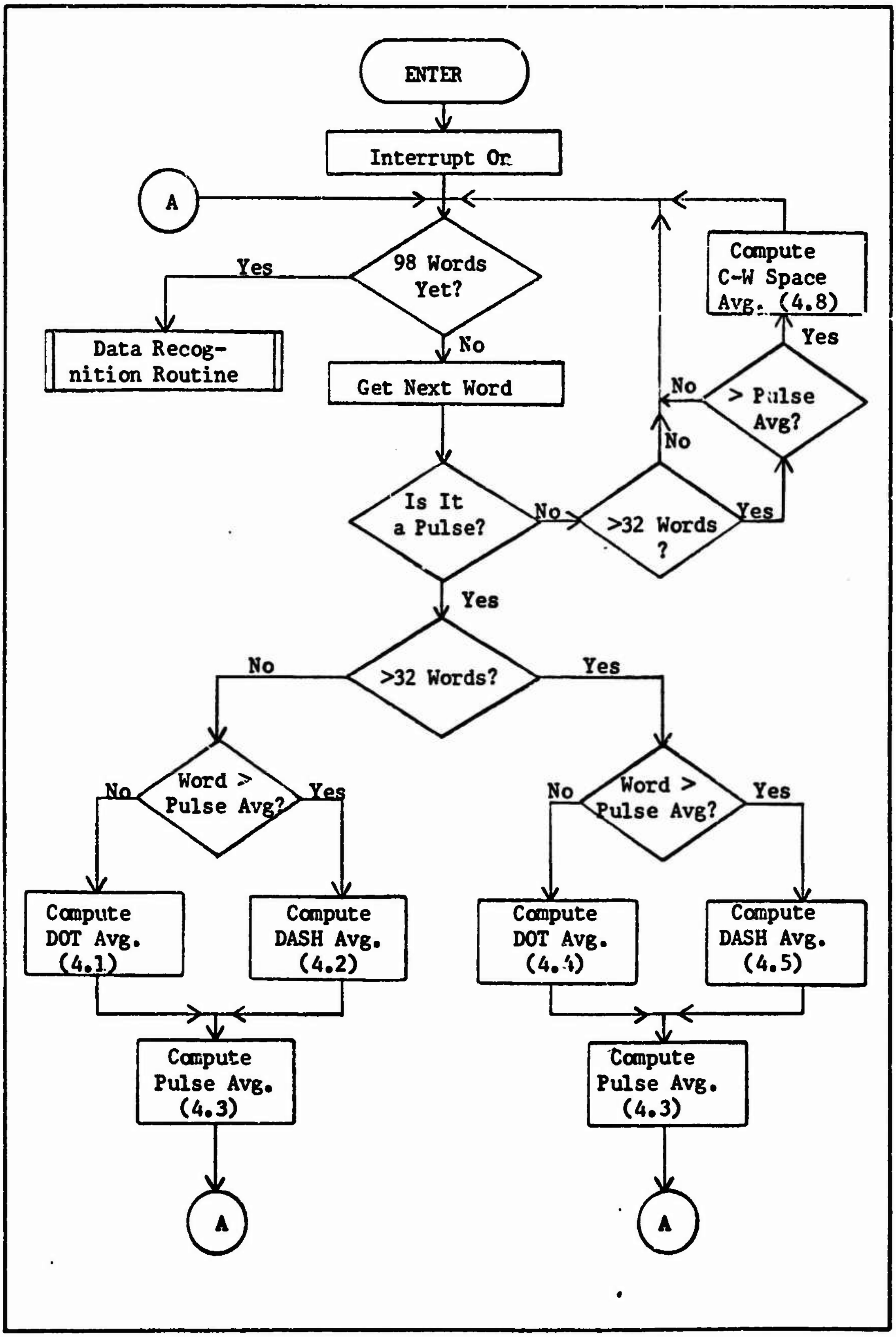


Fig. 4-6. Initialization Routine Flowchart.

$$\text{DASH AVG.} = \frac{\text{DASH AVG.}}{2} + \frac{\text{NEW DASH}}{2} \quad (4.2)$$

$$\text{PULSE AVG.} = \frac{\text{DOT AVG.}}{4} + \frac{\text{DASH AVG.}}{2} \quad (4.3)$$

All averages are initially set at 0. The first pulse is automatically classified as a DASH, regardless of its actual classification, because it is greater than the pulse average. The DASH and pulse averages are then computed according to the above equations. The second pulse is then compared with the pulse average and classified as a DOT or a DASH and the DOT average or DASH average is computed, as applicable. After three or four of each type of pulse has been processed, the resulting averages approach their true values. Note that the DOT and DASH averages are heavily influenced by the time duration of each new pulse. This permits the rapid establishment of initial averages; however, these averages are too sensitive to extreme deviations from the mean and are not desirable for long term use. Also note that the pulse average is not the mean of the DOT and DASH averages, but is, instead, shifted slightly towards the DOT average. As was shown in Chapter III, this slight compensation positions the pulse linear decision boundary in the center of the gap between DOT and DASH time duration clusters. Equation (4.3) is used throughout the recognition program to compute the pulse average.

In the second step of the Initialization routine, an improved set of DOT and DASH average equations, less sensitive to temporary time duration deviations from the mean, are used to refine the DOT, DASH and pulse averages:

$$\text{DOT AVG.} = \text{DOT AVG.} - \frac{\text{DOT AVG.}}{4} + \frac{\text{NEW DOT}}{4} \quad (4.4)$$

$$\text{DASH AVG.} = \text{DASH AVG.} - \frac{\text{DASH AVG.}}{4} + \frac{\text{NEW DASH}}{4} \quad (4.5)$$

The time durations of the remaining 33 pulses are averaged according to these equations. The pulse average, as always, is recomputed after each DOT or DASH average computation.

Upon completion of the initialization process, the DOT and DASH averaging equations are again changed to the following for use throughout the rest of the program:

$$\text{DOT AVG.} = \text{DOT AVG.} - \frac{\text{DOT AVG.}}{8} + \frac{\text{NEW DOT}}{8} \quad (4.6)$$

$$\text{DASH AVG.} = \text{DASH AVG.} - \frac{\text{DASH AVG.}}{8} + \frac{\text{NEW DASH}}{8} \quad (4.7)$$

The initial CHARACTER-WORD space average is also established during the Initialization routine. After the first 16 pulses have been examined and the preliminary pulse averages determined, the space averaging process begins. The space time duration is first compared with the pulse average to determine whether it is a SYMBOL space or not. If it is not, the CHARACTER-WORD space average is computed according to the following equation:

$$\text{C-W SPACE AVG.} = \text{C-W SPACE AVG.} - \frac{\text{C-W SPACE AVG.}}{4} + \frac{\text{NEW SPACE}}{4} \quad (4.8)$$

Upon completion of the initialization process, the CHARACTER-WORD space average computation is performed only for non-SYMBOL spaces preceeded by a DOT according to the following equation:

$$\text{C-W SPACE AVG.} = \text{C-W SPACE AVG.} - \frac{\text{C-W SPACE AVG.}}{8} + \frac{\text{NEW SPACE}}{8} \quad (4.9)$$

These final averaging equations allow the program to adjust to gradual changes without overly reacting to temporary fluctuations in pulse and space durations.

<u>Data Recognition Routine</u>. The Data Recognition routine (Fig. 4-7) begins after the initializing is complete. The first word is taken from the 200_8-word storage loop and identified as a pulse or space. If it is a pulse, it is compared to the pulse average and identified as a DOT or DASH by the following equation:

$$X = \frac{\text{PULSE AVG.}}{2} - \frac{\text{NEW PULSE}}{2} \quad (4.10)$$

$$(X \geq 0 \Longrightarrow \text{DOT}; X < 0 \Longrightarrow \text{DASH})$$

The respective averages are then recomputed to include the new input. A 0 or a 1 is stored in the word register to indicate receipt of the DOT or DASH, respectively, and the number register is incremented to keep track of the number of pulses received. The time duration of the pulse or space is successively stored in a 30_8-word memory location for use by the Error Correction process.

When a space is received, it is first catagorized by whether or not

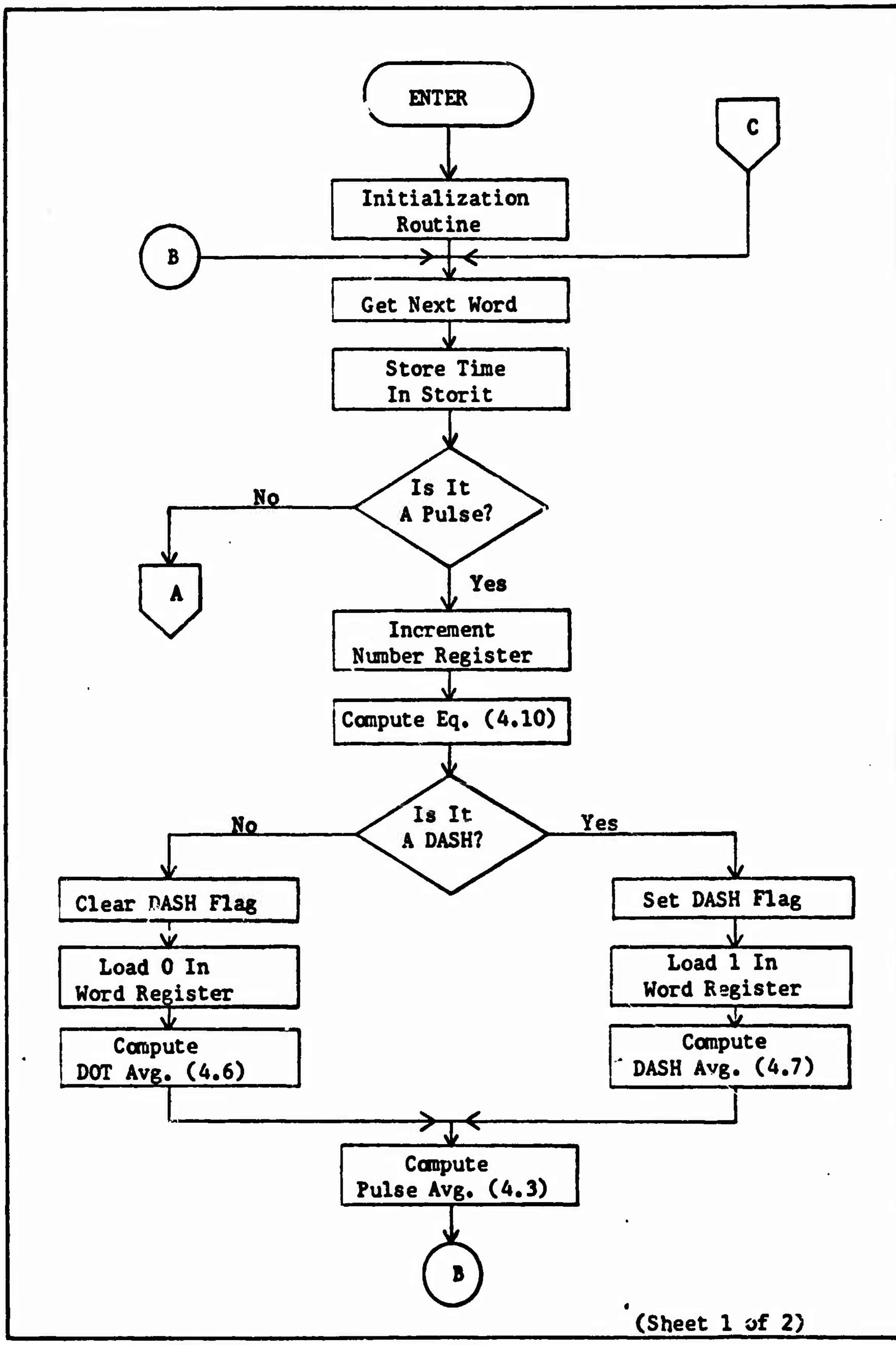


Fig. 4-7. Data Recognition Routine Flowchart.

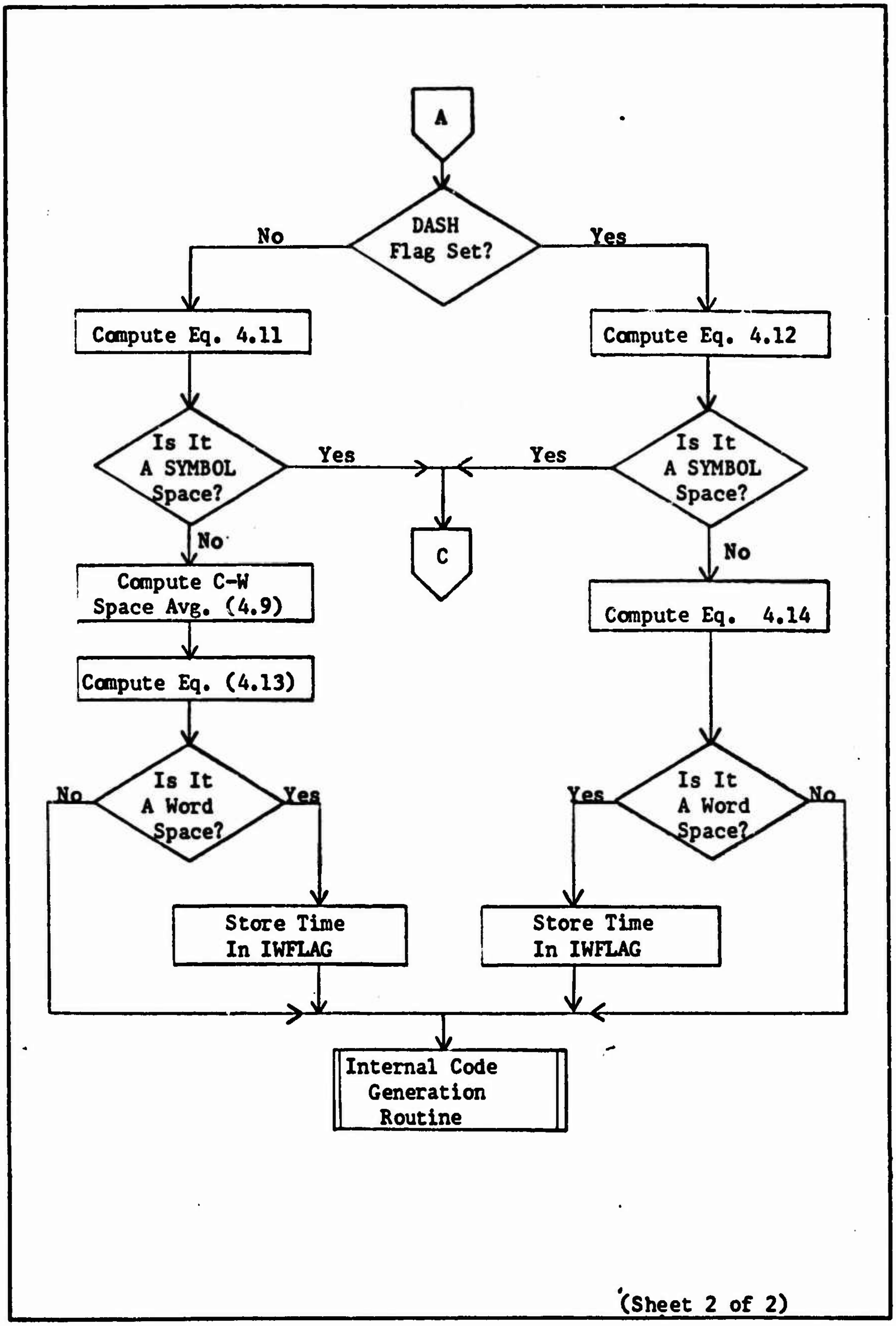


Fig. 4-7. Data Recognition Routine Flowchart.

it follows a DASH. This distinction is necessary to permit use of the proper decision algorithms as specified in Chapter III. The next step is to determine if it is a SYMBOL space or not. When the space follows a DOT, the following equation applies:

$$X = \frac{\text{NEW SPACE}}{2} - \frac{\text{PULSE AVG.}}{2} \tag{4.11}$$

$$(X < 0 \Longrightarrow \text{SYMBOL SPACE})$$

When the space follows a DASH, the equation is:

$$X = \text{NEW SPACE} - \frac{\text{PULSE AVG.} - \left[\frac{\text{DASH} - \text{PULSE AVG.}}{4}\right]}{2} \tag{4.12}$$

$$(X < 0 \Longrightarrow \text{SYMBOL SPACE})$$

If the space is identified as a SYMBOL space, the Data Recognition routine is repeated by examining the next word. If the space is not a SYMBOL space, then it must be identified as either a CHARACTER space or a WORD space. Again, this decision depends on the type of preceding pulse.

When the space follows a DOT, the following equation is used:

$$X = \frac{\text{NEW SPACE}}{2} - \frac{\text{C-W SPACE AVG.}}{2} \tag{4.13}$$

$$(X < 0 \Longrightarrow \text{CHARACTER SPACE; } X \geq 0 \Longrightarrow \text{WORD SPACE})$$

When the space follows a DASH, the equation is:

$$X = \frac{\text{NEW SPACE}}{2} - \frac{\text{C-W SPACE AVG.} - \left[\frac{\text{DASH} - \text{PULSE AVG.}}{4}\right]}{2} \quad (4.14)$$

$$(X < 0 \Longrightarrow \text{CHARACTER SPACE; } X \geq 0 \Longrightarrow \text{WORD SPACE})$$

When the space is identified as a WORD space, the time duration is stored in a special register (IWFLAG) for use by the WORD Space Correction routine. Normally, the identification of a WORD space causes the Teletypewriter to skip a space following the printed character.

Internal Code Generation Routine. The identification of either a CHARACTER space or a WORD space signals the end of a Morse code character. The Internal Code Generation routine (Fig. 4-8) then forms the internal code word by combining the contents of the word register with the number register to yield a unique 12-bit code word (See Appendix C for a listing of internal code words).

An example of this process is shown in Fig. 4-9. A "P" (DOT-DASH-DASH-DOT) is received and correctly identified by the Data Recognition Process. As each pulse is received, a 0 or a 1 is stored in the least significant bit of the word register and the number register is incremented by 1. Previously received 0's or 1's stored in the word register are shifted left one position to allow room for the new pulse. When a CHARACTER or WORD space is received, the content of the word register is shifted left 12-N positions (N = number register value), the content of the number register is added, and the result is stored in the code register.

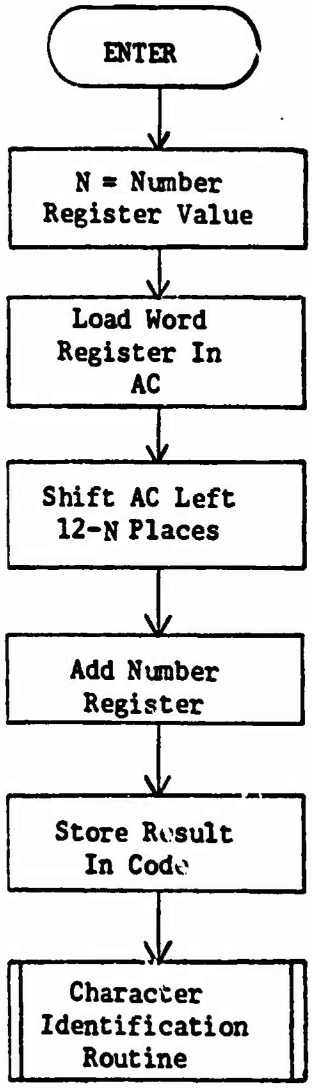


Fig. 4-8. Internal Code Generation Routine Flowchart.

Morse Code Character "P" (• — — •)
0 0 0 0 0 0 0 0 0 1 1 0
Word Register
0 0 0 0 0 0 0 0 0 1 0 0
Number Register
0 1 1 0 0 0 0 0 0 1 0 0
Internal Code Register (3004_8)

Fig. 4-9. Internal Code Word Generation

Because of the 12-bit register limitation on the PDP-12 computer, this internal process can only recognize Morse Code characters having eight or less pulses. Since most Morse code characters are 6 or less pulses long (error character has 8 pulses), this process is sufficient to handle the Morse code character set. The 12-bit register presents a limitation, however, to the Error Correction process, as discussed later in this chapter.

Character Identification Routine. The Character Identification routine (Fig. 4-10) compares the internal code word with a stored alphabet of 49 internal codes and selects the correct ASCII code for printer output. The comparison process has been divided into four steps to reduce computer execution time.

The first step determines which 4000_8 code subgroup ($0000_8 \longrightarrow 3777_8$ or $4000_8 \longrightarrow 7777_8$) the internal code word falls in. The second step identifies the 1000_8 subgroup containing the internal code. The third step identifies which half of the 1000_8 subgroup the code word is in.

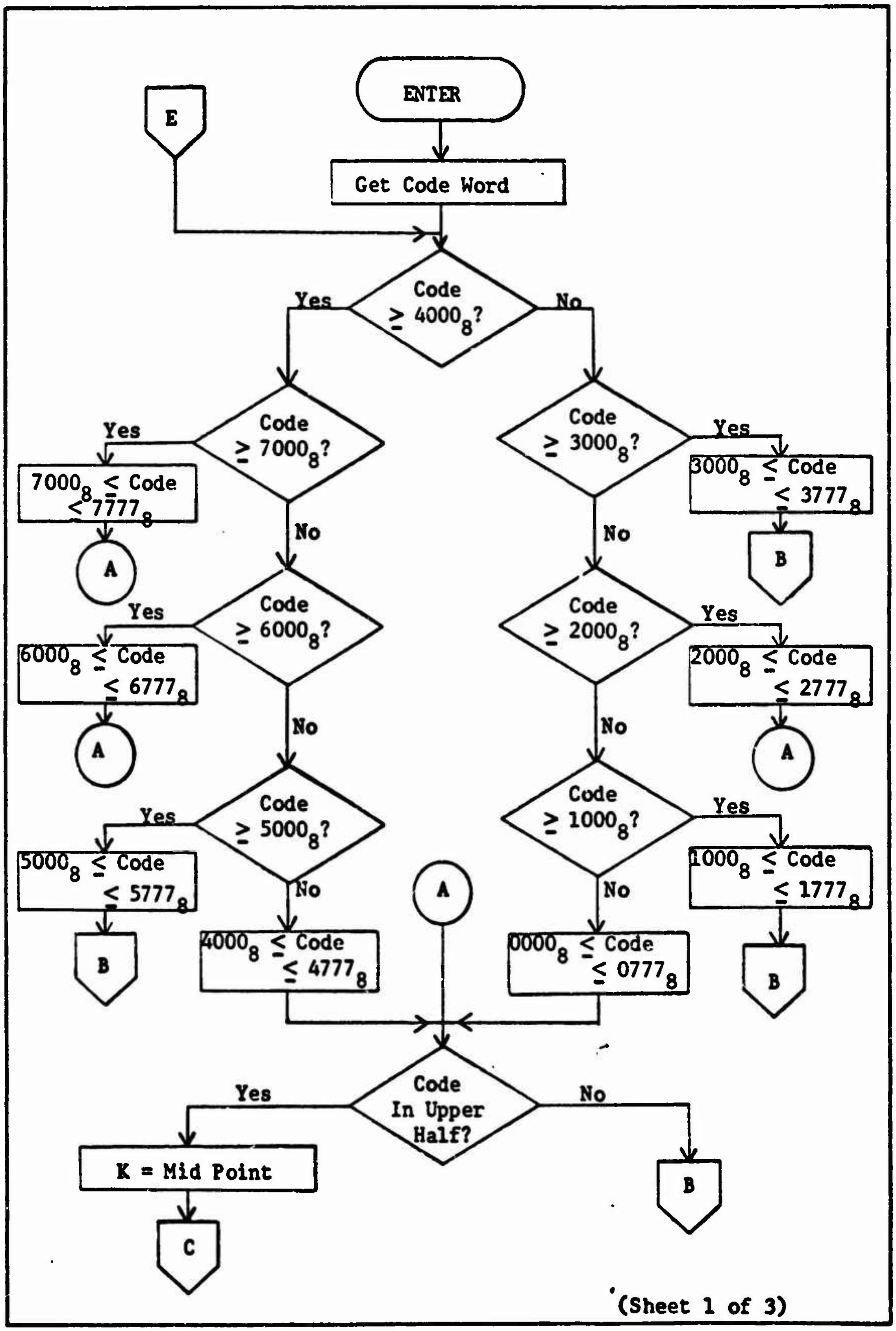


Fig. 4-10. Character Identification Routine Flowchart.

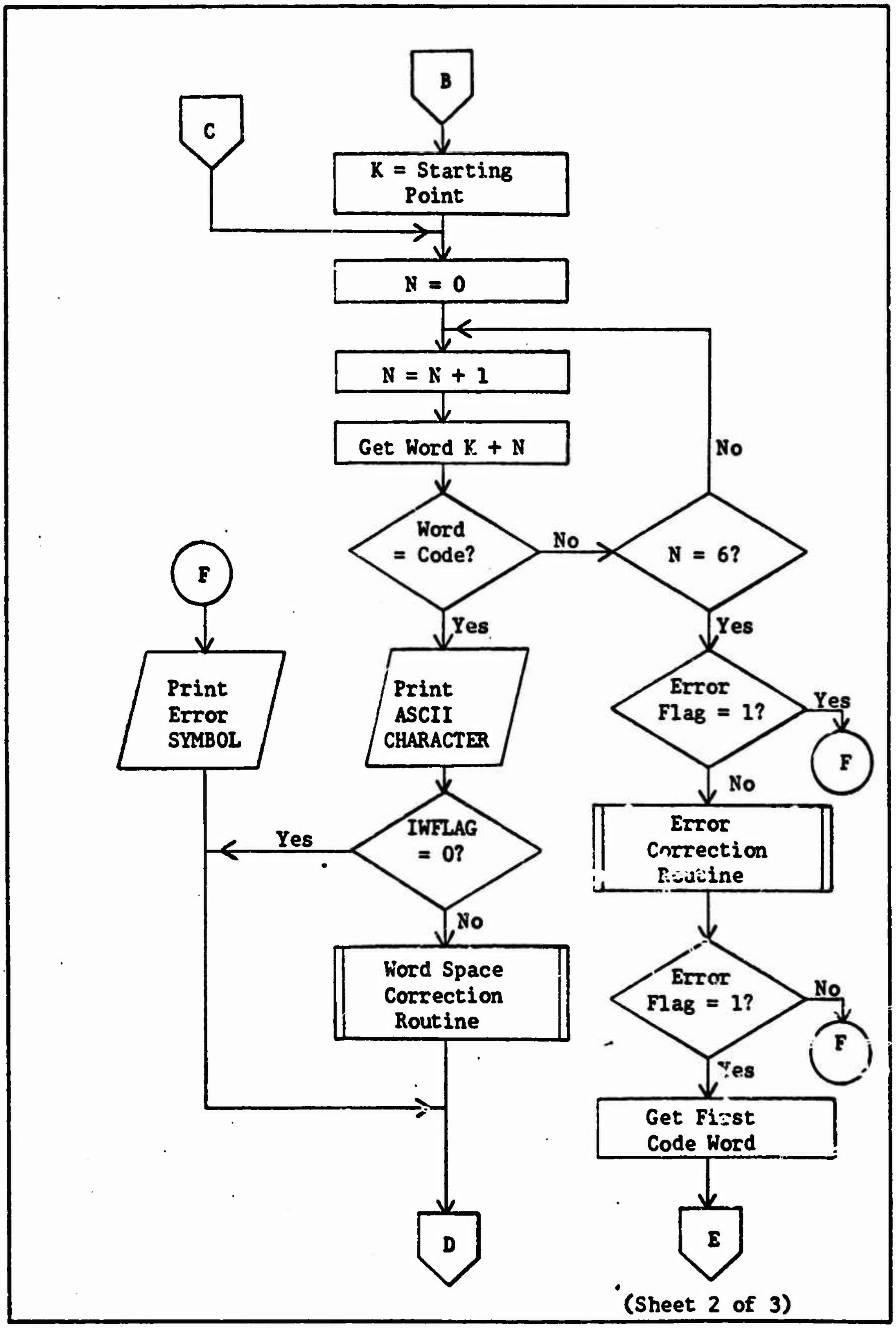
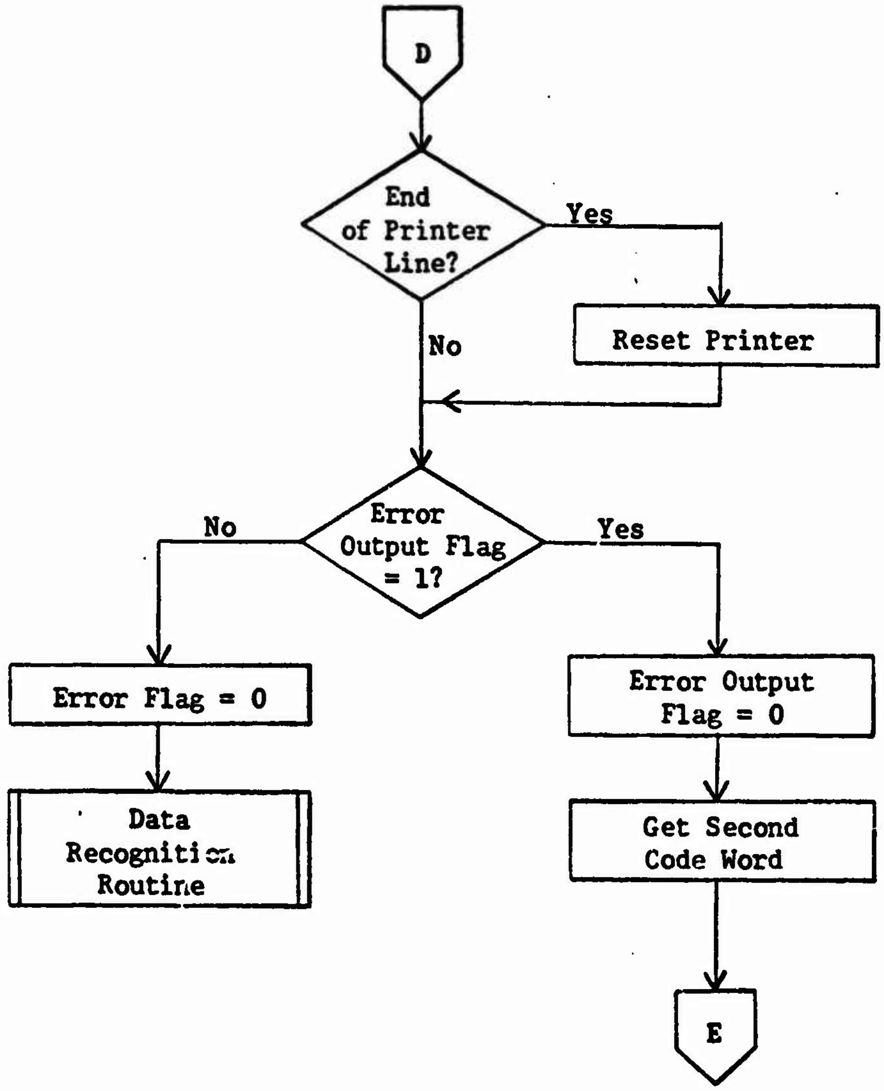


Fig. 4-10. Character Identification Routine Flowchart.



(Sheet 3 of 3)

Fig. 4-10. Character Identification Routine Flowchart.

Step 3 is only used for those subgroups having five or more code words. Finally, the fourth step identifies the correct internal code and corresponding ASCII code.

The identified ASCII character is then printed on the Teletypewriter. If a WORD space is identified, a blank is also printed. The printer carriage is controlled to provide double-spaced, 60-character lines.

If an internal code word cannot be identified, the Error Correction routine is entered. However, if the invalid code word is one which has been produced by the Error Correction routine, an error symbol is printed. Since it is possible for the Error Correction routine to generate two "corrected" code words, a network of flag checks is used to process each code word separately.

WORD Space Correction Routine. For the case of English language clear text transmissions, the occurrence of certain letters of the alphabet as the last character of a word is highly improbable, but not impossible. Six such letters are I, J, Q, U, V, and Z. When any of these characters is identified as the last character of a word, (i.e., followed by a WORD space), the WORD Space Correction Process is entered (Fig. 4-11). In this process, the word space is compared to a larger CHARACTER-WORD Space average than previously used. The adjusted average is the sum of the current CHARACTER-WORD Space average and the Pulse average, as shown below:

$$X = \frac{\text{C-W SPACE AVG.} + \text{PULSE AVG.}}{2} - \frac{\text{WORD SPACE}}{2} \qquad (4.15)$$

$$(X < 0 \Longrightarrow \text{WORD SPACE}; \; X \geq 0 \Longrightarrow \text{CHARACTER SPACE})$$

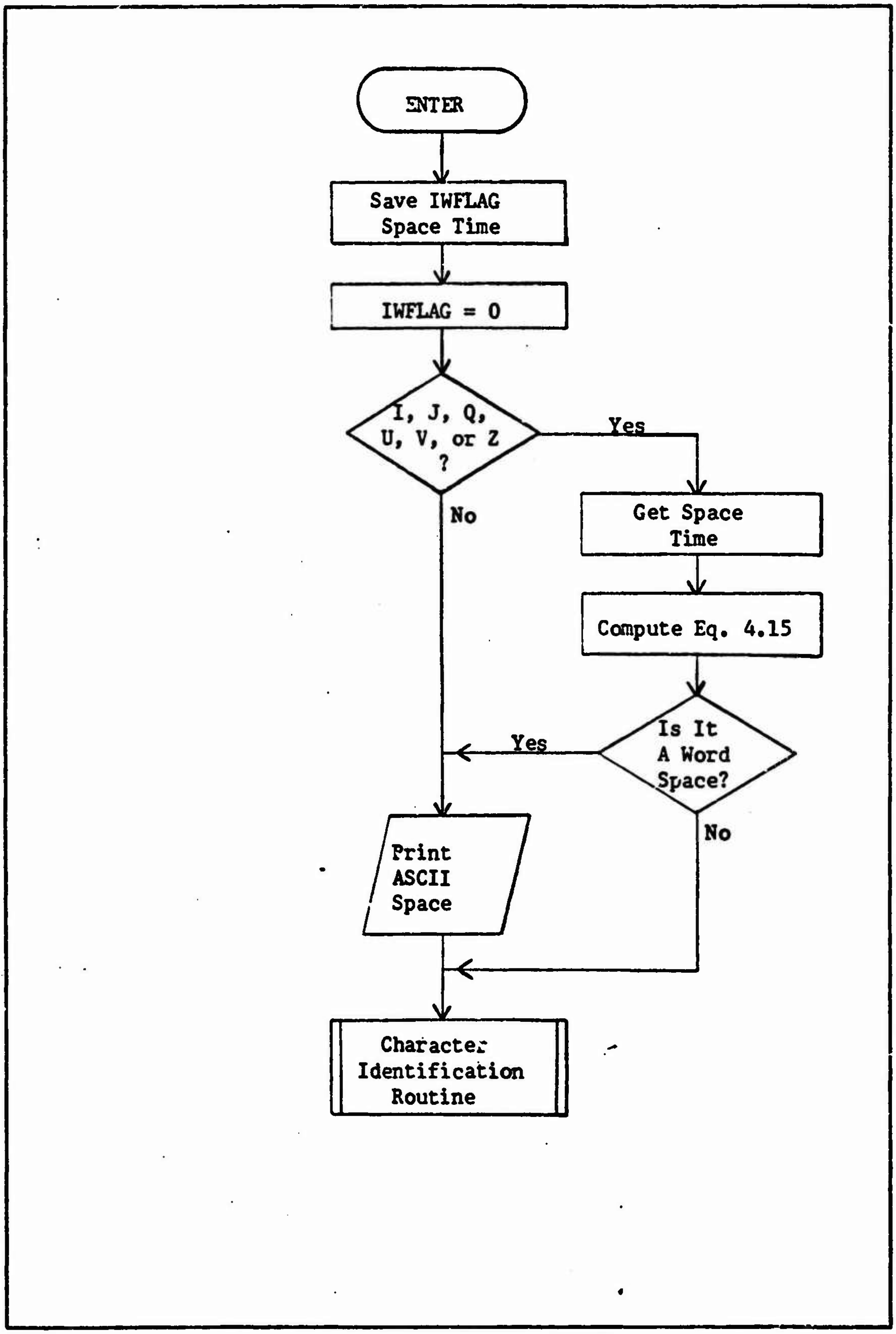


Fig. 4-11. Word Space Correction Routine Flowchart.

This calcualtion is used regardless of the type of preceding pulse.

If the space duration is greater than this adjusted average, it is still considered a WORD space. If, on the other hand, the space is less than the adjusted average, it is reclassified as a CHARACTER space instead of a WORD space.

The WORD Space Correction routine is applicable to English language clear-text transmissions only. If coded transmissions are received, this process may prove to be more of a hindrance than a help. The process is designed to correct mistakes on the part of the human sender, thus improving the readability of the recognition program output.

Error Correction Routine. The Error Correction routine (Fig. 4-12) is designed to correct errors due to either operator mistakes or signal noise. The Error Correction routine is entered only if the internal code word resulting from either of these two errors is unrecognizable by the Character Identification routine.

The Error Correction routine contains three successive parts, ordered by their relative importance to the process. In the first part, the number register is examined to determine if the maximum capability of 8 pulses has been exceeded in the invalid code word. If it has been exceeded, the Error Correction routine is exited and an error symbol is printed. If the limit has not been exceeded, the process advances to part 2.

The second part of the Error Correction routine is designed to eliminate extremely small DOT's caused by noise in the received Morse code signal. The pulses stored by the Data Recognition process are compared to a rejection value equal to one-half of the DOT average. The actual computation is:

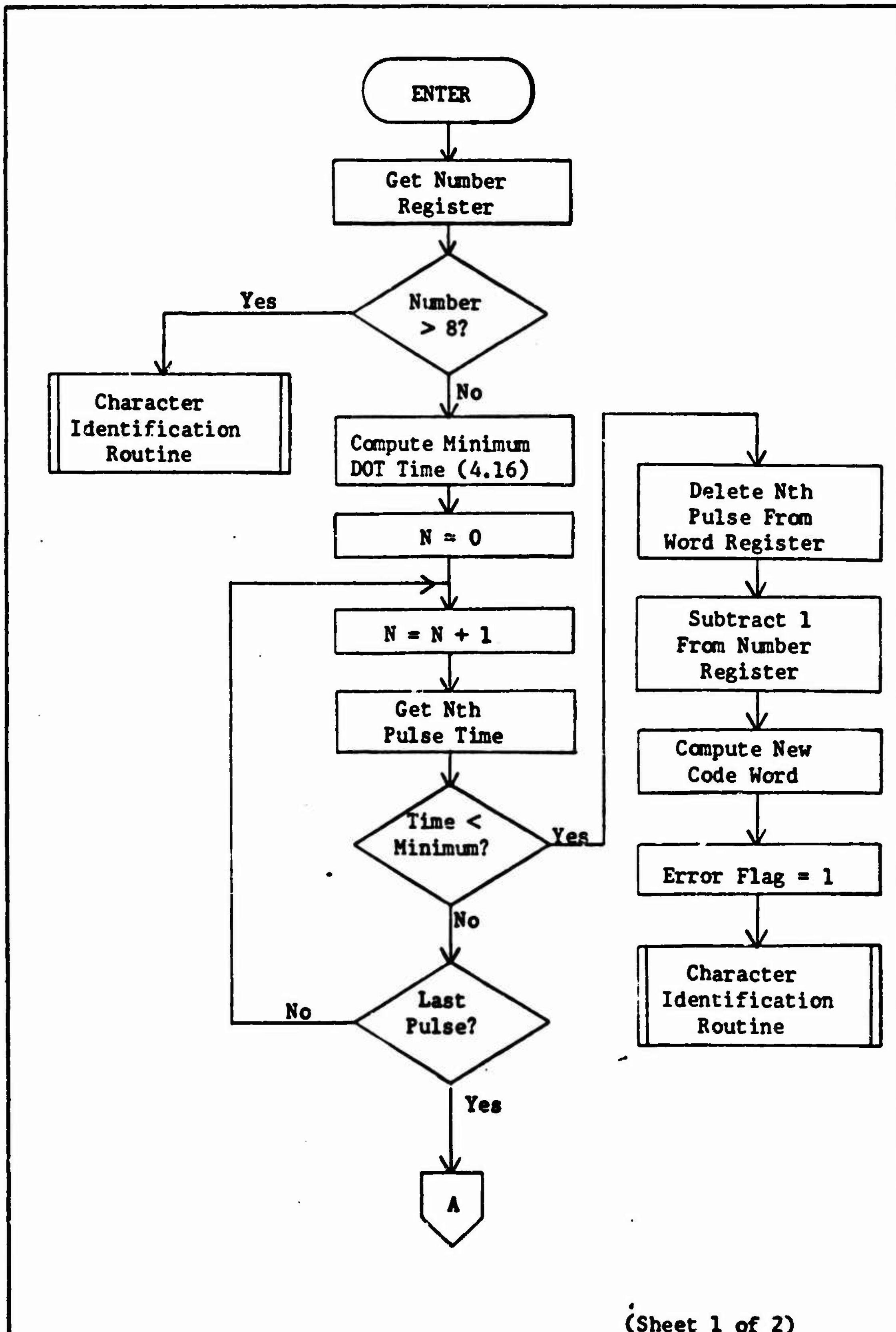


Fig. 4-12. Error Correction Routine Flowchart.

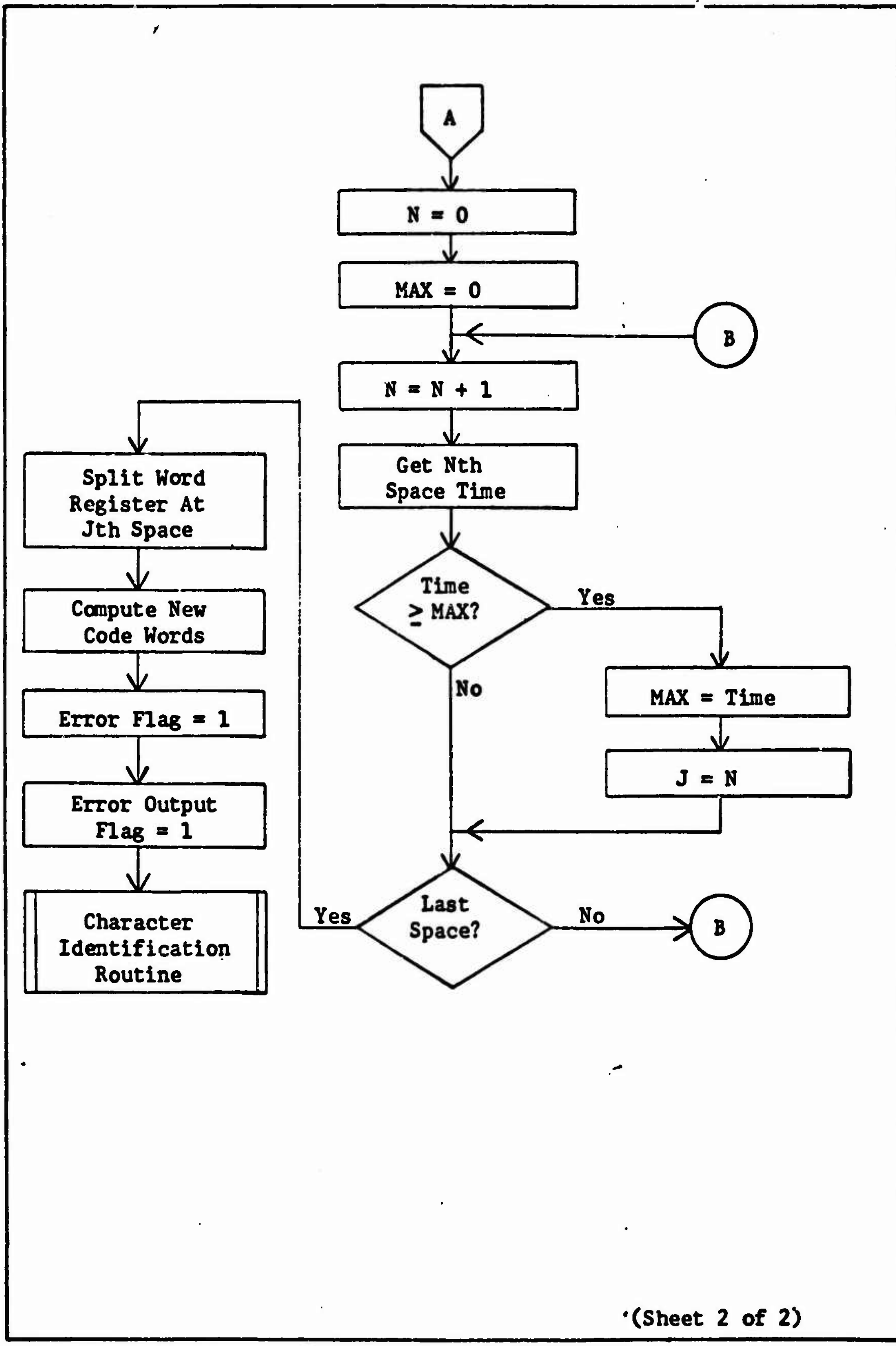


Fig. 4-12. Error Correction Routine Flowchart.

$$\text{MINIMUM DOT TIME} = \frac{\text{DOT AVG.}}{2} \tag{4.16}$$

If none of the pulses have a time duration less than the minimum value, the process advances to part 3. If, however, one of the pulses is less than the minimum value, a new internal code is generated by eliminating the erroneous DOT. The corrected code is then processed by the Character Identification routine.

The third and final part of the Error Correction routine is designed to separate two run-on characters caused by a short CHARACTER space. This program operates on the assumptions that the invalid character is composed of two and only two run-on characters, and that the intended CHARACTER space is the longest of the SYMBOL spaces contained in the invalid character. Spaces stored by the Data Recognition process are examined to determine the largest space within the invalid character. Two new internal codes are then formed by separating the invalid character at that point. These codes are then processed one at a time by the Character Identification routine. In addition, if the space following the invalid character was identified as a WORD space, a blank is printed following the second new character, unless prohibited by the WORD Space Correction routine.

New code words generated by either part 2 or part 3 may not be identifiable by the Character Identification routine. Since the stored time durations for the original invalid character no longer apply to the new code words, entrance into the Error Correction routine caused by invalid new codes must be prohibited. This is done by setting appropriate flags for use in the Character Identification routine.

V. Operational Procedure

This chapter describes the operational procedure used to initialize, run, and reset the recognition program listed in Appendix A. This procedure applies specifically to the particular PDP-12 computer and associated peripheral devices used in this project, as shown in Fig. 5-1; however, the procedure will apply, in general, to other possible configurations utilizing the techniques presented in this report.

System Initialization

After the recognition program is loaded into the PDP-12 computer, several steps must be performed to initialize the system, as follows: (Note: These steps can be accomplished in any order. Refer to Fig. 5-1 for equipment interconnections and control locations.)

1. Set the external Real-Time clock frequency. A value of 6000 Hz is best for hand-sent Morse code transmitted between 10 and 40 words per minute. Slightly higher or lower frequencies may be necessary for faster or slower transmission speeds, respectively.

2. Set the external program interrupt frequency. A value of 5000-6000 Hz is suggested; however, 6000 Hz is the maximum frequency that will allow proper operation of the Code Translation section. Higher program interrupt frequencies do not allow enough computer execution time for the Code Translation section to keep up with the output of the Signal Processing section.

3. Set the input signal threshold level. This value, set by rotating an A-D internal input channel control knob, has a range of $\pm 777_8$. A value of $+777_8$ is suggested; however, any value above 400_8 will suffice. The threshold level is displayed on the CRT Display screen during the initialization process as a horizontal line. A setting of $+400_8$ corresponds to the line being positioned in the center of the screen; $+777_8$ corresponds to the top

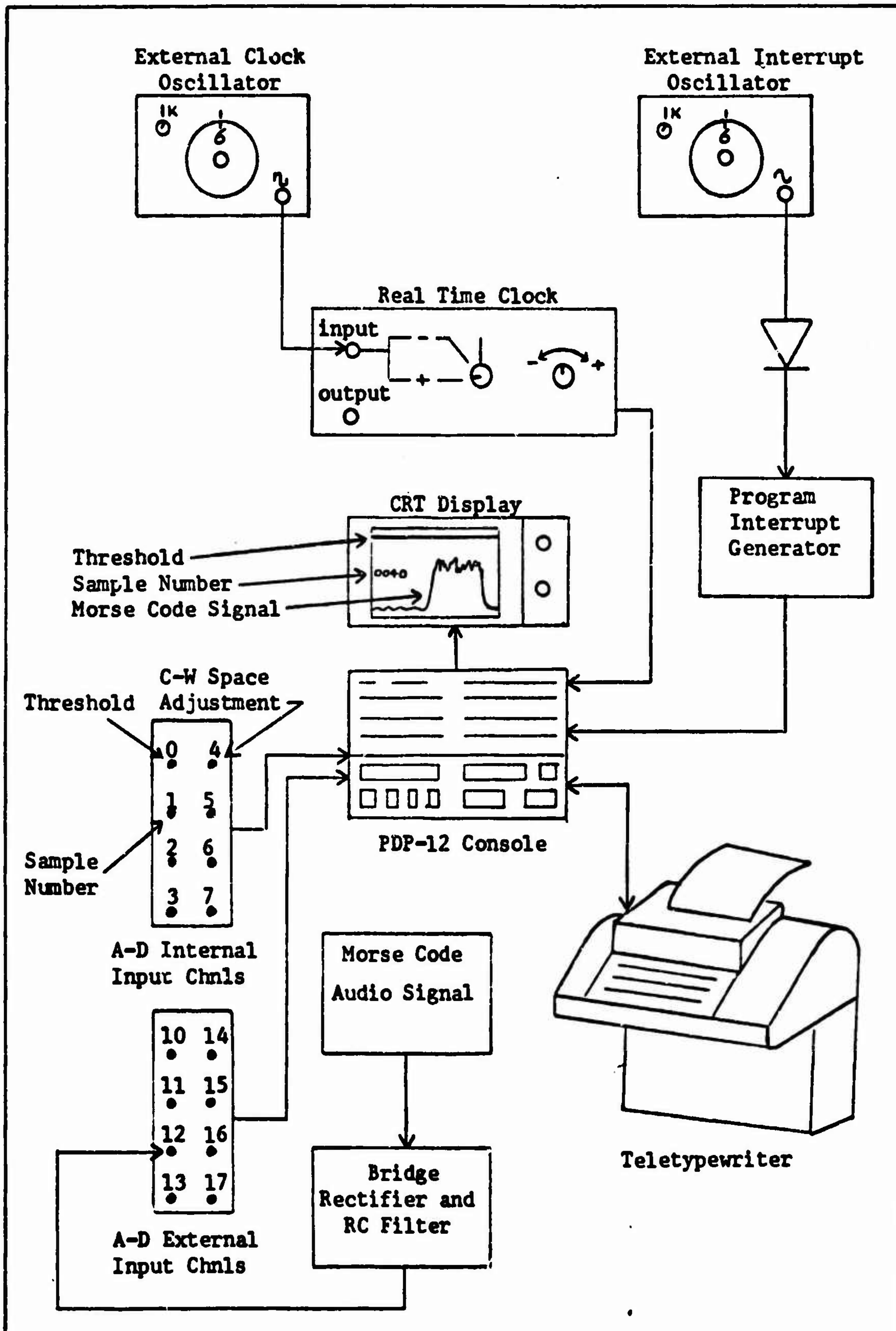


Fig. 5-1. Recognition Program Operational Configuration.

of the screen.

4. Set the peak rectified input signal voltage to approximately 2 volts. This signal is also displayed on the screen during the initialization process, provided a signal is being transmitted. The signal appears as a series of pulses flashing on the screen. As the input voltage level is increased, the peak of these pulses gets higher. The 2 volt level is reached when the pulse peaks disappear from view.

5. Set the number of input signal samples to be averaged. This number appears in the center left-hand side of the CRT Display screen during the initialization process. The number is set by rotating an A-D internal input channel control knob. An initial value of 0040_8 is recommended.

6. Set the CHARACTER-WORD space adjustment value to 0000_8. This value is also set by an A-D internal input channel control knob. These control knobs have a 10-turn stop-to-stop movement. 0000_8 corresponds to the center of the knob movement.

When these six steps have been completed, the Recognition program is ready to process Morse code transmissions. Since the CRT Display only functions during the initialization process, the internal input channel control knobs should be calibrated for use during Recognition program operation. Recognition program operation is started by depressing any one of the Teletype keys.

Real Time Adjustments

The settings established in the initialization process will, in most instances, provide satisfactory recognition program output. Under unusual circumstances, however, certain readjustments may improve overall performance and readability of the printed program output. A list of possible programs and suggested readjustments is presented in Table III.

The presence of an extreme amount of interference on the Morse code input signal will adversely affect recognition program performance. Such noise, generally having a time duration near that of a DOT or longer, causes the DOT, DASH, and pulse averages to be offset, resulting in an erroneous output. The respective averages will, however, be restored to normal when the interference subsides.

TABLE III

Recognition Program Real-Time Adjustments

Problem	Solution
1. Too many split words.	1. Increase the CHARACTER-WORD Space adjustment setting.
2. Too many run-on words.	2. Decrease the CHARACTER-WORD Space adjustment setting.
3. Too many error symbol printouts (a) Clear Morse Code Signal (b) Noisy Morse Code Signal	3. (a) Increase or decrease the Sample Number setting to obtain the best output. (b) Lower the peak input signal voltage slightly and readjust Sample Number setting.
4. Long succession of E's or I's.	4. Most likely due to extremely noisy Morse Code signal. Increase Sample Number setting and perform restart procedure.

Restart Procedure

The restart feature provides the capability to return to the System Initialization point at the beginning of the recognition program. This is done by depressing and resetting (rocking) Sense Switch 1 on the PDP-12 console at any time during program operation. Program operation may be resumed again by depressing any one of the Teletype keys.

The restart feature provides two important capabilities to the program. First, it erases current average information. This is most useful in the case where the averages are offset due to extreme signal interference. By performing a quick restart procedure (i.e., rocking Sense Switch 1 followed immediately by depressing a Teletype key), the erroneous averages are erased and new averages are established. Morse code information is lost only during the brief interval between the two actions.

Second, the restart procedure permits the last character of a Morse code transmission to be printed out. Normally, a Morse code character is not identified until either a CHARACTER space or WORD space is recognized. These spaces are recognized, as are all pulses and spaces, by their relative time durations. Space time durations are obtained when the succeeding pulse begins. If the pulse never occurs, as is the case at the end of a transmission, the last space time is never obtained and, as a result, the last Morse code character is not processed. Depression of the restart switch (Sense Switch 1) causes all unprocessed words stored in the 200_8-word memory buffer to be processed, including the last Morse code character received.

VI. Results

This chapter presents an evaluation of recognition program performance. Various types of Morse code transmissions were used to test the program. These include hand-sent Morse code transmitted via a simple hand key, a bug, and an electronic keyer, as well as machine-sent Morse code (Kleinschmidt-paper tape). The effects of noise on the performance of the recognition program was also tested.

The types of errors made by the program were mainly due to characteristics peculiar to the sender. A classification of the errors encountered during program testing is given along with error rates and program limitations.

Man vs. Machine Comparison

The method by which the performance of the recognition program should be evaluated is open to question. To base the evaluation strictly on a comparison of human recognition versus machine recognition of a Morse code transmission is unfair. The following excerpts from Gold's paper (Ref 4:18) makes this point very clear:

> Morse code is itself not a language but a way of representing or coding a given language, such as English or German. It is analogous to handwriting in that there is a symbol for each character in an alphabet.
> Some people write very clearly so that anyone can read their writing and, further, even those who cannot understand the language of the clear writer may still be able to understand and reproduce each symbol (letter of the alphabet) that was written. It is, however, very helpful to know the language being written; in fact, it is usually more difficult to read handwriting in a foreign language, even if this language is somewhat familiar, than to read one's native language in the same handwriting. Thus we see that, for handwriting, knowledge of the code

> is sometimes (in the case of the clear writer) sufficient to discern each intended symbol; in many cases, a high knowledge, i.e., of the language, is necessary to do so. Note that understanding of the meaning is not being discussed, but merely the identification, symbol for symbol, of what was written. ...it was noted that a man, who knows Morse code, will never remember a sample of data as accurately as a machine; yet he decodes a Morse message well enough to make any machine thus far built turn green with envy. Why? The answer can only be that to a very great extent he knows what to expect because he knows Morse code and the language being sent.

Thus we see that man's knowledge of the language being sent give him a tremendous advantage over a machine, unless the machine has a similar knowledge of the language. The machine described in this project does not have this knowledge and should not be evaluated on a strict man versus machine basis.

However, it is permissable to evaluate performance on a man versus machine-plus-man basis. That is, compare man's ability to recognize a Morse message with man's ability to interpret the message recognized by the machine. Again, man has the decided edge in this comparison. However, man must be able to interpret the output of the machine or the machine is of no value at all. The following excerpt from Gold's paper (Ref 4:22) gives his point of view on this subject:

> It is felt that the effectiveness of a machine... depends on the percentage of received messages that it can adequately decode. The word "adequately" pinpoints the vagueness of this statement; this is interpreted to mean "capable of reconstruction in a reasonable length of time;" even here the problem becomes too subjective.

Testing Procedure

The performance of the recognition program was evaluated in the following manner. Tape recordings of hand-sent Morse code transmissions were used as the input signal to the machine. These tapes contain examples of messages transmitted by hand key, semi-automatic key ("bug"), electronic keyer, and machine. The type of messages recorded include plain text and code groups. Transmission speeds vary from 7 words per minute (wpm) to 35 wpm. In all, seven different recording sessions were used to evaluate machine performance. Table IV lists the key features and error rates for each recording session.

A 550-word plain text was used as the transmitted message for Recording Sessions 1 through 4. The prepared text and the recognition program printout for each of these recording sessions is contained in Appendix D, Figures D-1 through D-5. On all but Recording Session 4, a copy of the prepared text was given to two people listening to the Morse code transmission. These people annotated their copy to indicate transmission mistakes made by the sender. The two annotated copies were then used to identify recognition program errors (i.e., discrepancies between the prepared text and the machine output) due to the sender and not the machine itself. The remaining errors were used to approximate machine error rate percentages.

All recognition program errors, whether due to sender error or the machine itself, have been classified and are presented in the following section.

Classification of Errors

A classification of the errors encountered in recognition program translations of hand-sent Morse code plain text transmissions is now presented.

TABLE IV

Recording Session Variables and Error Rates

Recording Session	Sending Unit	Transmission Rate (wpm)	Type of Message	Character Errors/ Characters Sent	Error Percentage	Remarks
1	"Bug"	16	Plain Text	8[a]/2927	0.273	Sending Unit Malfunction
2	Hand Key	12	Plain Text	5[a]/2927	0.171	
3	"Bug"	18	Plain Text	43[a]/2927	1.47	Sending Unit Malfunction
4	Electronic Keyer	35	Plain Text	45[b]/2927	1.53	
5	Electronic Keyer	7	Plain Text/ Code Groups	0[b]/825	0.00	
6	Machine	18	Plain Text	44[b]/633	6.9	Radio Broadcast Interference and Signal Fading
7	Hand Key	8-10-12	Code Groups	3[b]/914	0.33	"white" noise

a Machine errors only
b Total errors

1) Two Characters run together. Examples: ME → G, TH → 6, NA → X. Caused by too short a space separating the characters.

2) Split characters. Examples: Y → TW, V → ST. Caused by too long a space separating pulses within a character.

3) Extra DOT (valid code). Examples: W → AA, Y → TU, C → ND. Caused by transmission of an extra DOT. The resulting character, in this case, is not a valid one. The two printed characters are the product of the Error Correction routine.

5) Missing DOT (valid code). Examples: H → S, C → K, R → A. Caused by absence of a required DOT.

6) Missing DOT (invalid code). Examples: Period → AK or CT, 9 → MM. Caused by absence of a required DOT resulting in an invalid code. The two printed characters are a result of the Error Correction routine.

7) Simple pulse errors. Examples: Y → TU, K → O, C → B. Caused by an extra-long DOT being recognized as a DASH, or an extra-short DASH being recognized as a DOT. Occurs most frequently when a hand key is used. One or two characters may be printed, depending on whether the resulting internal code word is valid or not.

8) Complex pulse errors. Examples: B → K, O → X, B → M. Caused by two or more DOTs, spaced closer together than usual, being recognized as a DASH. Also caused by a DASH being broken up into two or more DOTs. Occurs most frequently in the presence of input signal noise.

9) Space errors. Examples: all run-on or split words. Caused by either too short a WORD space or too long a CHARACTER space,

respectively. Consistant run-on or split words are caused by an incorrect CHARACTER-WORD Space Adjustment control knob setting.

10) Complex errors. Indicated by the error symbol (=) printout. The source of these errors cannot be traced. The invalid code, resulting from an unknown source, could not be corrected by the Error Correction routine.

Errors of the type 3) through 6) occurred most frequently when a semiautomatic key was used. This can be explained by noting that the number of DOTs transmitted in succession is a function of how long the DOT lever is depressed on these types of sending units. Occasionally the sender, through fatigue or carelessness, sends too many or too few DOTs by not depressing the lever for the correct amount of time.

Error type 8) occurred quite frequently during Recording Sessions 1 and 3. The cause of these errors was traced to improper adjustment of the DOT-sending portion of the "bug" used for both transmissions. Indeed, both recording sessions had to be stopped several times to allow readjustments to be made on the sending unit. Noise induced by contact bounce as a result of the malfunctioning unit was the primary cause of the type 8) errors experienced.

Recording Session 3 contained many type 2) errors. In almost every instance where a V (• • • –) was transmitted, the recognition program printed an S (• • •) T (–) instead. The SYMBOL space following the third DOT was misinterpreted as a CHARACTER space by the machine. Fig. 3-4 (Chapter III) reveals the cause of these machine errors. Notice that the DOT-SYMBOL cluster extends above the SYMBOL linear decision boundary, and that the SYMBOL space variance is much larger in this cluster than it is in corresponding clusters for Recording Sessions

1 and 2 (Figures 3-2 and 3-3 respectively).

There are two possible explanations for this abnormally large SYMBOL space variance: 1) "bug" contact bounce causing the time duration of the last automatically generated DOT to be shorter than usual and, correspondingly, the time duration of the following space to be longer than usual, and 2) too fast a transmission rate setting on the automatic DOT generator, as compared to the actual transmission rate of the message itself. The latter of these two possible explanations is the most feasible, since the DOT portion of the "bug" had a very restricted transmission rate adjustment range over which it would satisfactorily operate. In fact, readjustment was required several times during the 30-minute transmission period. It is quite possible, then, that the actual transmission rate used was too fast, i.e., faster than the rate of the manually transmitted portion of the message. Under these circumstances, the time duration of automatically generated SYMBOL spaces would be shorter than the time duration of manually generated SYMBOL spaces, thereby accounting for the wide time duration variance, and the resulting abundance of type 2) errors.

Analysis of Performance

Recognition program performance was analyzed by comparing the printouts obtained for Recording Sessions 1, 2, and 3 with the annotated worksheets provided by the human receivers. Errors identified on the worksheets were marked on the corresponding machine printout to eliminate them from consideration in the error analysis. These errors are marked with an asterisk on the machine printouts shown in Appendix D. The remaining discrepancies contained in the machine printouts were noted and used to compute the error rate percentages given below. These errors are marked with a number symbol (#) on the printouts.

Error Rates. The error rates calculated for Recording Sessions 1, 2, and 3 by the previously described method are given in Table IV. Note that error rates are given for character errors only. Space errors causing run-on or split words, although having an effect on the readability of the message, are not considered essential to the overall performance of the recognition program. Character error rate percentages were calculated by dividing the number of incorrect characters noted on the machine printout by the total number of characters in the transmitted message.

The error rate indicated for Recording Session 4 was calculated by dividing all the "uncorrected" character errors by the total number of characters transmitted. "Uncorrected" errors are those machine printout errors occurring in words which were not retransmitted by the operator. During this transmission, the operator followed the standard practice of retransmitting words in which a mistake was made and noted by the operator. The error rates for Recording Sessions 5, 6, and 7 were calculated by dividing all machine printout errors by the number of characters transmitted.

It is interesting to note that many errors annotated by the human receivers did not occur on the machine printout. This, of course, is due mainly to the Error Correction feature of the recognition program. The Error Correction routine was used a total of 15 times during Recording Session 1, 5 times during Recording Session 2, and 5 times during Recording Session 3.

Limitations. Recording Sessions 4 through 7 provide a means of determining the operational limitations of the recognition program. Knowledge of these limitations is necessary to determine the weak points of the program and to try to correct them.

In general, the recognition program performs well for all types of Morse code transmissions. The major weakness is input signal noise; especially interference having a time duration large enough to alter the DOT, DASH, and pulse averages used by the program to establish linear decision boundaries in two-dimensional pattern space. Although the respective pulse averages do return to their correct values when the interference subsides, the program output during the interference period is, in most cases, unintelligible.

A brief discussion on the results obtained for Recording Sessions 4 through 7 will now be given. Recording Sessions 4 and 5 were transmitted by the same person using the same equipment. Recording Session 4 (Fig. D-5) was transmitted at varying rates ranging from the individual's maximum rate of 35 wpm to a low of approximately 15 wpm. Most of the text was transmitted at the 35 wpm rate. The operator, by his own admission, was sending at his maximum capability and made many mistakes, not all of which were noticed and corrected by the repetition procedure previously described.

Recording Session 5 (Fig. D-6) consists of sentences and code groups used in teaching Morse code to a group of students. With the exception of one sentence, all transmissions were sent one character at a time at a steady 7 wpm rate. This explains the spaces appearing between each character on the machine printout. No machine errors occurred during this recording session.

Recording Session 6 (Fig. D-8) is a radio broadcast of an American

Radio Relay League W1AW cw bulletin, transmitted by machine at 18 wpm. A copy of the transmitted bulletin is shown in Appendix D, Fig. D-7. Much interference and signal fading occurred during this recording session, although not severe enough to prevent a human from correctly copying the message. These disturbances, however, had a great affect on the performance of the machine, as is indicated on the machine printout.

Recording Session 7 (Fig. D-9) consists of code groups transmitted at 8, 10, and 12 wpm on a hand key. These transmissions were obtained from tape recordings of hand-sent Morse code used by the U.S. Army to teach Morse code during WWII. The tapes contained a background "white" noise which did not, as the machine output shows, affect recognition program performance.

Analysis of all results obtained from the seven recording sessions indicates that the recognition program is capable of recognizing hand-sent Morse code at speeds up to at least 35 wpm with moderate signal noise. The main limitation thus far discovered in this project is pulse-type interference.

VII. Conclusions and Recommendations

This chapter presents the conclusions reached from the limited testing performed on the recognition program. Also, recommendations concerning further testing procedures and possible program changes are given.

Conclusions

Although only seven different types of Morse code transmissions were used to evaluate the performance of the recognition program, the results obtained clearly define the attributes and weaknesses of the program in its present form. Certainly more work must be done on the Signal Processing section to limit the detrimental effects of input signal pulse-type interference, since signal interference is prevalent on the radio bands used for cw transmissions. Perhaps a simpler algorithm than that of the low-pass digital filter technique used in the program will produce better results. A combination of digital filtering and other noise reduction techniques might prove to be optimum.

Aside from the interference problem, the performance of the recognition program is very satisfactory. The character error rates calculated for Recording Sessions 1, 2, and 3 are well within an acceptable limit. The readability of the machine output, a function of the particular sender, is optimizable by real-time adjustment. Since it is desirable to have the machine operate with as little human intervention as possible, preferably none, procedures are given in the next section to automate the readability adjustment as well as certain other controls now requiring real-time adjustments to maximize performance.

These procedures and recommendations are now presented.

Recommendations

The recommendations presented in this section deal with recognition program improvements and hardware realization suggestions.

Recognition Program Improvements. The recognition program, in its present form, represents an attempt to perform machine recognition of hand-sent Morse code by methods other than those previously documented. Admittedly, when the project was undertaken there was no guarantee that the techniques used in this program would be as good as or better than those other methods.

The use of averaging algorithms can be very misleading. Extreme care must be exercised when trying to fit an averaging technique to a particular physical phenomenon. For example, the average human being has one testicle and half a uterus. Basing decisions on this type of average is certainly absurd. However, the distribution properties of hand-sent Morse code indicate that averaging techniques are indeed applicable. Test results confirm this conclusion.

Unfortunately, the use of averaging techniques presents a problem when pulse-type interference is present in the input signal. Interference of this type offsets the pulse averages used in the program. One possible solution to this problem is the establishment of upper and lower bounds around the DOT and DASH averages computed in the program. Data distribution plots indicate a relatively tight grouping of DOT and DASH time durations for a particular sender. These time durations may be assumed to have a normal distribution with a mean approximated by the calculated averages (Ref 3:27). A 2-sigma confidence interval can easily be established and used to exclude time durations not within this interval from the averaging process. This method should be capable of detecting time duration average differences present in a two-way conversation. The data distribution plots reveal that time duration intervals remain within a 2-sigma interval of each other for transmission rates between 10 and 20 wpm. Quite possibly this overlap exists for an even larger difference in transmission rates. It is recommended that additional data be obtained to confirm or deny this possibility.

The human intervention now required to optimize readability of the machine printout can easily be eliminated by an additional program routine. The number of spaces printed on each line of machine output can be compared with an upper and lower limit to determine whether adjustment is needed. For example, if the number of spaces printed exceeds 15, the CHARACTER-WORD space adjustment should be increased; if the number of spaces is less than 5, the adjustment should be decreased. The amount of readjustment per change can be optimized to prevent over correction while still allowing the optimum value to be reached within a reasonable amount of time. The upper and lower limits and the incremental adjustment value must be determined experimentally.

Human intervention now necessary to optimize the number of input signal samples to be averaged for the change detection process can also be replaced by computer programming. An initial value, preset at the start of the program, can be adjusted to an optimum value as a function of the DOT average. For example, the value can be adjusted to filter out all pulses having a time duration of less than one half the DOT average. The low-pass cut-off frequency of the digital filter is determined by the number of samples averaged and the interrupt frequency.

Since the interrupt frequency is a constant, set at the maximum value permitting proper Code Translation section operation, the relationship between number of samples and cut-off frequency is linear. The number of samples to be averaged is thus directly proportional to the DOT average. The actual relationship must be determined experimentally.

Hardware Realization. Many of the peripheral devices and control knobs used in this project can be eliminated in a hardware realization of the recognition program. The input signal threshold level can be set at a constant value of $+777_8$, thereby eliminating the threshold control knob. A feedback control circuit can be used to regulate the peak dc voltage of the rectified input signal to an optimum value for the constant threshold. Inclusion of the program changes recommended in the previous section would eliminate the need for sample number and readability control knobs. It may be desirable, however, to retain these controls to permit human intervention if required under unusual circumstances. The two switches used to perform a program restart can be replaced by one START/RESET pushbutton.

The entire program, now requiring about 3K of memory, can easily be reduced to fit within a 1K 12-bit memory unit by elimination of those instructions now used to control the CRT Display and sample switches. Elimination of these instructions has the added benefits of faster program execution time, better reliability, and less construction cost.

The use of a 16-bit structure will provide additional programming capabilities not possible with the 12-bit structure of the PDP-12 computer. First of all, a constant Real Time Clock frequency can be used for all Morse code transmission rates, since the 16-bit word length will provide a 65,536 (2^{16}) clock counter overflow range. For example, an external clock frequency of 65,536 Hz will permit recognition of pulse and space time durations ranging from 1 or 2 milliseconds to one second in length. This corresponds to transmission rates in the range of 5 to 500 wpm.

The 16-bit structure will also permit increased error correction capability. The 12-bit structure used in the recognition program permits error correction of a run-on Morse characters not exceeding 8 pulses in length. The 16-bit structure will permit correction of run-on characters up to 12 pulses in length. Effective use of this increased capability will require revision of the Error Correction routine to allow for the possibility of three run-on characters.

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Appendix A

Recognition Program Listing

The Recognition Program was written for use on the PDP-12 computer equipped with a CRT Display, Teletype or DECWRITER, KW12-A Real Time Interface, Data Terminal, and a TU56 Dual Drive Transport. The program is written in LAP6-DIAL assembly language.

The listing contains six columns of information. These are, from left to right, program line number, memory field location, octal value assigned to the location, user-assigned symbols, program and assembly instructions or data, and comments.

```
                   *20
                   /     HAND SENT MORSE CODE
                   /     RECOGNITION PROGRAM
                   /
                   /
                   /
                   /
                           PMODE
                           *0
0000  0000                 0                  /PMODE
0001  5402                 JMP I 2            /INTERUPT
0002  0233                 SERVE
                           *5
0005  0000                 0
0006  0000                 0
0007  0000                 0
0010  0000                 0
0011  6000        SIGNAL,  6000
0012  0577        STORE,   577
0013  0577        WORD,    577
0014  4017        STORIT,  4017               /ASCII MEMORY
                           *17
0017  7767                 7767
                           *20
0020  0000        CHECK,   0
0021  0000        NUM,     0
0022  0000        COUNT,   0
0023  0400        SADIS0,  SADIS
0024  1200        ADSAM0,  ADSAM
0025  1600        PROCE0,  PROCES
0026  0011        KCLR,    0011
0027  0000        CHANGE,  0
0030  0271        SENSE0,  SENSE
0031  7001        M777,    -777
0032  0577        K577,    577
0033  0000        NUMR,    0
0034  2214        EFL10,   EFL1
0035  2251        EFL20,   EFL2
0036  0000        EFLAG1,  0
0037  0000        EFLAG2,  0
                           LMODE
0040  0000                 0                  /LMODE
0041  6221                 JMP SERVEL         /INTERUPT
                           PMODE
0042  2300        SETPT0,  SETPTR
0043  0000        MSTART,  0
0044  0000        WDREG,   0
0045  2400        IPROC0,  IPROC
0046  0000        CODE,    0
0047  3000        C01,     AUNK
0050  3014        C02,     A5
0051  3026        C11,     ASPAC
0052  3036        C21,     AU
```

0053	3044	C22,	AWAIT
0054	3052	C31,	A
0055	3062	C41,	W
0056	3072	C42,	A6
0057	3102	C51,	T
0060	3114	C61,	K
0061	3122	C62,	A7
0062	3130	C71,	M
0063	3134	C72,	A9

0064	3202	CHKIT,	CHCK
0065	3013	CN5,	N5
0066	3043	CWAIT,	WAIT
0067	3071	CN6,	N6
0070	3121	CN7,	N7
0071	3133	CN9,	N9
0072	2607	ASC0,	ASCII
0073	1602	PRCAG0,	PRCAGN
0074	7700	KLINE,	7700
0075	7700	LINE,	7700
0076	0000	IWFLAG,	0
0077	7777	M1,	-1
0100	0001	K1,	1
0101	1777	K1777,	1777
0102	0000	PX,	0
0103	7140	M640,	-640
0104	0000	DOTAV,	0
0105	0000	DASHAV,	0
0106	0000	PAVG,	0
0107	0000	FUDGE,	0
0110	0000	SAFUDG,	0
0111	0000	HOLDWD,	0
0112	0377	K377,	377
0113	0000	TEMP,	0
0114	0240	K240,	240
0115	0215	K215,	215
0116	0212	K212,	212
0117	0100	RATE0,	0100
0120	0000	CWAVG,	0
0121	0013	K13,	13
0122	7776	M2,	-2
0123	7776	KM2,	-2
0124	2050	PWD0,	PWD
0125	2200	ICODE0,	ICODE
0126	0217	RSTAR0,	RSTART
0127	6000	K6000,	6000
0130	0000	PFLAG,	0
0131	0000	KCHANG,	0
0132	0430	CONDI0,	CONDIS
0133	2000	SDASH0,	SDASH
0134	2254	DIAL0,	DIAL
0135	0777	K777,	777

```
0136 7777 PAST,   7777              /INTL VAL = -1
0137 0000 THRESH, 0
0140 1443 AOUT0,  AOUT
0141 1404 RESET0, RESET
0142 1400 TIMER0, TIMER
0143 1332 ADSAM1, ADSAM2
0144 0000 NEW1,   0
0145 0000 PORS,   0
0146 0000 WHICH,  0
0147 0000 TIME,   0
0150 0000 IWF1,   0
0151 0000 IWF2,   0
0152 0000 NUM31,  0
0153 0000 NUM32,  0
0154 4017 KSTOR,  4017
0155 0000 UNFLG,  0
0156 0000 UNCK1,  0
0157 0000 UNCK2,  0
0160 0000 UNCK3,  0
0161 0000 ERWDNM, 0
0162 3400 UNKCH0, UNKCHK

0163 0000 TEMPMN, 0
0164 0000 MNUM,   0
0165 0000 LMNUM,  0
0166 1500 FIG10,  FIG1
0167 3467 RFIG10, RFIG1
0170 1516 FIG20,  FIG2
0171 3600 RFIG20, RFIG2
0172 0000 TALLY,  0
0173 0000 TALLY1, 0
0174 0000 TALLY2, 0
0175 2404 IPRTN0, IPRTN
0176 1723 CALSP0, CALSPA
0177 0000 CDE32,  0
                  SHL=7413
                  CAM=7621
          /
          /
                  LMODE
                  KCC=6032
                  KSF=6031
                  RMF=6244
                  ION=6001
          /
          /
                  PMODE
          /
          /
          /
          /
          /
```

```
                             *200
0200  7300  START,  CLA CLL
0201  1127          TAD K6000
0202  6132          CLLR              /EXTNL CLK RATE
0203  7200          CLA
0204  1322          TAD CFLAG
0205  6134          CLEN              /ENABLE INPUT 1
0206  7200          CLA
0207  6046          TLS
0210  6032          KCC
0211  6141          LINC
                    LMODE
0212  1020          LDA I
0213  0240          0240
0214  0004          ESF               /FULL SZ DSPLY &
0215  0002          PDP               /DSABL TTY INTRP
                    PMODE
0216  4442          JMS I SETPT0      /CR + 2 LFS
0217  4423  RSTART, JMS I SADIS0      /SET AD SMPL SIZ
0220  5425          JMP I PROCE0      /GO TO MAIN PROG
            /
            /
            /
            /
            /  INTERUPT SERVICE ROUTINE
            /
            /
                    LMODE
0221  4325  SERVEL, STC AC            /SAVE AC
0222  0261          ROL I 1
0223  4323          STC LINK          /SAVE LINK
0224  2040          ADD 0040          /GET RTN ADDRSS
0225  1620          BSE I
0226  6000          6000
0227  4270          STC LRTN          /CREATE RTN JMP
0230  2100          ADD K1
0231  4326          STC LFLAG         /SET LFLAG
0232  6241          JMP LCONT
                    PMODE
0233  3325  SERVE,  DCA AC            /STORE AC VALUE
0234  7204          GLK
0235  3323          DCA LINK          /STORE LINK
0236  1000          TAD 0000
0237  3324          DCA HOLDIN        /STORE PC
0240  6141          LINC
                    LMODE
0241  0643  LCONT,  LDF 3             /SET DF = 3
0242  0002          PDP
                    PMODE
0243  4424          JMS I ADSAM0      /YES GO TO ADSAM
0244  7300  EXIT,   CLA CLL
```

```
0245  1326            TAD LFLAG
0246  7640            SZA CLA           /LFLAG SET?
0247  5257            JMP LOUT          /YES
0250  1323            TAD LINK          /NO
0251  7010            RAR               /RESTORE LINK
0252  1324            TAD HOLDIN
0253  3000            DCA 0000          /RESTORE PC
0254  1325            TAD AC            /RESTORE AC
0255  6001            ION               /INTERUPT ON
0256  5400            JMP I 0           /RTN TO PROGRAM
0257  3326  LOUT,     DCA LFLAG         /CLEAR LFLAG
0260  6141            LINC
                      LMODE
0261  0011            CLR
0262  2323            ADD LINK
0263  0321            ROR I 1           /RESTORE LINK
0264  2325            ADD AC            /RESTORE AC
0265  0006            DJR
0266  0500            IOB
0267  6001            ION               /INTERUPT ON
0270  0000  LRTN,     0
                      PMODE
            /
            /
            /
            /
            /   SENSE SWITCH ROUTINE
            /
            /   SENSE SW 1 = DUMP MEMORY & RESTART
            /   SENSE SW 2 = DUMP MEMORY & GO TO DIAL
            /
            /
0271  0000  SENSE,    0
0272  6141            LINC
                      LMODE
0273  0461            SNS I 1           /SENSE SW 1 SET?
0274  6301            JMP SW1           /YES
0275  0462            SNS I 2           /NO  SW 2 SET?
0276  6306            JMP SW2           /YES
0277  0002            PDP               /NO
                      PMODE
0300  5671            JMP I SENSE
                      LMODE
0301  0002  SW1,      PDP
                      PMODE

0302  7200            CLA
0303  7001            IAC
0304  3036            DCA EFLAG1        /SET SW1 FLAG
0305  5312            JMP EMPTY
                      LMODE
0306  0002  SW2,      PDP
```

```
                       PMODE
0307  7300             CLA CLL
0310  7001             IAC
0311  3037             DCA EFLAG2        /SET SW2 FLAG
0312  7100   EMPTY,    CLL
0313  1323             TAD LINK
0314  7010             RAR               /RESTORE LINK
0315  1324             TAD HOLDIN
0316  3000             DCA 0000          /RESTORE PC
0317  1325             TAD AC            /RESTORE AC
0320  6244             RMF               /RESTORE IF & DF
0321  5400             JMP I 0
             /
             /
0322  0020   CFLAG,    0020
0323  0000   LINK,     0
0324  0000   HOLDIN,   0
0325  0000   AC,       0
0326  0000   LFLAG,    0
             /
             /
             /
             /  AD SAMPLE & DISPLAY ROUTINE
             /
             /
                       *460
0400  0000   SADIS,    0
0401  6141             LINC
                       LMODE
0402  0011             CLR
0403  2001             ADD 0001
0404  4526             STC HOLD          /SAVE PI JMP
0405  0011   AGNDS,    CLR
0406  0112             SAM 12            /SMPL INPUT SGNL
0407  1560             BCL I
0410  7000             7000
0411  4530             STC SIG           /STORE INPUT
0412  2137             ADD THRESH
0413  2122             ADD M2
0414  0017             COM
0415  2530             ADD SIG
0416  0451             APO               /PULSE OR SPACE?
0417  0467             SKP               /SPACE
0420  6425             JMP P3            /PULSE
0421  0011             CLR
0422  2077             ADD M1
0423  1071             STA I SIGNAL      /STORE -1
0424  6430             JMP CONDIS
0425  0011   P3,       CLR
0426  2100             ADD K1
0427  1071             STA I SIGNAL      /STORE +1
0430  0011   CONDIS,   CLR
0431  0101             SAM 1             /GET SAMPLE NBR
0432  4022             STC COUNT
```

```
0433  0100        SAM 0           /SMPL THRESHOLD
0434  4137        STC THRESH
0435  2531        ADD M377

0436  2137        ADD THRESH
0437  0166        DIS I 6         /DSPLY THRESHOLD
0440  0011        CLR
0441  2531        ADD M377
0442  2530        ADD SIG
0443  0167        DIS I 7         /DSPLY INPUT
0444  0011        CLR
0445  4001        STC 0001        /CLEAR 0001
0446  2022        ADD COUNT
0447  1560        BCL I
0450  0777        0777
0451  0311        ROR 9
0452  4033        STC NUMR        /GET FIRST BIT
0453  7001        JMP DISCPY      /DISPLAY IT
0454  2022        ADD COUNT
0455  1560        BCL I
0456  7077        7077
0457  0306        ROR 6
0460  4033        STC NUMR        /GET SECOND BIT
0461  7001        JMP DISCPY      /DISPLAY IT
0462  2022        ADD COUNT
0463  1560        BCL I
0464  7707        7707
0465  0303        ROR 3
0466  4033        STC NUMR        /GET THIRD BIT
0467  7001        JMP DISCPY      /DISPLAY IT
0470  2022        ADD COUNT
0471  1560        BCL I
0472  7770        7770
0473  4033        STC NUMR        /GET FOURTH BIT
0474  7001        JMP DISCPY      /DISPLAY IT
0475  0500        IOB
0476  6031        KSF             /KEYBOARD HIT?
0477  6405        JMP AGNDS       /NO
0500  0500        IOB             /YES
0501  6032        KCC
0502  2527        ADD MAINDO
0503  1620        BSE I
0504  6000        6000            /CREATE JMP
0505  4430        STC CONDIS
0506  2022        ADD COUNT
0507  1660        BCO I
0510  7777        7777
0511  2100        ADD K1          /FORM 2S COMP
0512  4131        STC KCHANG      /OF COUNT
0513  2131        ADD KCHANG
0514  4027        STC CHANGE
0515  2027        ADD CHANGE
```

```
0516   2027              ADD CHANGE
0517   2123              ADD KM2
0520   4020              STC CHECK         /TWICE KCHANG
0521   0011   MAINDS,    CLR
0522   2526              ADD HOLD
0523   4001              STC 0001          /RESTORE PI
0524   0002              PDP               /JMP INSTR
                         PMODE
0525   5600              JMP I SADIS
              /
              /
0526   0000   HOLD,      0
0527   0521   MAIND0,    MAINDS
0530   0000   SIG,       0
0531   7401   M377,      -377

              /
              /
              /
              /
              /  CHARACTER DISPLAY ROUTINE
              /
              /
                         *1000
1000   0000              0                 /SENSE SW1 STORE
                         LMODE
1001   0011   DISCPY,    CLR
1002   2000              ADD 0000
1003   5114              STC HOLDRN        /SAVE JMS RTN
1004   2033              ADD NUMR
1005   0470              AZE I             /NUMR = 0?
1006   7061              JMP NUM0          /YES
1007   2123              ADD KM2           /NO
1010   0470              AZE I             /NUMR = 1?
1011   7067              JMP NUM1          /YES
1012   2123              ADD KM2           /NO
1013   0470              AZE I             /NUMR = 2?
1014   7075              JMP NUM2          /YES
1015   2123              ADD KM2           /NO
1016   0470              AZE I             /NUMR = 3?
1017   7103              JMP NUM3          /YES
1020   2123              ADD KM2           /NO
1021   0470              AZE I             /NUMR = 4?
1022   7037              JMP NUM4          /YES
1023   2123              ADD KM2           /NO
1024   0470              AZE I             /NUMR = 5?
1025   7945              JMP NUM5          /YES
1026   2123              ADD KM2           /NO
1027   0470              AZE I             /NUMR = 6?
1030   7053              JMP NUM6          /YES
1031   0011              CLR               /NO NUM = 7
1032   1760              DSC I
```

```
1033  4443           4443
1034  1760           DSC I
1035  6050           6050              /DISPLAY 7
1036  7110           JMP DISOUT
1037  0011  NUM4,    CLR
1040  1760           DSC I
1041  2414           2414
1042  1760           DSC I
1043  0477           0477              /DISPLAY 4
1044  7110           JMP DISOUT
1045  0011  NUM5,    CLR
1046  1760           DSC I
1047  5172           5172
1050  1760           DSC I
1051  0651           0651              /DISPLAY 5
1052  7110           JMP DISOUT
1053  0011  NUM6,    CLR
1054  1760           DSC I
1055  1506           1506
1056  1760           DSC I
1057  4225           4225              /DISPLAY 6
1060  7110           JMP DISOUT
1061  0011  NUM0,    CLR
1062  1760           DSC I
1063  4136           4136
1064  1760           DSC I
1065  3641           3641              /DISPLAY 0

1066  7110           JMP DISOUT
1067  0011  NUM1,    CLR
1070  1760           DSC I
1071  2101           2101
1072  1760           DSC I
1073  0177           0177              /DISPLAY 1
1074  7110           JMP DISOUT
1075  0011  NUM2,    CLR
1076  1760           DSC I
1077  4523           4523
1100  1760           DSC I
1101  2151           2151              /DISPLAY 2
1102  7110           JMP DISOUT
1103  0011  NUM3,    CLR
1104  1760           DSC I
1105  4122           4122
1106  1760           DSC I
1107  2651           2651              /DISPLAY 3
1110  0011  DISOUT,  CLR
1111  3114           ADD HOLDRN
1112  4000           STC 0000          /RESTORE RTN
1113  6000           JMP 0
            /
            /
```

```
1114  0000  HOLDRN, 0
                    PMODE
            /
            /
            /
            /
            /  AD SAMPLE DECISION ROUTINE
            /
            /
                    *1200
1200  0000  ADSAM,  0
1201  4423          JMS I SADIS0     /SMPL & DSPLY
1202  7200          CLA
1203  2027          ISZ CHANGE       /N SAMPLES YET?
1204  5600          JMP I ADSAM      /NO
1205  1146          TAD WHICH        /YES
1206  7440          SZA              /CHANGE OR CHK?
1207  5246          JMP ENDCHK       /END OF CHECK
1210  1127          TAD K6000        /END OF CHANGE
1211  3011          DCA SIGNAL       /RESET MEMORY
1212  1131          TAD KCHANG
1213  3027          DCA CHANGE       /RESET SMPL NBR
1214  1411          TAD I SIGNAL
1215  2027          ISZ CHANGE
1216  5214          JMP .-2          /ADD SMPLD INPTS
1217  7700          SMA CLA          /PULSE OR SPACE?
1220  5224          JMP P1           /PULSE
1221  1077          TAD M1           /SPACE
1222  3144          DCA NEW1         /STORE -1
1223  5227          JMP COMP
1224  7200  P1,     CLA
1225  7001          IAC
1226  3144          DCA NEW1         /STORE +1
1227  1127  COMP,   TAD K6000
1230  3011          DCA SIGNAL       /RESET MEMORY
1231  1136          TAD PAST         /COMPARE WITH
1232  1144          TAD NEW1         /PREVIOUS VALUE
1233  7650          SNA CLA          /CHANGE?
1234  5241          JMP .+5          /YES

1235  1131          TAD KCHANG       /YJ
1236  3027          DCA CHANGE       /RESET CHANGE
1237  4430          JMS I SENSE0     /CHK SNS SWS
1240  5600          JMP I ADSAM      /RTN TO PROG
1241  1020          TAD CHECK
1242  3027          DCA CHANGE       /SET SMPL NBR
1243  1100          TAD K1
1244  3146          DCA WHICH        /SET FLAG
1245  5600          JMP I ADSAM
1246  7200  ENDCHK, CLA
1247  1127          TAD K6000
1250  3011          DCA SIGNAL       /RESET MEMORY
```

```
1251  1020          TAD CHECK
1252  3027          DCA CHANGE      /RESET SMPL NBR
1253  1411          TAD I SIGNAL
1254  2027          ISZ CHANGE
1255  5253          JMP .-2         /ADD SMPLD INPTS
1256  7700          SMA CLA         /PULSE OR SPACE?
1257  5263          JMP P2          /PULSE
1260  1077          TAD M1          /SPACE
1261  3144          DCA NEW1        /STORE -1
1262  5266          JMP COMP1
1263  7200  P2,     CLA
1264  1100          TAD K1
1265  3144          DCA NEW1        /STORE +1
1266  1127  COMP1,  TAD K6000
1267  3011          DCA SIGNAL      /RESET MEMORY
1270  1136          TAD PAST
1271  1144          TAD NEW1
1272  7440          SZA             /PERMANENT CHG?
1273  5540          JMP I AOUT0     /NO
1274  1136          TAD PAST        /YES
1275  3145          DCA PORS        /SET P/S FLAG
1276  1144          TAD NEW1
1277  3136          DCA PAST        /SET NEW LEVEL
1300  6141          LINC
                    LMODE
1301  0101          SAM 1           /SAMPLE COUNT
1302  4022          STC COUNT
1303  0100          SAM 0           /SMPL THRESHOLD
1304  4137          STC THRESH
1305  0104          SAM 4           /SAMPLE FUDGE
1306  4107          STC FUDGE
1307  2107          ADD FUDGE
1310  2107          ADD FUDGE
1311  2107          ADD FUDGE
1312  4107          STC FUDGE
1313  0002          PDP
                    PMODE
1314  1022          TAD COUNT       /GET LATEST
1315  7041          CIA             /SAMPLE NBR
1316  3131          DCA KCHANG
1317  1131          TAD KCHANG
1320  3027          DCA CHANGE      /SET CHANGE NBR
1321  1027          TAD CHANGE
1322  1027          TAD CHANGE
1323  3020          DCA CHECK       /SET CHECK NBR
1324  6135          CLSA
1325  7700          SMA CLA         /CLOCK OVRFLW?
1326  5542          JMP I TIMER0    /NO GET TIME
1327  7240          STA             /YES
1330  3147          DCA TIME        /SET TIME=7777
1331  5541          JMP I RESET0
```

```
1332  5600  ADSAM2,  JMP I ADSAM
                /
                /
                         *1400
1400  7200  TIMER,   CLA
1401  6133           CLAB
1402  6137           CLCA
1403  3147           DCA TIME          /STORE TIME
1404  6133  RESET,   CLAB
1405  1117           TAD RATE0
1406  6132           CLLR              /CLEAR CLK CNTR
1407  6135           CLSA
1410  7200           CLA
1411  1127           TAD K6000
1412  6132           CLLR              /RESET CLOCK
                /
                /
                /  PREPARE TIME & TYPE OF SIGNAL
                /  FOR STORAGE
                /
                /
1413  7200           CLA
1414  1145           TAD PORS
1415  7700           SMA CLA           /PULSE OR SPACE?
1416  5225           JMP PULSE         /PULSE
1417  1147           TAD TIME          /SPACE
1420  7010           RAR
1421  7100           CLL
1422  7004           RAL               /SET AC 11=0
1423  3412           DCA I STORE       /STORE DATA
1424  5233           JMP AOUT1
1425  7200  PULSE,   CLA
1426  1147           TAD TIME
1427  7010           RAR
1430  7120           STL
1431  7004           RAL               /SET AC 11=1
1432  3412           DCA I STORE       /STORE DATA
1433  1012  AOUT1,   TAD STORE
1434  1031           TAD M777
1435  7440           SZA               /LAST WD OF MEM?
1436  5243           JMP .+5           /NO
1437  1032           TAD K577          /YES
1440  3012           DCA STORE         /RESET MEM LOC
1441  7001           IAC
1442  3043           DCA MSTART        /SET FLAG
1443  7200  AOUT,    CLA
1444  3146           DCA WHICH         /RESET CHG FLAG
1445  1131           TAD KCHANG
1446  3027           DCA CHANGE        /RESET CHANGE
1447  5543           JMP I ADSAM1      /IND RETURN
                /
                /
                /
                         *1500
```

```
1500  6141  FIG1,   LINC
                    LMODE
1501  0011  MNAGN,  CLR
1502  2163          ADD TEMPMN
1503  0241          ROL 1
1504  4163          STC TEMPMN
1505  2164          ADD MNUM
1506  1120          ADA I
1507  0001          0001

1510  4164          STC MNUM
1511  2164          ADD MNUM
1512  0450          AZE                 /MNUM = 0?
1513  7501          JMP MNAGN           /NO
1514  0002          PDP                 /YES
                    PMODE
1515  5567          JMP I RFIG10
1516  6141  FIG2,   LINC
                    LMODE
1517  0011  ROTAGN, CLR
1520  2163          ADD TEMPMN
1521  0301          ROR 1
1522  4163          STC TEMPMN
1523  2165          ADD LMNUM
1524  1120          ADA I
1525  0001          0001
1526  4165          STC LMNUM
1527  2165          ADD LMNUM
1530  0451          APO                 /LMNUM POSITIVE?
1531  7517          JMP ROTAGN          /NO
1532  0011          CLR                 /YES
1533  2163          ADD TEMPMN
1534  1560          BCL I
1535  0077          0077
1536  2153          ADD NUM32
1537  4177          STC CDE32           /2ND CODE WORD
1540  2163          ADD TEMPMN
1541  1560          BCL I
1542  7700          7700
1543  4163          STC TEMPMN
1544  0002          PDP
                    PMODE
1545  5571          JMP I RFIG20
            /
            /
            /
            /
            /
            /  MAIN DATA PROCESSING ROUTINE
            /
            /
                    *1600
```

```
1600  7300  PROCES, CLA CLL        /
1601  4445          JMS I IPROCW   /INITIALIZE
1602  7200  PRCAGN, CLA
1603  1013          TAD WORD
1604  7041          CIA
1605  1012          TAD STORE
1606  7540          SMA SZA        /STORE-WORD>0?
1607  5223          JMP GETNW      /YES
1610  7200          CLA            /NO
1611  1043          TAD MSTART
1612  7440          SZA            /MSTART SET?
1613  5223          JMP GETNW      /YES
1614  1036          TAD EFLAG1     /NO
1615  7440          SZA            /EFLAG1 SET?
1616  5434          JMP I EFL10    /YES
1617  1037          TAD EFLAG2     /NO
1620  7440          SZA            /EFLAG2 SET?
1621  5435          JMP I EFL20    /YES
1622  5202          JMP PRCAGN     /NO
1623  7300  GETNW,  CLA CLL
1624  1413          TAD I WORD

1625  3111          DCA HOLDWD
1626  1111          TAD HOLDWD
1627  3414          DCA I STORIT   /STORE TIME
1630  1014          TAD STORIT
1631  1321          TAD M4050
1632  7640          SZA CLA        /STORIT = 4050?
1633  5236          JMP .+3        /NO
1634  1154          TAD KSTOR      /YES
1635  3014          DCA STORIT     /RESET STORIT
1636  1013          TAD WORD
1637  1031          TAD M777
1640  7440          SZA            /WORD=777?
1641  5245          JMP PORSWD     /NO
1642  1032          TAD K577       /YES
1643  3013          DCA WORD       /RESET WORD
1644  3043          DCA MSTART     /CLEAR MSTART
1645  7300  PORSWD, CLA CLL
1646  1111          TAD HOLDWD
1647  7010          RAR
1650  7430          SZL            /PULSE OR SPACE?
1651  5524          JMP I PWD0     /PULSE
1652  7200          CLA            /SPACE
1653  1102          TAD PX
1654  7440          SZA            /LAST PULSE?
1655  5533          JMP I SDASH0   /DASH
1656  1111          TAD HOLDWD     /DOT
1657  7010          RAR            /COMPARE WITH
1660  3113          DCA TEMP       /AVERAGE
1661  1106          TAD PAVG
1662  7010          RAR
```

```
1663  7041            CIA
1664  1113            TAD TEMP
1665  7710            SPA CLA        /INTER OR INTRA?
1666  5473            JMP I PRCAG0   /INTRA
1667  1120            TAD CWAVG      /INTER
1670  7012            RTR            /COMPUTE NEW
1671  7010            RAR            /CWAVG
1672  0135            AND K777
1673  7041            CIA
1674  3322            DCA CTEMP
1675  1111            TAD HOLDWD
1676  7012            RTR
1677  7010            RAR
1700  0135            AND K777
1701  1322            TAD CTEMP
1702  1120            TAD CWAVG
1703  3120            DCA CWAVG      /NEW CWAVG
1704  1120            TAD CWAVG
1705  1107            TAD FUDGE      /ADD CORRECTION
1706  3110            DCA SAFUDG     /NEW SAFUDG
1707  7100            CLL
1710  1110            TAD SAFUDG
1711  7010            RAR
1712  7041            CIA
1713  1113            TAD TEMP
1714  7710            SPA CLA        /INTER CH OR WD?
1715  5525            JMP I ICODE0   /INTER CHAR
1716  1111            TAD HOLDWD     /INTER WORD
1717  3076            DCA IWFLAG
1720  5525            JMP I ICODE0
                /
1721  3730  M4050,  -4050
1722  0000  CTEMP,  0


                /
                /
1723  7300  CALSPA, CLA CLL      /COMPUTE
1724  1120            TAD CWAVG      /INITIAL
1725  7012            RTR            /CWAVG
1726  0101            AND K1777
1727  7041            CIA
1730  3113            DCA TEMP
1731  1111            TAD HOLDWD
1732  7012            RTR
1733  0101            AND K1777
1734  1113            TAD TEMP
1735  1120            TAD CWAVG
1736  3120            DCA CWAVG      /NEW CWAVG
1737  5575            JMP I IPRTN0
                /
                /
                /
```

```
                        *2000
2000  7300  SDASH,      CLA CLL
2001  1106              TAD PAVG
2002  7041              CIA
2003  1102              TAD PX              /COMPUTE
2004  7012              RTR                 /INTER/INTRA
2005  0101              AND K1777           /SPACE(DASH)
2006  7041              CIA                 /EQUATION
2007  1106              TAD PAVG
2010  7100              CLL
2011  7010              RAR
2012  7041              CIA
2013  3113              DCA TEMP
2014  1111              TAD HOLDWD
2015  7100              CLL
2016  7010              RAR
2017  1113              TAD TEMP
2020  7700              SMA CLA             /INTER OR INTRA?
2021  5223              JMP .+2             /INTER
2022  5473              JMP I PRCAG0        /INTRA
2023  7300              CLA CLL
2024  1106              TAD PAVG
2025  7041              CIA                 /COMPUTE
2026  1102              TAD PX              /INTER CH
2027  7012              RTR                 /OR
2030  0101              AND K1777           /INTER WORD
2031  7041              CIA                 /EQUATION
2032  1110              TAD SAFUDG
2033  7100              CLL
2034  7010              RAR
2035  7041              CIA
2036  3113              DCA TEMP
2037  1111              TAD HOLDWD
2040  7100              CLL
2041  7010              RAR
2042  1113              TAD TEMP
2043  7710              SPA CLA             /CH OR WORD?
2044  5525              JMP I ICODE0        /INTER CH
2045  1111              TAD HOLDWD          /INTER WORD
2046  3076              DCA IWFLAG          /SET IWFLAG
2047  5525              JMP I ICODE0
2050  7200  PWD,        CLA
2051  1021              TAD NUM
2052  7001              IAC
2053  3021              DCA NUM             /INCRMNT NUM


2054  1111              TAD HOLDWD
2055  7041              CIA
2056  1106              TAD PAVG
2057  7700              SMA CLA             /DOT OR DASH?
2060  5320              JMP PDOT            /DOT
2061  7100              CLL                 /DASH
```

```
2062  1111          TAD HOLDWD
2063  7010          RAR
2064  7041          CIA
2065  1105          TAD DASHAV
2066  7700          SMA CLA        /HOLDWD>2DASHAV?
2067  5274          JMP .+5        /NO
2070  1105          TAD DASHAV     /YES
2071  1105          TAD DASHAV
2072  1100          TAD K1
2073  3111          DCA HOLDWD     /HOLDWD=2DASHAV
2074  1111          TAD HOLDWD
2075  3102          DCA PX         /STORE IN PX
2076  7120          STL
2077  1044          TAD WDREG
2100  7004          RAL
2101  3044          DCA WDREG      /PUT 1 IN WDREG
2102  1111          TAD HOLDWD
2103  7012          RTR
2104  7010          RAR
2105  0135          AND K777       /COMPUTE
2106  3113          DCA TEMP       /NEW
2107  1105          TAD DASHAV     /DASHAV
2110  7012          RTR            /AVERAGE
2111  7010          RAR
2112  0135          AND K777
2113  7041          CIA
2114  1113          TAD TEMP
2115  1105          TAD DASHAV
2116  3105          DCA DASHAV     /NEW AVERAGE
2117  5343          JMP PAVGCP
2120  7200  PDOT,   CLA
2121  3102          DCA PX         /CLEAR PX
2122  7100          CLL
2123  1044          TAD WDREG
2124  7004          RAL
2125  3044          DCA WDREG      /PUT 0 IN WDREG
2126  1111          TAD HOLDWD
2127  7012          RTR
2130  7010          RAR
2131  0135          AND K777
2132  3113          DCA TEMP       /DOTAV
2133  1104          TAD DOTAV      /AVERAGE
2134  7012          RTR
2135  7010          RAR
2136  0135          AND K777
2137  7041          CIA
2140  1113          TAD TEMP
2141  1104          TAD DOTAV
2142  3104          DCA DOTAV      /NEW AVERAGE
2143  7100  PAVGCP, CLL            /COMPUTE
2144  1104          TAD DOTAV
2145  7010          RAR
2146  7100          CLL
2147  1105          TAD DASHAV     /NEW PAVG
```

```
2150  7010          RAR
2151  3106          DCA PAVG          /NEW AVERAGE
2152  5473          JMP I PRCAG0


                /
                /
                    *2200
2200  7200  ICODE,  CLA
2201  1021          TAD NUM           /COMPUTE
2202  7041          CIA               /INTERNAL
2203  1121          TAD K13           /CODE
2204  3210          DCA SHFTN         /WORD
2205  7621          CAM
2206  1044          TAD WOREG
2207  7413          SHL
2210  0000  SHFTN,  0
2211  1021          TAD NUM
2212  3046          DCA CODE          /STORE IT
2213  5472          JMP I ASC0
2214  7200  EFL1,   CLA
2215  2122          ISZ M2            /FIRST TIME?
2216  5246          JMP EFL11         /YES
2217  7200          CLA               /NO SECOND
2220  3036          DCA EFLAG1        /RESET EFLAG1
2221  1077          TAD M1
2222  3136          DCA PAST          /RESET PAST
2223  1032          TAD K577
2224  3013          DCA WORD          /RESET WORD
2225  1032          TAD K577
2226  3012          DCA STORE         /RESET STORE
2227  1026          TAD KCLR
2230  3532          DCA I CONDI0      /RESET CLR INST
2231  1123          TAD KM2
2232  3122          DCA M2            /RESET M2
2233  1074          TAD KLINE
2234  3075          DCA LINE          /RESET LINE
2235  3172          DCA TALLY         /RESET TALLY
2236  3173          DCA TALLY1
2237  3174          DCA TALLY2
2240  3120          DCA CWAVG
2241  3104          DCA DOTAV
2242  3105          DCA DASHAV
2243  3106          DCA PAVG
2244  4300          JMS SETPTR        /CR + 2 LFS
2245  5526          JMP I RSTAR0      /RESTART PROG
2246  1123  EFL11,  TAD KM2
2247  3412          DCA I STORE       /PUT LW SP IN ST
2250  5473          JMP I PRCAG0      /PRINT LAST CH
2251  7200  EFL2,   CLA
2252  2122          ISZ M2            /FIRST TIME?
2253  5246          JMP EFL11         /YES
2254  6141  DIAL,   LINC              /NO
```

```
                          LMODE
0255   0011               CLR
0256   0001               AXO                /CLEAR FLAGS
0257   0602               LIF 2
0260   6016               JMP 16
                          SEGMNT 2
                          *16
0016   0701               0701
0017   7300               7300               /RTN TO DIAL
                          PMODE
               /
               /
               /
                          *2300
2300   0000    SETPTR,    0

2301   7200               CLA
2302   1115               TAD K215
2303   4311               JMS TYPE           /CR
2304   1116               TAD K212
2305   4311               JMS TYPE           /LF
2306   1116               TAD K212
2307   4311               JMS TYPE           /LF
2310   5700               JMP I SETPTR
2311   0000    TYPE,      0
2312   6041               TSF
2313   5312               JMP .-1
2314   6046               TLS                /PRINT CH
2315   7200               CLA
2316   5711               JMP I TYPE
               /
               /
               /
               /
               /  INITIAL DATA PROCESSING ROUTINE
               /
               /
                          *2400
2400   0000    IPROC,     0
2401   1127               TAD K6000
2402   3011               DCA SIGNAL         /RESET SIGNAL
2403   6001               ION                /INTERUPT ON
2404   7200    IPRTN,     CLA
2405   1013               TAD WORD
2406   1376               TAD M741
2407   7650               SNA CLA            /38 WORDS YET?
2410   5365               JMP IPEXIT         /YES
2411   1012               TAD STORE          /NO
2412   7041               CIA
2413   1013               TAD WORD
2414   7640               SZA CLA            /WORD = STORE?
2415   5222               JMP .+5            /NO
```

```
2416  1037         TAD EFLAG2      /YES
2417  7440         SZA             /EFLAG2 SET?
2420  5534         JMP I DIALO     /YES
2421  5204         JMP IPRTN       /NO.CHK AGN
2422  7200         CLA
2423  1413         TAD I WORD      /GET NEW WORD
2424  3111         DCA HOLDWD      /STORE IT
2425  1111         TAD HOLDWD
2426  7100         CLL
2427  7010         RAR
2430  7620         SNL CLA         /PULSE OR SPACE?
2431  5370         JMP GT32        /SPACE
2432  1013         TAD WORD        /PULSE
2433  1103         TAD M640
2434  7710         SPA CLA         /> 32 WORDS YET?
2435  5315         JMP IPPUL       /NO
2436  7100         CLL             /YES
2437  1111         TAD HOLDWD
2440  7010         RAR
2441  7041         CIA
2442  3113         DCA TEMP
2443  7100         CLL
2444  1106         TAD PAVG
2445  7010         RAR
2446  1113         TAD TEMP
2447  7700         SMA CLA         /DOT OR DASH?
2450  5267         JMP IPDOT       /DOT

2451  1105         TAD DASHAV      /DASH
2452  7012         RTR
2453  7010         RAR
2454  0135         AND K777        /COMPUTE
2455  7041         CIA             /NEW
2456  3113         DCA TEMP        /DASHAV
2457  1111         TAD HOLDWD      /AVERAGE
2460  7012         RTR
2461  7010         RAR
2462  0135         AND K777
2463  1113         TAD TEMP
2464  1105         TAD DASHAV
2465  3105         DCA DASHAV      /NEW AVERAGE
2466  5305         JMP IPPAV
2467  7300  IPDOT, CLA CLL
2470  1104         TAD DOTAV
2471  7012         RTR
2472  7010         RAR             /COMPUTE
2473  0135         AND K777        /NEW
2474  7041         CIA             /DOTAV
2475  3113         DCA TEMP        /AVERAGE
2476  1111         TAD HOLDWD
2477  7012         RTR
2500  7010         RAR
```

```
2501 0135          AND K777
2502 1113          TAD TEMP
2503 1104          TAD DOTAV
2504 3104          DCA DOTAV     /NEW AVERAGE
2505 7100 IPPAV,   CLL           /COMPUTE NEW
2506 1104          TAD DOTAV     /PAVG
2507 7010          RAR
2510 7100          CLL
2511 1105          TAD DASHAV
2512 7010          RAR
2513 3106          DCA PAVG      /NEW AVERAGE
2514 5204          JMP IPRTN
2515 7300 IPPUL,   CLA CLL
2516 1111          TAD HOLDWD
2517 7010          RAR
2520 7041          CIA
2521 3113          DCA TEMP
2522 7100          CLL
2523 1106          TAD PAVG
2524 7010          RAR
2525 1113          TAD TEMP
2526 7700          SMA CLA       /DOT OR DASH?
2527 5342          JMP IPPDOT    /DOT
2530 7100          CLL           /DASH
2531 1111          TAD HOLDWD
2532 7010          RAR           /COMPUTE
2533 3113          DCA TEMP      /NEW
2534 7100          CLL           /DASHAV
2535 1105          TAD DASHAV    /AVERAGE
2536 7010          RAR
2537 1113          TAD TEMP
2540 3105          DCA DASHAV    /NEW AVERAGE
2541 5353          JMP IPPPAV
2542 7300 IPPDOT,  CLA CLL
2543 1111          TAD HOLDWD    /COMPUTE
2544 7010          RAR           /NEW
2545 3113          DCA TEMP      /DOTAV
2546 7100          CLL           /AVERAGE
2547 1104          TAD DOTAV

2550 7010          RAR
2551 1113          TAD TEMP
2552 3104          DCA DOTAV     /NEW AVERAGE
2553 7100 IPPPAV,  CLL
2554 1105          TAD DASHAV
2555 7010          RAR           /COMPUTE NEW
2556 3113          DCA TEMP      /PAVG
2557 7100          CLL
2560 1104          TAD DOTAV
2561 7010          RAR
2562 1113          TAD TEMP
2563 3106          DCA PAVG      /NEW AVERAGE
```

```
2564  5204              JMP IPRTN
2565  1032  IPEXIT.     TAD K577
2566  3013              DCA WORD           /RESET WORD
2567  5600              JMP I IPROC
2570  1013  GT32,       TAD WORD
2571  1103              TAD M640
2572  7710              SPA CLA            />32 WORDS YET?
2573  5204              JMP IPRTN          /NO
2574  5576              JMP I CALSP0       /YES
            /
            /
2575  7142  M636,       -636
2576  7037  M741,       -741
            /
            /
            /
            /
            /   INTERNAL TO ASCII CODE PROGRAM
            /
            /
                        *2600
2600  7000  J1,         7000
2601  6000  J2,         6000
2602  5000  J3,         5000
2603  4000  J4,         4000
2604  3000  J5,         3000
2605  2000  J6,         2000
2606  1000  J7,         1000
2607  0000  ASCII,      0
2610  7200              CLA
2611  1046              TAD CODE
2612  7700              SMA CLA
2613  5234              JMP PCODE
2614  1206              TAD J7
2615  1046              TAD CODE
2616  7700              SMA CLA
2617  5350              JMP C7000
2620  1205              TAD J6
2621  1046              TAD CODE
2622  7700              SMA CLA
2623  5333              JMP C6000
2624  1204              TAD J5
2625  1046              TAD CODE
2626  7700              SMA CLA
2627  5327              JMP C5000
2630  1203              TAD J4
2631  1046              TAD CODE
2632  7700              SMA CLA
2633  5312              JMP C4000
2634  7200  PCODE,      CLA
2635  1202              TAD J3
```

```
2636  1046           TAD CODE
2637  7700           SMA CLA
2640  5306           JMP C3000
2641  1201           TAD J2
2642  1046           TAD CODE
2643  7700           SMA CLA
2644  5271           JMP C2000
2645  1200           TAD J1
2646  1046           TAD CODE
2647  7700           SMA CLA
2650  5265           JMP C1000
2651  1465           TAD I CN5
2652  1046           TAD CODE
2653  7510           SPA
2654  5261           JMP .+5
2655  7200           CLA
2656  1047           TAD C01
2657  3010           DCA 10
2660  5464           JMP I CHKIT
2661  7200           CLA
2662  1050           TAD C02
2663  3010           DCA 10
2664  5464           JMP I CHKIT
2665  7200  C1000,   CLA
2666  1051           TAD C11
2667  3010           DCA 10
2670  5464           JMP I CHKIT
2671  7200  C2000,   CLA
2672  1466           TAD I CWAIT
2673  1046           TAD CODE
2674  7510           SPA
2675  5302           JMP  +5
2676  7200           CLA
2677  1052           TAD C21
2700  3010           DCA 10
2701  5464           JMP I CHKIT
2702  7200           CLA
2703  1053           TAD C22
2704  3010           DCA 10
2705  5464           JMP I CHKIT
2706  7200  C3000,   CLA
2707  1054           TAD C31
2710  3010           DCA 10
2711  5464           JMP I CHKIT
2712  7200  C4000,   CLA
2713  1467           TAD I CN6
2714  1046           TAD CODE
2715  7510           SPA
2716  5323           JMP .+5
2717  7200           CLA
2720  1055           TAD C41
2721  3010           DCA 10
2722  5464           JMP I CHKIT
2723  7200           CLA
```

```
2724 1056           TAD C42
2725 3010           DCA 10
2726 5464           JMP I CHKIT
2727 7200 C5000,    CLA
2730 1057           TAD C51
2731 3010           DCA 10
2732 5464           JMP I CHKIT
2733 7200 C6000,    CLA
2734 1470           TAD I CN7


2735 1046           TAD CODE
2736 7510           SPA
2737 5344           JMP .+5
2740 7200           CLA
2741 1060           TAD C61
2742 3010           DCA 10
2743 5464           JMP I CHKIT
2744 7200           CLA
2745 1061           TAD C62
2746 3010           DC9 10
2747 5464           JMP I CHKIT
2750 7200 C7000,    CLA
2751 1471           TAD I CN9
2752 1046           TAD CODE
2753 7510           SPA
2754 5361           JMP .+5
2755 7200           CLA
2756 1062           TAD C71
2757 3010           DCA 10
2760 5464           JMP I CHKIT
2761 7200           CLA
2762 1063           TAD C72
2763 3010           DCA 10
2764 5464           JMP I CHKIT
          /
          /
          /
          /
                    *3000
3000 0275 AUNK,     275
3001 7173 N3,       7173
3002 0263 A3,       263
3003 7272 ENDW,     7272
3004 0244 AENDW,    244
3005 7374 NV,       7374
3006 0326 V,        326
3007 7573 N4,       7573
3010 0264 A4,       264
3011 7770 ERR,      7770
3012 0274 AERR,     274
3013 7773 N5,       7773
3014 0265 A5,       265
```

2326	3015	7774	NH,	7774
2327	3016	0310	H,	310
2330	3017	7775	NS,	7775
2331	3020	0323	S,	323
2332	3021	7776	NI,	7776
2333	3022	0311	AI,	311
2334	3023	7777	NE,	7777
2335	3024	0305	E.	305
2336	3025	0000	SPAC,	0000
2337	3026	0240	ASPAC.	240
2340	3027	6173	N2,	6173
2341	3030	0262	A2,	262
2342	3031	6372	QM,	6372
2343	3032	0277	AQM,	277
2344	3033	6774	NF,	6774
2345	3034	0306	F,	306
2346	3035	6775	NU,	6775
2347	3036	0325	AU,	325
2350	3037	5272	PER,	5272
2351	3040	0256	APER.	256
2352	3041	5373	ENDM,	5373
2353	3042	0252	AENDM,	252
2354	3043	5773	WAIT,	5773
2355	3044	0334	AWAIT,	334
2356	3045	5774	NL,	5774
2357	3046	0314	L,	314
2360	3047	5775	NR,	5775
2361	3050	0322	R,	322
2362	3051	5776	NA,	5776
2363	3052	0301	A,	301
2364	3053	4173	N1,	4173
2365	3054	0261	A1,	261
2366	3055	4374	NJ,	4374
2367	3056	0312	J,	312
2370	3057	4774	NP,	4774
2371	3060	0320	P,	320
2372	3061	4775	NW,	4775
2373	3062	0327	W,	327
2374	3063	3373	FRAC,	3373
2375	3064	0257	AFRAC,	257
2376	3065	3374	NX,	3374
2377	3066	0330	X,	330
2400	3067	3573	DASH,	3573
2401	3070	0255	ADASH,	255
2402	3071	3773	N6,	3773
2403	3072	0266	A6,	266
2404	3073	3774	NB,	3774
2405	3074	0302	B,	302
2406	3075	3775	ND,	3775
2407	3076	0304	D,	304
2410	3077	3776	NN,	3776

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3100  0316  N,       316
3101  3777  NT,      3777
3102  0324  T,       324
3103  2272  PAR,     2272
3104  0251  APAR,    251
3105  2374  NY,      2374
3106  0331  Y,       331
3107  2572  SCOL,    2572
3110  0273  ASCOL,   273
3111  2774  NC,      2774
3112  0303  C,       303
3113  2775  NK,      2775
3114  0313  K,       313
3115  1374  NQ,      1374
3116  0321  Q,       321
3117  1472  COMM,    1472
3120  0254  ACOMM,   254
3121  1773  N7,      1773
3122  0267  A7,      267
3123  1774  NZ,      1774
3124  0332  AZ,      332
3125  1775  NG,      1775
3126  0307  G,       307
3127  1776  NM,      1776
3130  0315  M,       315
3131  0173  N0,      0173
3132  0260  A0,      260
3133  0373  N9,      0373
3134  0271  A9,      271
3135  0772  COL,     0772
3136  0272  ACOL,    272
3137  0773  N8,      0773
3140  0270  A8,      270

3141  0775  NO,      0775
3142  0317  O,       317
            /
            /
            /
            /
                     *3200
3200  7772  UNK,     7772
3201  7772  UNK1,    7772
3202  7200  CHCK,    CLA
3203  1410           TAD I 10
3204  1046           TAD CODE
3205  7450           SNA
3206  5214           JMP .+6
3207  1410           TAD I 10
3210  2201           ISZ UNK1
3211  7410           SKP
3212  5216           JMP UNK2
```

```
3213  5202          JMP CHCK
3214  1410          TAD I 10
3215  5224          JMP ATSF
3216  7200  UNK2,   CLA
3217  1172          TAD TALLY
3220  7001          IAC
3221  3172          DCA TALLY
3222  4562          JMS I UNKCH0
3223  1447          TAD I C01
3224  6041  ATSF,   TSF
3225  5224          JMP .-1
3226  6046          TLS
3227  3350          DCA SPACHK      /STORE ASCII CH
3230  3021          DCA NUM         /CLEAR NUM
3231  1154          TAD KSTOR
3232  3014          DCA STORIT      /RESET STORIT
3233  3044          DCA WDREG       /CLEAR WDREG
3234  1200          TAD UNK
3235  3201          DCA UNK1
3236  1076          TAD IWFLAG
3237  7650          SNA CLA         /IWFLAG SET?
3240  5323          JMP LNCK        /NO
3241  1076          TAD IWFLAG      /YES
3242  3150          DCA IWF1        /STORE SPACE
3243  3076          DCA IWFLAG      /CLEAR IWFLAG
3244  2075          ISZ LINE        /END OF PTR LNE?
3245  5247          JMP .+2         /NO
3246  5325          JMP RSLN        /YES
3247  1350          TAD SPACHK
3250  1351          TAD MI
3251  7650          SNA CLA         /ASCII = I?
3252  5277          JMP CHORWD      /YES
3253  1350          TAD SPACHK      /NO
3254  1352          TAD MJ
3255  7650          SNA CLA         /ASCII = J?
3256  5277          JMP CHORWD      /YES
3257  1350          TAD SPACHK      /NO
3260  1353          TAD MQ
3261  7650          SNA CLA         /ASCII = Q?
3262  5277          JMP CHORWD      /YES
3263  1350          TAD SPACHK      /NO
3264  1354          TAD MU
3265  7650          SNA CLA         /ASCII = U?
3266  5277          JMP CHORWD      /YES
3267  1350          TAD SPACHK      /NO

3270  1355          TAD MV
3271  7650          SNA CLA         /ASCII = V?
3272  5277          JMP CHORWD      /YES
3273  1350          TAD SPACHK      /NO
3274  1356          TAD MZ
3275  7640          SZA CLA         /ASCII = Z?
```

```
3276  5313            JMP ITSOK        /NO
3277  7100  CHORWD,   CLL              /YES
3300  1110            TAD SAFUDG
3301  1106            TAD PAVG
3302  7010            RAR
3303  3113            DCA TEMP
3304  7100            CLL
3305  1150            TAD IWF1
3306  7010            RAR
3307  7041            CIA
3310  1113            TAD TEMP         /SPACE > SADOT
3311  7700            SMA CLA          /  + PAVG?
3312  5330            JMP UNKFLG       /NO. OMIT SPACE
3313  2075  ITSOK,    ISZ LINE         /YES. PRNT SPACE
3314  7410            SKP
3315  5325            JMP RSLN
3316  1114            TAD K240
3317  6041            TSF
3320  5317            JMP .-1
3321  6046            TLS              /PRINT SPACE
3322  5330            JMP UNKFLG
3323  2075  LNCK,     ISZ LINE         /END OF PTR LNE?
3324  5330            JMP UNKFLG       /NO
3325  4442  RSLN,     JMS I SETFT0     /YES, CR + 2 LFS
3326  1074            TAD KLINE
3327  3075            DCA LINE         /RESET LINE
3330  7200  UNKFLG,   CLA
3331  1155            TAD UNFLG
3332  7650            SNA CLA          /IN ERROR RTNE?
3333  5336            JMP .+3          /NO
3334  2161            ISZ ERWDNM       /YES. 2ND WD PTD?
3335  5343            JMP .+6          /NO
3336  3155            DCA UNFLG        /YES.  RST UNFLG
3337  3156            DCA UNCK1        /RESET
3340  3157            DCA UNCK2        /RESET
3341  3160            DCA UNCK3        /RESET
3342  5473            JMP I PRCAG0     /RETURN
3343  1177            TAD CDE32
3344  3046            DCA CODE         /GET 2ND WORD
3345  1151            TAD IWF2
3346  3076            DCA IWFLAG       /RESTORE IWFLAG
3347  5472            JMP I ASC0       /PRINT 2ND WORD
                /
3350  0000  SPACHK,   0
3351  7467  MI,       -311
3352  7466  MJ,       -312
3353  7457  MQ,       -321
3354  7453  MU,       -325
3355  7452  MV,       -326
3356  7446  MZ,       -332
                /
                /
                /
                /
```

```
                          /       ERROR CHECKING ROUTINE
                          /

                          /
                          /  1.  ELIMINATE EXTREMELY SMALL DOTS
                          /      DUE TO NOISY TRANSMISSION.
                          /
                          /  2.  CORRECT RUN-ON CHARACTERS DUE TO
                          /      TOO SMALL AN INTER CHARACTER SPACE
                          /      BY DESIGNATING THE LARGEST OF THE
                          /      INTRA CHARACTER SPACES AS AN INTER
                          /      CHARACTER SPACE.
                          /
                          /
                                 *3400
        3400  0000  UNKCHK,      0
        3401  7300               CLA CLL
        3402  1156               TAD UNCK1
        3403  7650               SNA CLA          /UNCK1 SET?
        3404  5214               JMP UNCK10       /NO.  DO CHECK
        3405  1157               TAD UNCK2        /YES
        3406  7650               SNA CLA          /UNCK2 SET?
        3407  5225               JMP UNCK20       /NO.  DO CHECK
        3410  1160               TAD UNCK3        /YES
        3411  7650               SNA CLA          /UNCK3 SET?
        3412  5312               JMP UNCK30       /NO.  DO CHECK
        3413  5600               JMP I UNKCHK     /YES.  RETURN
        3414  1173  UNCK10,      TAD TALLY1
        3415  7001               IAC
        3416  3173               DCA TALLY1
        3417  1021               TAD NUM
        3420  1354               TAD M11
        3421  7700               SMA CLA          /NUM > 8?
        3422  5600               JMP I UNKCHK     /YES.  PRT ERROR
        3423  7001               IAC              /NO
        3424  3156               DCA UNCK1        /SET UNCK1 FLAG
        3425  1174  UNCK20,      TAD TALLY2
        3426  7001               IAC
        3427  3174               DCA TALLY2
        3430  1154               TAD KSTOR
        3431  3014               DCA STORIT       /RESET MEM LOC
        3432  1021               TAD NUM
        3433  7041               CIA
        3434  3164               DCA MNUM
        3435  1104               TAD DOTAV
        3436  7012               RTR
        3437  0101               AND K1777
        3440  7041               CIA
        3441  3355               DCA PULCHK       /LOWER DOT TIME
        3442  1414  UNCAGN,      TAD I STORIT     /GET NEXT PULSE
        3443  7100               CLL
        3444  7010               RAR
```

```
3445 1355          TAD PULCHK
3446 7710          SPA CLA            /PULSE < LIMIT?
3447 5257          JMP ELIM           /YES
3450 2164          ISZ MNUM           /NO. LAST PULSE?
3451 5255          JMP .+4            /NO
3452 7001          IAC                /YES
3453 3157          DCA UNCK2          /SET UNCK2 FLAG
3454 5312          JMP UNCK30         /GO TO NXT CHECK
3455 2014          ISZ STORIT         /INC MEM LOC
3456 5242          JMP UNCAGN         /CHECK NXT PULSE
3457 1164 ELIM,    TAD MNUM
3460 3113          DCA TEMP
3461 1044          TAD WDREG          /GET BAD WORD
3462 7010          RAR
3463 2113          ISZ TEMP           /ERROR IN LINK?

3464 5262          JMP .-2            /NO
3465 3163          DCA TEMPMN         /YES. STORE
3466 5566          JMP I FIG10
3467 7300 RFIG1,   CLA CLL
3470 1021          TAD NUM
3471 1077          TAD M1
3472 3021          DCA NUM
3473 1021          TAD NUM
3474 7041          CIA
3475 1121          TAD K13
3476 3302          DCA SHFTN1
3477 7621          CAM
3500 1163          TAD TEMPMN
3501 7413          SHL
3502 0000 SHFTN1,  0
3503 1021          TAD NUM
3504 3046          DCA CODE           /CORRECTED WORD
3505 7001          IAC
3506 3157          DCA UNCK2          /SET UNCK2 FLAG
3507 7001          IAC
3510 3160          DCA UNCK3          /SET UNCK3 FLAG
3511 5472          JMP I ASC0         /PRINT NEW WORD
3512 1154 UNCK30,  TAD KSTOR
3513 1100          TAD K1
3514 3014          DCA STORIT         /SET MEM TO 1ST
3515 1021          TAD NUM            /SPACE LOCATION
3516 7041          CIA
3517 1100          TAD K1
3520 3164          DCA MNUM
3521 3353          DCA LGSPA          /SET LGSPA = 0
3522 1414 TRYAGN,  TAD I STORIT       /GET SPACE
3523 7100          CLL
3524 7010          RAR
3525 3113          DCA TEMP
3526 1113          TAD TEMP
3527 1353          TAD LGSPA
```

```
3530 7710        SPA CLA          /SPACE > LGSPA?
3531 5337        JMP SMALL        /NO
3532 1113        TAD TEMP         /YES
3533 7041        CIA
3534 3353        DCA LGSPA        /NEW LGSPA
3535 1164        TAD MNUM
3536 3165        DCA LMNUM        /LOC OF LGST SPA
3537 2014 SMALL, ISZ STORIT       /INC MEM LOC
3540 2164        ISZ MNUM         /LAST SPACE?
3541 5322        JMP TRYAGN       /NO
3542 1165        TAD LMNUM        /YES
3543 7041        CIA
3544 3153        DCA NUM32        /LENGTH OF 2ND
3545 1165        TAD LMNUM        /WORD
3546 1021        TAD NUM
3547 3152        DCA NUM31        /LENGTH OF 1ST
3550 1044        TAD WDREG        /WORD
3551 3163        DCA TEMPMN
3552 5570        JMP I FIG20
          /
3553 0000 LGSPA, 0
3554 7767 M11,   -11
3555 0000 PULCHK, 0
          /
          /
          /
                 *3600

3600 7200 RFIG2, CLA
3601 1152        TAD NUM31
3602 7041        CIA
3603 1121        TAD K13
3604 3210        DCA SHFTN2
3605 7621        CAM
3606 1163        TAD TEMPMN
3607 7413        SHL
3610 0000 SHFTN2, 0
3611 1152        TAD NUM31
3612 3227        DCA CDE31        /1ST CODE WORD
3613 1076        TAD IWFLAG
3614 3151        DCA IWF2         /STORE IWFLAG
3615 3076        DCA IWFLAG       /CLEAR IWFLAG
3616 1122        TAD M2
3617 3161        DCA ERWDNM       /SET WD COUNTER
3620 7001        IAC
3621 3160        DCA UNCK3        /SET UNCK3 FLAG
3622 7001        IAC
3623 3155        DCA UNFLG        /SET UNFLG FLAG
3624 1227        TAD CDE31
3625 3046        DCA CODE
3626 5472        JMP I ASC0       /PRNT 1ST WORD
          /
3627 0000 CDE31, 0
```

Appendix B

Hand-Sent Morse Code Data Plots

This appendix contains plots of hand-sent Morse code pulse and space time durations. Pulses and spaces are divided into 10 categories each for data analysis purposes. Pulses (DOTs and DASHes) are categorized by their position within a transmitted Morse code character. Spaces are categorized by the type of pulse they follow. Points contained on the individual and combined cluster plots represent time durations of all pulses and following spaces transmitted during a 10-minute period. See Chapter III for further information.

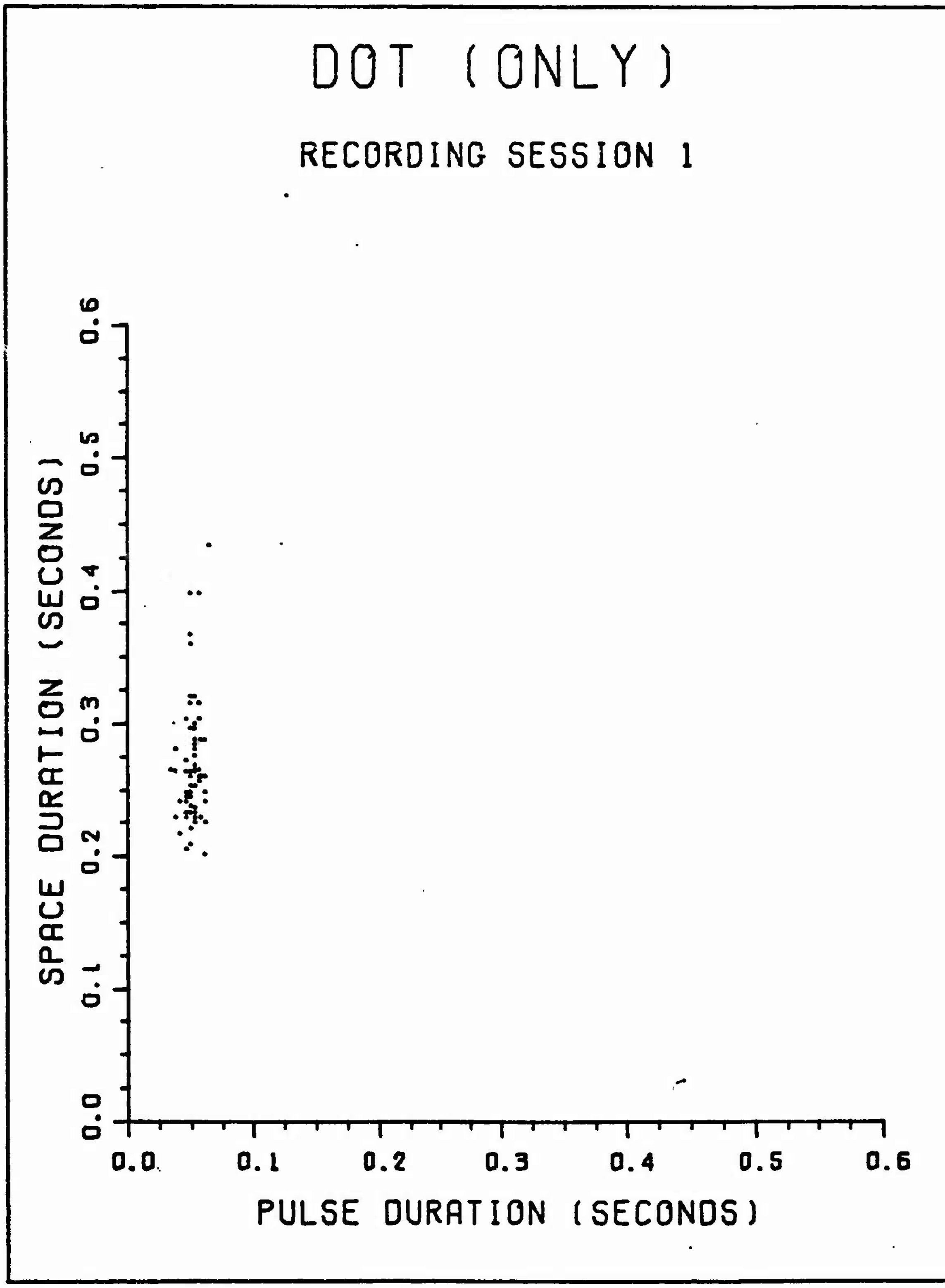

Fig. B-1. Morse Code Data Distribution Plot, DOT (Only) Time Duration vs. Time Duration of Following Space (Recording Session 1).

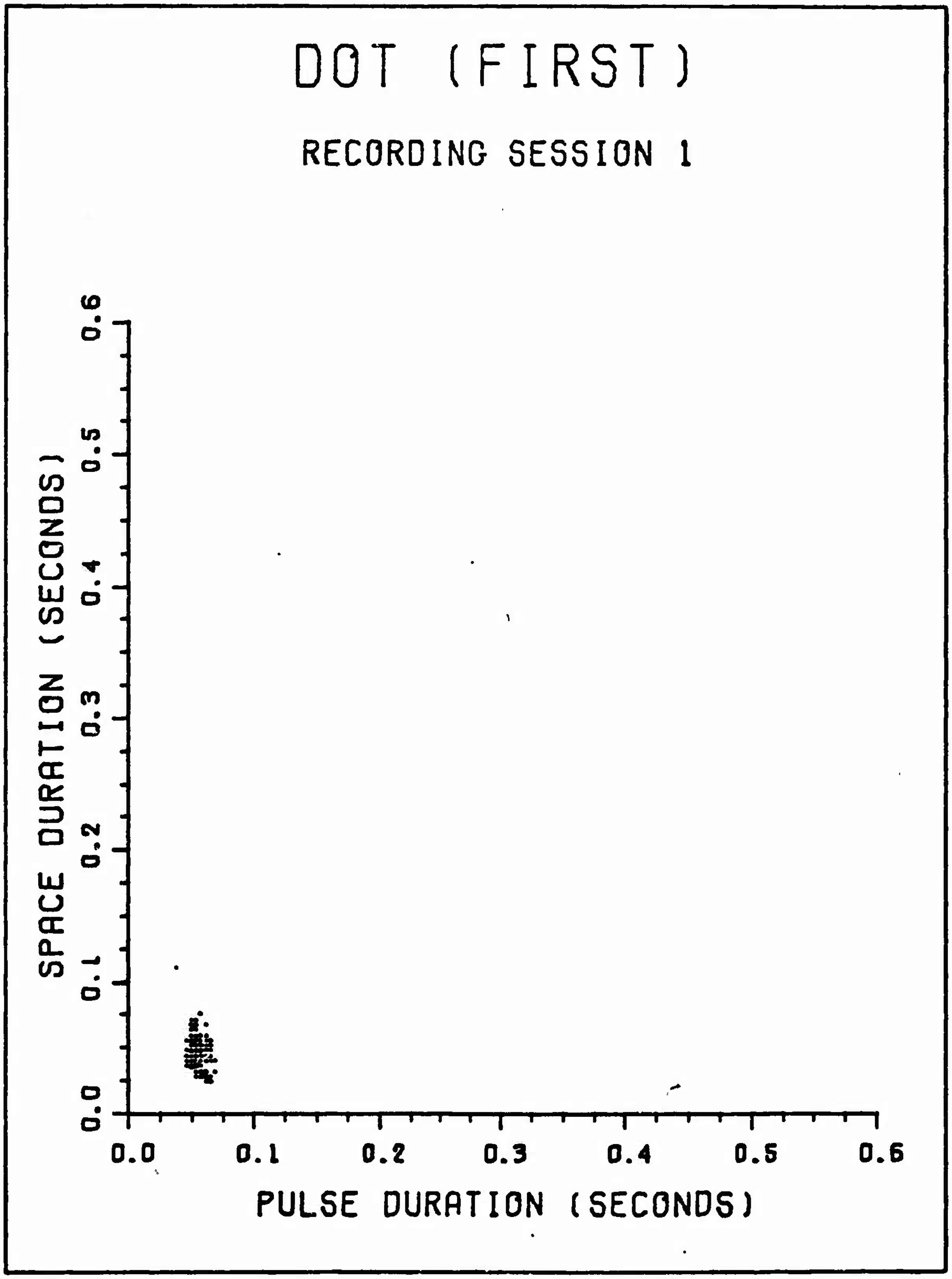

Fig. B-2. Morse Code Data Distribution Plot, DOT (First) Time Duration vs. Time Duration of Following Space (Recording Session 1).

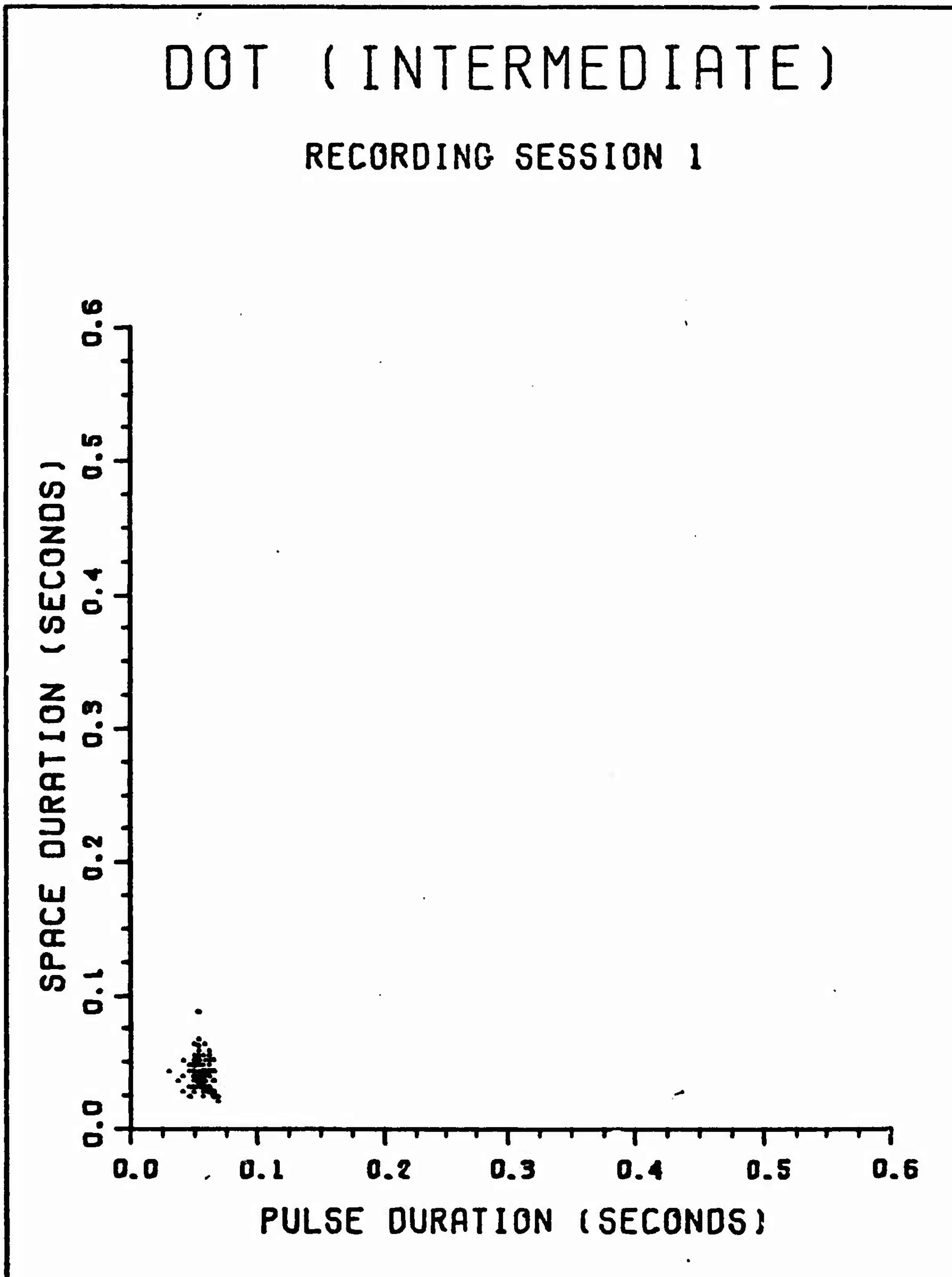

Fig. B-3. Morse Code Data Distribution Plot, DOT (Intermediate) Time Duration vs. Time Duration of Following Space (Recording Session 1).

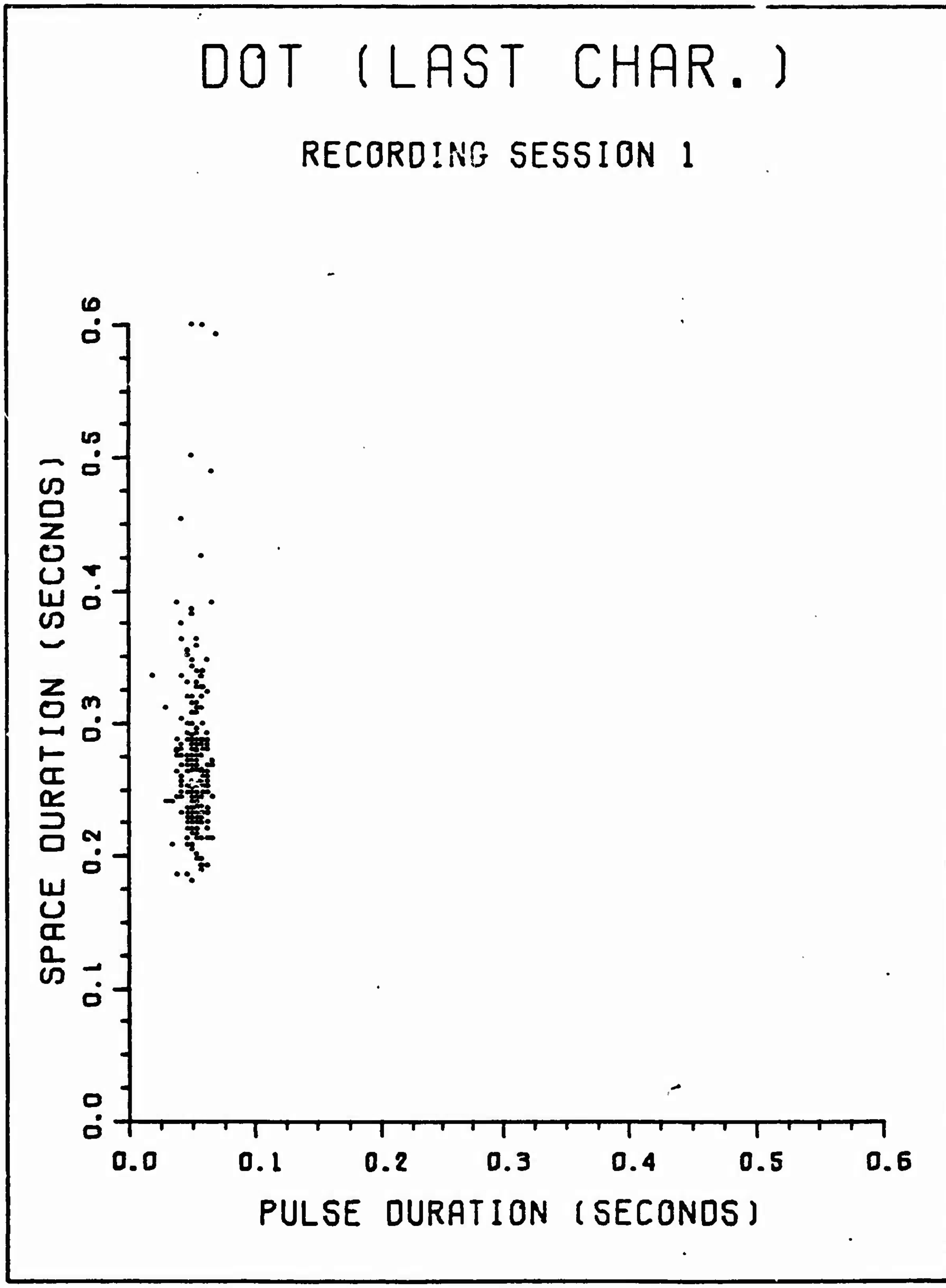

Fig. B-4. Morse Code Data Distribution Plot, DOT (Last Character) Time Duration vs. Time Duration of Following Space (Recording Session 1).

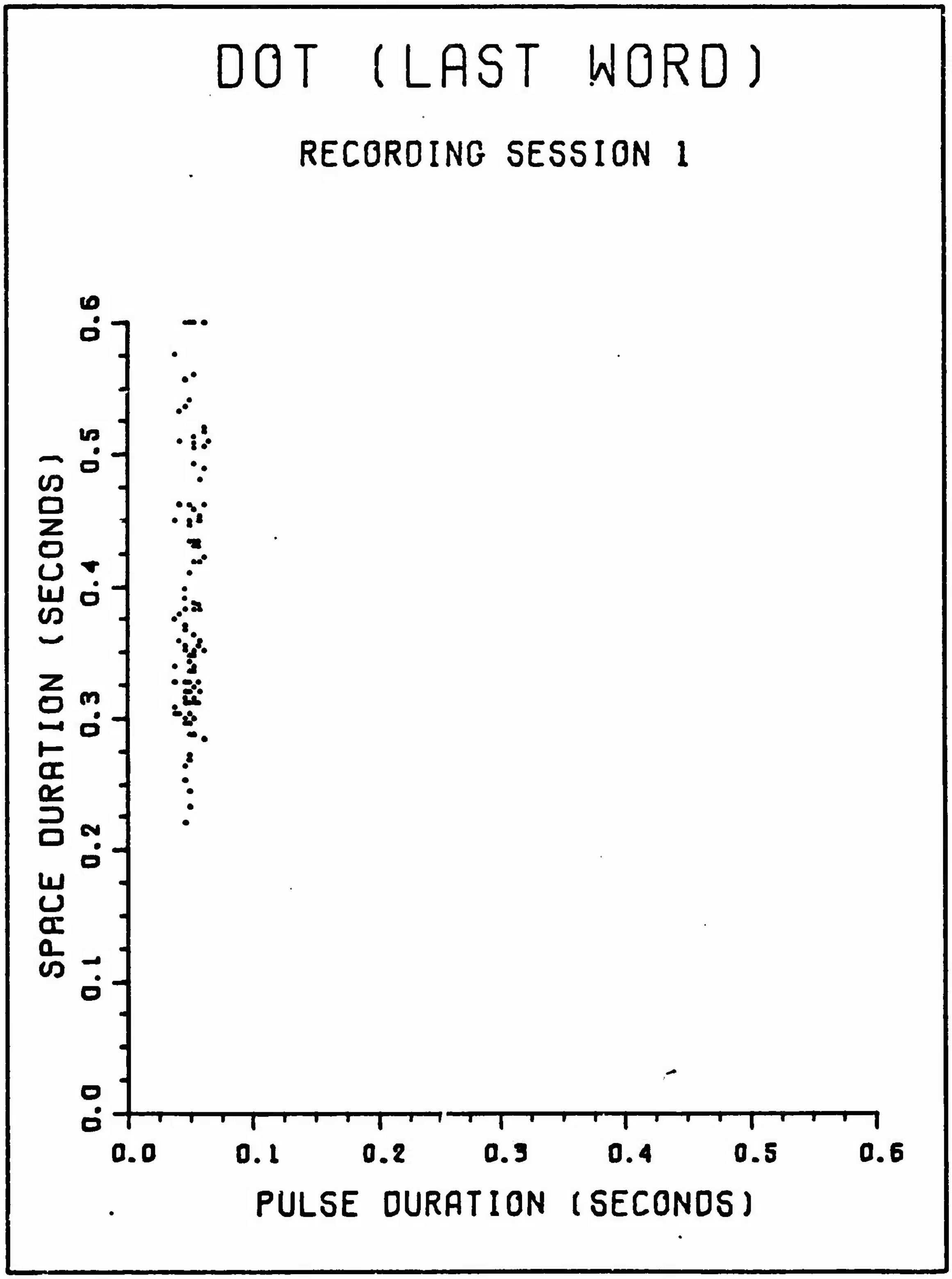

Fig. E-5. Morse Code Data Distribution Plot, DOT (Last Word) Time Duration vs. Time Duration of Following Space (Recording Session 1).

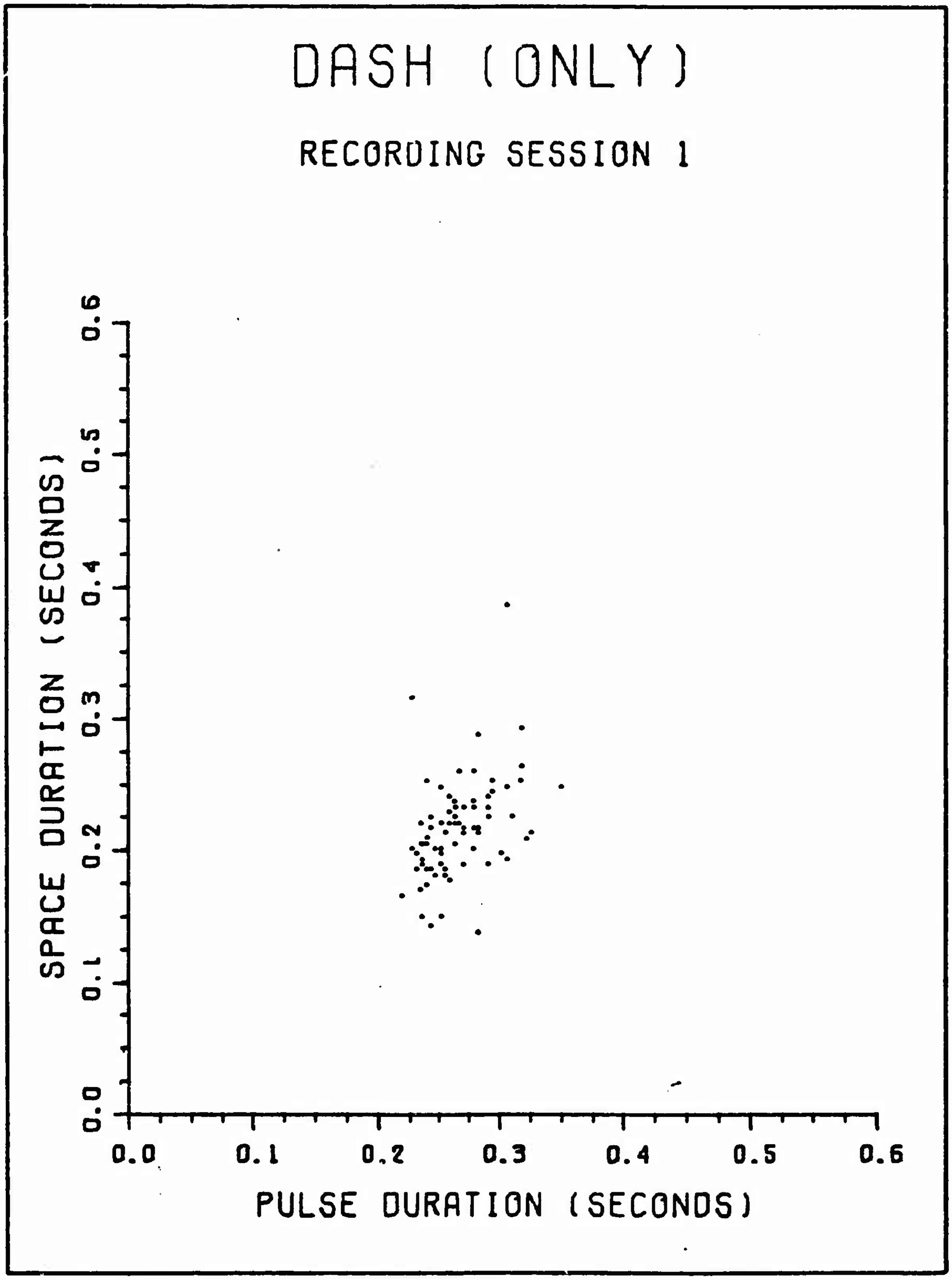

Fig. B-6. Morse Code Data Distribution Plot, DASH (Only) Time Duration vs. Time Duration of Following Space (Recording Session 1).

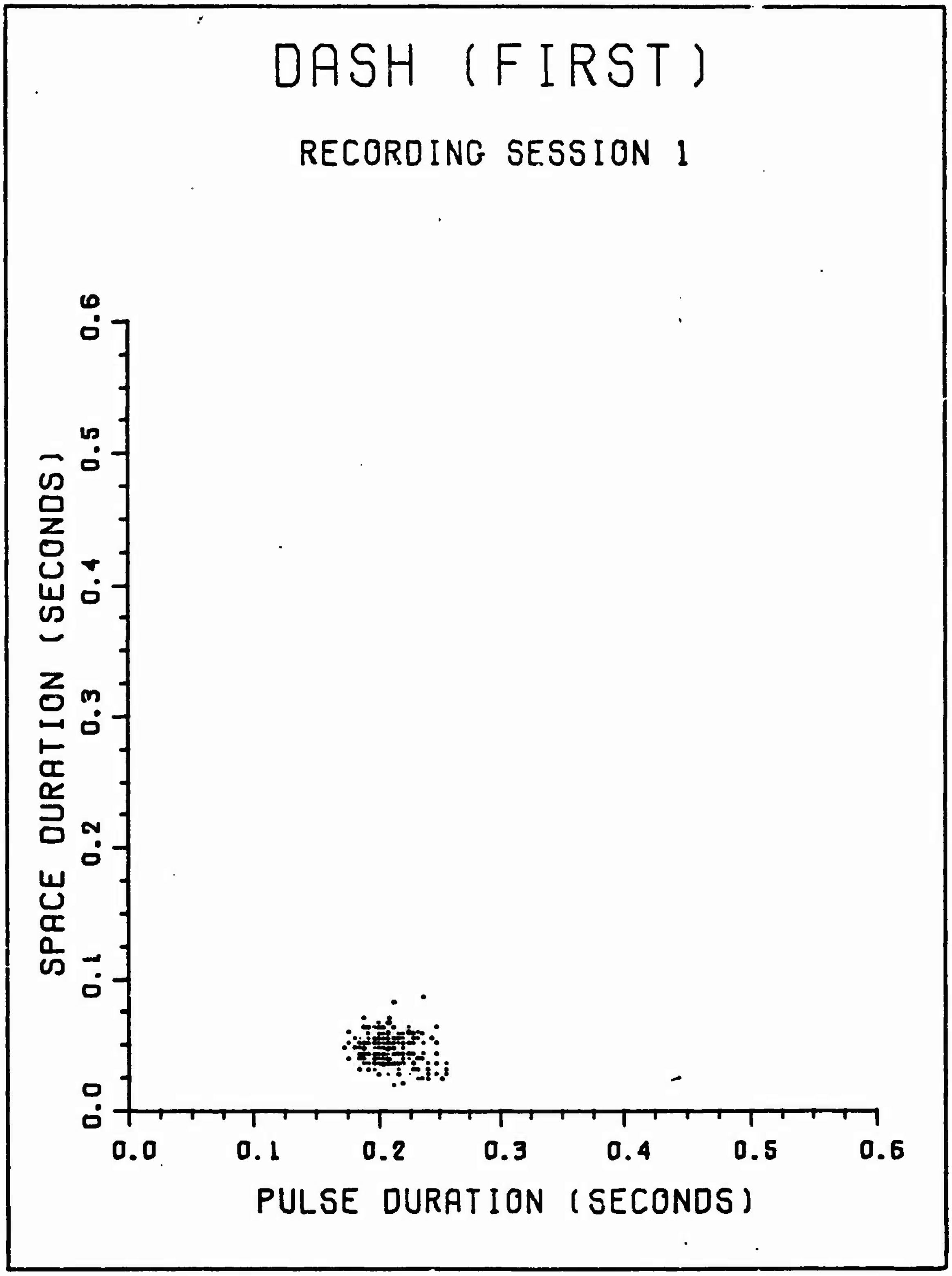

Fig. B-7. Morse Code Data Distribution Plot, DASH (First) Time Duration vs. Time Duration of Following Space (Recording Session 1).

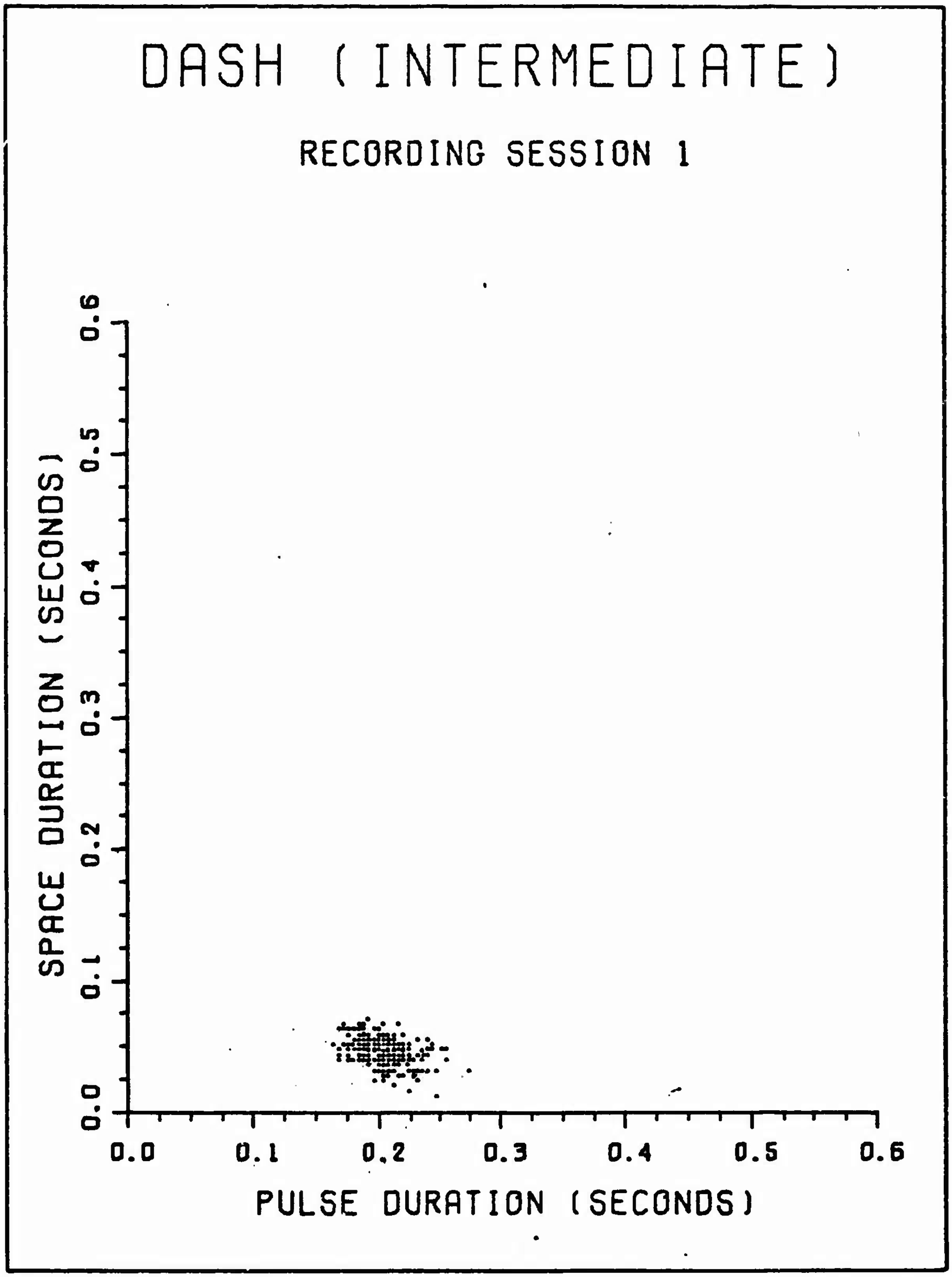

Fig. B-8. Morse Code Data Distribution Plot, DASH (Intermediate) Time Duration vs. Time Duration of Following Space (Recording Session 1).

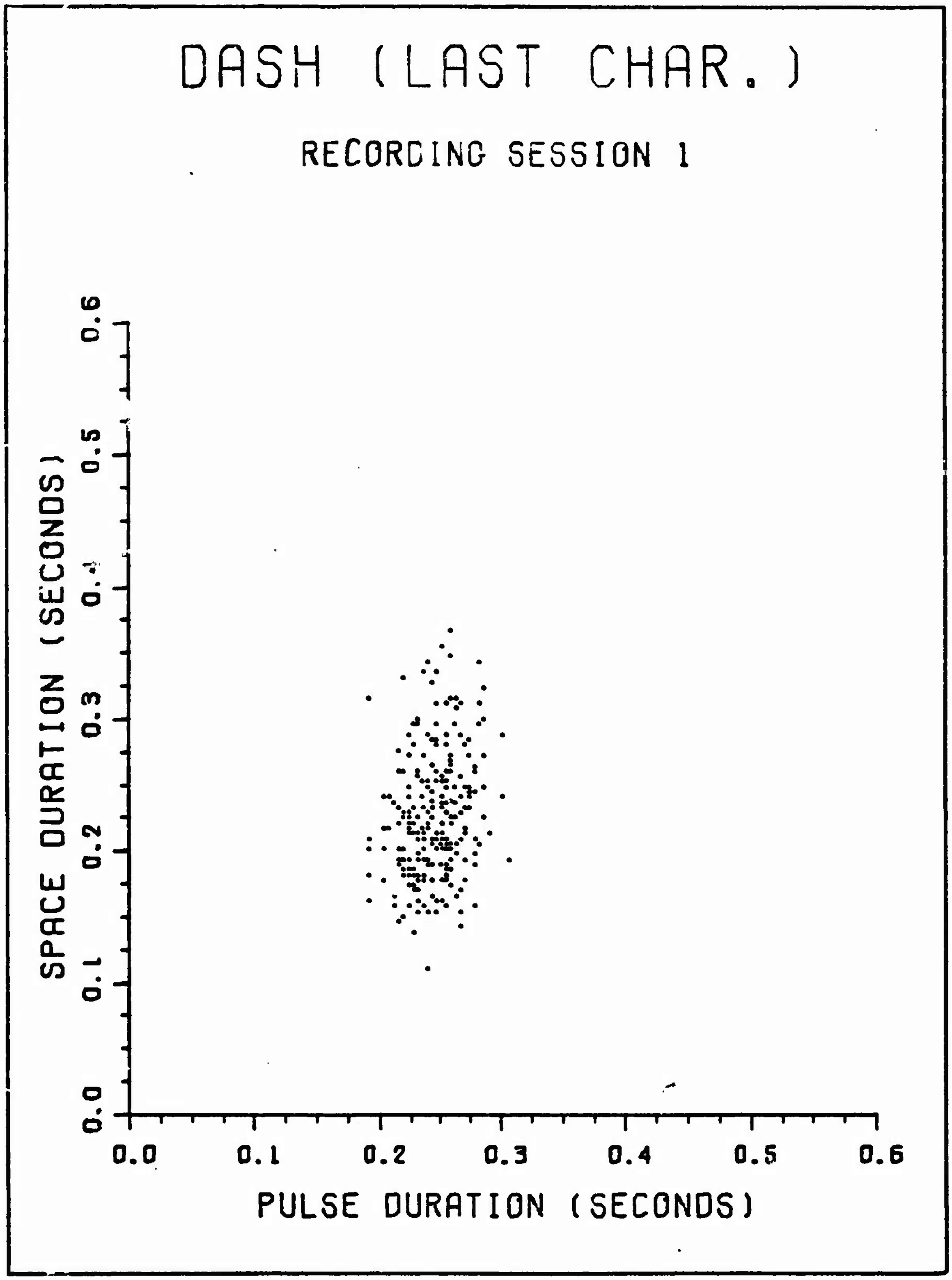

Fig. B-9. Morse Code Data Distribution Plot, DASH (Last Character) Time Duration vs. Time Duration of Following Space (Recording Session 1).

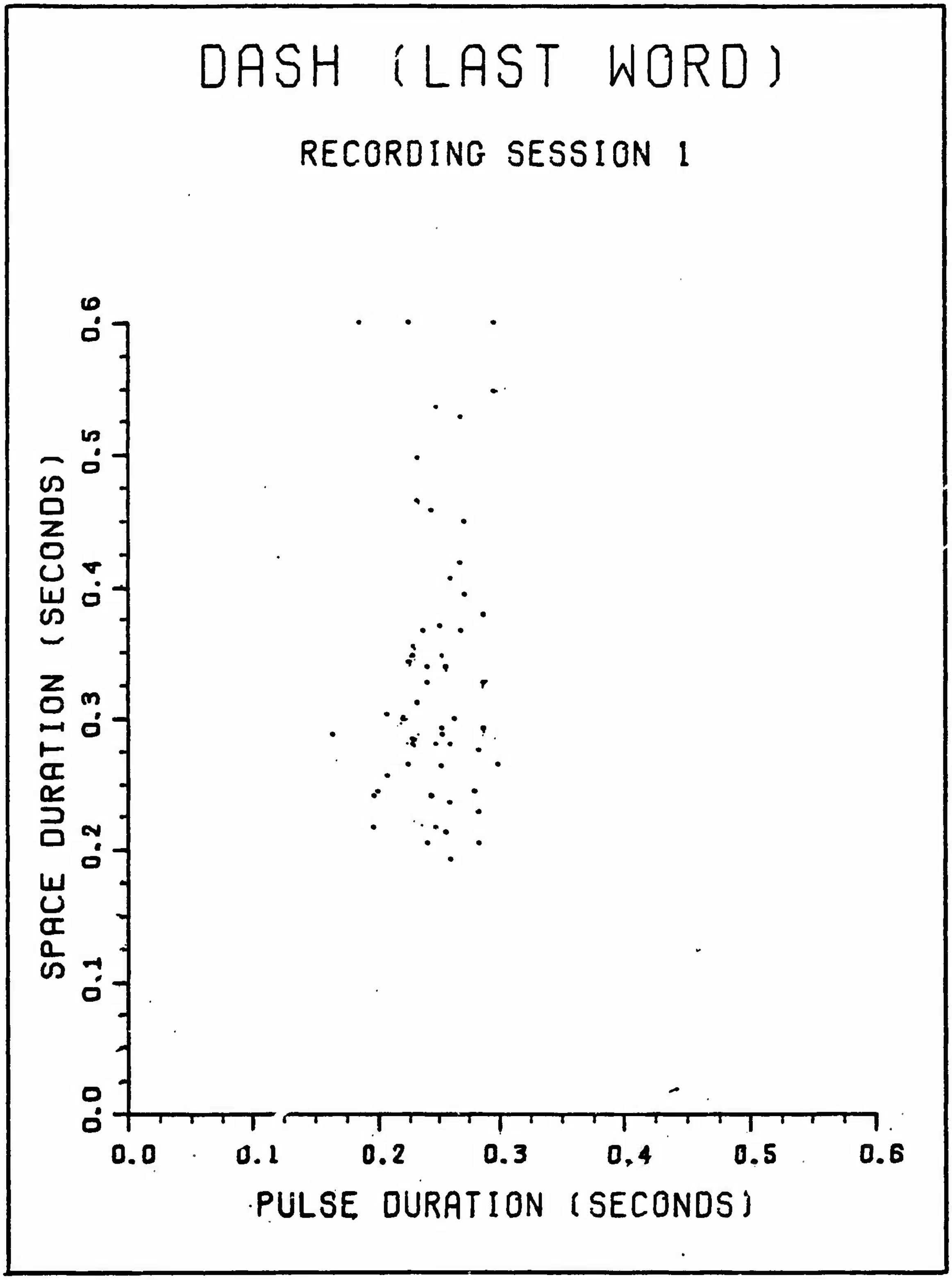

Fig. B-10. Morse Code Data Distribution Plot, DASH (Last Word) Time Duration vs. Time Duration of Following Space (Recording Session 1).

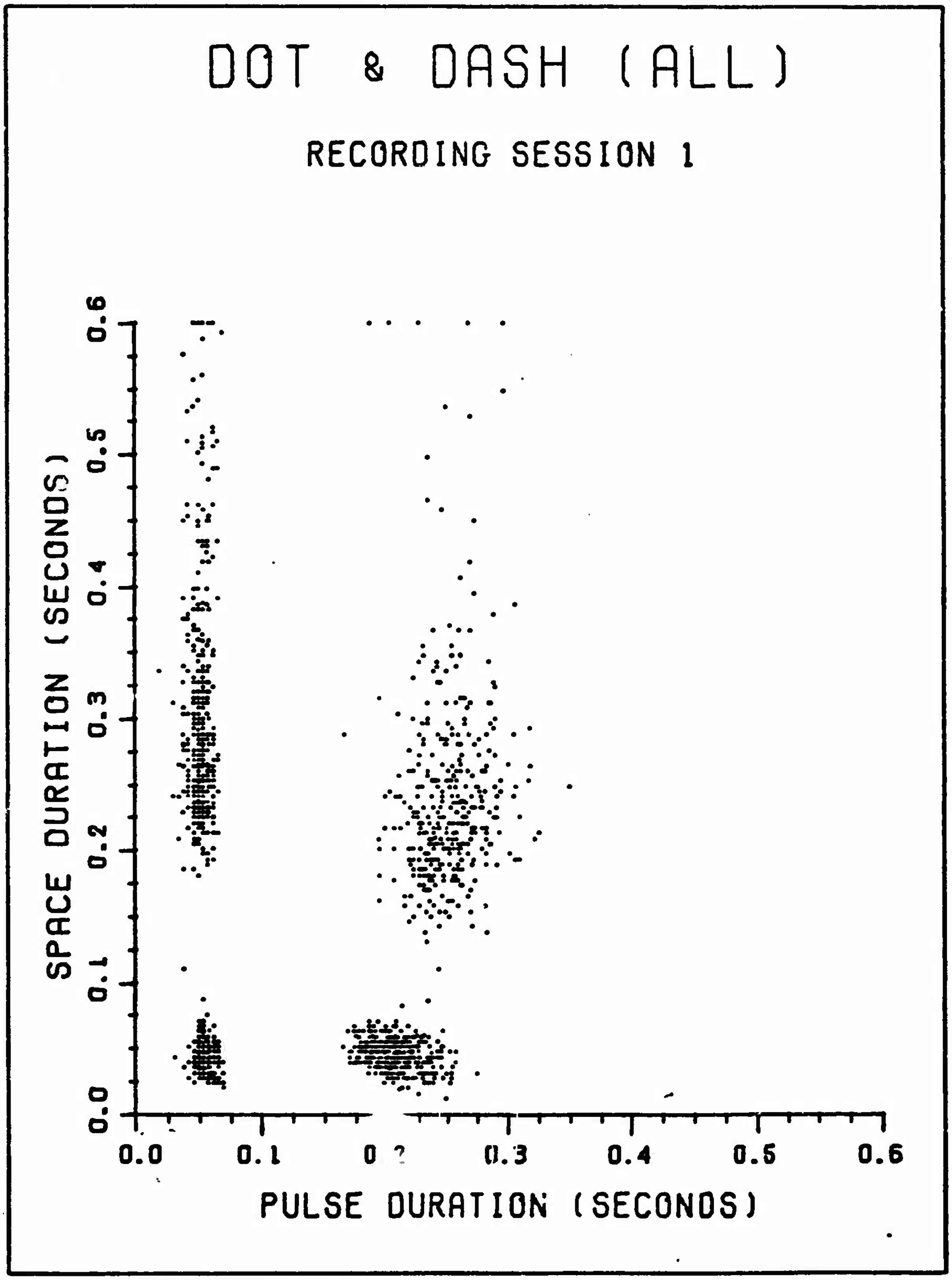

Fig. B-11. Morse Code Data Distribution Plot, Pulse Time Duration vs. Time Duration of Following Space (Recording Session 1).

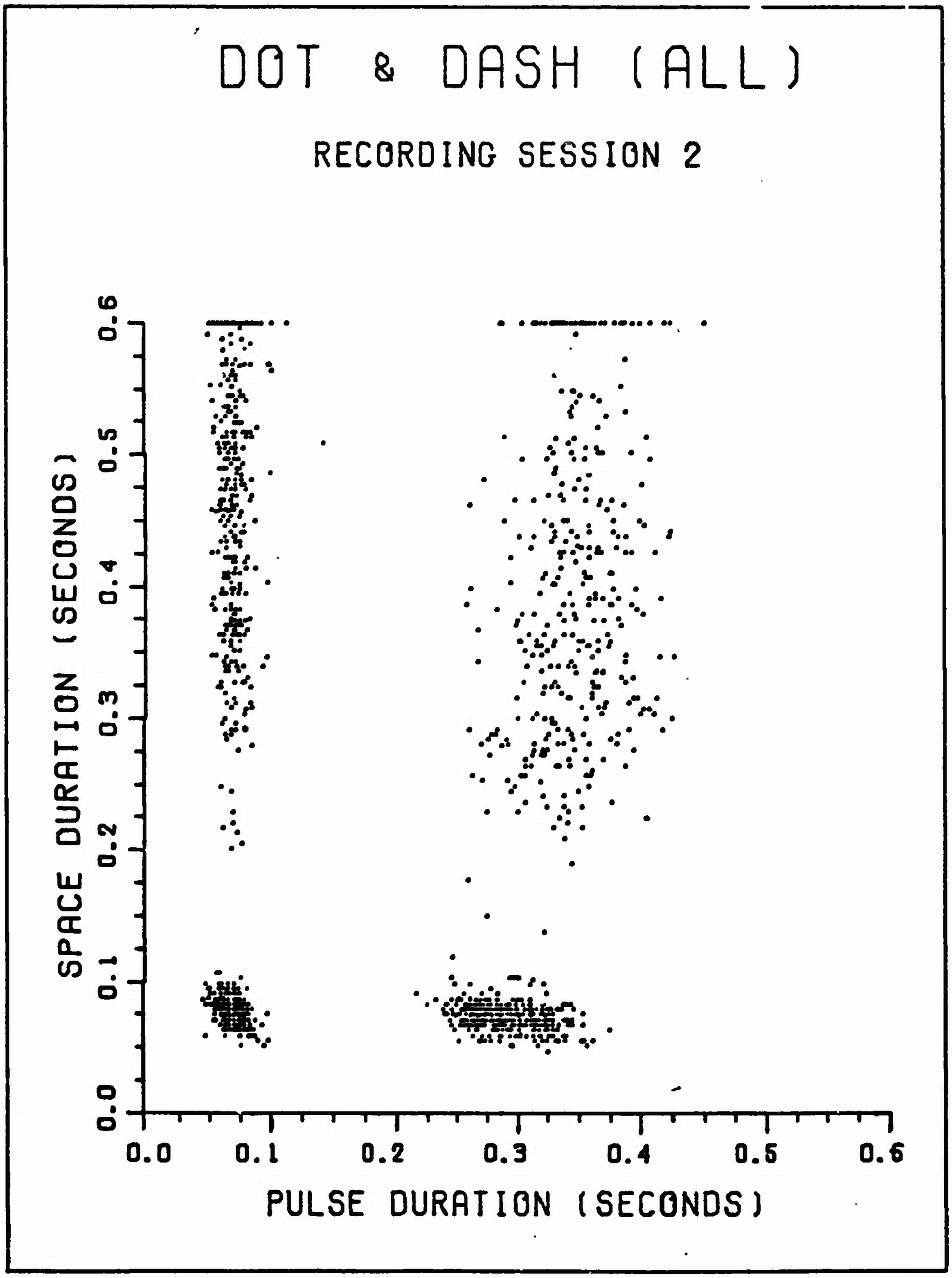

Fig. B-12. Morse Code Data Distribution Plot, Pulse Time Duration vs. Time Duration of Following Space (Recording Session 2).

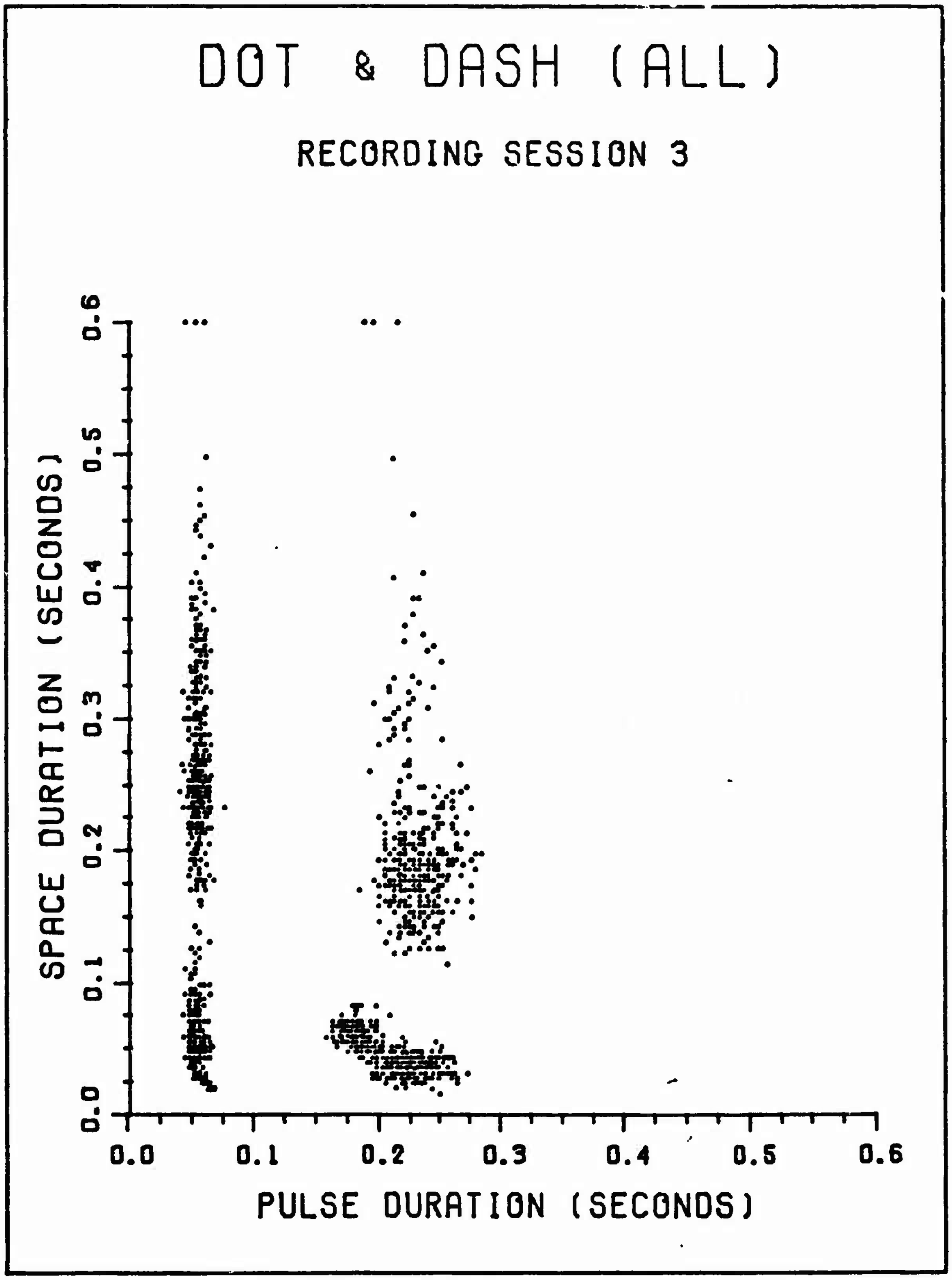

Fig. B-13. Morse Code Data Distribution Plot, Pulse Time Duration vs. Time Duration of Following Space (Recording Session 3).

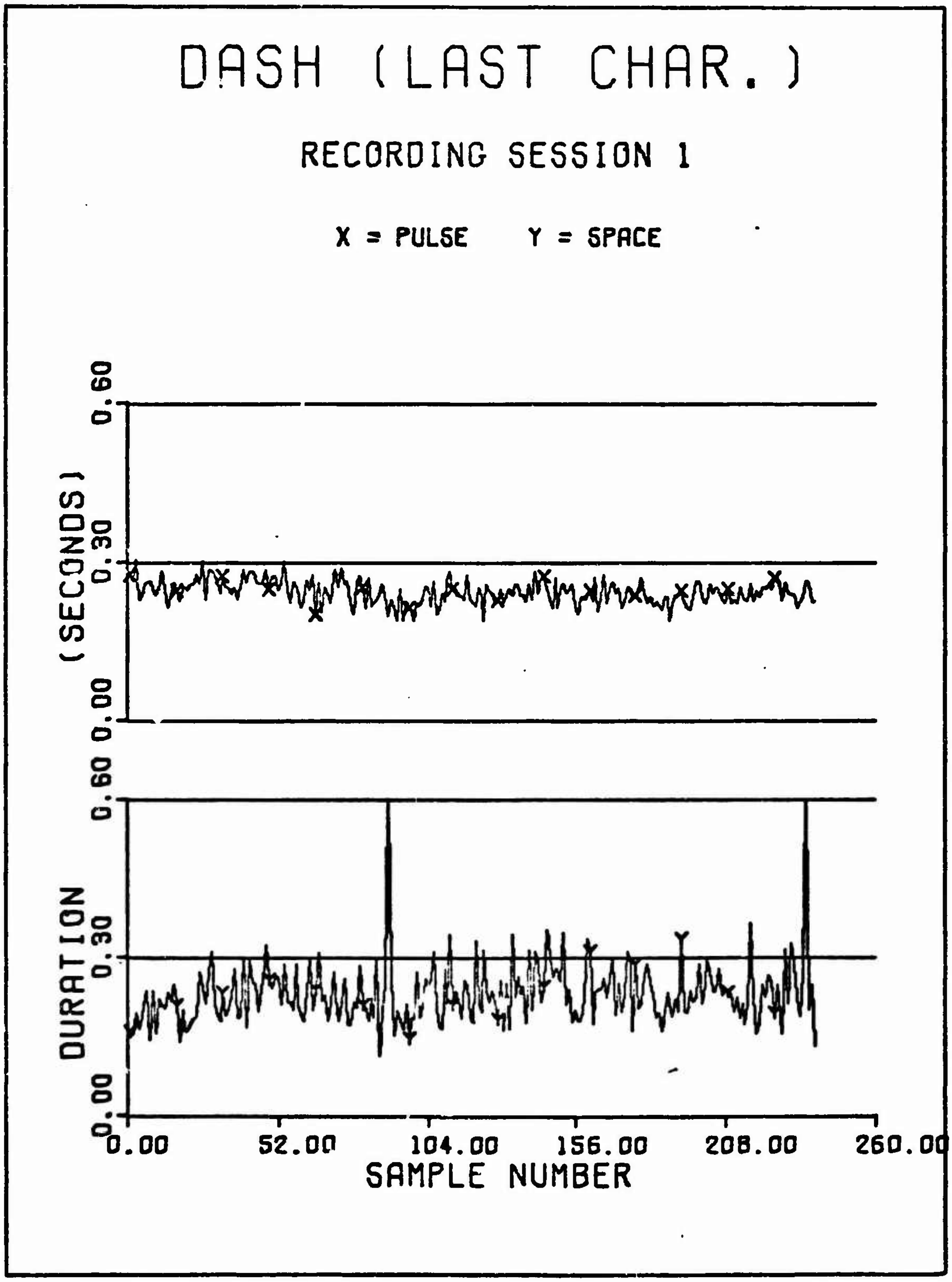

Fig. B-14. DASH (Last Character) and Following Space Time Duration Fluctuations (Recording Session 1).

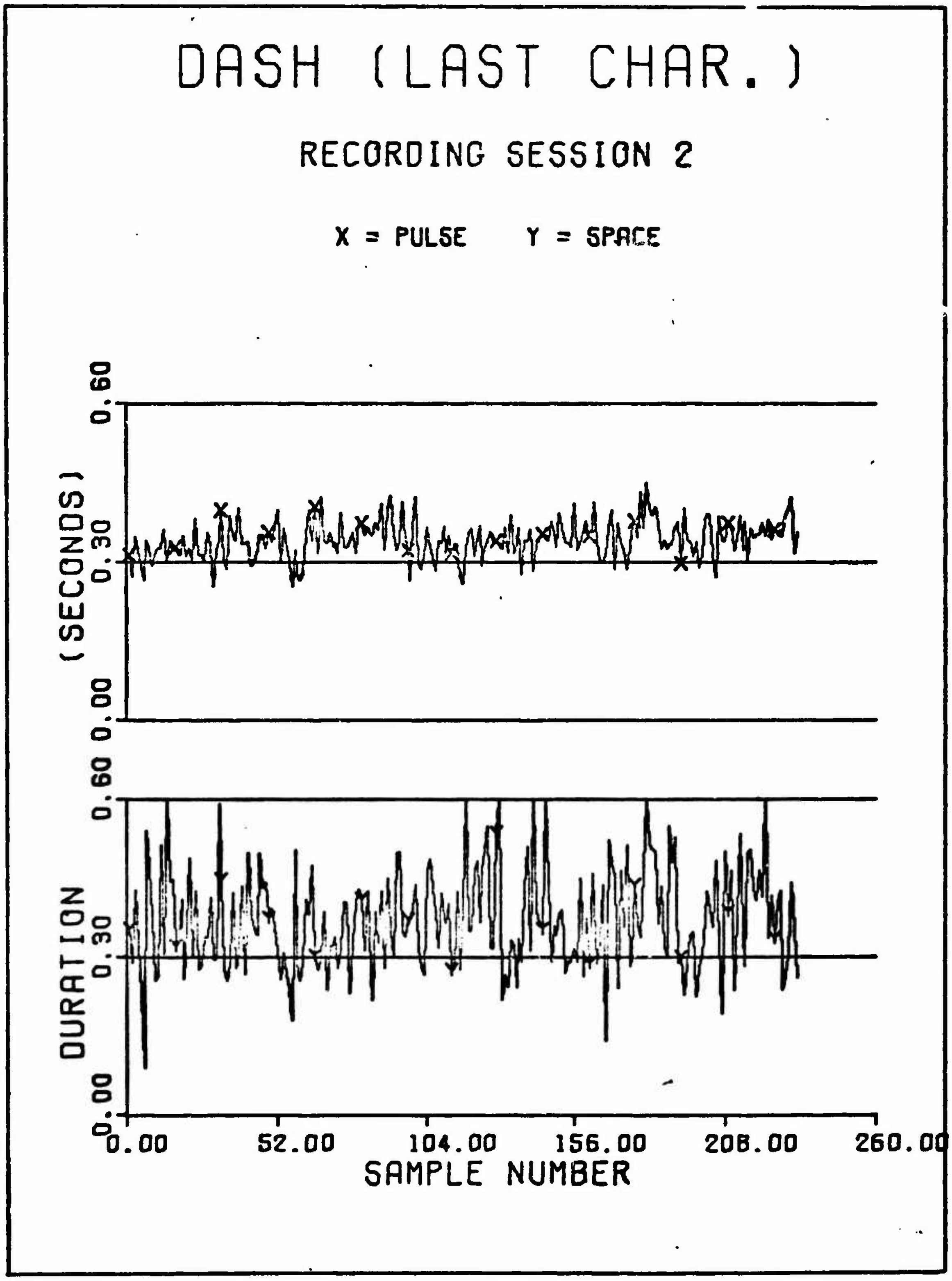

Fig. B-15. DASH (Last Character) and Following Space Time Duration Fluctuations (Recording Session 2).

Appendix C

Code and Character Listing

This appendix contains a list of 47 international Morse code characters and code representations. Corresponding internal code words and Teletypewriter output characters used in the recognition program are also listed.

Letters

Morse Character	Morse Code	Internal Code	Printer Character
A	• -	2002	A
B	- • • •	4004	B
C	- • - •	5004	C
D	- • •	4003	D
E	•	0001	E
F	• • - •	1004	F
G	- - •	6003	G
H	• • • •	0004	H
I	• •	0002	I
J	• - - -	3404	J
K	- • -	5003	K
L	• - • •	2004	L
M	- -	6002	M
N	- •	4002	N
O	- - -	7003	O
P	• - - •	3004	P
Q	- - • -	6404	Q
R	• - •	2003	R
S	• • •	0003	S
T	-	4001	T
U	• • -	1003	U
V	• • • -	0404	V
W	• - -	3003	W
X	- • • -	4404	X

Letters Cont.

Morse Character	Morse Code	Internal Code	Printer Character
Y	- • - -	5404	Y
Z	- - • •	6004	Z

Numbers

Morse Character	Morse Code	Internal Code	Printer Character
0	- - - - -	7605	0
1	• - - - -	3605	1
2	• • - - -	1605	2
3	• • • - -	0605	3
4	• • • • -	0205	4
5	• • • • •	0005	5
6	- • • • •	4005	6
7	- - • • •	6005	7
8	- - - • •	7005	8
9	- - - - •	7405	9

Punctuations and Special Functions

Morse Character	Morse Code	Internal Code	Printer Character
Period	• - • - • -	2506	.
Comma	- - • • - -	6306	,
Question Mark	• • - - • •	1406	?
Colon	- - - • • •	7006	:
Semicolon	- • - • - •	5206	;
Double Dash	- • • • -	4205	-
Parenthesis	- • - - • -	5506	)

Punctuations and Special Functions Cont.

Morse Character	Morse Code	Internal Code	Printer Character
Fraction Bar	– • • – •	4450	/
Error[a]	• • • • • • • •	0010	<
Wait	• – • • •	2005	\
End of Message	• – • – •	2405	*
End of Work	• • • – • –	0506	$
Space[b]	(none)	0000	(Space)
Unknown[b]	?	?	=

a Usually a string of 8 DOTs. May be 6 or more.

b Unique to Recognition Program.

Appendix D

Computer Test Messages

This appendix contains recognition program outputs for Recording Sessions 1 through 7. Copies of the text used to transmit Recording Sessions 1 through 4 and Recording Session 6 are also presented. Output errors (discrepancies between the text and the output) are indicated by astericks (*) and number symbols (#) located below the error. Astericks indicate errors made by the message sender; number symbols indicate errors made by the recognition program. See Table IV (Chapter VI) for recording session statistics and error percentages.

AMATEUR RADIO IS A SCIENTIFIC HOBBY, A MEANS OF GAINING PERSONAL SKILL IN THE FASCINATING ART OF ELECTRONICS AND AN OPPORTUNITY TO COMMUNICATE WITH FELLOW CITIZENS BY PRIVATE SHORT WAVE RADIO. SCATTERED OVER THE GLOBE ARE OVER 350,000 AMATEUR RADIO OPERATORS WHO PERFORM A SERVICE DEFINED IN INTERNATIONAL LAW AS ONE OF SELF TRAINING, INTERCOMMUNICATION AND TECHNICAL INVESTIGATIONS CARRIED ON BY DULY AUTHORIZED PERSONS INTERESTED IN RADIO TECHNIQUE SOLELY WITH A PERSONAL AIM AND WITHOUT PECUNIARY INTEREST. FROM A HUMBLE BEGINNING AT THE TURN OF THE CENTURY, AMATEUR RADIO HAS GROWN TO BECOME AN ESTABLISHED INSTITUTION. TODAY THE AMERICAN FOLLOWERS OF AMATEUR RADIO NUMBER OVER 250,000, TRAINED COMMUNICATORS FROM WHOSE RANKS WILL COME THE PROFESSIONAL COMMUNICATIONS SPECIALISTS AND EXECUTIVES OF TOMORROW - JUST AS MANY OF TODAYS RADIO LEADERS WERE FIRST ATTRACTED TO RADIO BY THEIR EARLY INTEREST IN AMATEUR RADIO COMMUNICATION. A POWERFUL AND PROSPEROUS ORGANIZATION NOW PROVIDES A BOND BETWEEN AMATEURS AND PROTECTS THEIR INTERESTS. AN INTERNATIONALLY RESPECTED MAGAZINE IS PUBLISHED SOLELY FOR THEIR BENEFIT. THE MILITARY SERVICES SEEK THE COOPERATION OF THE AMATEUR IN DEVELOPING COMMUNICATIONS RESERVES. AMATEUR RADIO SUPPORTS A MANUFACTURING INDUSTRY WHICH, BY THE VERY DEMANDS OF AMATEURS FOR THE LATEST AND BEST EQUIPMENT, IS ALWAYS UP TO DATE IN ITS DESIGNS AND PRODUCTION TECHNIQUES - IN ITSELF A NATIONAL ASSET. AMATEURS HAVE WON THE GRATITUDE OF THE NATION FOR THEIR HEROIC PERFORMANCES IN TIMES OF NATURAL DISASTER. TRADITIONAL AMATEUR SKILLS IN EMERGENCY COMMUNICATION ARE ALSO THE STAND BY SYSTEM FOR THE NATIONS CIVIL DEFENSE. AMATEUR RADIO IS, INDEED, A MAGNIFICENTLY USEFUL INSTITUTION.

(Sheet 1 of 2)

Fig. D-1. Prepared Text for Recording Sessions 1 through 4.

ALTHOUGH AS OLD AS THE ART OF RADIO ITSELF, AMATEUR RADIO DID NOT ALWAYS ENJOY SUCH PRESTIGE. ITS FIRST ENTHUSIASTS WERE PRIVATE CITIZENS OF AN EXPERIMENTAL TURN OF MIND WHOSE IMAGINATIONS WENT WILD WHEN MARCONI FIRST PROVED THAT MESSAGES ACTUALLY COULD BE SENT BY WIRELESS. THEY SET ABOUT LEARNING ENOUGH ABOUT THE NEW SCIENTIFIC MARVEL TO BUILD HOMEMADE SPARK TRANSMITTERS. BY 1912 THERE WERE NUMEROUS GOVERNMENT AND COMMERCIAL STATIONS, AND HUNDREDS OF AMATEURS. REGULATION WAS NEEDED, SO LAWS, LICENSES AND WAVELENGTH SPECIFICATIONS APPEARED. THERE WAS THEN NO AMATEUR ORGANIZATION NOR SPOKESMAN. BUT AS THE YEARS ROLLED ON, AMATEURS FOUND OUT HOW, AND DX JUMPED FROM LOCAL TO 500 MILE AND EVEN OCCASIONAL 1000 MILE TWO WAY CONTACTS. BECAUSE ALL LONG DISTANCE MESSAGES HAD TO BE RELAYED, RELAYING DEVELOPED INTO A FINE ART - AN ABILITY THAT WAS TO PROVE INVALUABLE WHEN THE GOVERNMENT SUDDENLY CALLED HUNDREDS OF SKILLED AMATEURS INTO WAR SERVICE IN 1917. MEANWHILE U.S. AMATEURS BEGAN TO WONDER IF THERE WERE AMATEURS IN OTHER COUNTRIES ACROSS THE SEAS AND IF, SOME DAY, WE MIGHT NOT SPAN THE ATLANTIC ON 200 METERS. MOST IMPORTANT OF ALL, THIS PERIOD WITNESSED THE BIRTH OF THE AMERICAN RADIO RELAY LEAGUE, THE AMATEUR RADIO ORGANIZATION WHOSE NAME WAS TO BE VIRTUALLY SYNONYMOUS WITH SUBSEQUENT AMATEUR PROGRESS AND SHORT WAVE DEVELOPMENT. CONCEIVED AND FORMED BY THE FAMOUS INVENTOR, THE LATE HIRAM PERCY MAXIM, ARRL WAS FORMALLY LAUNCHED IN EARLY 1914. IT HAD JUST BEGUN TO EXERT ITS FULL FORCE IN AMATEUR ACTIVITIES WHEN THE UNITED STATES DECLARED WAR IN 1917, AND BY THAT ACT SOUNDED THE KNELL FOR AMATEUR RADIO FOR THE NEXT TWO AND A HALF YEARS. THERE WERE THEN OVER 6000 AMATEURS. OVER 4000 OF THEM SERVED IN THE ARMED FORCES DURING THAT WAR.

(Sheet 2 of 2)

Fig. D-1. Prepared Text for Recording Sessions 1 through 4.

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ON BYDUL, AUTHORIZED PERSON S INTERESTED INRADIO E TECHNI Y UE S
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(Sheet 1 of 3)

Fig. D-2. Recognition Program Output for Recording Session 1.

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S OF NATURAL DISASTER. TRAD ITIONAL AMATEUR SKILLS IN EMERGEN CY

COMMUN ICATION ARE ALSO THESTAND BY SYSTEM FOR THENATIONS CIVIL

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00 MILE AND EVENOCCASIONAL 1 000 MILE TWOWAYCONTACTS. BECAUSE ALL

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SMPORTANT OFALT , TS IS PERIODWIT NESSED THE BIRTHOF THE AM ERIC
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(Sheet 2 of 3)

Fig. D-2. Recognition Program Output for Recording Session 1.

AN RADIO RELAY LEAG UE , TH E AMATEUR RADIO OR GANIZA TIO N WHOS
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PROM R ESSAND S HORT WAVE DEVELOPMENT . CONCE IVEDAND F ORMED BY
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LY LAU NCHED IN EARLY 1 914 . R I T HADJUST BEGUN TO EXERT ITS F
ULL FORCE INAM A TEUR ACTIVITIES WHEN THEE NITED STATE S DECLARE
D WAR IN191 7 , AND BY THAT ACT SOUNDED THE K NELL FOR A MA T EU
R RADIO FOR THE NEX T TWO AND A S ALFYEARS. TH ERE WERE THET OVE
R 6 000AMATEURS. OVER4000 OF THEM S ERVED IN THE ARM E DFORCES D
URING THATWAR.

(Sheet 3 of 3)

Fig. D-2. Recognition Program Output for Recording Session 1.

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SO NAL SK ILL IN THEFASCINAT INGARTOF ELECTRA ON ICS AND AN OPPO
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ED TO RADIO BY TH EIR EARLY INTER EST IN AMATEUR RADIO CTT MMUN
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BENEFIT . TH E M IL ITARY S ERVICES SEEK THE COOP ERATION OF THE
AMATEUR IN DEVELOPING COMMUNICATIONS RESERVES. AMATEUR RADIO SUP
PORTS A MANUFACTURING INK US TRY WHICH, BY THE VERY DEMAND S OF
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IN ITS D ES IGNS AND PROE D UC TION TECHN IQUES - IN ITSELF A NA
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(Sheet 1 of 3)

Fig. D-3. Recognition Program Output for Recording Session 2.

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TIONAL ASS E T . AMATEURS HAVE WON THE GRATITUDE OF THE NATION F
OR THEIR HEROIC P ERFORMANC E S IN TIME S OF NATURAL D ISAS TER.
TRADITIONAL AMATEUR SKILL S IN EMERG ENC Y COMMUNICATION ARE ALS
O THE STAND BY SY STEM FOR THE NATIONS CIVIL DEF ENS E. AMA TEUR
RADIOIS, INDEED , A MAGNIF IC ENTLY USEFUL INSTITUTION . ALTHOUG
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AYS ENJOY SUCH PRESTIG E. ITSF IR ST ENTHUSIASTS WER E PR IVATE
C ITIZENS OF AN EXPERIMEN TALTURN OF MIND WHOS E IMAGINATIONS WE
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WERE AMATE URS INOTHER COUNTRIES ACROSS THE SEAS AND IF , SOME D
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(Sheet 2 of 3)

Fig. D-3. Recognition Program Output for Recording Session 2.

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NAME WAS TO B E VIRTUALLY SYNONO MOUS WITH SUB S E QUE N T AMATE
UR PROGRESS AND SHOR T WAVE DEVELOPMENT. CONCEIVED AND FORMED K
Y TH E FAMOUS INVE NTOR , THE LATE HIL AM PERCY MAX IM, ARRL AA
S FORMALL Y LAUNC H ED IN EARLY 19 15 . IT HAD JUST B EG UN TO E
XERT ITS FULL FORC E IN AMITEUR ACTIVITIES WH EN THE UN ITED STA
TES D EC L AR E D WA R I N 19 1 7 , AN D BY THAT ACT SOUNDED THE
KNELL FOR AMATEUR RADIO FOR THE N EXT TWO AND A HALF Y EARS. TH
ERE WERE THEN OVER 6 000AMATEURS. OVER 4000 OF THEM SERVEDINTHE
ARMEDFORCES DURING THA T WAR .
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(Sheet 3 of 3)

Fig. D-3. Recognition Program Output for Recording Session 2.

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AMATEUR RADIO IS ASCIENTIFIC HOBBY, AMEANSOF GAINING PERSONAL
SKILL IN THE FASCINATING ART OF ELECTRONICS AND ANOPPORTUNITY TO
COMMUNICATE WITH FELLOWCITIZENS BY PRIVATE SHORT WASTE RADIO. SC
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(Sheet 1 of 3)

Fig. D-4. Recognition Program Output for Recording Session 3.

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IN EMERGENCY COMMUNICATION ARE ALSOTUE STAND BYSYSTEMFORTHENATIO
NSCIVIL DEFENSE. AMATEUR R ADIOIS, IND E ED, A MAGNIFICENTLYUSEF
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DIODIDNOTALWAYS ENJOY SUCH PRESTIGE. ITSFIRSTENTHUS IAS TS WERE
EP RIVATE CITIZENSOFAN EXY EXPERIMENTAL TURNOF MIT ED WHOSE IMAG
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COULDBE SENTBYWIRELESS. THEYSE T ABOUTLEARNING ENOUG5ABOUTTHE NE
WSCIENTIFIC MARSTEL TOBUILDUOME MAD SPARKTRANSMITTERS. BY1911D TH
ERE WERE NUMEROUSGOSTERNMENTANDCOMMERCIAL STATIONS, ANDHUNDREDSOF
AMATEURS. REGULATIXN WASNEEDED , SO LAWS, LICENSES AND WASTELENGTH
SPECIFICATIONS APPEARED. THERE YAS THENNOAMATE URORGANIZATION NOR
SPOKESMAN. BUTASTHEYEARS ROLLEDON, AMATEURSFOUNDOUTHOW, ANDDXJUMP
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CTS. BECAYSE ALLLONGDISTANCE ME SSAG ESHADTOFERELAYED, R ELAYING
DESTELOPED INTO AEN INEART ETAN ABILITYT5AT WAS TO T PROSTE INST
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AND IF, SOMEDAY, WEMIGHTNOTSPANTHE ATLANTICON200METERS. MOSTIMPOR
TANTOF ALL, THISPERIODWITN E SSED THIBIRTHOFTHE W AMERICAN RADIOR
ELAYLEAGUE, THEAMATEUR R RADIOORGANIZATION WHOSE NAMEWAS TOBESTIR
TUALLYSYNONYMOUS WITH SUBSEQIJENT AMATEUR R PROGRESSANDSHORTWAST
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(Sheet 2 of 3)

Fig. D-4. Recognition Program Output for Recording Session 3.

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E DESTELOPMENT. CONCEISTED ANDFORMED BY THE FAMOUS INSTENTOR, THE
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HAD JUSTBEGUN TOEXERTITSFULL FORCE IN AMATEURACTISTITIESWHENTU E
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UNITED STATESDECLARED WAR IN1917 ,ANDBYTHATACTSOUNDEDTHEKNELLFOR
AMATEUR RADIOFOR THE NEXT TWO ANDAHALFYEARS. THERE WERE THEN OVE
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(Sheet 3 of 3)

Fig. D-4. Recognition Program Output for Recording Session 3.

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TWAVE RADIO. SCA TTERED OVER THEGLOBE ARE OVER350,0 0 0AMATEURRA
DIO OPERATORS WS O PERFORM A SERVICE DEFINED IN INTERNA TIONAL L
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AW ASONE OFSELFTRAINING,INTERCO MMUNICATION,AND TECHNICAL INVESTI
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NTURY,AMAT EUR RADIO H>GROWNTOBECOME ANESTABLISHED INSTITUTION.
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THEIR EARLY INTEREST INAMATEUR RADIO CO M MUNICATION. A POWEA =
A POWERFUL AND PROSPEROUS ORGANIZATION NOW PROVIDES A BO ND BETW
EEN AMATEURS AND PROTECTS THEIR INTERESTS. AN INTERNA TIONALLY R
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LATEST AND BEST EQUIPMENT,IS ALWAYSUP TODATE IN ITS DESIGNS AND
PRODUCTION TECHNQI= PRODUCT2N TECHNIQUES - IN ITSELF A NATIONA L
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(Sheet 1 of 3)

Fig. D-5. Recognition Program Output for Recording Session 4.

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ASSET . AMATEURS HAVE WONTHEGRATITUDEOFTHE NATION FOR THEIR HERO
IC PERFORMANCES IN TIMES OF NATURAL DISASTER. TRADITIONAL AMATEU
RSKILLS IN EMERGENCY COMMUNICATION ARE ALSO THE STAND BYSYSTEM F
OR T5 NATIONS CIVILDEFENSE . A MATEUR RADIOIS, INDEED , A MAGNIF
ICENTLY USEFUL INSTITUTION. ALTHOUGH AS OLD AS THE ART OF RADIO
ITSELF, AMATEURRADIO DID NOT ALWAYS ENJOY SUCH PREST IGE . ITS F
IRST ENTHUSIASTS WERE PRIVATE CITIZENS OF AN EXPERI =E OFANEXPER
IMENTALTURNOFMINDWHOSE IMAGINATIONSWENTWILD WHEN MARCM = M WHEN
MARCONIFIRST PROVEDTHAT MESSAGESACTUALLY COULD BE SENTBY WIRELES
S. TH E Y M E 15E T H EY SET A BOUT LEARNING ENOUGH ABOUT THE NE
W SCIENTIFICMARVEL TO BUILD HOMEMADESPARK=ZTNRS. BY1912T5REPRE-ME
RM SH EMERE NUMEROUSGOVERNMENT PDCOMMERCIT =EANDCONGRCIAL STATI9
S,ANDHUNDLDIOFAMATE==T R EGULATIONW\NEEDED,SOLAWSZT LICENSES AND
WAVELENGTH SPE =I< WAVELENGTH SPECIFICATIONSAPPEARED. THERE W\ T
HEN NO AMATEURO T =EA MATEUR ORGANIZATIONNOR SPOKESMAN. BUTASTHE
YEARS ROLLEDON,AMATEURSFOUNDOUTHOW,AND DX JUMPEDFROMLOCAL TO50 0
MILE ANDEVEN OCCA5ONAL1 0 0 0 MI\ TWOWAYCONTACTS. BEC=ALR L= 6CA
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AFID ART - PABILUYTHATW\TOPROVE IN=UA BLE WHENTHEGOVERNMENTS?DEN
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RIFTHEREWERE AMATEURSINOTHERCOUNTRIES ACROSS THE SEASANDIF,SOME
DAY, WEMIGHTNOT SPAN THEATLANTIC ON20 0 METERS. M OS T IMPORT A
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(Sheet 2 of 3)

Fig. D-5. Recognition Program Output for Recording Session 4.

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NT OF ALL, THIS PERIODWITNESSED THEBIRTH OF THEAMERICAN RADIO RE
LAY LEAGUE , THE AMATEUR RADIO ORGANIZA TION WHOSE NAME WAS TO B
E VI RTUALLY SYNONYMOUSWITH SUBEQUENT AMATEURPROGLSS ANDSS = AND
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S H ORTWAVE DEVELOPMENT . K CONCEIVEDADFORMEDBYTHEFAMOUSINVENTOR
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,THELATEHIRAMPERCY MAXIM,ARRLWASFORMALLYLAUNCHEDINEARLY1914. ITHA
DJUS BEGUN TOEXERT IB FULLFORCE INAMATEURACTIVIT IES WHEN THEUNI
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TE DSTATES DECLAREDWAR U < WAR ET < WAR IN191 7,AND BY
  THAT ACT SOUNDED THE KNELLFORAMATEURRADIOFOR TS E N < FORTHE N
EXT TWOAND A HALF YEARS . T H ERE WE RE THEN O VE R 60 0 0AMATEU
RSJ=E 600 0AMAT EURS. OVF4000 OFTHEMSERVEDINTHEARMEDFORCESDA 9EF
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ORCESDURINGTHAT WAR *
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'(Sheet 3 of 3)

Fig. D-5. Recognition Program Output for Recording Session 4.

K U I E W 9 1 2 1 S A R X M D I K K H N U M J Q U 4 5 0 9 4
J W Z B J6 1 4 0 S M A I W N T B Z O E C T T J O 3 4 8 3 9 P K R
C S E R P O I M N E H O Z U P T C C X P F G C O N A Y 3 5 6 1 8
Y A H G B B Z Q Q F 0 3 7 2 5 V Y Y D X 0 9 6 6 2 RT E

2 4 8 4 9 I D L K R L N W Q B E I H C D 4 2 2 5 3 I A U B T
G L R O 3 3 4 8 3 M B N R A T M O Z I 0 3 2 0 8 U C I E U J Z Y
W I E J V W D Y Z B A B 4 8 5 1 6 G Z Q T Y A S V F Q C K U X K
G Q N S V J P X S C M H C D G P F H P H 5 2 4 7 1 4 1 5 5 0 *

G O O F Y P Y G M Y C O G I T A T E S Q U I Z Z I C A L L Y
. J O N Q U I L S G L O R I F Y K I N G L Y P A C I F I E Y A =
P A C I F I C Y A C H T S . .

I T I S A G O O D I D E A T O W R A P T H E B A L U N W I T
H V I N Y L E L E C T R I C A L T A P E F O R I T S EE N T I R E
L E N G T H T O P R O T E C T T H E F I N E A I R E S O F T H E
S H I E L D .

S M O O T H I T O U T A N D T A P E I T I N P O S I T I O N
E V E R Y F O O T :

(Sheet 1 of 2)

Fig. D-6. Recognition Program Output for Recording Session 5.

SMOOTH IT OUT AND TAPE IT IN POSITION EVERY FOOT .

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P Q 9 5 4 0 0 X 2 3 W J V 4 1 Y 9 U B C K 1 7 6 D 9 L 4 P V

1 3 2 R 5 F 3 M 0 J *

B E S T R E S U L T S W I L L B E O B T A I N E D W H E N T

H E A N T E T < T H E A N T E N N A I S F O R T Y O R F I F T Y

F E E T H I G H A N D W E L L I N T H E C L E A R .

W E D I S L I K E T O E X C H A N G E J O B L O T S O F S I

Z E S V A R Y I N G F R O M A Q U A R T E R U P .

D I M E N S I O N S O F T H E A N T E N N A S U I T A B L E

F O R T H E A M A T E U R B A N D S A R E G I V E N I N F I G U

R E 3 .

T H E 8 0 M E T E R A N T E N N A S H O U L D B E M A D E O F

H A R D D R A W N C O P P E R W I R E T O P R E V E N T S T R E

T C H I N G A N D S A G G I N G I N H E A V Y W I N D S .

(Sheet 2 of 2)

Fig. D-6. Recognition Program Output for Recording Session 5.

QST DE W1AW W1AW W1AW OB 450, OSCAR 309 AND APT 388 FOLLOW QST QST QST DE W1AW W1AW W1AW QST QST QST DE W1AW W1AW W1AW OB 450, OSCAR 309 AND APT 388 FOLLOW QST DE W1AW HR OFFICIAL BULLETIN NR 450 FROM ARRL HEADQUARTERS CK 92 NEWINGTON CT OCTOBER 25, 1973 TO ALL RADIO AMATEURS - NOVEMBER PRESENTS AN EXCELLENT OPPORTUNITY FOR EVERY AMATEUR TO TEST HIS FREQUENCY MEASURING SKILLS BY TAKING PART IN AN ARRL FREQUENCY MEASURING TEST. W1AW WILL TRANSMIT SIGNALS FOR MEASUREMENT ON NOVEMBER 10 AT 0230 AND 0530 GMT. THIS WILL BE THE EVENING OF NOVEMBER 9 AT 2130 EST ON APPROXIMATELY 3527 7078 AND 14079 KHZ. A SECOND SERIES OF TEST SIGNALS WILL BE TRANSMITTED THREE HOURS LATER ON ABOUT 3563 7083 AND 14072 KHZ. FULL DETAILS ON HOW TO PARTICIPATE APPEAR ON PAGE 110 OF OCTOBER QST.

Fig. D-7. Recording Session 6 Text (W1AW Bulletin).

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QST DE W1AWA1AW W1AW OB 450, OSCAR 309 AND APT 388 FOLLT E
KST QST QST DE W1AW W1AW WAWAA E TIT QST QST DE E T1AW W1AW W1AW
OB 450, OSCAR 309 AND APT 388 =THOW ES EIE QST DE W1AW HR OFFICI
AL BULLETIN NR 450 FROM ARR\=EADQUARTERS ECK 92 NEWINGTON CT OCT
OBER 25, 1973 TO ALL RADIO AMATEURS - NOVEMBER PRESENTS AN EXCEL
LENT O=NORTUN= FOR EVERYEAMATIUR TO TEST BI_ FREQUENCY MEASURING
SKILLS BY TAKING PART IT ES NRL FREQUEND M MEASURING TEST. W1AR
TILL TRANSMIT SIGNAMRE FOWMVSUREMENT ON NO=BER 10 AT 0230 MNOE05
H0 GMT. THIS W?L BE THEETVENING OF NOVEMBIR 9 AT 2130 EST ON APP
ROXIMATELY 3527 7078 AND 14079 KHZ= II E IEEOND SEI OF TEST SIGN
ALS WILL BE TRANSMITTED THREE HOURS LATER ON ABOUT 3563 7083 AND
14072 KHZ. FULL DEA=OWN= PARTICIPATE U=PVR ON PAGE 110EOFEOCTOBE
LPTST.
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Fig. D-8. Recognition Program Output for Recording Session 6.

(8 wpm)

2 4 8 4 9 I D L K R L N W QB E IH C D 4 22 5 3 IA UB X T G L

R 0 3 3 4 3 8 M B N R A T M 0 Z I 0 3 2 0 S U C I E U J Z Y W I

E J V W D Y Z B A B 4 8 516 GZO T Y A S VF QC K UX K G QN S VJP

X ES C M H C D G P F H P H 5 2 4 7 1 415 5 0 F KN P Y E MR X T 1

2 6 9 1 W V Q 0 J S U L D L 7 2 6 2 8 9 F J K H E G R Q N M X Z

W O S T P V A U Ü C A F Y C 0 7 6 1 D B G L Y E Z H K X J W R R

Q N C G V B D L X T M O F N S Y E Q Z B PE H JU A K I W O H D 1

3 0 7 6 Q Z K V S R C W M E P T X U L

(10 wpm)

E V H M X 11 3 4 0 F WIB WW 25 659 IL B ZA YFNTEEOCSP JGQGK RP

POK 25309 41687 11240 3378524996 BHFDY WCUJE IE 0PXAT QIZQ T C J

SD EHLOK MG NFR UC ZBY VWACX DWGSE FXTPR OINUH VJKYA L ZB ML 09

576 05327 DIOVS YUSEK ZMFRW AHNQX 1498 6 GJPTB 09612 COMID QFPJE

LNHRK GSBVULTZA M WHEWY PYJXE K IS G T 3478 5 XVOZA 10945

(12 wpm)

R Q ZJ T S R A I 21369 DUOCG EUNDF 02589CTPBH 30258 FWMED G

XLFE 10478HYKGC IZJHB41047JZIJA KYHIZ52136 LXGKY M WFLX 85203 NV

EMW OUDNV 63025 PTCOUQSBPT 74114 RQAQS SRARQTPBSR UOC TP VIVDU96

302 WMEVN XLFWM YGKYL ZJHYR AIJZJ BHIZICGKYH 88521 79630 DFLYG E

DMWF FENVE GCOUD HBPTC IAQSB 97410 JZRQA KYSRA 69741LXTPB 58852

MWUOC NVW

Fig. D-9. Recognition Program Output for Recording Session 7.

VITA

Joel Arthur Guenther was born on [redacted], [redacted] He graduated from high school in [redacted] and attended Newark College of Engineering from which he received the degree of Bachelor of Science in Electrical Engineering and a commission in the U.S. Air Force in 1965. He served as a Deputy Missile Combat Crew Commander and Instructor in the Minuteman II Weapon System, Malmstrom Air Force Base, from 1966 to 1969. He was then assigned as Program Manager for Minuteman I operational testing at Vandenberg Air Force Base. He entered the Air Force Institute of Technology in June 1972.

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