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MM-71 MAGNETIC HEAD/TAPE STICK-SLIP STUDY

Final Report

IITRI Project No. E6169
Contract No. 952832

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

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Prepared by

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Submitted by

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to

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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FOREWORD

This is the final report on IIT Research Institute Project No. E6169 entitled, "MM-71 Magnetic Head/Tape Stick-Slip Study." The work was performed for the Jet Propulsion Laboratory of the California Institute of Technology under Contract No. 952832. Technical direction was provided by W. W. Van Keuren. Additional guidance was provided by, among others, J. Hoffman, R. Harrington, and M. Deese.

The work was completed over a nine-month period. IITRI personnel active on the program included: M.E. Anderson, H.G. Tobin, G.S.L. Benn, R.J. Owen, R.B. Schwab, L.B. Townsend, J. Pokorny, R.N. Spangler, T.M. Scopelite, E. Swider, and W.J. Swistek. Pertinent data is recorded in logbooks numbers C19884, 19889, 20203, 20205, and 20206.

Respectfully submitted.

IIT RESEARCH INSTITUTE

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ABSTRACT

A study program was undertaken to investigate the head to tape interface problems peculiar to the special requirements of the Mariner Mars 1971 Data Storage Subsystem Tape Transport and as such contribute to the understanding of the fundamentals relating to the stick-slip phenomena. A series of tests were conducted in which the magnetic heads, magnetic tape, tape tension, wrap angle, tape speed, and number of tape passes were controlled as the basic test variables. The relationship between these tests variables and their correlation with the stick-slip phenomena was established by measuring and subsequently analyzing certain test parameters which included drag forces, dynamic tape tension, tape flutter, dropouts, and output signal characteristics. The change in value of certain test parameters with increasing number of tape passes allowed distinct patterns of performance to be extracted for certain combinations of test variables. Further analysis allowed these combinations to be ranked in order of their desiribility in minimizing the stick-slip phenomena.

Certain results which emerged from this series of tests stimulated additional activity which resulted in the generation of boundary locus that divides the disturbed from the undisturbed output signal. Further experimental and analytical work at a variety of tape speeds produced a family of boundary curves, from which a non-linear relationship was formulated between tape tension and the critical velocity at which a disturbance occurred. The results obtained are compared with previously published data and the possible explanations for differences observed outlined. The study concluded with specific recommendations for minimizing the stick-slip capability of a particular system.

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ABBREVIATIONS AND SYMBOLS

A	Head tape contact area (in^2)
D	Drag force (oz)
E_D	Dynamic modulus of elasticity
E_S	Static modulus of elasticity
F_N	Total radial force (oz)
$\overline{P}$	Total radial force per unit area ($oz\text{-}in^{-2}$)
T_0	Incoming tension (oz)
T_2	Outgoing tension (oz)
V_{CR}	Critical velocity (ips)
b	Tape thickness (in)
r	Head radius (in)
s	Tape speed (ips)
w	Tape width (in)
θ	Wrap angle (rad)
μ_g	Dynamic coefficient of friction
μ_s	Static coefficient of friction
ν	Poisson's ratio
ρ	Density

MM-71 MAGNETIC HEAD TAPE STICK-SLIP STUDY

SECTION I

INTRODUCTION

A. Program Objectives

The overall objective of this study program was to investigate the head to tape stick-slip phenomena experienced under a variety of mechanical and environmental conditions, and as such contribute to the understanding of the fundamentals relating to the stick-slip problem. This study was specifically directed towards conditions pertaining to the Mariner Mars 1971 Data Storage Subsystem Tape Transport. This directive influenced both the choice of values of test variables as well well as the specific parameters measured.

The overall program was divided into two distinct phases. During Phase I effort a series of tests were conducted in which the magnetic heads, magnetic tape, tape speed, tape tension, tape wrap angle, and the number of tape passes were controlled as the basic test variables. Required objectives during this phase were to establish the relationship between these test variables and their correlation with the stick-slip phenomenon by measuring and subsequently analyzing certain test parameters. These test parameters which included tape drag forces, static and dynamic tape tension, tape flutter, tape reproduce characteristics, and signal dropouts were chosen as they were considered to be indicative of any disturbance relating to the head to tape interface.

The main objective of the second phase of the overall program was changed from repeating a selected number of Phase I tests under a variety of environmental conditions to that of attempting to correlate what was found to be certain critical values of some test variables that would induce into the system a severe stick-slip disturbance at the head to tape interface. This change in the directive of the second phase effort was agreed upon, as the preliminary results so achieved appeared more germane to the overall understanding of the stick-slip phenomena.

Other objectives relavent to this program included the assessment of both head and tape degradation under various conditions and the general surveillance of any other factors of which it was felt that additional understanding would affect future design and minimize future difficulties.

B. Objectives Achieved and Final Results

The overall objectives of the first phase of this study program were successfully achieved in that, within the constraints of the specified test variables, distinct patterns of performance were extracted from the test data. Additional analysis allowed specific combinations of the test variables to be placed in order relating to their desirability in minimizing the stick-slip capability. From this, a qualitative assessment of each variable was possible which allowed direct comparison not only of individual variables but that of any specific combinations with regards to their desirability index.

During the second phase effort, valuable information was gained of the relationships between the basic head to tape parameters associated with interface disturbances. Of these parameters, tape speed and its correlation with signal disturbance was emphasized as some disagreement with predicted theory was experienced.

It is considered that the final results of this Magnetic Head Stick-Slip Study not only fulfilled the major program objectives in that a greater understanding of the stick-slip phenomena was generated, but that the results obtained will afford greater insight into directions required for further investigation and thereby allow design optimization of magnetic heads, tape, and transport characteristics.

C. Report Organization

The technical discussion in Section II of this report is divided into two parts. The first addresses itself to the Phase I effort where a description of the test procedures together with the signal processing techniques are outlined. This is followed by a detailed description of the results obtained during this activity, the analytical techniques used in extracting data and concludes with a matrix presentation of the final results and a qualitative assessment of the individual test variables. The second part of the technical discussion deals with the boundary disturbance investigation which was generated from certain results obtained during Phase I activity. A brief description of the procedure is followed by the results obtained. This leads to the observed relationships extracted from the data and an attempt to explain these relationships. Reference is made to relating studies and comparison are made.

The final section, Section III, summarizes the overall program and concludes with specific recommendations for minimizing the stick-slip disturbance within a specific system.

SECTION II

TECHNICAL DISCUSSION

A. Phase I

1. Test Parameters and Test Variables

During this first phase of this program a series of tests were conducted in which the magnetic heads, magnetic tape, tape speed, tape tension, tape wrap angle, and the number of tape passes were controlled as the basic test variables. During this series of tests, the following test parameters were selected and closely monitored in order to derive correlation between the test variables and the stick slip phenomenon.

- Tape drag forces
- Tape playback signal characteristics
- Flutter
- Tape tension, static and dynamic
- Tape dropouts

In addition, both tape degradation and head wear were observed throughout the program.

It was agreed that momentary measurement of the majority of the test parameters would not be representative of the head/tape interface condition. As such, in as many cases as possible, continuous measurements were made during the reproduce mode over a substantial length of the magnetic tape.

In order to monitor these parameters over an extended time period, extensive use was made of chart recorders, counters, and an instrumentation tape recorder. Such continuous records allowed average, rms, or peak-to-peak variation to be observed and logged. Continuous monitoring with an instrumentation tape recorder allowed certain critical areas of the test length to be observed and re-examined. This technique also allowed a more critical analysis of parameter variation to be made as the stored data could later be retraced at a variety of chart speeds.

The following parameter measuring techniques were therefore designed specifically to meet the test requirements described above. Extensive use was made of standard laboratory equipment available at IITRI and supplemented where necessary by JPL government furnished equipment. In addition to this standard equipment, a need for special electronic circuitry existed in order to obtain measurements of flutter and tape dropouts. This was designed using standard package electronics breadboarded and calibrated.

Tape Drag Force

The tape drag force at the head/tape interface was monitored by connecting an adapted Minnetech LVDT device to the reproduce head. Variations in the drag force resulted in the displacement of the spindle and hence an output from the linear variable differential transformer (LVDT). The output was fed via an amplifier to one channel of a chart recorder.

Signal Playback Characteristics

It had been agreed that a qualitative measurement only was required for this test parameter. As amplitude variations are considered to be the prime characteristics, the suggested procedure was to peak detect and monitor the output envelope only. This was monitored, during the reproduce mode, on one channel of a chart recorder and allowed serious amplitude variation to be observed and correlated with the other test parameters.

Flutter

The measurement of flutter at the very low tape speed experienced during the reproduce mode required the construction of a special detecting circuit. This signal processing system is shown in Fig. 1. Pre-recorded data at 3400 bpi was detected using one track of the reproduce head; this signal appeared at a frequency of 510 Hz at 0.15 inches per second and 1020 Hz at 0.30 inches per second. The reproduce head output signal was amplified, filtered, and then fed to a comparator employed as a zero crossing detector. The output of this detector drove a one shot multivibrator which in turn drove a 200 Hz low pass filter. The system functioned as a pulse type discriminator producing an output voltage proportional to input frequency, and hence providing a measurement a tape flutter over a bandwidth of DC to 200 Hz. The output of this system was fed to chart recorder and continuously recorded during the reproduce mode. The system was functional for both 0.15 and 0.30 inches per second reproduce speed without modification.

Dropouts

The monitoring of dropouts was achieved with the remainder of the signal processing circuit shown in Fig. 1. A peak level detector was used to set a flip-flop when the signal amplitude deviated below a set level, chosen at the 50% level. This inturn was gated to a counter which registered the number of times a 50% dropout level occurred. Re-setting of the flip-flop was achieved using the output from the zero crossing detector. Additional control of this system included a monitor gate which allowed dropout counting to occur only during a precise time period and not during the transport speed-up and slow-down period.

Dynamic Tension

Dynamic tension was measured continuously during the slow reproduce speeds using a Minnetech Labs, Inc. tensiometer MTM-103.

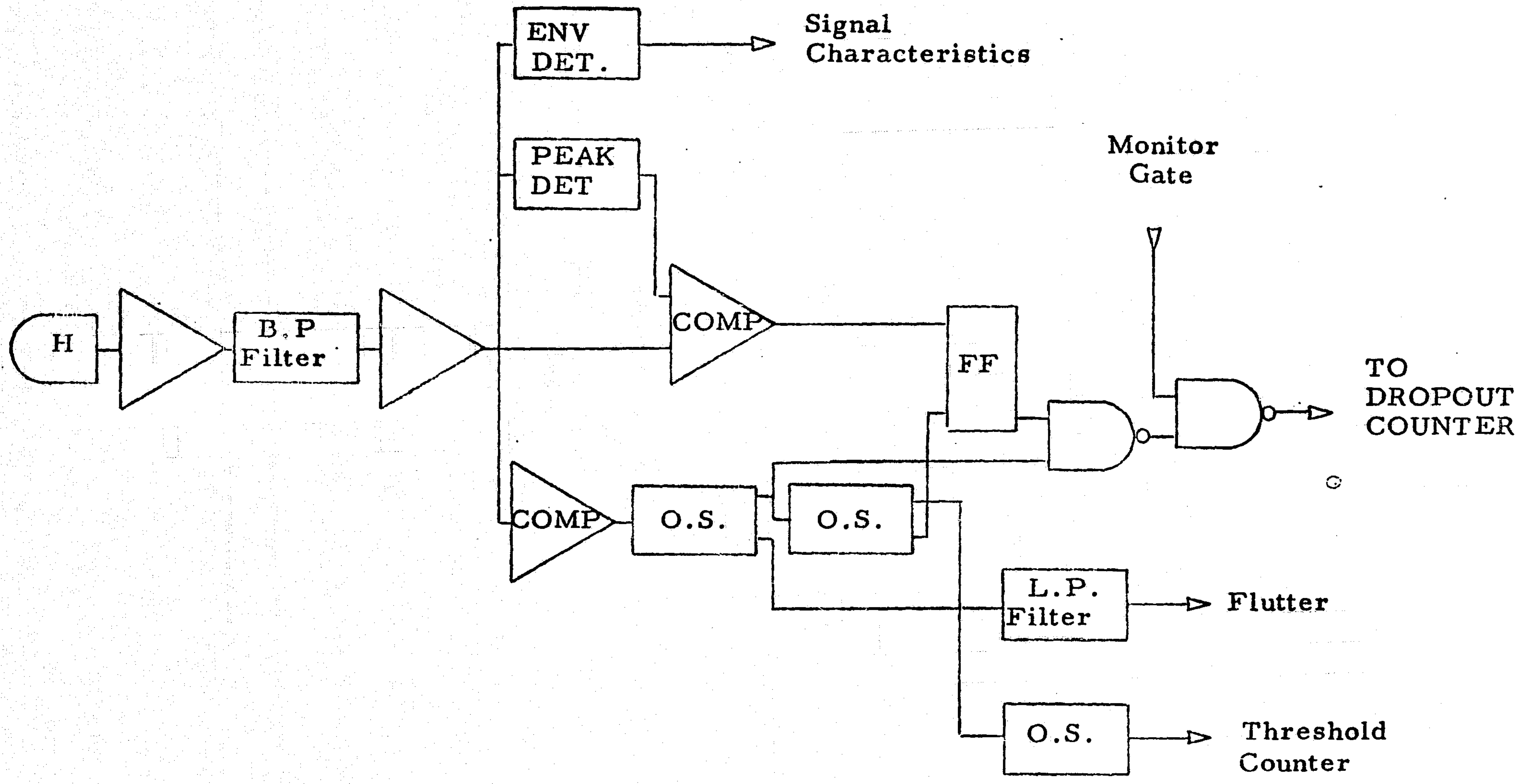


Figure 1 Block Diagram of Signal Processing Electronics

This instrument was placed in the tape path only during the reproduce mode. The output of this LVDT device was fed via an amplifier to one channel of a chart recorder. The resulting plot indicated any variations in this parameter during the reproduce period.

Automatic Control of Data Collection

In order to compress the time required to complete the large number of tests during this study it was considered advisable to automate the parameter measuring and data collection techniques as much as possible. A circuit was designed which, by detection of a pre-recorded pulse on an auxiliary head channel, allowed the measuring equipment to be automatically activated. This technique proved invaluable in ensuring that the data collected did not include any overlapped information.

The choice of the individual test variables was influenced by the desire to relate this study directly towards conditions pertaining to the Mariner Mars 1971 Data Storage Subsystem Tape Transport. The selection of each test variable was therefore made after consultation with engineers at the Jet Propulsion Laboratory. The test variables chosen were as follows:

Magnetic Recording Heads

Type A - A pair of nine track DSST mangetic recording heads with conventional permalloy pole tips mounted in brass bracket material.

Type B - A pair of nine track DSST magnetic recording heads with hard faced alfesil pole tips mounted in an aluminum bracket material.

The magnetic recording heads used throughout this program were identical to those fitted to the MM-71 DSST transport and conform to specification number 2430-A-1170.

Magnetic Tape

Type A - A half-inch wide magnetic tape chosen for its low tendency to stick-slip.

Type B - A half-inch wide magnetic tape chosen for its high tendency to stick-slip.

The selection of the above two magnetic tapes was made to include not only the tape to be used during the proposed Mariner Mars 1971 Mission (tape A) but a tape type that previous tests had indicated would have a high tendency to stick-slip. It was considered that the use of such a magnetic tape would allow greater ease in attempting to relate specific parameters to the stick-slip phenomena.

Tension/Wrap Angle Combination

1. 7 oz with 5° wrap
2. 7 oz with 8° wrap
3. 12 oz with 8° wrap

Selection of these three combinations of tension and wrap angle allowed conditions similar to those used on the DSST to be investigated. The three combinations also allowed either a change in wrap angle or a change in tension to be examined separately while the combinations resulted in the three different levels of total radial force experienced at the head/tape interface.

Tape Speed

1. Reproduce speed of 0.15 inches per second
2. Reproduce speed of 0.30 inches per second

These two reproduce speeds were chosen as they represent the two lowest playback speeds that will be used during the Mariner Mars 1971 mission.

Tape Passes

A maximum of 2,000 tape passes, measurements were made in ten discrete steps, namely; 8, 20, 40, 60, 100, 200, 400, 800, 1400, 2000

A total of 2,000 running tape passes at a slew speed of 19.4 inches per second was considered to be comparable to mission life and adequate enough to determine any specific trends. The ten discrete testing steps were chosen to allow both short term and long term changes to be investigated.

These test variables were grouped together so as to give twelve combinations of head, tape, and tension/wrap angle as shown in Table I.

2. Test Procedure

Two identical endless loop tape transports were run in parallel during this phase in order to compress the actual testing time (Fig. 2). As the magnetic heads were considered to be the more difficult of the test variables to change, a different head set was mounted to each of these endless loop transports. Prior to mounting on their specified transports the heads were examined using a surface finish profilometer in order to achieve a datum for subsequent wear measurements.

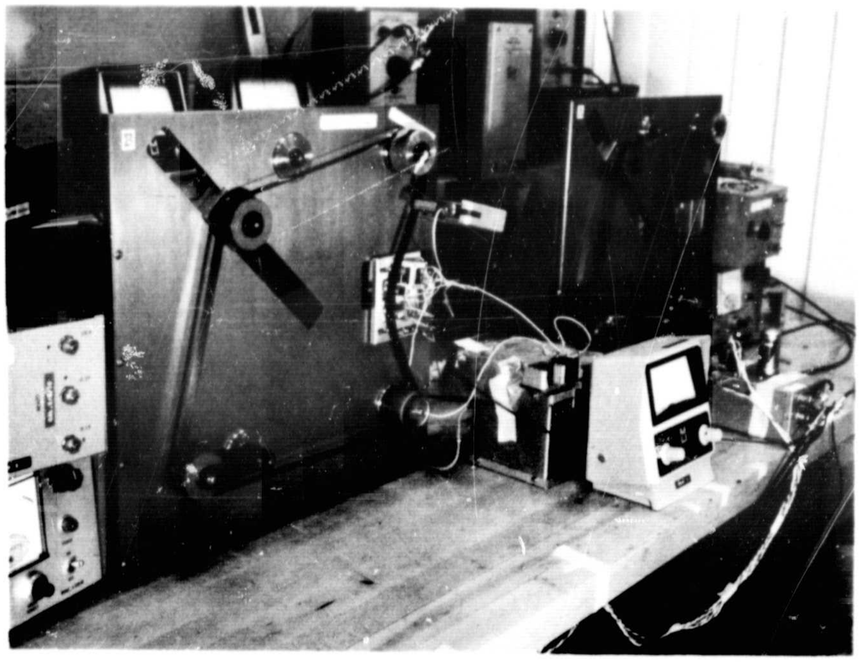
A. A suitable length of tape between 4-5 feet long was cut from a selected reel of tape and after splicing (with a Prestoseal thermal splicer, Model 450) placed on to a loop tape transport.

B. A set of conditions of wrap angle and tension were specified and adjusted accordingly. Static tension was measured using a Minnetech tensiometer which was then removed from the tape path.

Table I

COMBINATION OF TEST VARIABLES

Test No.	Wrap	Tension	Head Type	Tape Type
1	8°	7 oz	Soft	TAPE A
2	8°	12 oz	Faced	
3	5°	7 oz	Heads	
4	8°	7 oz	Hard	
5	8°	12 oz	Faced	
6	5°	7 oz	Heads	
7	8°	7 oz	Soft	TAPE B
8	8°	12 oz	Faced	
9	5°	7 oz	Heads	
10	8°	7 oz	Hard	
11	8°	12 oz	Faced	
12	5°	7 oz	Heads	



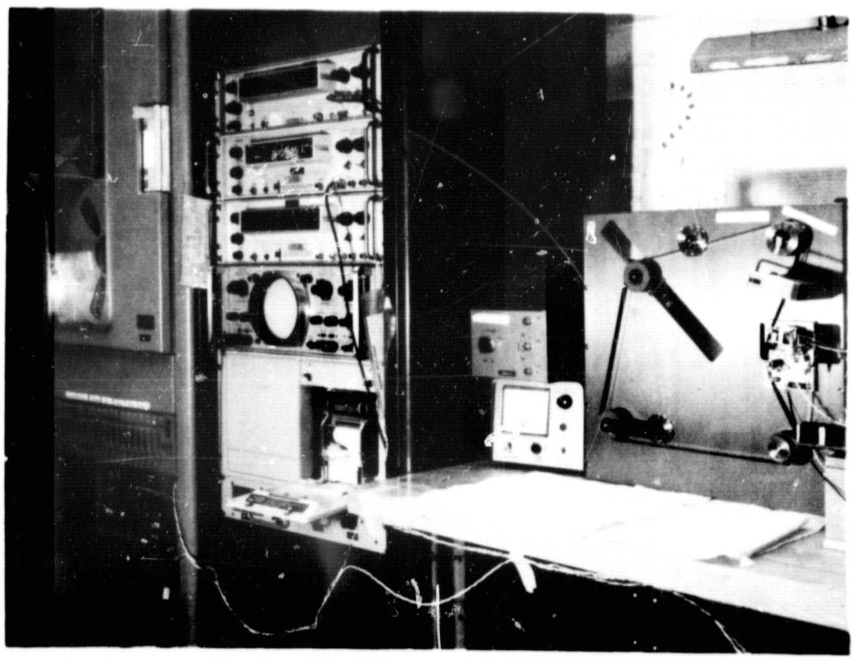


Fig. 2 ENDLESS LOOP TAPE TRANSPORTS
AND AUXILLIARY TEST EQUIPMENT

C. A tape speed of 19.4 inches per second was selected and several channels of C.W. information recorded onto the tape at a packing density of 3400 bpi. The recorded information was gated to the head to ensure that the signals were not over-recorded and did not cover the spliced area of tape.

D. This recorded tape was then passed over the head system for an initial number of tape passes (8) and the tape stopped.

E. A tensiometer was then placed in the tape path in between the reproduce head and the drive capstan. It is in this position that the most meaningful information of tension is achieved.

F. A transport tape speed of 0.15 inches per second was then selected and one pass only made across the head assembly.

G. At this time, measurement of flutter, dropouts, dynamic tension, tape drag forces, and signal characteristics were made during approximately 6.0 minutes required for one complete pass.

H. A tape speed of 0.30 inches was then selected and one additional pass made. During which time the five test parameters were again measured.

I. The tape was stopped, the tensiometer removed, and a tape speed of 19.4 inches per second reselected.

J. The recorded tape was again passed over the head system for an additional number of passes and then stopped.

K. Paragraphs E and J were then repeated in order, upto a maximum of 2,000 tape passes in ten discrete steps.

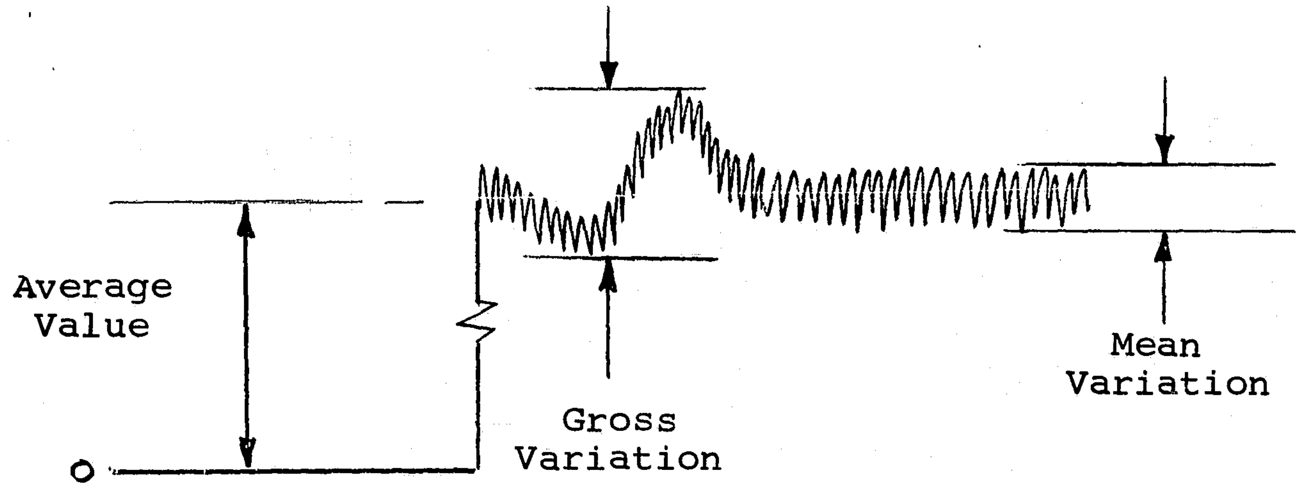
L. At the end of this specific test the tape was removed from the machine and stored for a visual examination of wear and degradation. The head assembly was visually inspected, cleaned, and submitted for a profilometer surface finish measurement.

M. The head assembly was then remounted and paragraphs A through L repeated for a new set of conditions with the same tape type.

N. Following the completion of all tests for this tape type, the heads were refurbished to their original front face surface condition and Paragraphs A through M repeated for the second tape type.

3. Test Results

Actual data acquisition during the first phase resulted in continuous chart from recording of the major test parameters. Analysis of these analog results consisted of digitizing the complex signal waveforms of each test by extracting average values, mean deviations, and gross deviations for each of the test variables. These terms are defined as follows:



Average Value	-	The average dynamic value of the measured parameter for one complete tape pass.
Mean Variation	-	The short term (high frequency) variation about the average value expressed as a peak-to-peak value.
Gross Variation	-	The long term (low frequency) variation for one complete pass, expressed as a peak-to-peak variation by subtracting the lowest value from the highest value during that test.

In displaying the results, emphasis has been placed on the low speed tests (0.15 ips) as the preliminary analysis indicated that an increase in speed simply delays the production of the stick-slip phenomena. This relationship with speed is amplified during the Phase II technical discussion where a variety of reproduce tape speeds were examined.

The overall test results displayed in the section are for simplicity divided as follows. The first part tabulates the actual data extracted from the chart recordings. The second (Figs. 3-8) graphically displays some of the more interesting relationships of the test parameters with number of tape passes. The third (Figs. 9-14) summarizes the overall results by showing typical trends observed from the plotted data, categorizes the 12 basic test combinations and illustrates the method used for ranking individual tests. The fourth part displays the 12 combinations in a tabular form to which a desirability index for individual variables has been assigned, and concludes with a comparison of the test variables.

a. Result Tabulation

TEST NO. 1

Head Type = A   Wrap Angle = 8°   Tape Speed = 0.15 ips

Tape Type = A   Tension = 7 oz   Initial Passes = 25

PARAMETER			NUMBER OF PASSES: 0	8	20	40	60	100	200	400	800	1400	2000
Tension	Average	oz	8.0	8.0	8.3	8.8	8.2	9.0	9.5	9.5	9.6	10.5	9.9
	Mean	oz	0.74	0.81	0.81	0.96	0.59	0.74	0.89	0.89	0.74	0.74	0.67
	Gross	oz	1.26	1.29	1.63	2.0	1.33	2.06	2.37	1.92	1.48	1.48	1.11
Drag	Average	oz	1.63	1.87	2.23	2.22	1.76	2.59	3.11	3.60	3.36	3.51	3.51
	Mean	oz	0.13	0.15	0.18	0.31	0.13	0.18	0.24	0.23	0.20	0.18	0.20
	Gross	oz	0.40	0.60	0.72	1.28	0.35	1.18	1.57	0.91	0.69	0.57	0.42
Envelope	Average	mv	1750	1800	1650	1700	1750	1770	1750	1750	1750	1800	1600
		db	0.26	0.0	0.77	0.8	0.26	0.15	0.15	0.26	0.26	0.0	1.0
	Mean	mv	300	400	400	420	300	300	350	400	350	350	400
Dropouts	Total		652	502	581	823	767	—	208	543	325	143	155
	$\frac{1}{2}$ Count		474	410	354	690	433	304	192	506	223	139	155
Flutter		mv	500	650	650	775	550	525	550	525	500	600	625
Tension	T_o	oz	6.37	6.13	6.09	6.58	6.44	6.44	6.36	5.87	6.20	6.99	6.34
Friction	μ		0.91	1.09	1.31	1.20	0.98	1.44	1.75	2.19	1.94	1.79	1.98

Torque (Start) = 6.0 oz   Average T_o Value = 6.35 oz   Temperature = 84°F

Torque (End) = 4.5 oz $Drag_{2k}/Drag_o$ = 2.16   Relative Humidity = 25%

TEST NO. 2

Head Type = A   Wrap Angle = 8°   Tape Speed = 0.15 ips

Tape Type = A   Tension = 12 oz   Initial Passes = 35

NUMBER OF PASSES

PARAMETER			0	8	20	40	60	100	200	400	800	1400	2000
Tension	Average	oz	12.5	12.7	13.4	13.1	13.3	13.4	13.9	14.2	14.3	14.7	15.5
	Mean	oz	0.45	0.38	0.45	0.45	0.56	0.45	0.45	0.45	0.45	0.56	0.56
	Gross	oz	1.56	1.45	1.67	1.67	1.67	1.67	1.22	1.11	1.0	1.11	1.22
Drag	Average	oz	2.0	2.36	2.43	3.06	3.2	3.35	4.0	3.9	4.03	4.82	5.62
	Mean	oz	0.22	0.22	0.26	0.25	0.29	0.22	0.22	0.18	0.2	0.22	0.31
	Gross	oz	0.79	1.2	1.47	1.03	1.15	1.2	0.9	0.6	0.6	0.66	0.83
Envelope	Average	mv	1950	1900	1950	1850	1750	1700	1250	1300	1050	1000	650
		db	0.0	0.2	0.0	0.46	0.94	1.2	3.87	3.52	5.38	5.8	9.54
	Mean	mv	300	250	350	350	350	400	500	500	500	550	400
Dropouts	Total		1388	509	330	394	4498	769	737	1590	687	1281	14k
	$\frac{1}{2}$ Count		143	114	139	110	106	190	325	1024	473	300	11k
Flutter		mv	600	550	575	600	600	625	550	630	725	625	600
Tension	T_o	oz	10.5	10.3	10.9	10.0	10.1	10.0	9.9	10.3	10.3	9.88	9.88
Friction	μ		0.68	0.82	0.79	1.09	1.13	1.19	1.44	1.35	1.40	1.74	2.03

Torque (Start) = 5.5 oz   Average T_o Value = 10.2 oz   Temperature = 85°F

Torque (End) = 4.5 oz $Drag_{2k}/Drag_o$ = 2.81   Relative Humidity = 30%

TEST NO. 3

Head Type = A   Wrap Angle = 5°   Tape Speed = 0.15 ips

Tape Type = A   Tension = 7 oz   Initial Passes = 25

NUMBER OF PASSES

PARAMETER			0	8	20	40	60	100	200	400	800	1400	2000
Tension	Average	oz	7.35	7.55	7.7	7.6	7.7	7.5	7.75	8.35	8.46	8.7	8.6
	Mean	oz	0.45	0.56	0.45	0.45	0.45	0.45	0.67	0.78	0.78	0.67	0.67
	Gross	oz	0.67	0.67	0.67	0.67	0.56	0.67	0.78	1.11	1.22	0.78	0.89
Drag	Average	oz	0.63	0.69	0.72	0.74	0.8	0.9	1.11	1.9	2.08	2.16	1.94
	Mean	oz	0.12	0.12	0.12	0.12	0.14	0.13	0.17	0.27	0.24	0.22	0.18
	Gross	oz	0.13	0.29	0.34	0.27	0.23	0.24	0.28	0.45	0.73	0.51	0.46
Envelope	Average	mv	950	950	900	1000	1000	1000	1000	950	900	1000	1000
		db	0.4	0.4	0.9	0.0	0.0	0.0	0.0	0.4	0.9	0.4	0.4
	Mean	mv	500	600	500	650	550	550	650	600	550	550	600
Dropouts	Total		739	508	961	668	360	338	1486	158	183	390	316
	$\frac{1}{2}$ Count		323	389	543	276	185	122	74	49	77	131	211
Flutter		mv	750	775	750	750	750	750	800	800	750	775	800
Tension	T_o	oz	6.72	6.86	6.98	6.86	6.90	6.6	6.64	6.45	6.38	6.54	6.66
Friction	μ		0.55	0.59	0.61	0.63	0.68	0.80	0.98	1.73	1.42	1.94	1.71

Torque (Start) = 5.5 oz   Average T_o Value = 6.69 oz   Temperature = 83°F

Torque (End) = 4.5 oz $Drag_{2k}/Drag_o$ = 1.5   Relative Humidity = 31%

TEST NO. 4

Head Type = B   Wrap Angle = 8°   Tape Speed = 0.15 ips
Tape Type = A   Tension = 7 oz   Initial Passes = 50

NUMBER OF PASSES

PARAMETER			0	8	20	40	60	100	200	400	800	1400	2000
Tension	Average	oz	6.9	7.12	7.12	7.12	7.12	7.12	7.12	7.12	7.35	7.35	7.35
	Mean	oz	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
	Gross	oz	0.45	0.45	0.45	0.67	0.90	0.67	0.90	0.67	0.67	0.45	0.67
Drag	Average	oz	0.60	0.68	0.72	0.81	0.84	0.92	0.99	0.97	0.98	1.00	1.00
	Mean	oz	0.04	0.04	0.04	0.06	0.04	0.06	0.07	0.06	0.06	0.06	0.06
	Gross	oz	0.07	0.09	0.09	0.09	0.13	0.17	0.17	0.15	0.11	0.09	0.09
Envelope	Average	mv	1600	1500	1450	1400	1450	1350	1300	1350	1300	1250	1200
		db	0.0	0.56	0.86	1.16	0.86	1.48	1.8	1.48	1.8	2.15	2.5
	Mean	mv	400	400	500	400	450	400	450	400	450	450	450
Dropouts	Total		262	23	202	287	73	294	51	293	167	207	418
	$\frac{1}{2}$ Count		0	0	9	107	3	3	2	5	63	2	8
Flutter		mv	800	750	800	725	775	800	750	775	758	775	750
Tension	T_o	oz	6.3	6.4	6.4	6.31	6.28	6.2	6.13	6.15	6.37	6.35	6.35
Friction	μ		0.34	0.38	0.40	0.46	0.48	0.53	0.58	0.56	0.55	0.56	0.56

Torque (Start) = 4.0 oz   Average T_o Value = 6.3 oz   Temperature = 84°F
Torque (End) = 4.2 oz $Drag_{2k}/Drag_o$ = 1.66   Relative Humidity = 30%

TEST NO. 5

Head Type = B Wrap Angle = 8° Tape Speed = 0.15 ips

Tape Type = A Tension = 12 oz Initial Passes = 10

NUMBER OF PASSES

PARAMETER			0	8	20	40	60	100	200	400	800	1400	2000
Tension	Average	oz	12.5	12.5	12.5	12.7	12.7	12.9	13.1	12.9	1.33	1.33	1.33
	Mean	oz	0.33	0.45	0.33	0.45	0.45	0.45	0.33	0.45	0.45	0.45	0.45
	Gross	oz	0.45	0.68	0.68	0.68	0.68	0.68	0.68	0.90	0.90	0.90	0.68
Drag	Average	oz	0.91	0.96	1.05	1.18	1.27	1.30	1.52	1.50	1.72	1.63	1.65
	Mean	oz	0.03	0.04	0.06	0.07	0.09	0.07	0.07	0.07	0.06	0.06	0.06
	Gross	oz	0.07	0.12	0.22	0.22	0.37	0.28	0.22	0.31	0.32	0.26	0.38
Envelope	Average	mv	1700	1600	1600	1600	1500	1500	1500	1200	1100	800	800
		db	0.0	0.53	0.53	0.53	1.09	1.09	1.09	3.03	3.78	6.56	6.56
	Mean	mv	500	500	500	600	600	600	500	500	600	500	500
Dropouts	Total		205	468	407	441	350	392	538	766	677	4643	4166
	$\frac{1}{2}$ Count		9	1	7	3	0	3	15	32	34	1664	1304
Flutter		mv	850	650	750	750	750	700	800	775	750	775	700
Tension	T_o	oz	11.5	11.5	11.4	11.5	11.4	11.6	11.6	11.4	11.6	11.7	11.7
Friction	μ		0.28	0.30	0.33	0.37	0.40	0.40	0.47	0.47	0.53	0.53	0.51

Torque (Start) = 7.0 oz Average T_o Value = 11.5 oz Temperature = 84°F

Torque (End) = 8.0 oz $Drag_{2k}/Drag_o$ = 1.81 Relative Humidity = 30%

TEST NO. 6

Head Type = B Wrap Angle = 5° Tape Speed = 0.15 ips

Tape Type = A Tension = 7 oz Initial Passes = 20

NUMBER OF PASSES

PARAMETER			0	8	20	40	60	100	200	400	800	1400	2000
Tension	Average	oz	7.34	7.28	7.34	7.34	7.34	7.34	7.34	7.12	7.12	7.12	7.12
	Mean	oz	0.33	0.44	0.44	0.44	0.44	0.44	0.44	0.33	0.44	0.44	0.44
	Gross	oz	0.33	0.44	0.66	0.56	0.56	0.44	0.44	0.44	0.44	0.44	0.44
Drag	Average	oz	0.5	0.5	0.5	0.52	0.56	0.58	0.57	0.50	0.62	0.62	0.58
	Mean	oz	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	Gross	oz	0.04	0.04	0.06	0.04	0.06	0.04	0.04	0.04	0.07	0.04	0.04
Envelope	Average	mv	1600	1500	1500	1500	1500	1500	1400	1500	1400	1300	1300
		db	0.0	0.56	0.56	0.56	0.56	0.56	1.16	0.56	1.16	1.8	1.8
	Mean	mv	600	600	600	600	500	500	600	400	500	600	600
Dropouts	Total		274	121	252	351	209	185	362	232	237	733	442
	$\frac{1}{2}$ Count		76	93	2	17	14	13	86	14	90	8	77
Flutter		mv	800	800	850	800	800	750	800	800	750	750	750
Tension	T_o	oz	6.84	6.78	6.84	6.82	6.78	6.76	6.77	6.62	6.50	6.50	6.54
Friction	μ		0.43	0.43	0.43	0.45	0.49	0.50	0.50	0.44	0.56	0.56	0.52

Torque (Start) = 4.9 oz Average T_o Value = 6.70 oz Temperature = 84°F

Torque (End) = 5.3 oz $Drag_{2k}/Drag$ = 1.16 Relative Humidity = 23%

TEST NO. 7

Head Type = A Wrap Angle = 8° Tape Speed = 0.15 ips
Tape Type = B Tension = 7 oz Initial Passes = 20

NUMBER OF PASSES

PARAMETER			0	8	20	40	60	100	200	400	800	1400	2000
Tension	Average	oz	6.7	7.1	6.7	7.1	7.1	7.1	7.6	7.6	7.6	8.4	8.4
	Mean	oz	0.88	0.88	0.66	0.66	0.66	0.88	0.66	0.66	0.66	0.66	0.66
	Gross	oz	0.88	0.88	0.66	0.88	0.88	0.88	0.66	0.66	0.66	0.66	0.66
Drag	Average	oz	0.79	0.83	0.92	0.97	0.99	0.99	1.08	1.20	1.46	1.91	2.10
	Mean	oz	0.08	0.09	0.08	0.09	0.09	0.11	0.15	0.23	0.41	0.60	0.71
	Gross	oz	0.11	0.11	0.11	0.11	0.17	0.15	0.26	0.34	0.52	0.86	0.97
Envelope	Average	mv	1600	1600	1600	1650	1700	1700	1700	1650	1500	1450	1450
		db	0.53	0.53	0.53	0.25	0.0	0.0	0.0	0.25	1.09	1.39	1.39
	Mean	mv	700	800	800	900	900	1200	1200	1300	1400	1300	1300
Dropouts	Total		130	462	2410	6265	9075	14k	20k	22k	37k	42k	42k
	$\frac{1}{2}$ Count		126	223	756	2203	3072	5525	8.5k	8.8	17k	20k	20k
Flutter		mv	925	1050	1100	1100	1150	1250	1250	1600	1700	1850	1900
Tension	T_o	oz	5.91	6.27	5.7	6.13	6.1	6.1	6.5	6.4	6.14	6.48	6.3
Friction	μ		0.48	0.47	0.58	0.57	0.58	0.58	0.60	0.67	0.85	1.05	1.2

Torque (Start) = 2.8 oz Average T_o Value = 6.2 oz Temperature = 81°F
Torque (End) = 2.0 oz $Drag_{2k}/Drag_o$ = 2.66 Relative Humidity = 25%

TEST NO. 8

Head Type = A Wrap Angle = 8° Tape Speed = 0.15 ips

Tape Type = B Tension = 12 oz Initial Passes = 20

NUMBER OF PASSES

PARAMETER			0	8	20	40	60	100	200	400	800	1400	2000
Tension	Average	oz	12.0	12.2	12.2	12.0	12.5	12.2	12.7	13.1	13.6	13.8	13.8
	Mean	oz	0.45	0.45	0.90	0.90	0.94	0.94	1.35	1.35	1.88	2.7	2.13
	Gross	oz	0.45	0.22	0.90	0.90	1.11	1.55	1.80	1.84	2.10	1.96	2.74
Drag	Average	oz	1.65	1.76	1.80	1.91	1.95	2.10	2.36	2.85	3.25	3.64	3.54
	Mean	oz	0.03	0.03	0.15	0.15	0.23	0.30	0.49	0.90	1.72	2.68	2.30
	Gross	oz	0.03	0.08	0.19	0.26	0.34	0.49	1.24	1.28	2.49	3.25	2.68
Envelope	Average	mv	1200	1350	1350	1350	1350	1400	1350	1400	1300	1200	1200
		db	1.34	0.31	0.31	0.31	0.0	0.31	0.31	0.0	0.66	1.34	1.34
	Mean	mv	500	800	1100	1100	1100	1200	1200	1300	1400	1400	1400
Dropouts	Total		93	3400	11k	25k	34k	42k	46k	44k	53k	55k	58k
	$\frac{1}{2}$ Count		8	1500	5500	11k	14k	19k	20k	21k	27k	27k	28k
Flutter		mv	750	1150	1300	1350	1550	1700	1600	1700	1550	1550	1550
Tension	T_o	oz	10.4	10.4	10.4	10.1	10.6	10.1	10.3	10.3	10.4	10.2	10.3
Friction	μ		0.57	0.60	0.62	0.68	0.66	0.74	0.82	0.99	1.12	1.27	1.23

Torque (Start) = 3.5 oz Average T_o Value = 10.3 oz Temperature = 80°F

Torque (End) = 2.5 oz $Drag_{2k}/Drag_o$ = 2.14 Relative Humidity = 24%

TEST NO. 9

Head Type = A   Wrap Angle = 5°   Tape Speed = 0.15 ips
Tape Type = B   Tension = 12 oz   Initial Passes = 20

NUMBER OF PASSES

PARAMETER			0	8	20	40	60	100	200	400	800	1400	2000
Tension	Average	oz	6.90	7.12	7.12	7.12	7.12	7.24	7.24	7.24	7.35	7.56	7.79
	Mean	oz	.556	.556	.556	.556	.556	.45	.556	.556	.90	.90	1.11
	Gross		.779	.779	.90	.668	.779	.668	.779	.90	1.00	1.34	1.56
Drag	Average	oz	0.63	0.69	0.78	0.80	0.80	0.84	0.92	1.04	1.14	1.25	1.29
	Mean	oz	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.06	0.08	0.13	0.30
	Gross	oz	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.11	0.15	0.23	0.45
Envelope	Average	mv	1400	1400	1450	1500	1500	1500	1600	1600	1600	1450	1400
		db	1.16	1.16	0.86	0.56	0.56	0.56	0.0	0.0	0.0	0.86	1.16
	Mean	mv	400	350	400	350	350	300	400	650	800	1050	1100
Dropouts	Total		320	408	434	298	262	403	338	3k	2k	9k	45k
	$\frac{1}{2}$ Count		133	283	292	186	163	159	238	2k	1k	4k	22k
Flutter		mv	750	750	775	775	825	800	825	1100	1100	1350	1650
Tension	T_o	oz	6.27	6.4	6.3	6.3	6.3	6.4	6.3	6.23	6.2	6.3	6.5
Friction	μ		0.59	0.63	0.73	0.75	0.75	0.77	0.85	0.95	1.08	1.17	1.17

Torque (Start) = 2.4 oz   Average T_o Value = 6.33 oz   Temperature = 82°F
Torque (End) = 2.0 oz $Drag_{2k}/Drag_o$ = 2.05   Relative Humidity = 25%

TEST NO. 10

Head Type = B Wrap Angle = 8° Tape Speed = 0.15 ips
Tape Type = B Tension = 7 oz Initial Passes = 20

			NUMBER OF PASSES										
PARAMETER			0	8	20	40	60	100	200	400	800	1400	2000
Tension	Average	oz	7.2	7.1	7.3	7.1	7.1	7.3	7.3	7.3	7.6	8.0	8.0
	Mean	oz	0.53	0.53	0.55	0.45	0.45	0.67	0.67	0.89	1.33	1.56	1.33
	Gross	oz	0.89	0.67	0.67	0.67	0.67	0.89	0.67	0.89	1.33	1.56	1.33
Drag	Average	oz	0.93	1.0	0.96	0.91	1.0	0.97	1.09	1.17	1.46	1.97	1.61
	Mean	oz	0.03	0.03	0.03	0.03	0.03	0.03	0.06	0.06	0.18	0.26	0.22
	Gross	oz	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.18	0.26	0.29	0.29
Envelope	Average	mv	1250	1250	1200	1200	1250	1250	1200	1200	1200	1200	1200
		db	0.0	0.0	0.36	0.36	0.0	0.36	0.36	0.36	0.36	0.36	0.36
	Mean	mv	550	500	450	700	600	800	800	1200	1200	1200	1200
Dropouts	Total		954	932	770	571	495	633	728	7119	35k	30k	30k
	$\frac{1}{2}$ Count		240	356	380	259	218	252	187	3887	16k	15k	15k
Flutter		mv	850	875	800	850	850	900	1000	1250	1750	1900	1750
Tension	T_o	oz	6.3	6.1	6.34	6.2	6.1	6.3	6.2	6.1	6.14	6.0	6.4
Friction	μ		0.53	0.59	0.54	0.52	0.59	0.55	0.63	0.69	0.85	1.17	0.90

Torque (Start) = 2.2 oz Average T_o Value = 6.2 oz Temperature = 80°F
Torque (End) = 1.8 oz $Drag_{2k}/Drag_o$ = 1.73 Relative Humidity = 22%

TEST NO. 11

Head Type = B Wrap Angle = 8° Tape Speed = 0.15 ips

Tape Type = B Tension = 12 oz Initial Passes = 20

PARAMETER			0	8	20	40	60	100	200	400	800	1400	2000
			NUMBER OF PASSES										
Tension	Average	oz	12.0	12.0	12.0	12.3	12.5	12.5	12.0	12.3	12.9	13.1	13.1
	Mean	oz	0.90	0.90	0.90	1.11	0.90	1.35	1.11	1.11	1.35	2.01	1.56
	Gross	oz	0.90	0.90	0.90	1.11	0.90	1.35	1.11	1.11	1.35	2.01	1.56
Drag	Average	oz	1.84	1.88	1.91	2.06	1.99	2.21	2.47	2.51	2.85	3.15	3.22
	Mean	oz	0.04	0.08	0.11	0.11	0.08	0.34	0.41	0.56	1.05	1.35	1.35
	Gross	oz	0.08	0.08	0.11	0.15	0.08	0.38	0.49	0.71	1.28	1.5	1.58
Envelope	Average	mv	1400	1400	1350	1400	1450	1450	1400	1300	1150	1050	1950
		db	500	1000	1000	1100	1300	1200	1100	1200	1200	1100	1200
	Mean	mv	900	1400	1300	1500	1100	1400	1400	1500	1300	1400	1300
Dropouts	Total		3	861	6700	12k	24k	44k	52k	57k	73k	82k	88k
	$\frac{1}{2}$ Count		3	212	2900	5400	11k	21k	24k	26k	34k	38k	41k
Flutter		mv	800	1150	1200	1200	1400	1600	1650	1600	1500	1400	1450
Tension	T_o	oz	10.2	10.1	10.1	10.2	10.5	10.3	9.5	9.8	10.1	10.0	9.9
Friction	μ		0.64	0.66	0.68	0.72	0.68	0.77	0.93	0.91	1.01	1.13	1.16

Torque (Start) = 3.0 oz Average T_o Value = 10.1 oz Temperature = 85°F

Torque (End) = 2.4 oz $Drag_{2k}/Drag$ = 1.75 Relative Humidity = 34%

TEST NO. 12

Head Type = B Wrap Angle = 5° Tape Speed = 0.15 ips

Tape Type = B Tension = 7 oz Initial Passes = 20

NUMBER OF PASSES

PARAMETER			0	8	20	40	60	100	200	400	800	1400	2000
Tension	Average	oz	7.35	7.35	7.46	7.46	7.46	7.57	7.57	7.68	7.91	7.91	7.91
	Mean	oz	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.55	0.78	0.67	0.67
	Gross	oz	0.78	0.78	0.78	0.89	0.89	0.89	0.89	0.78	1.00	0.89	1.00
Drag	Average	oz	0.71	0.73	0.77	0.79	0.81	0.81	0.84	0.92	0.98	1.10	1.16
	Mean	oz	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.06	0.06
	Gross	oz	0.06	0.06	0.08	0.06	0.06	0.08	0.08	0.08	0.08	0.08	0.09
Envelope	Average	mv	1500	1500	1500	1450	1450	1450	1400	1400	1400	1350	1400
		db	0	0	0	0.3	0.3	0.3	0.3	0.6	0.6	0.9	0.6
	Mean	mv	400	400	450	450	400	400	500	500	600	500	400
Dropouts	Total		231	146	132	194	122	27	145	453	391	211	168
	$\frac{1}{2}$ Count		46	19	23	72	13	175	37	72	164	47	17
Flutter		mv	775	750	775	750	800	800	850	1000	1050	975	925
Tension	T_o	oz	6.6	6.6	6.69	6.67	6.65	6.76	6.72	6.76	6.94	6.8	6.75
Friction	μ		0.64	0.65	0.68	0.69	0.71	0.70	0.74	0.80	0.83	0.96	1.01

Torque (Start) = 2.2 oz Average T_o Value = 6.73 oz Temperature = 83°F

Torque (End) = 2.0 oz $Drag_{2k}/Drag_o$ = 1.63 Relative Humidity = 34%

b. Relationships between Test Parameters and Number of Tape Passes (Figs. 3-8)

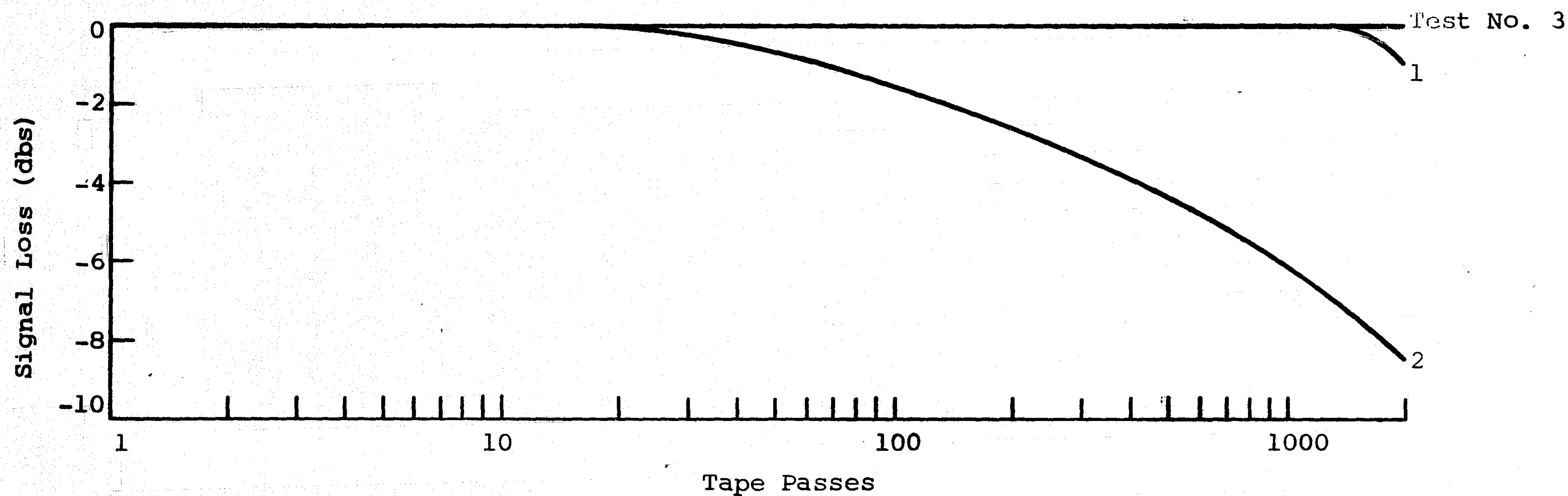


Fig. 3a AVERAGE VALUE OF OUTPUT ENVELOPE AGAINST NUMBER OF TAPE PASSES AT A REPRODUCE SPEED OF 0.15 INCHES PER SECOND

Tape type A Test No. 1, 2 & 3

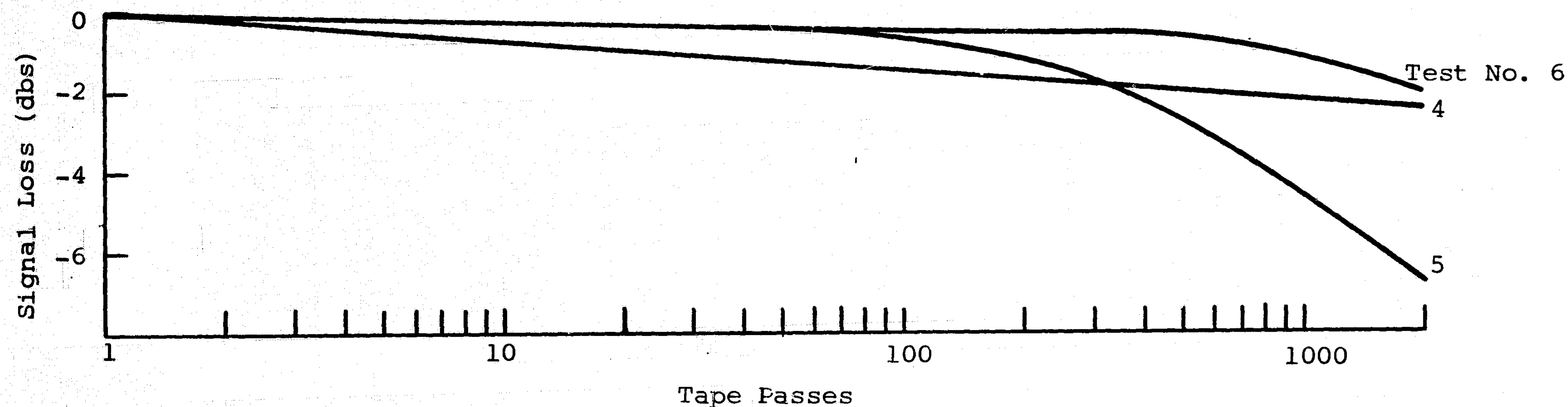


Fig. 3b AVERAGE VALUE OF OUTPUT ENVELOPE AGAINST NUMBER OF TAPE PASSES AT A REPRODUCE SPEED OF 0.15 INCHES PER SECOND

Tape type A Test No. 4, 5, & 6

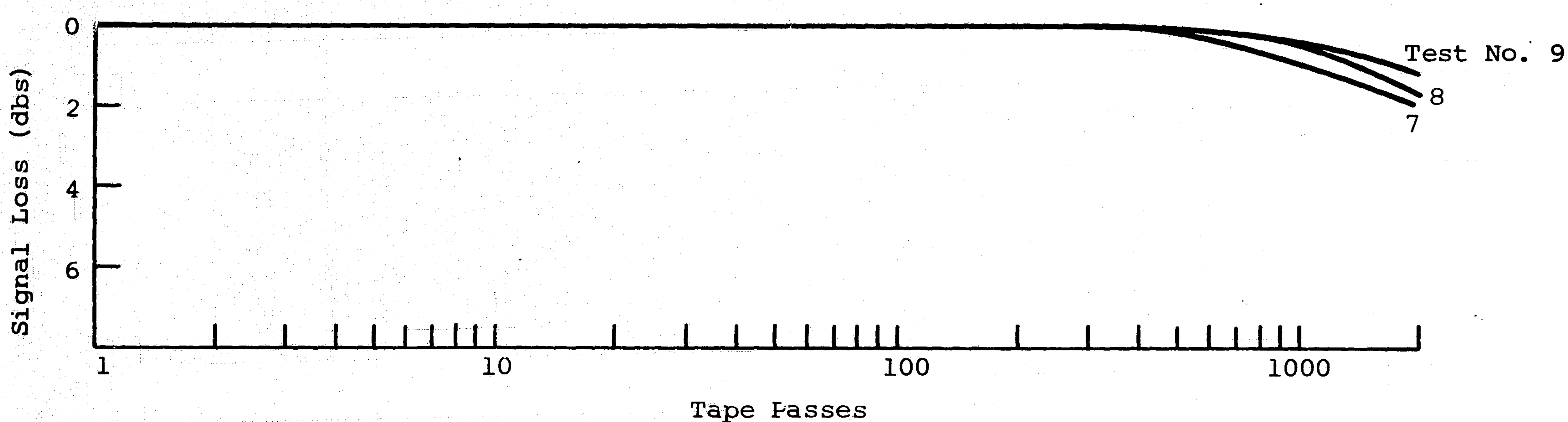


Fig. 3c AVERAGE VALUE OF OUTPUT ENVELOPE AGAINST NUMBER OF TAPE PASSES AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

Tape Type B Test No. 7, 8, & 9

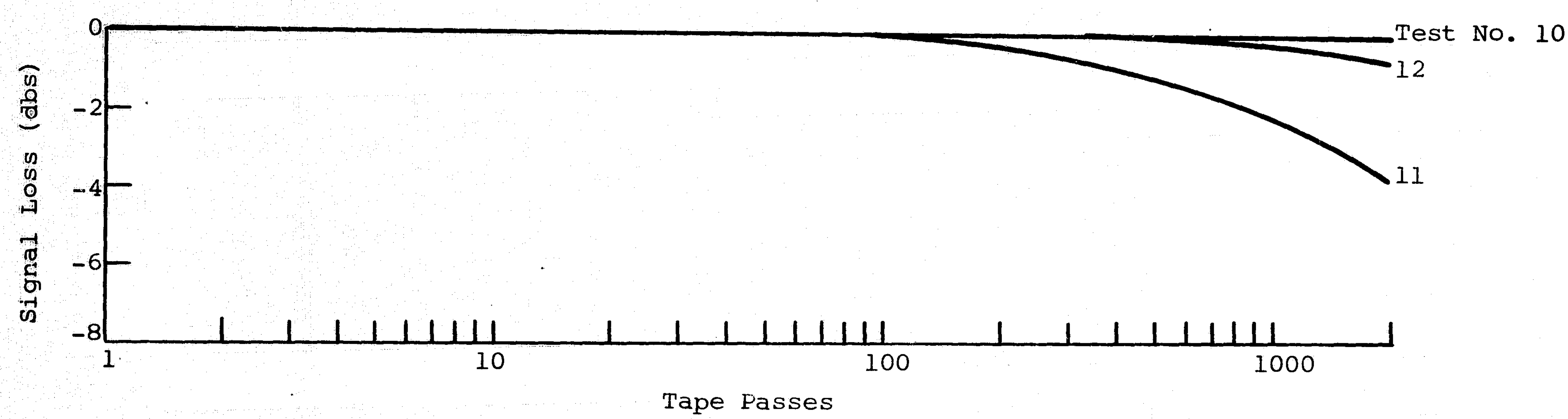


Fig. 3d AVERAGE VALUE OF OUTPUT ENVELOPE AGAINST NUMBER OF TAPE PASSES AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

Tape Type B Test No. 10, 11, & 12

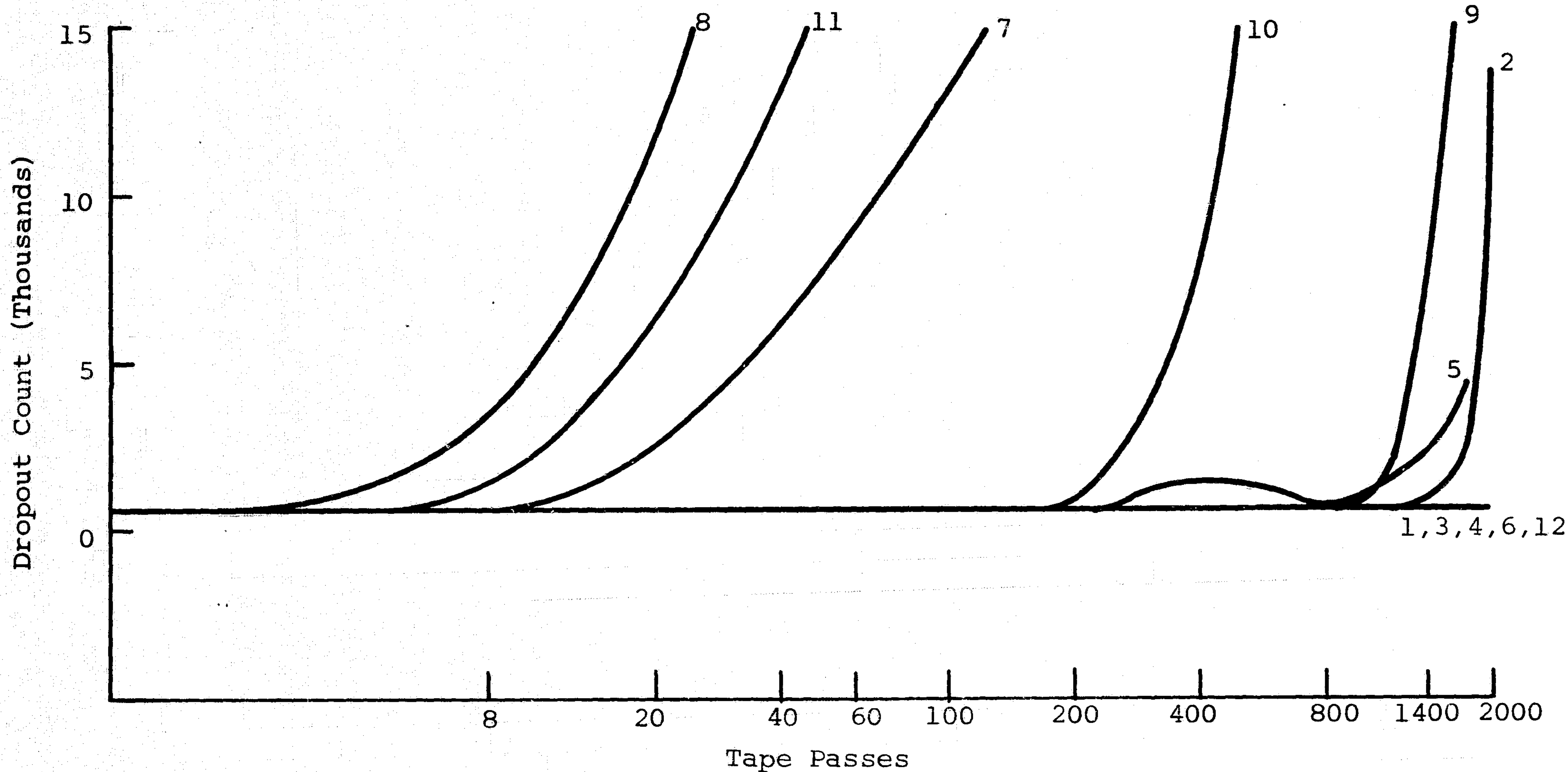


Fig. 4a DROPOUT COUNT AGAINST NUMBER OF TAPE PASSES FOR ALL TESTS AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

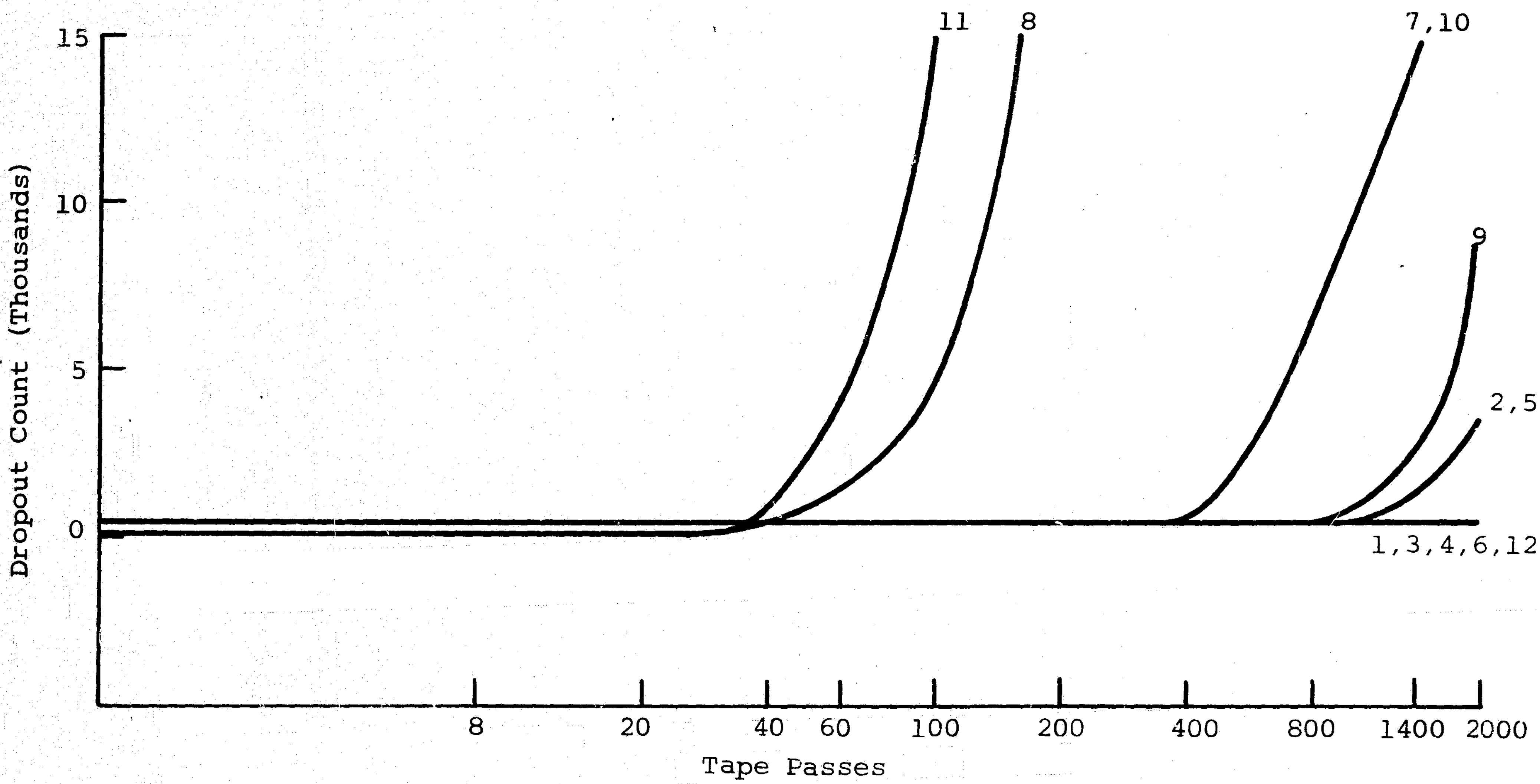


Fig. 4b DROPOUT COUNT AGAINST NUMBER OF TAPE PASSES FOR ALL TESTS AT A REPRODUCE TAPE SPEED OF 0.30 INCHES PER SECOND

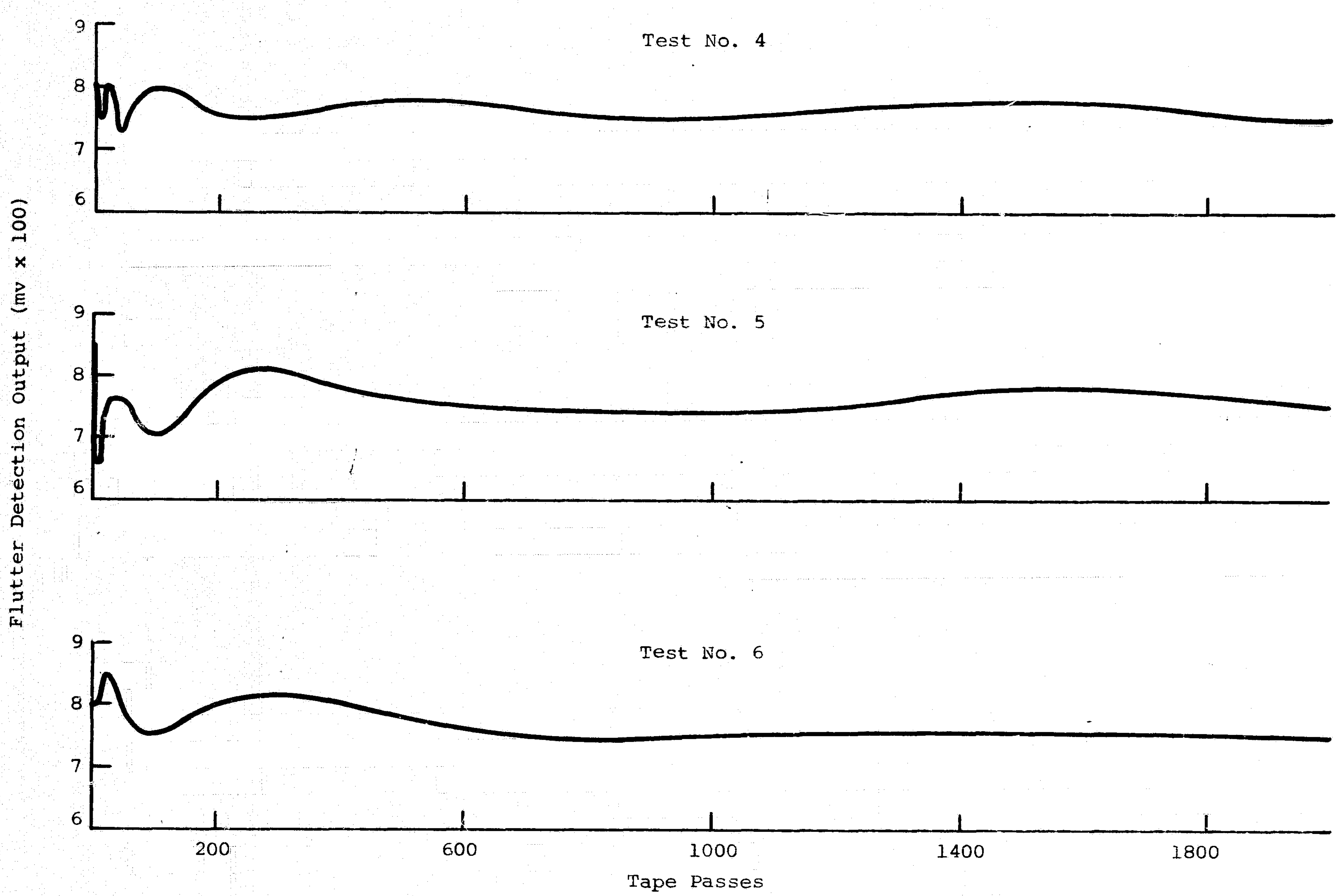


Fig. 5a FLUTTER VARIATION AGAINST NUMBER OF TAPE PASSES FOR A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

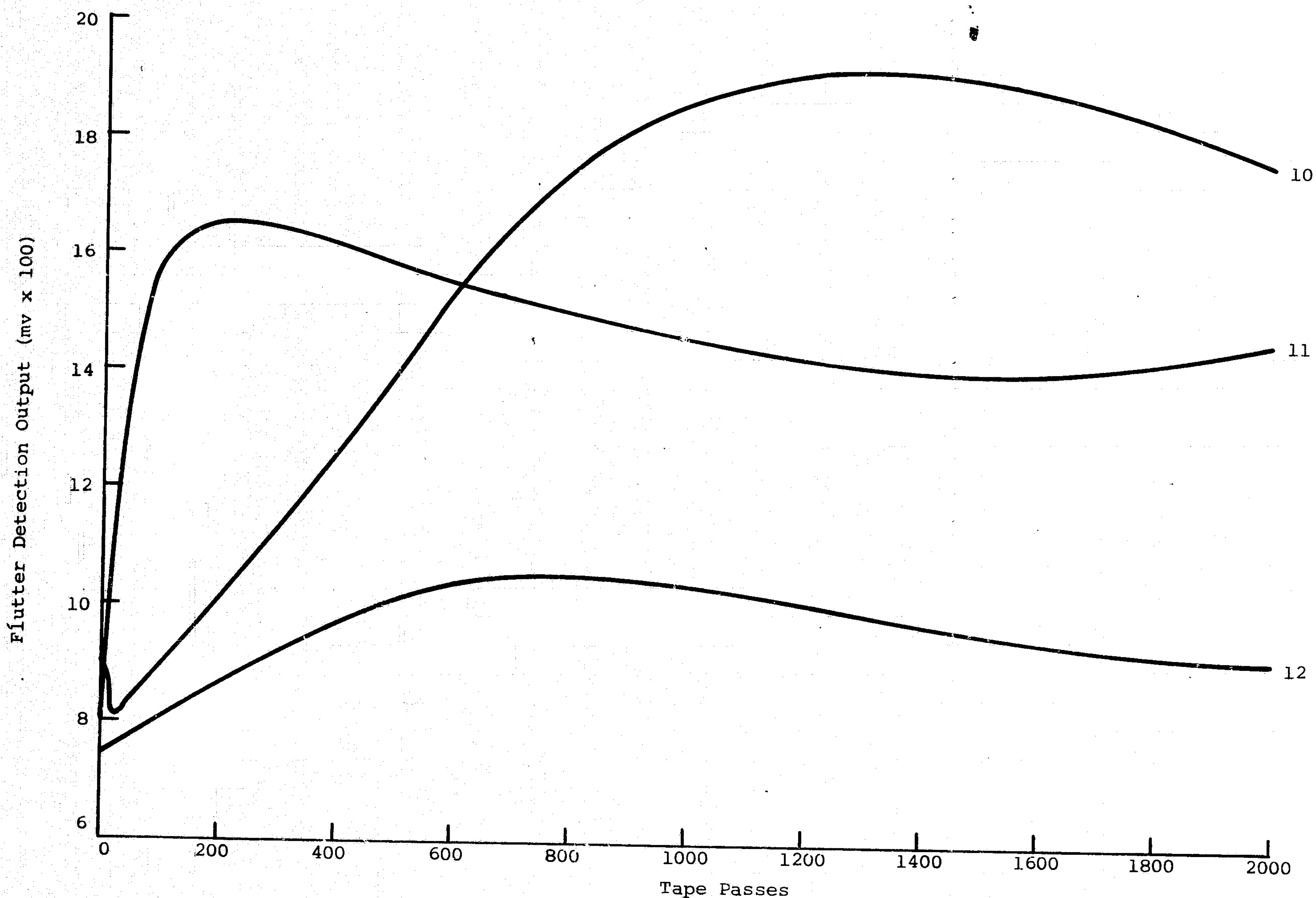


Fig. 5b FLUTTER VARIATION AGAINST NUMBER OF TAPE PASSES FOR A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

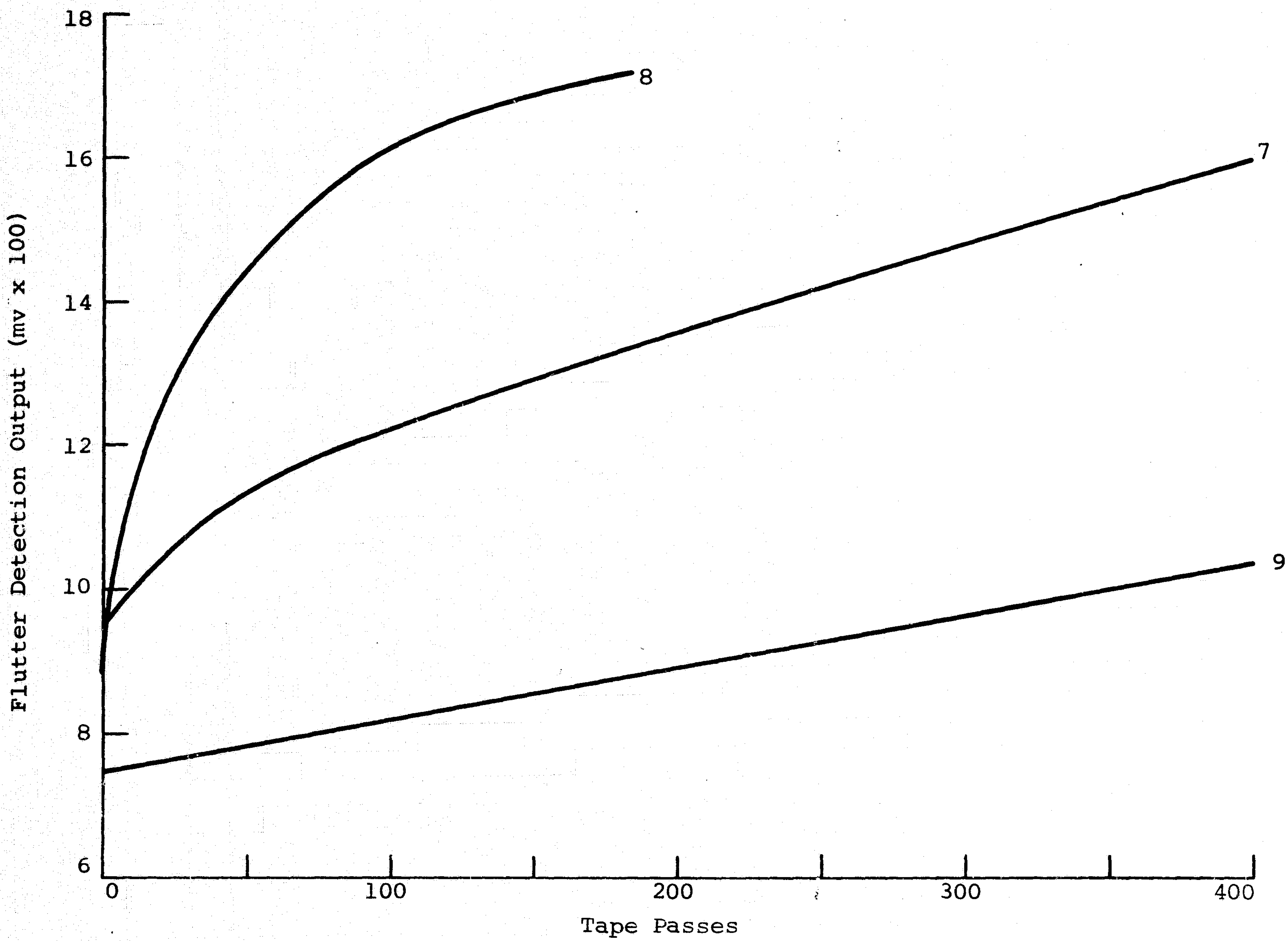


Fig. 5c CHANGE IN FLUTTER CHARACTERISTIC FOR AN INITIAL NUMBER OF TAPE PASSES WHILE USING TAPE TYPE B AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

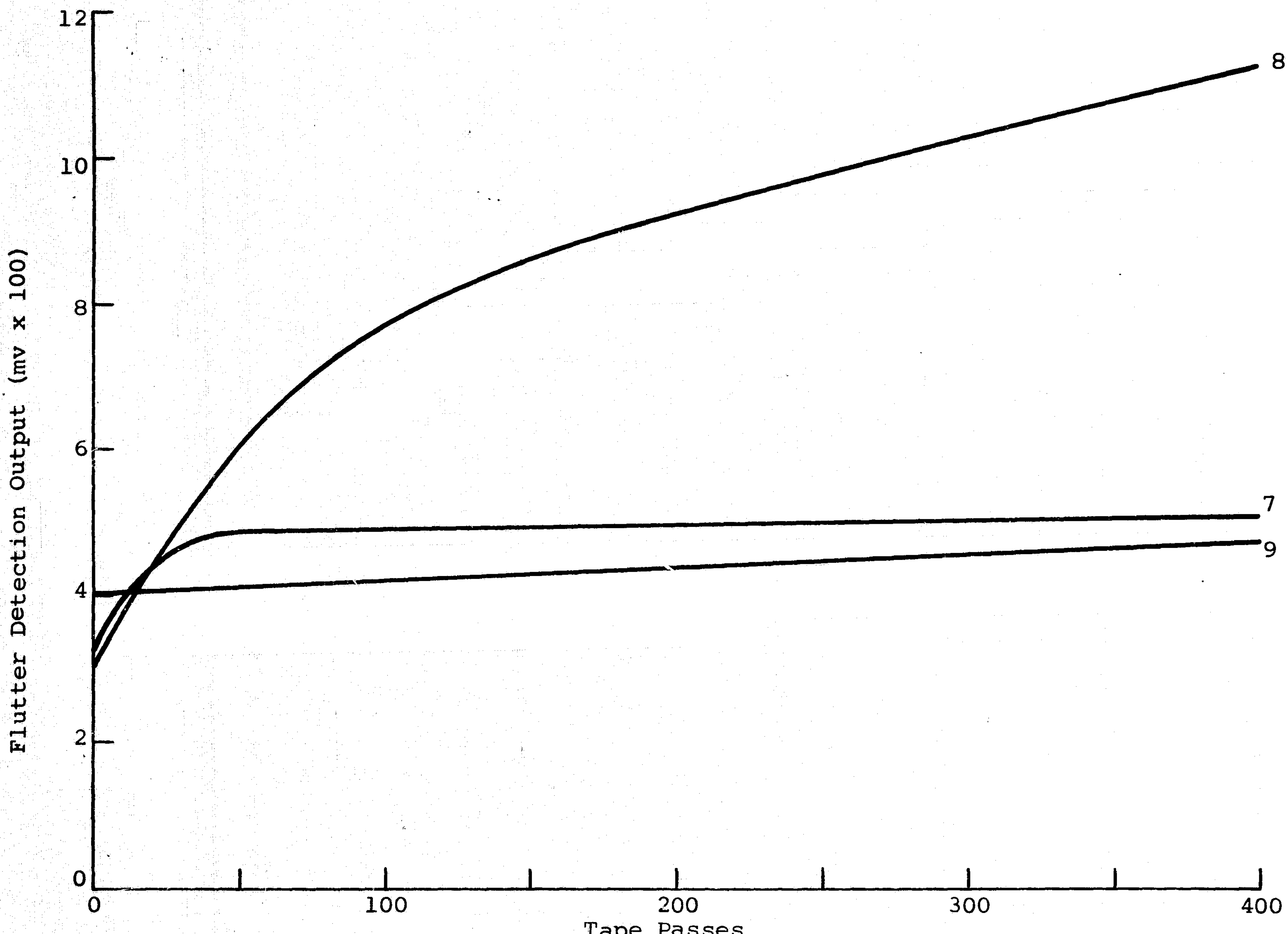


Fig.5d CHANGE IN FLUTTER CHARACTERISTIC FOR AN INITIAL NUMBER OF TAPE PASSES WHILE USING TAPE TYPE B AT A REPRODUCE TAPE SPEED OF 0.30 INCHES PER SECOND

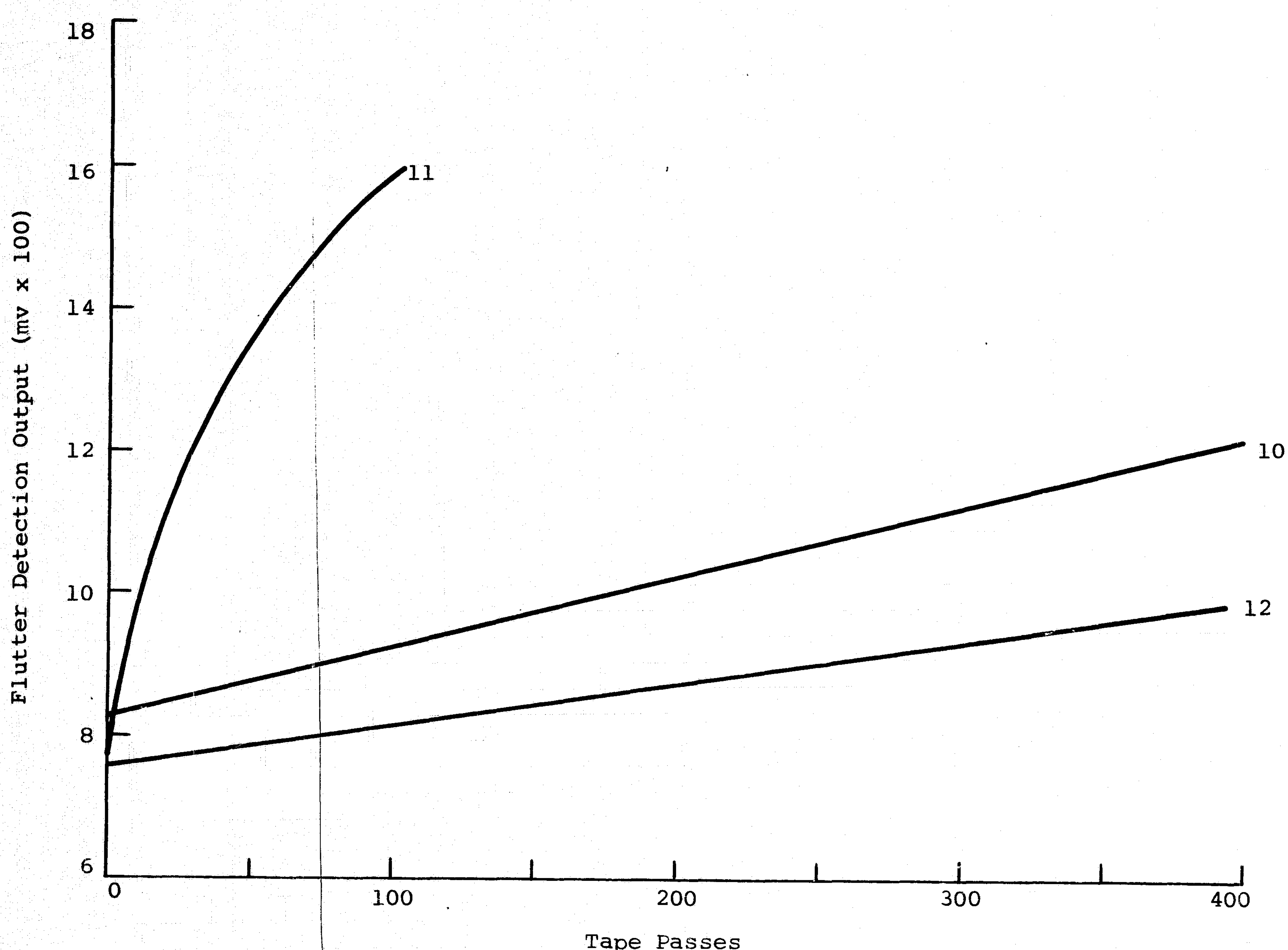


Fig. 5e CHANGE IN FLUTTER CHARACTERISTIC FOR AN INITIAL NUMBER OF TAPE PASSES WHILE USING TAPE TYPE B AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

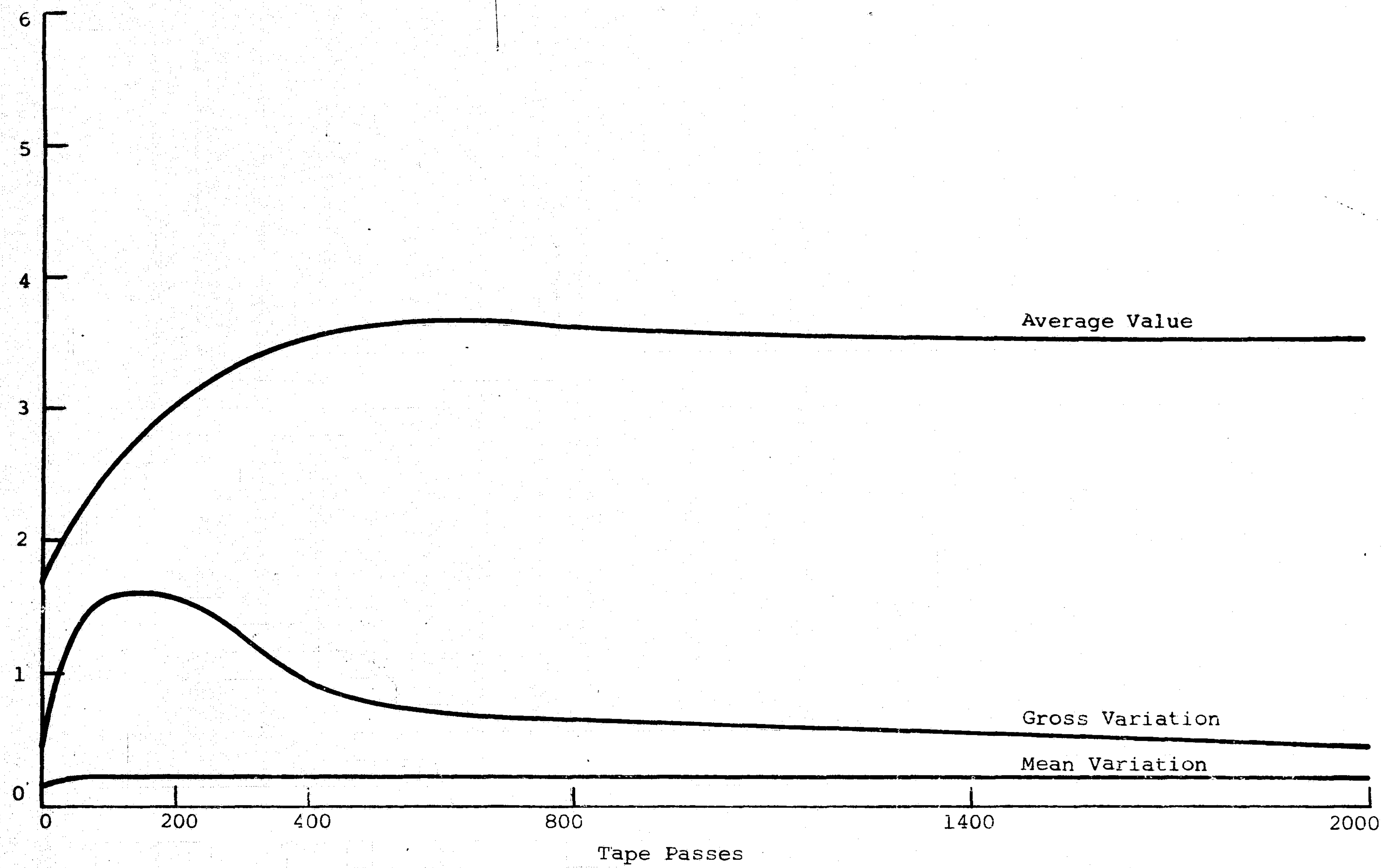


Fig. 6a AVERAGE, MEAN, AND GROSS VARIATIONS IN DRAG AGAINST NUMBER OF TAPE PASSES FOR TEST NUMBER 1 AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

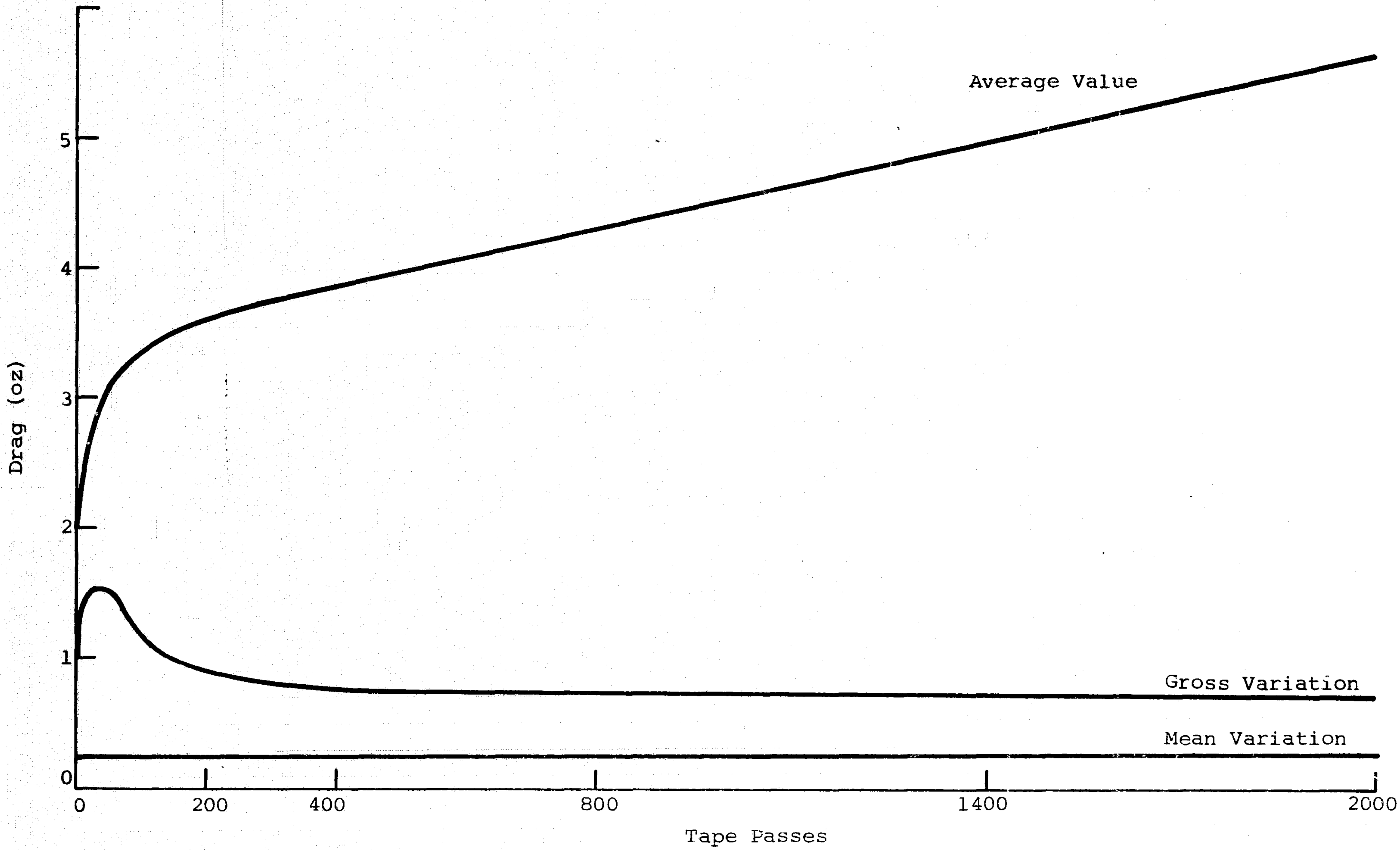


Fig. 6b AVERAGE, MEAN, AND GROSS VARIATIONS IN DRAG AGAINST NUMBER OF TAPE PASSES FOR TEST NUMBER 2 AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

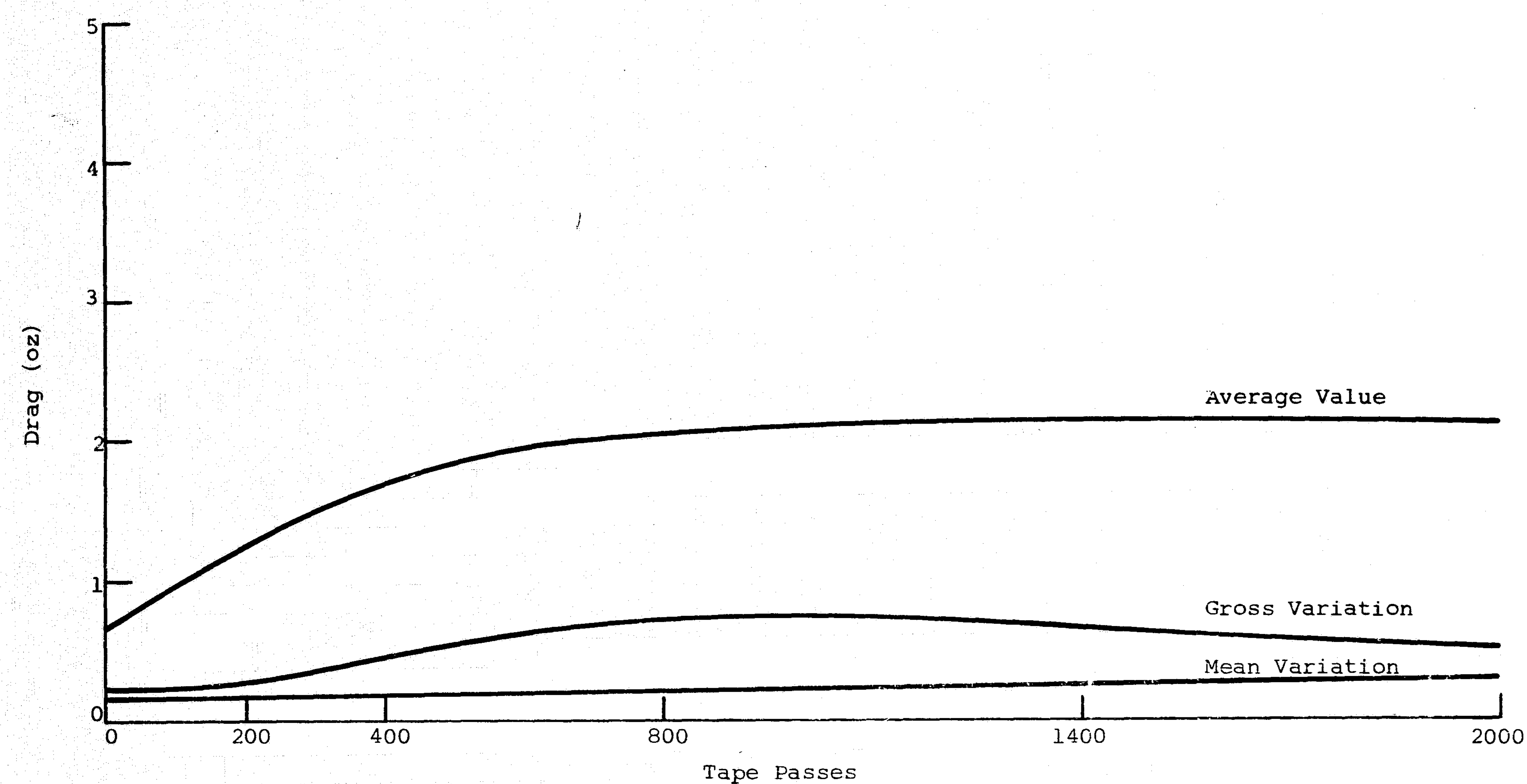


Fig. 6c AVERAGE, MEAN, AND GROSS VARIATIONS IN DRAG AGAINST NUMBER OF TAPE PASSES FOR TEST NUMBER 3 AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

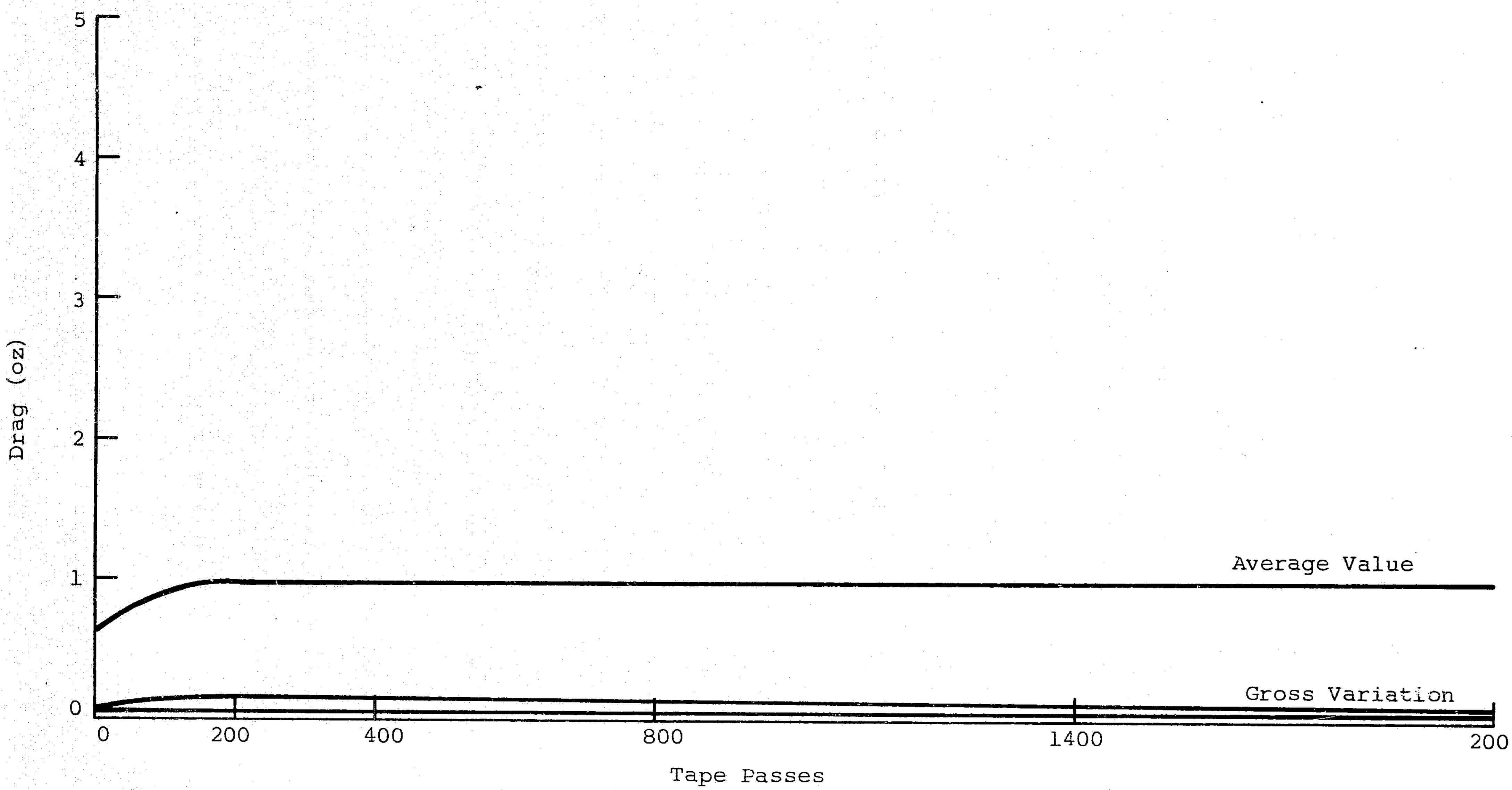


Fig. 6d AVERAGE, MEAN, AND GROSS VARIATIONS IN DRAG AGAINST NUMBER OF TAPE PASSES FOR TEST NUMBER 4 AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

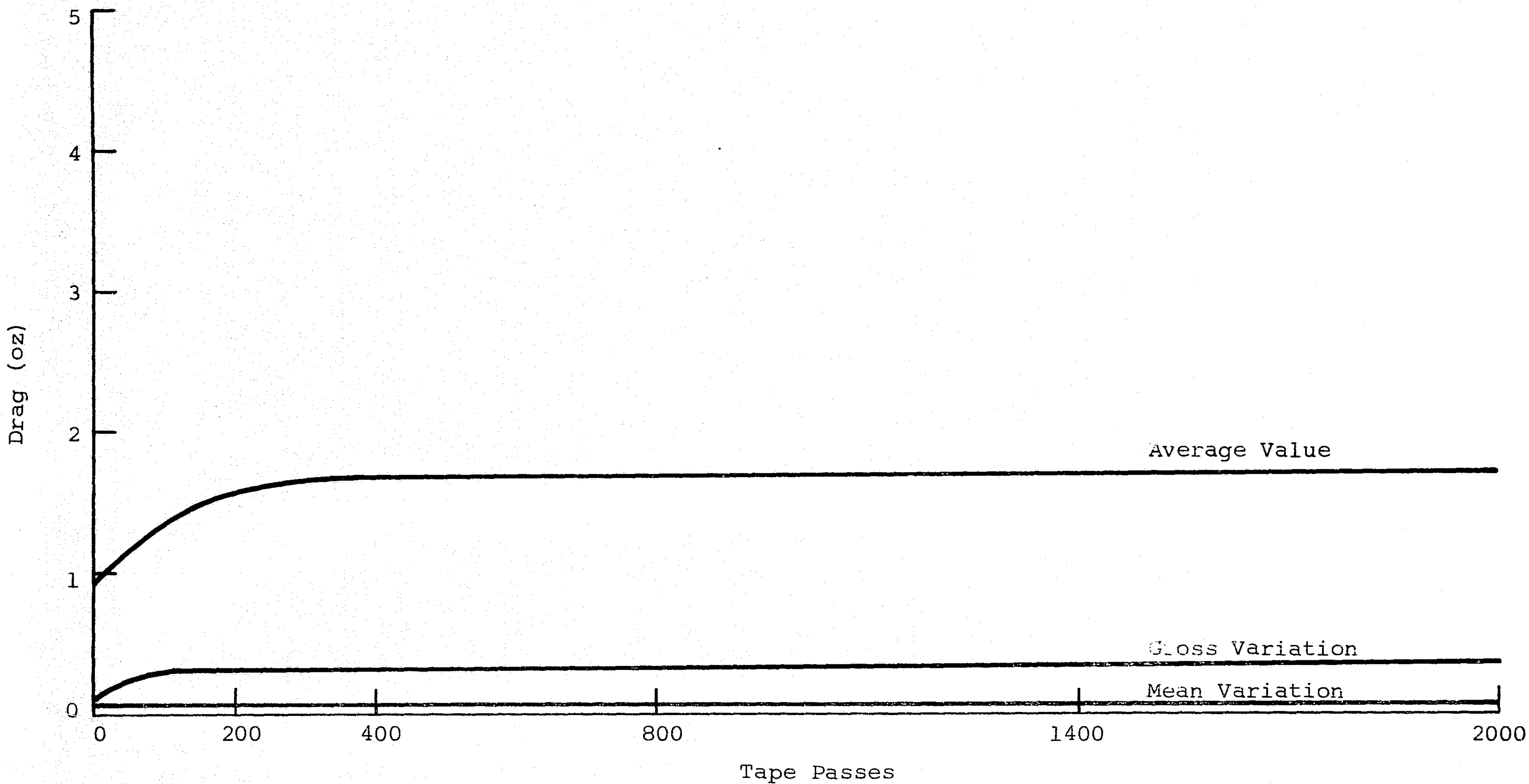


Fig. 6e AVERAGE, MEAN, AND GROSS VARIATIONS IN DRAG AGAINST NUMBER OF TAPE PASSES FOR TEST NUMBER 5 AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

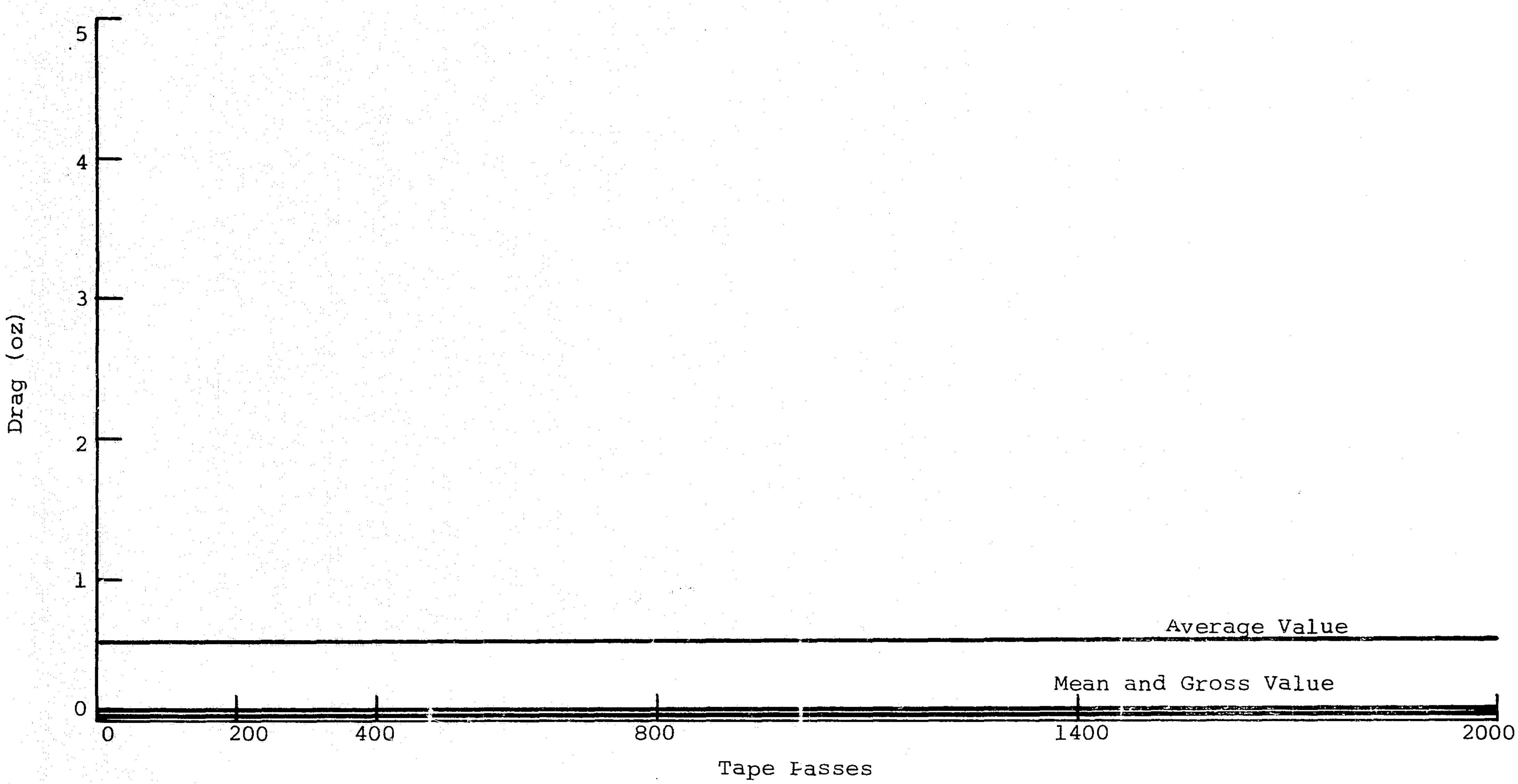


Fig. 6f AVERAGE, MEAN AND GROSS VARIATIONS IN DRAG AGAINST NUMBER OF TAPE PASSES FOR TEST NUMBER 6 AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

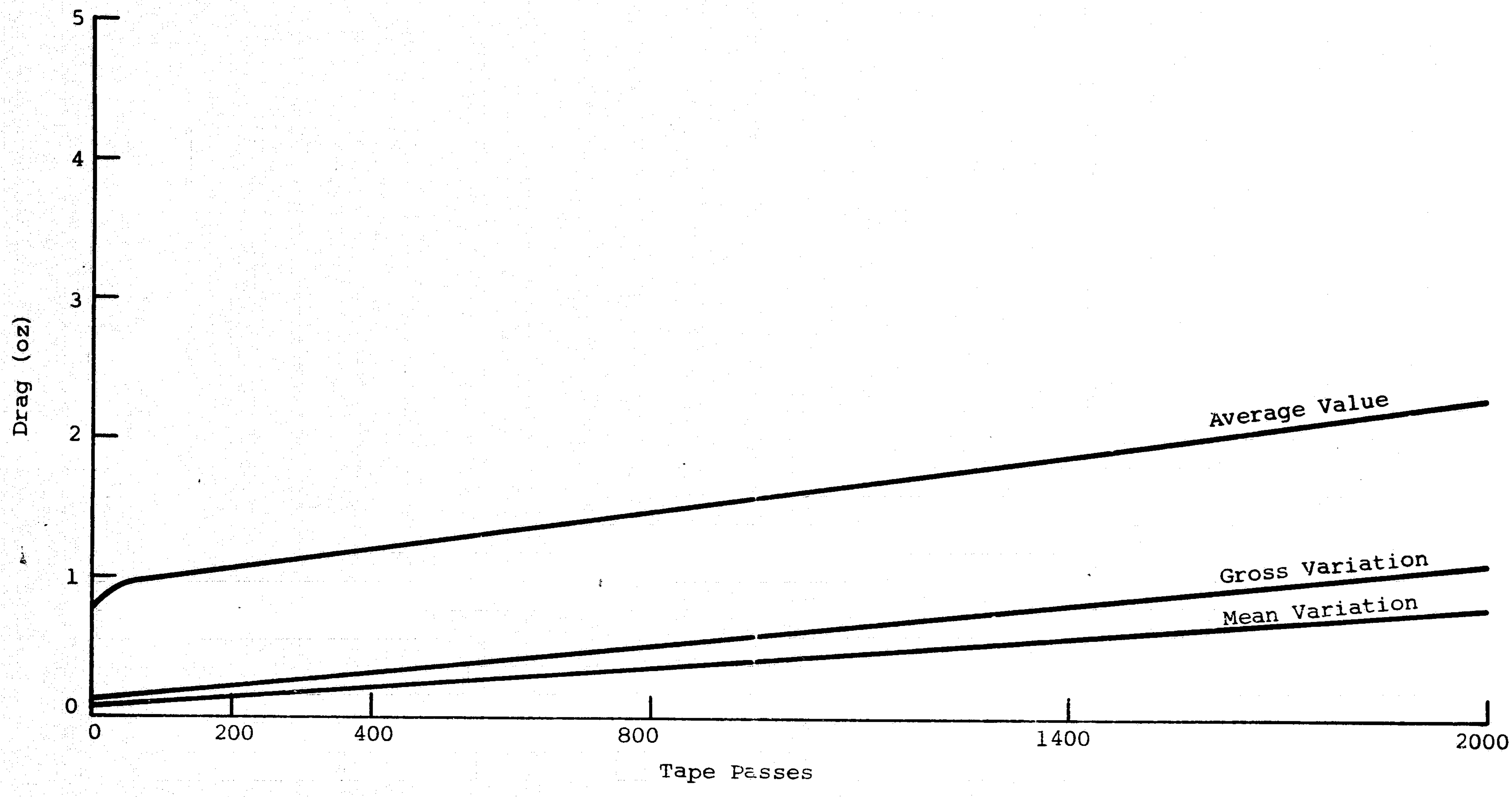


Fig. 6g AVERAGE, MEAN, AND GROSS VARIATIONS IN DRAG AGAINST NUMBER OF TAPE PASSES FOR TEST NUMBER 7 AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

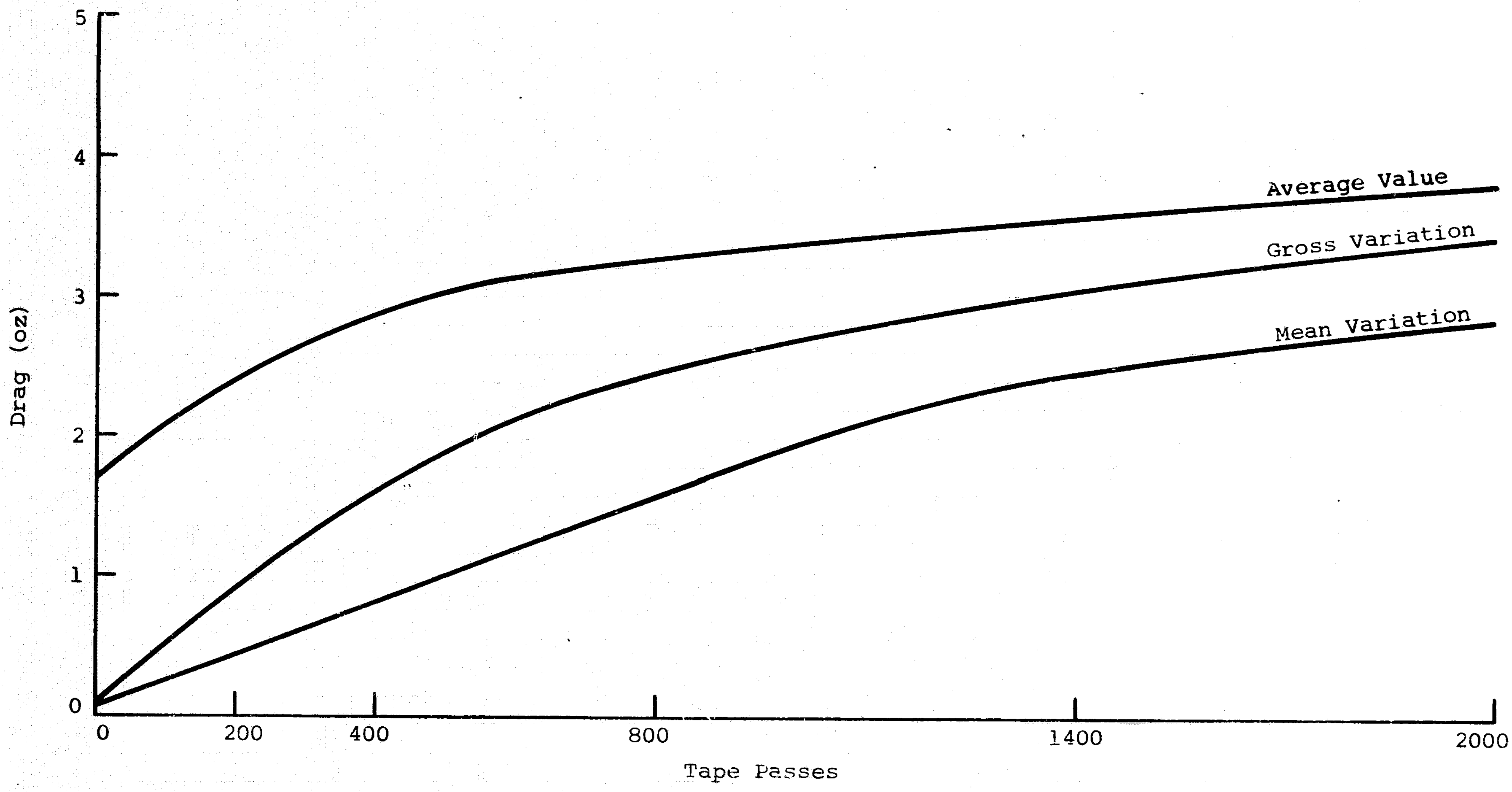


Fig. 6h AVERAGE, MEAN, AND GROSS VARIATIONS IN DRAG AGAINST NUMBER OF TAPE PASSES FOR TEST NUMBER 8 AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

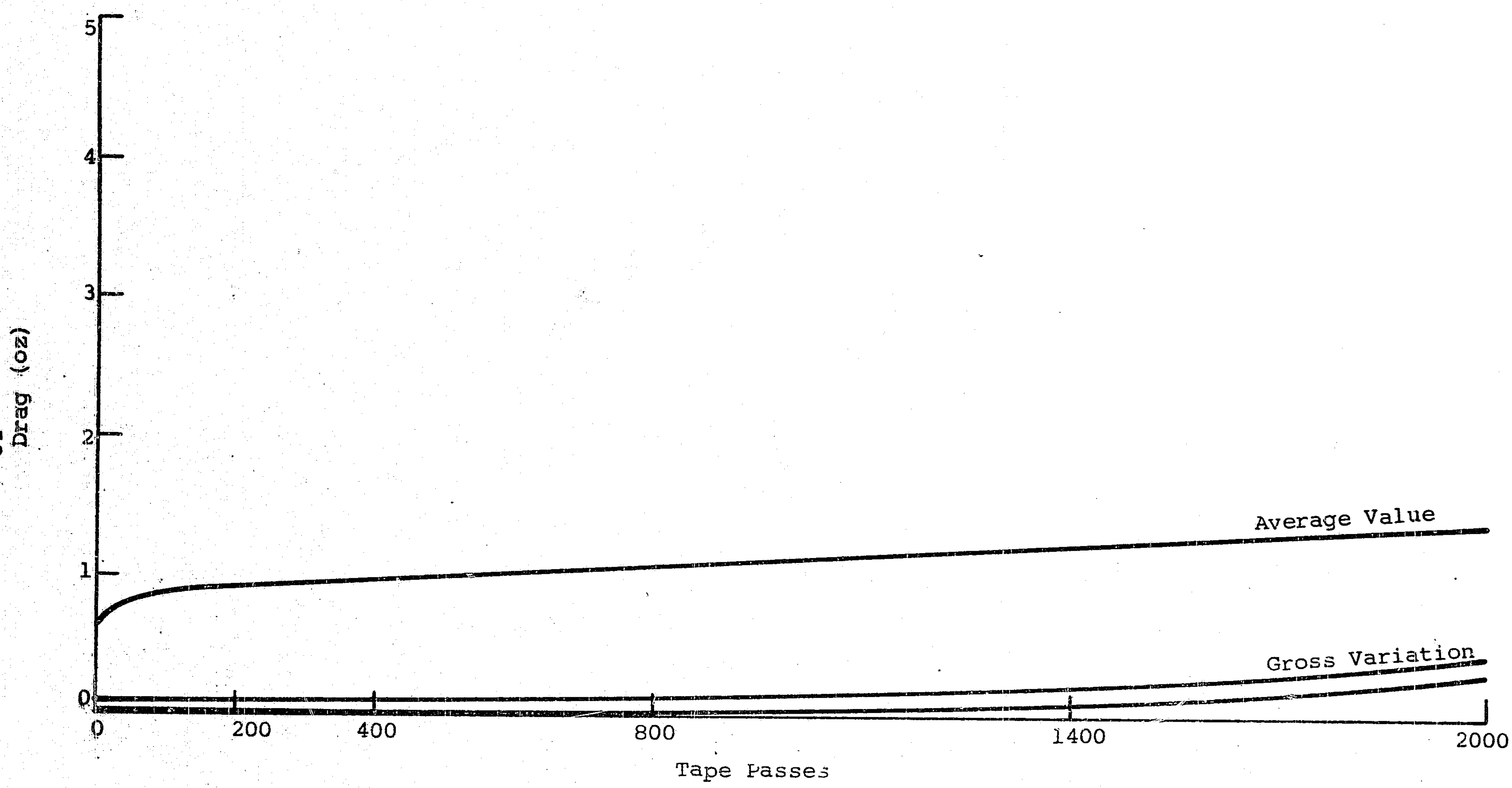


Fig. 6i AVERAGE, MEAN, AND GROSS VARIATIONS IN DRAG AGAINST NUMBER OF TAPE PASSES FOR TEST NUMBER 9 AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

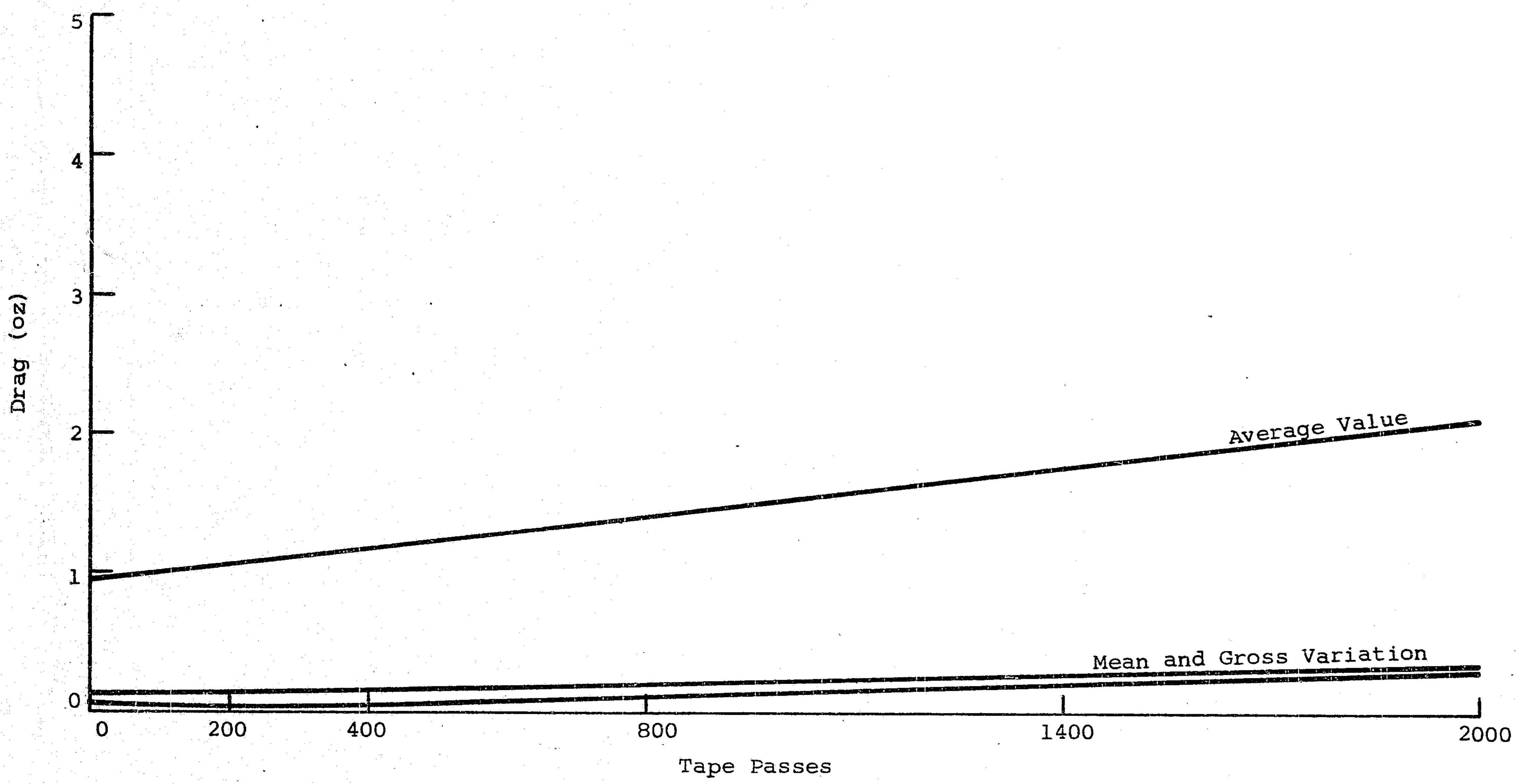


Fig. 6j AVERAGE, MEAN, AND GROSS VARIATIONS IN DRAG AGAINST NUMBER OF TAPE PASSES FOR TEST NUMBER 10 AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

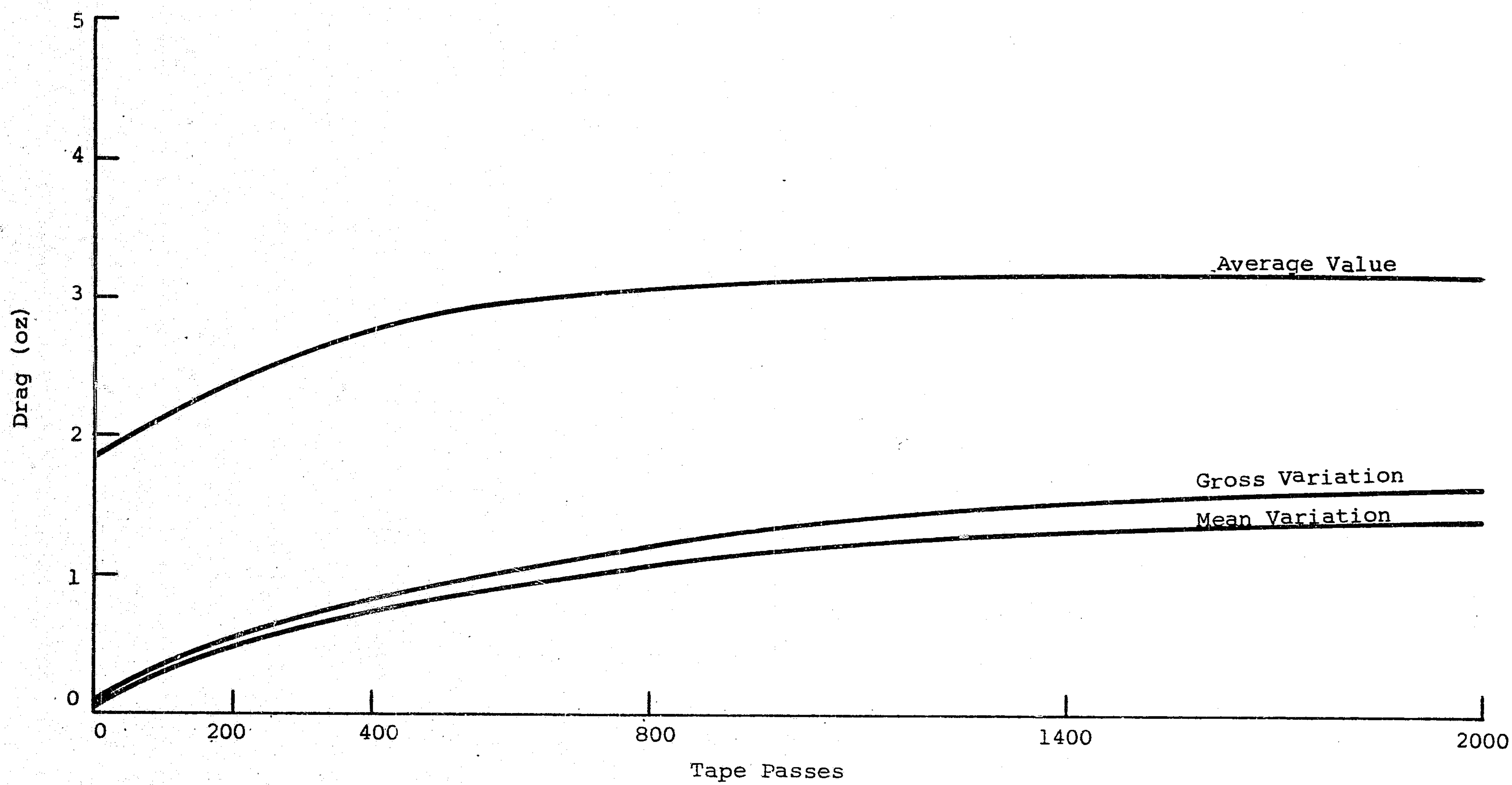


Fig. 6k AVERAGE, MEAN, AND GROSS VARIATIONS IN DRAG AGAINST NUMBER OF TAPE PASSES FOR TEST NUMBER 11 AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

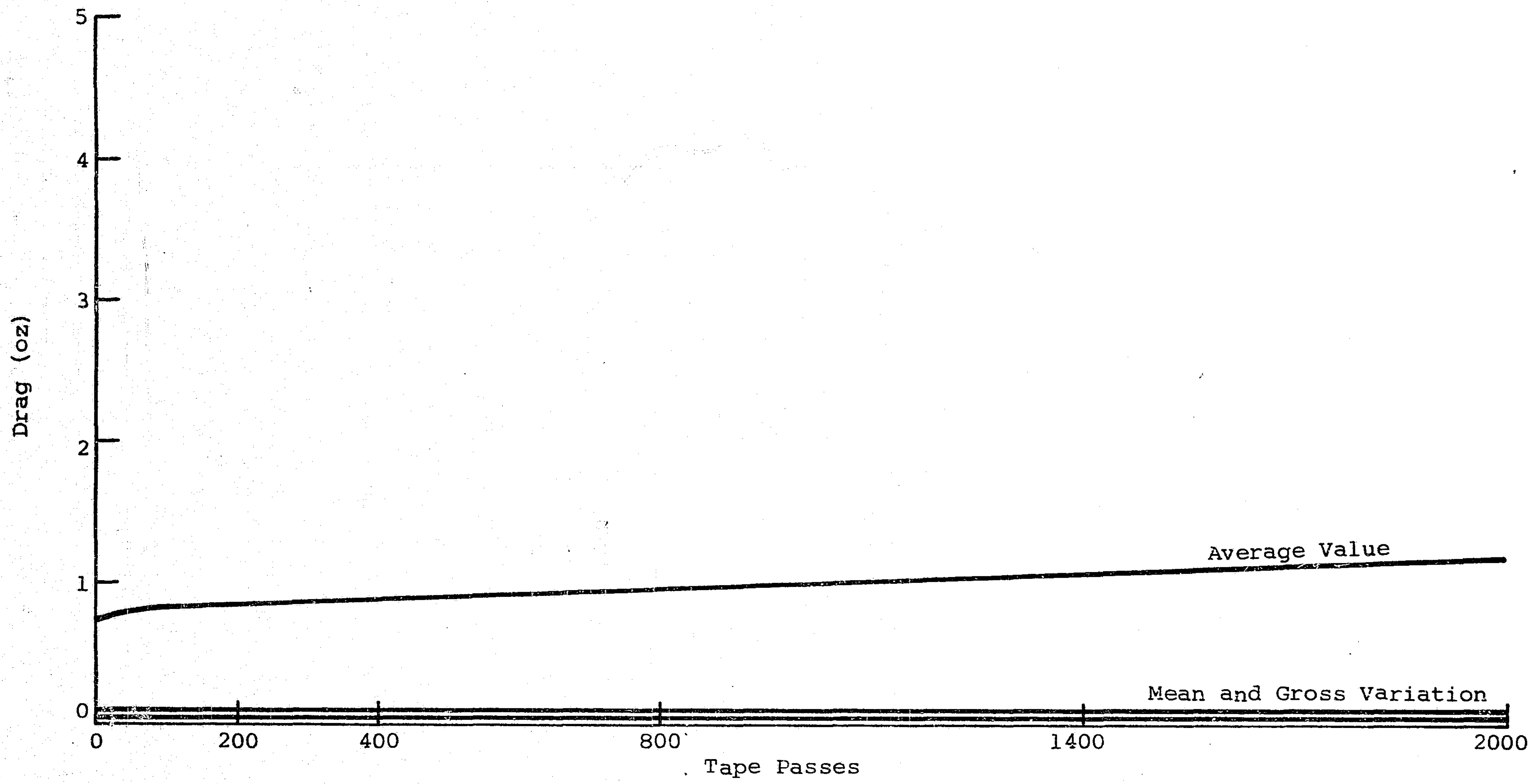


Fig. 6L AVERAGE, MEAN, AND GROSS VARIATIONS IN DRAG AGAINST NUMBER OF TAPE PASSES FOR TEST NUMBER 12 AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

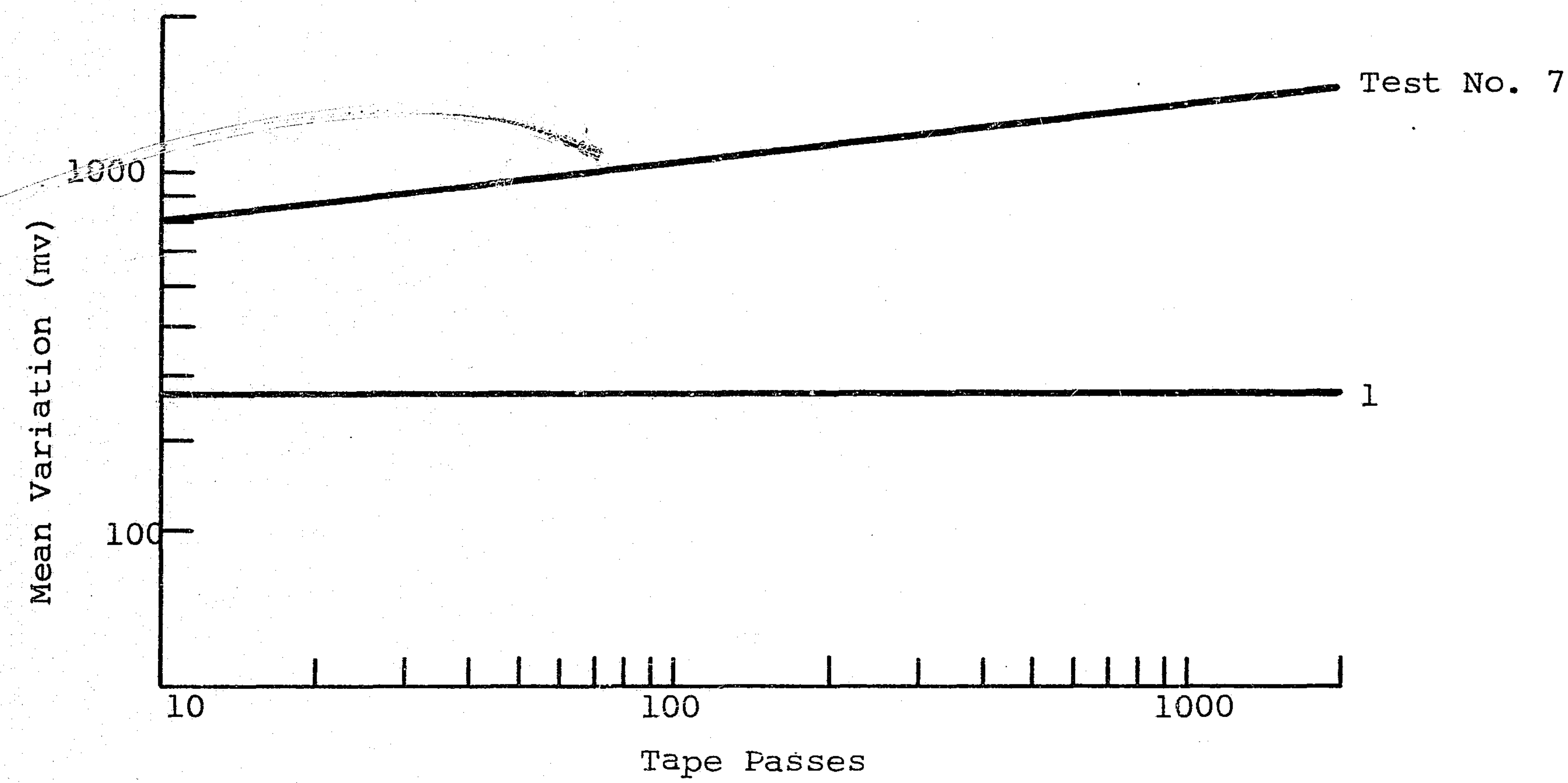


Fig.7a MEAN VARIATION OF OUTPUT ENVELOPE AGAINST NUMBER OF TAPE PASSES FOR A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

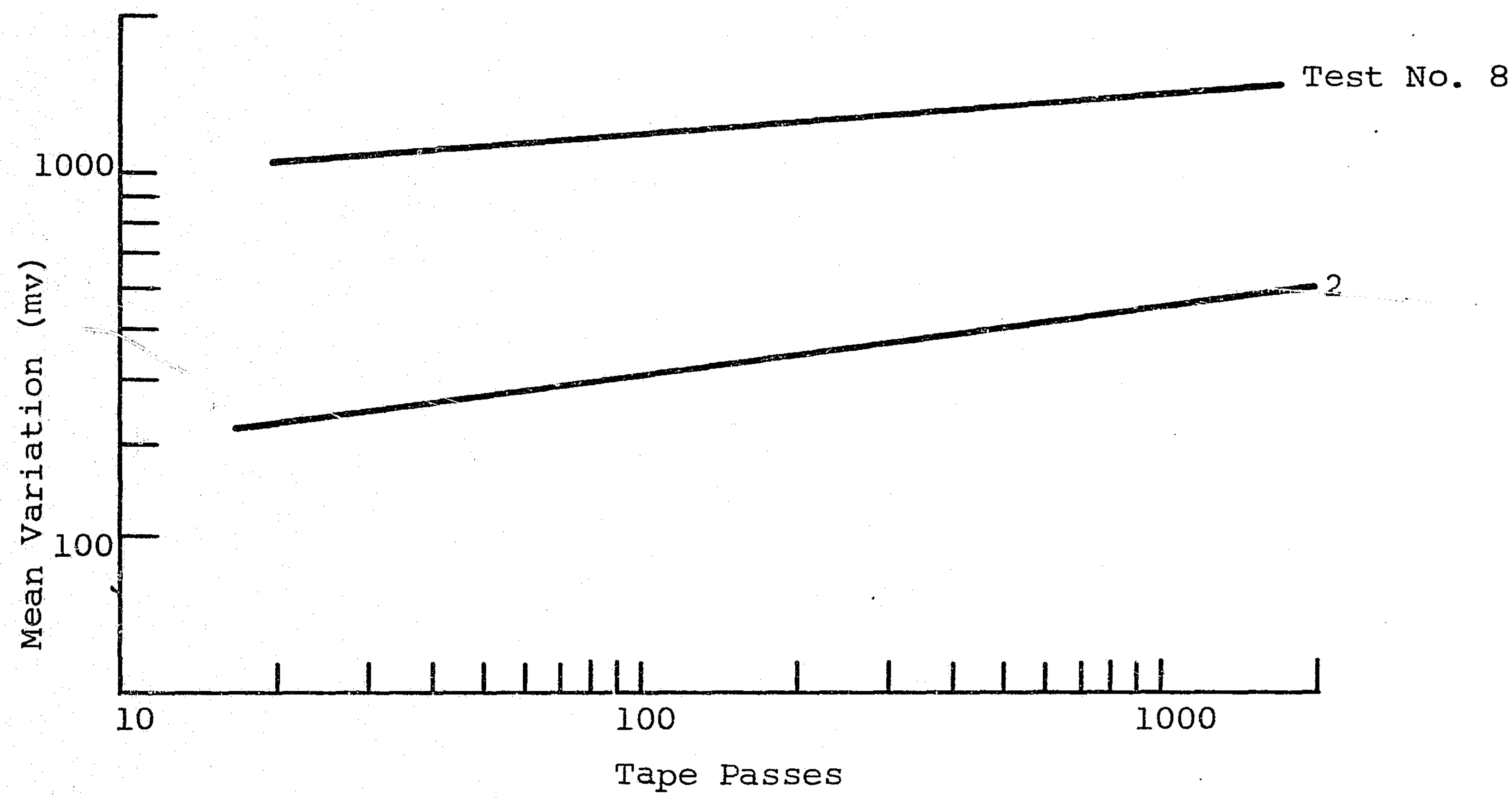


Fig. 7b MEAN VARIATION OF OUTPUT ENVELOPE AGAINST NUMBER OF TAPE PASSES FOR A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

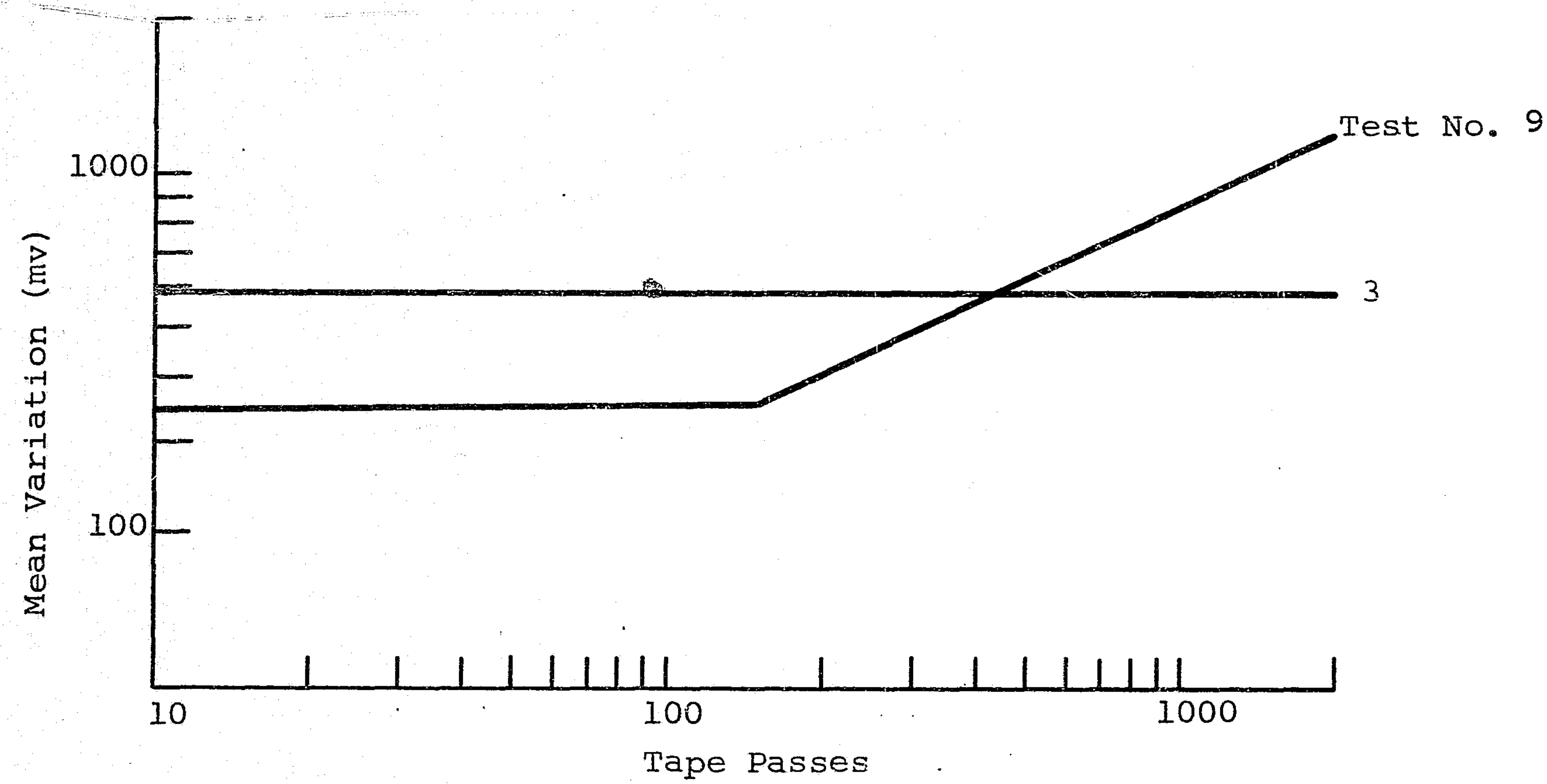


Fig. 7c MEAN VARIATION OF OUTPUT ENVELOPE AGAINST NUMBER OF TAPE PASSES FOR A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

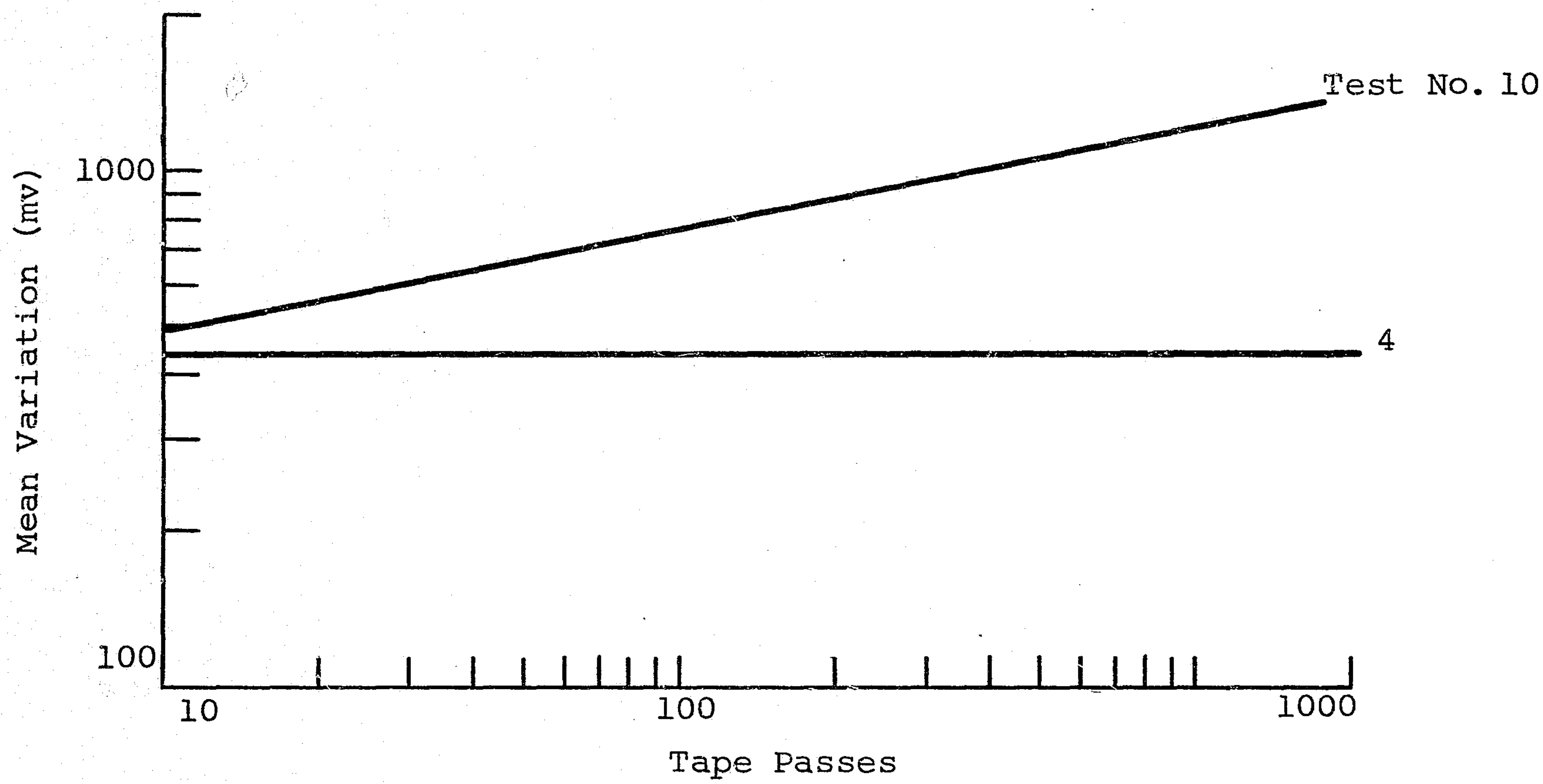


Fig.7d MEAN VARIATION OF OUTPUT ENVELOPE AGAINST NUMBER OF TAPE PASSES FOR A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

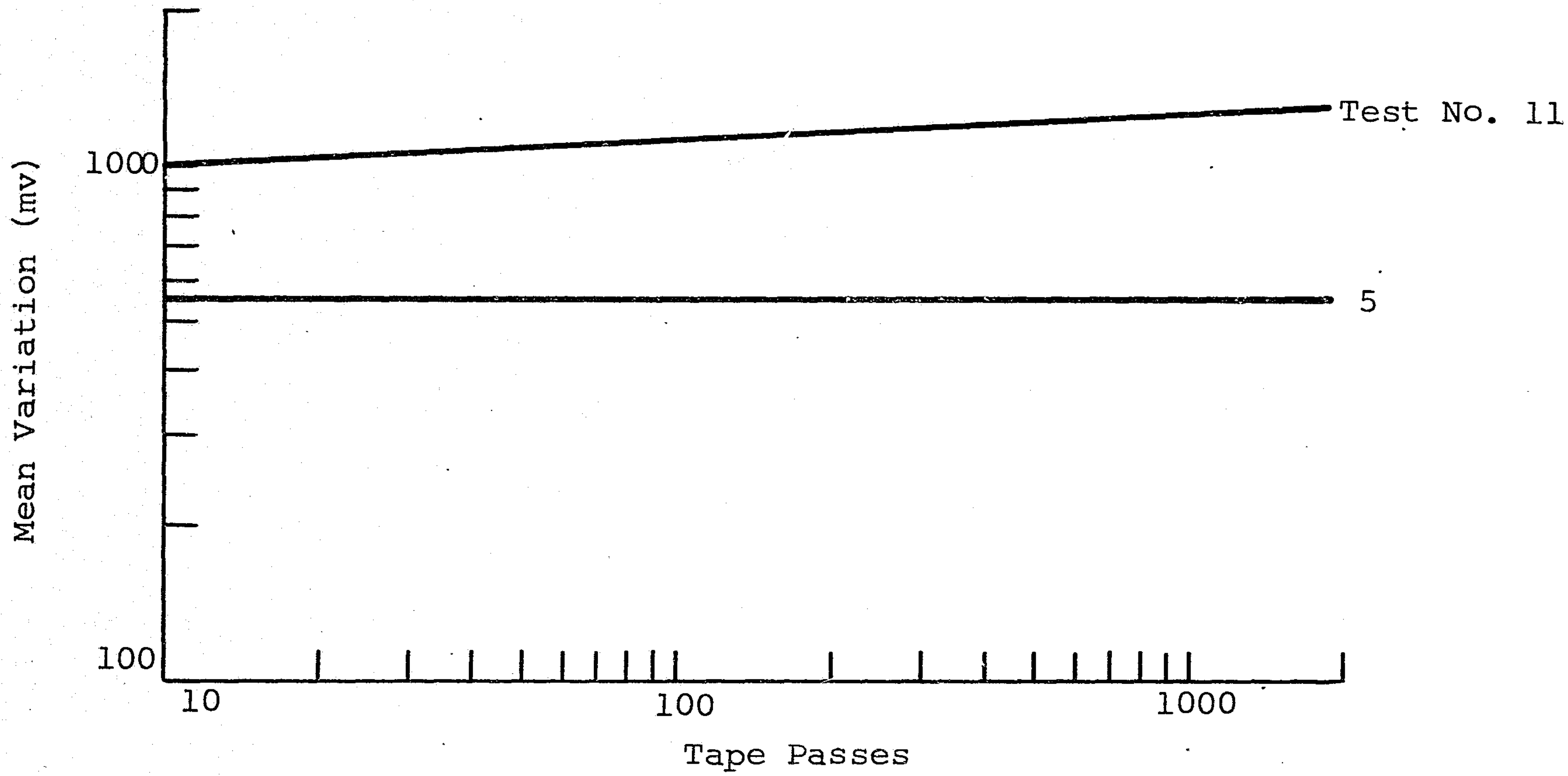


Fig. 7e MEAN VARIATION OF OUTPUT ENVELOPE AGAINST NUMBER OF TAPE PASSES FOR A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

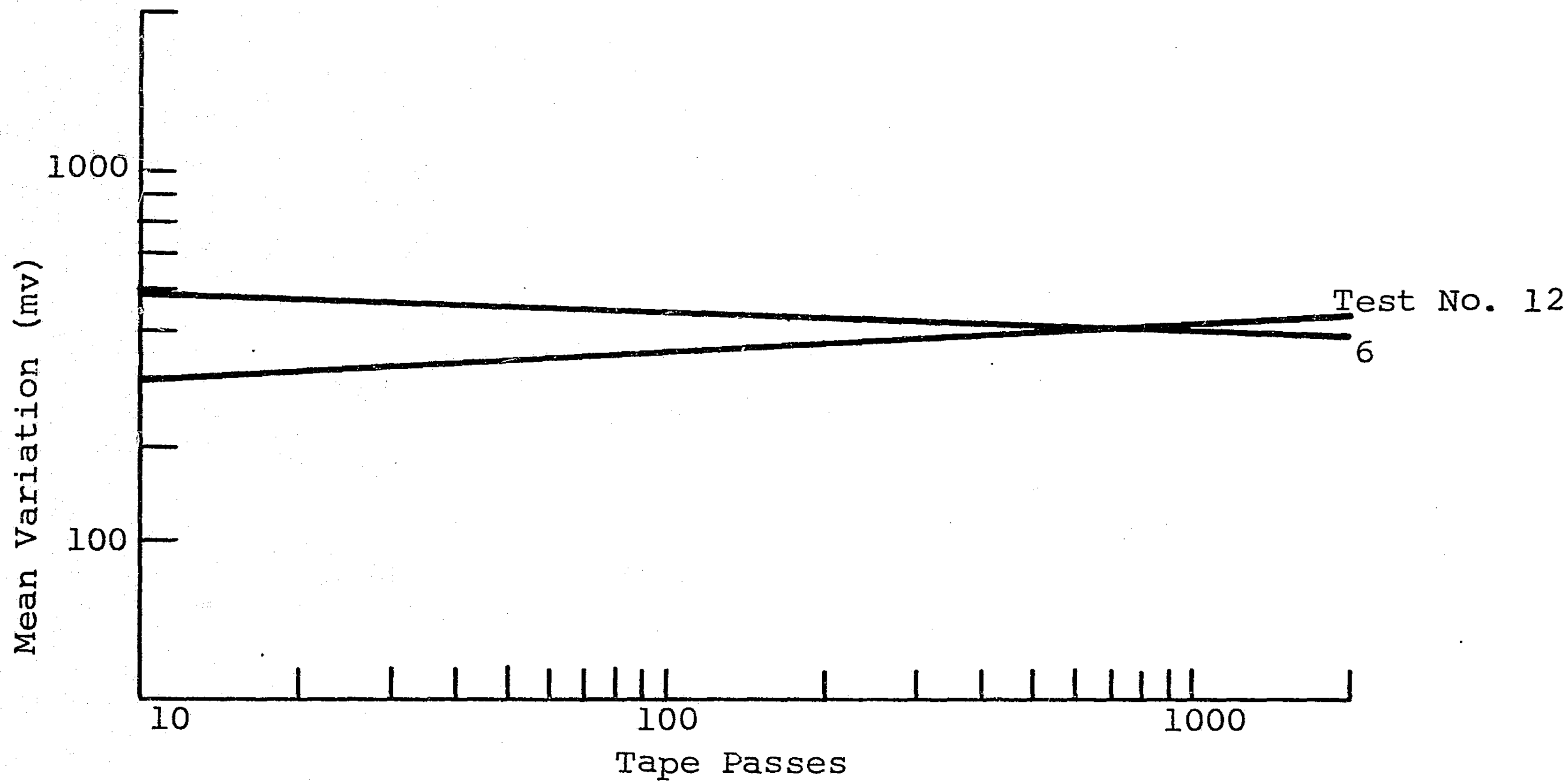


Fig. 7f MEAN VARIATION OF OUTPUT ENVELOPE AGAINST NUMBER OF TAPE PASSES FOR A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

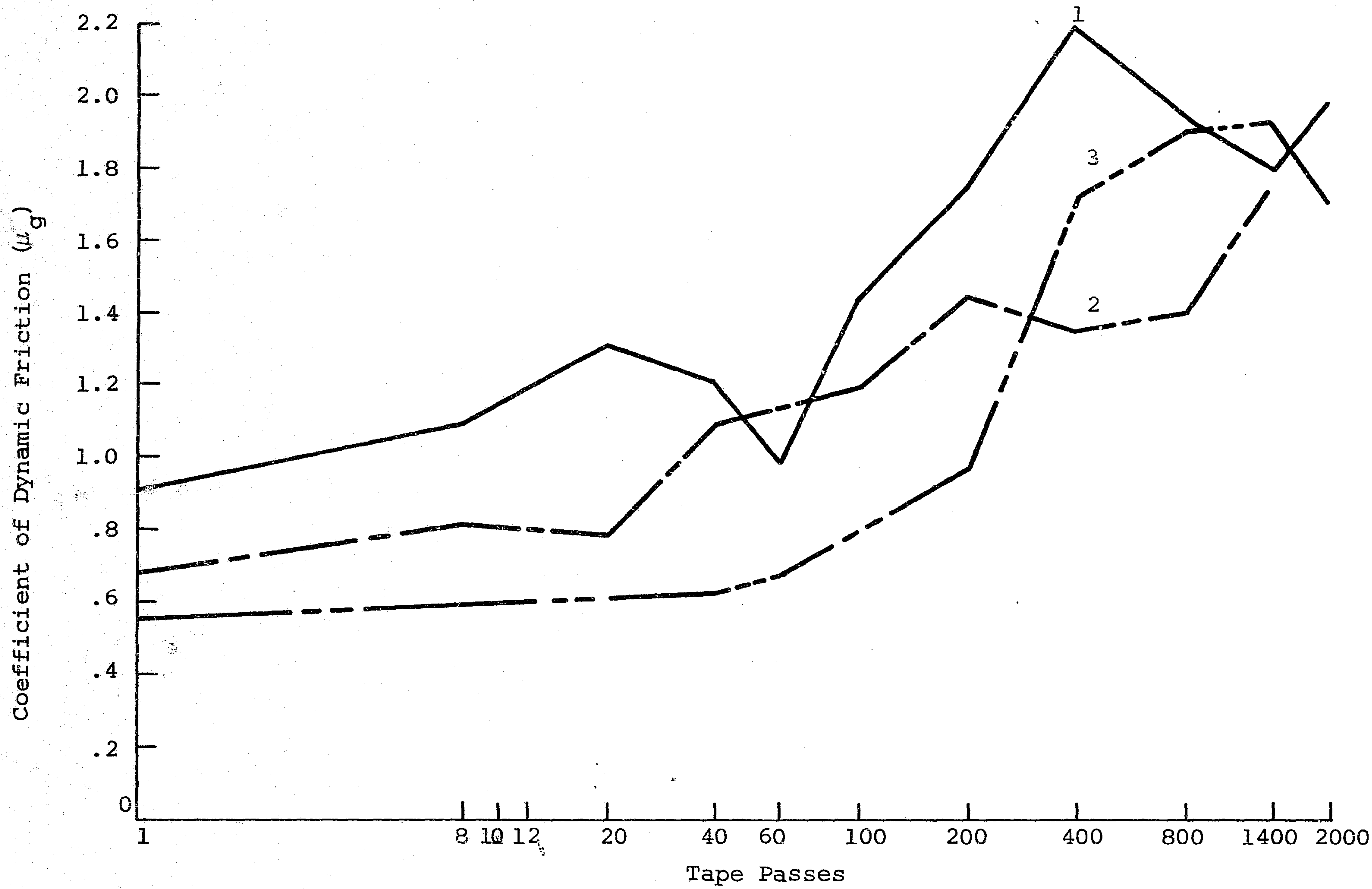


Fig. 8a CHANGE IN THE COEFFICIENT OF DYNAMIC FRICTION AGAINST NUMBER OF TAPE PASSES MEASURED AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

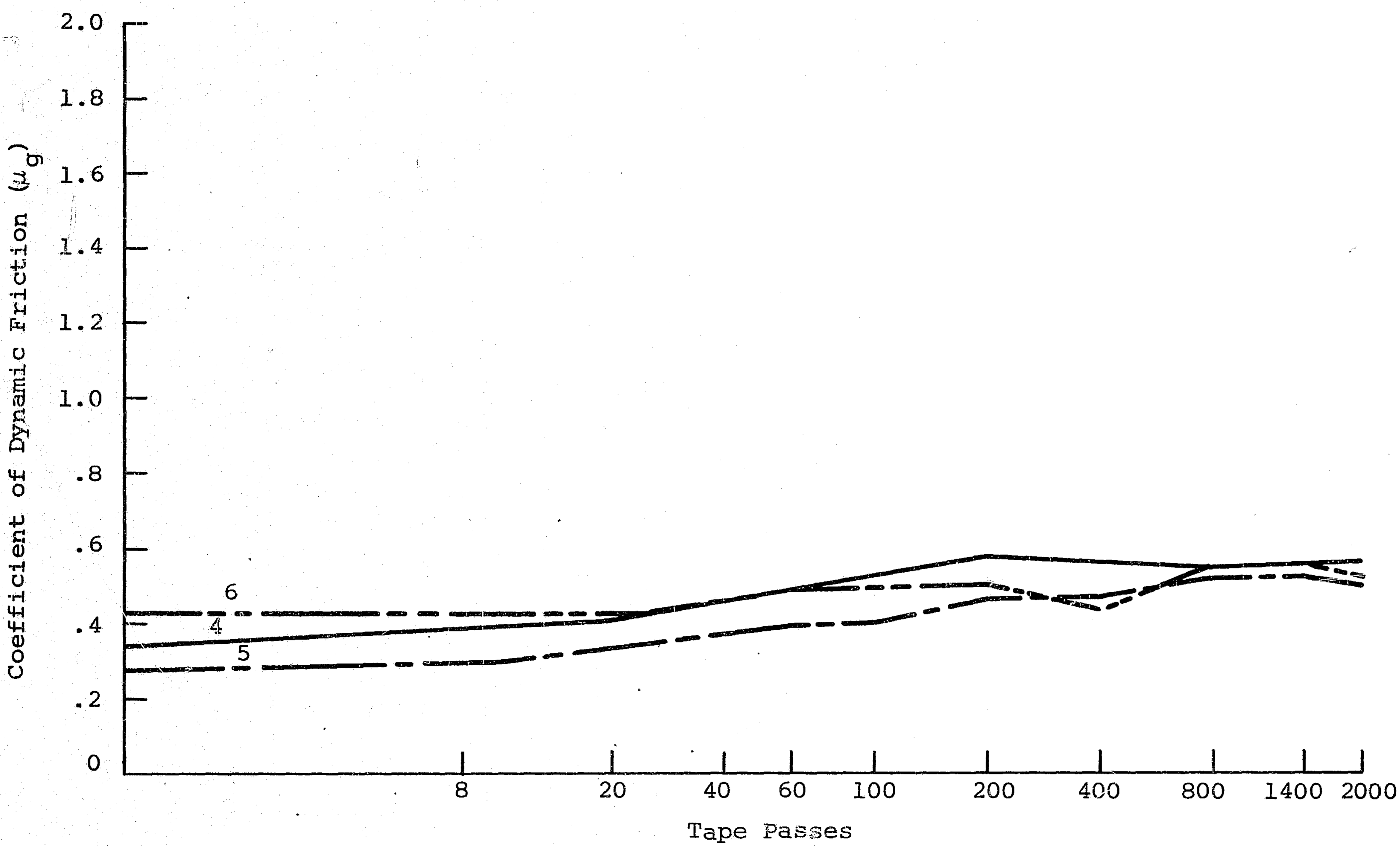


Fig. 8b CHANGE IN THE COEFFICIENT OF DYNAMIC FRICTION AGAINST NUMBER OF TAPE PASSES MEASURED AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

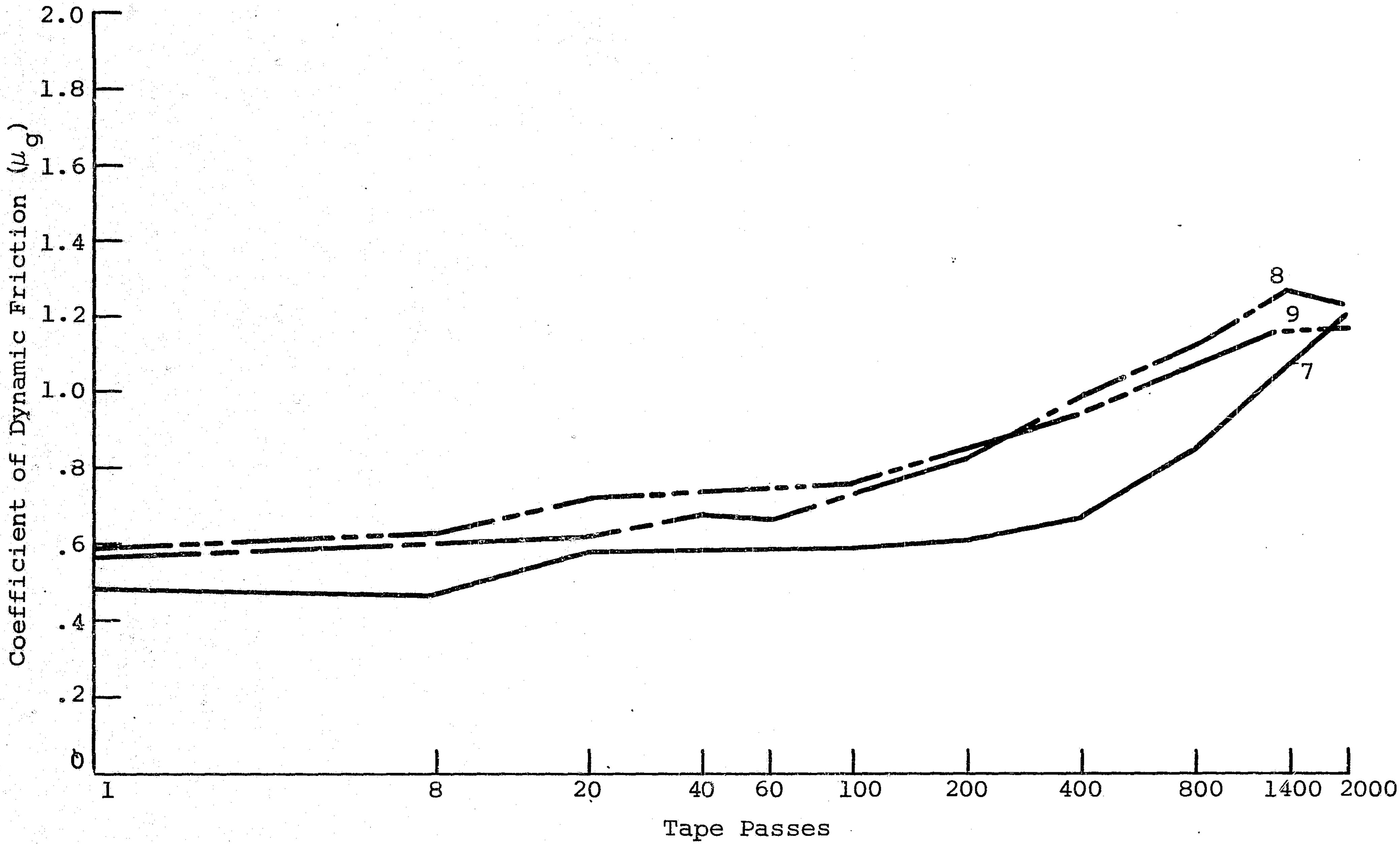


Fig. 8c CHANGE IN THE COEFFICIENT OF DYNAMIC FRICTION AGAINST NUMBER OF TAPE PASSES MEASURED AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

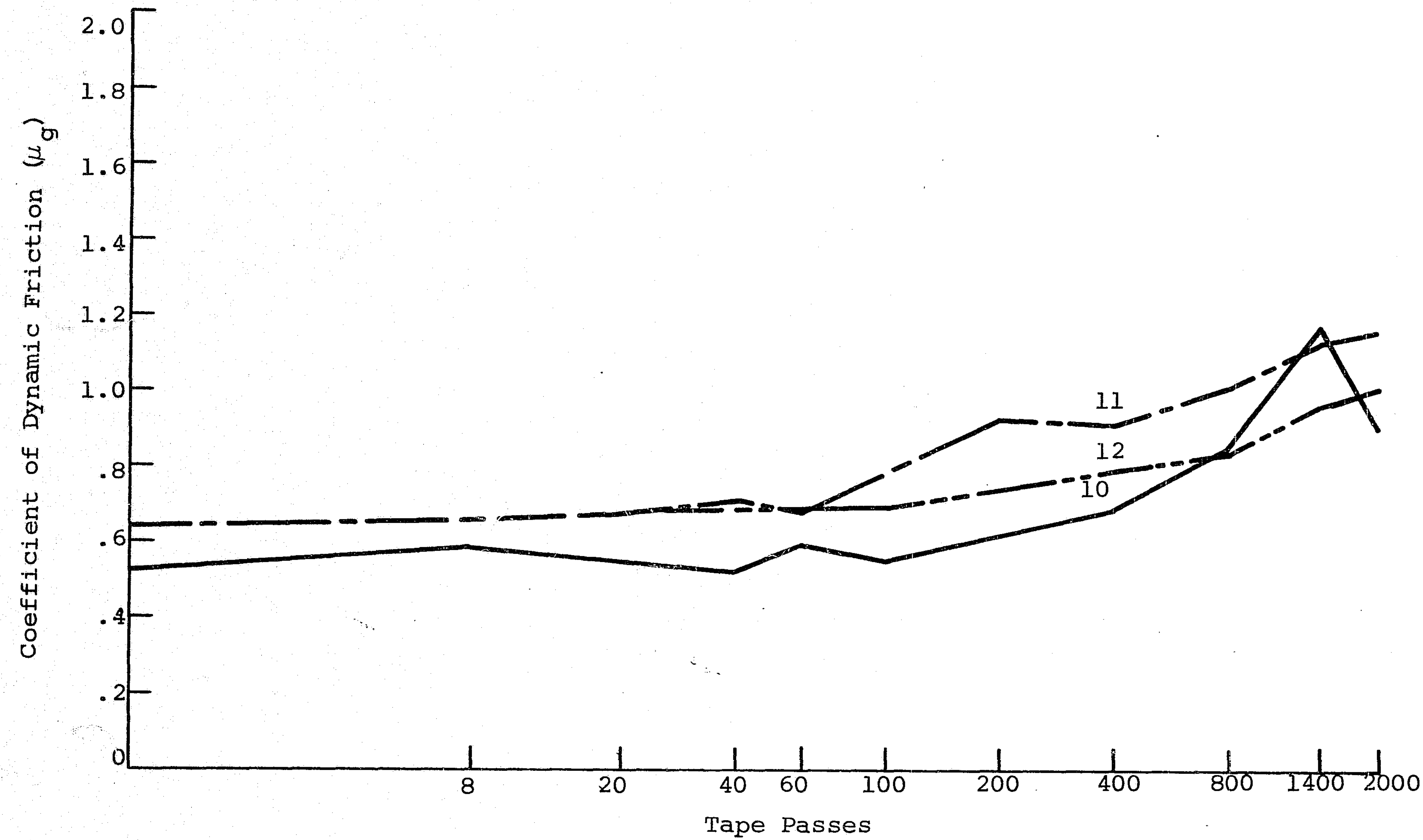


Fig. 8d CHANGE IN THE COEFFICIENT OF DYNAMIC FRICTION AGAIN AGAINST NUMBER OF TAPE PASSES MEASURED AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

c. Typical Trends

Figs. 9-14 are graphical representations of typical trends of the test parameters observed during the testing program. They should be used in conjunction with the actual data curves (Figs. 3-8) and are included in this section of the report to allow ease of comparison of the individual test parameters. The trend curves are identified using X, Y, and Z notation. This designation has no specific meaning but allows reference to the written text.

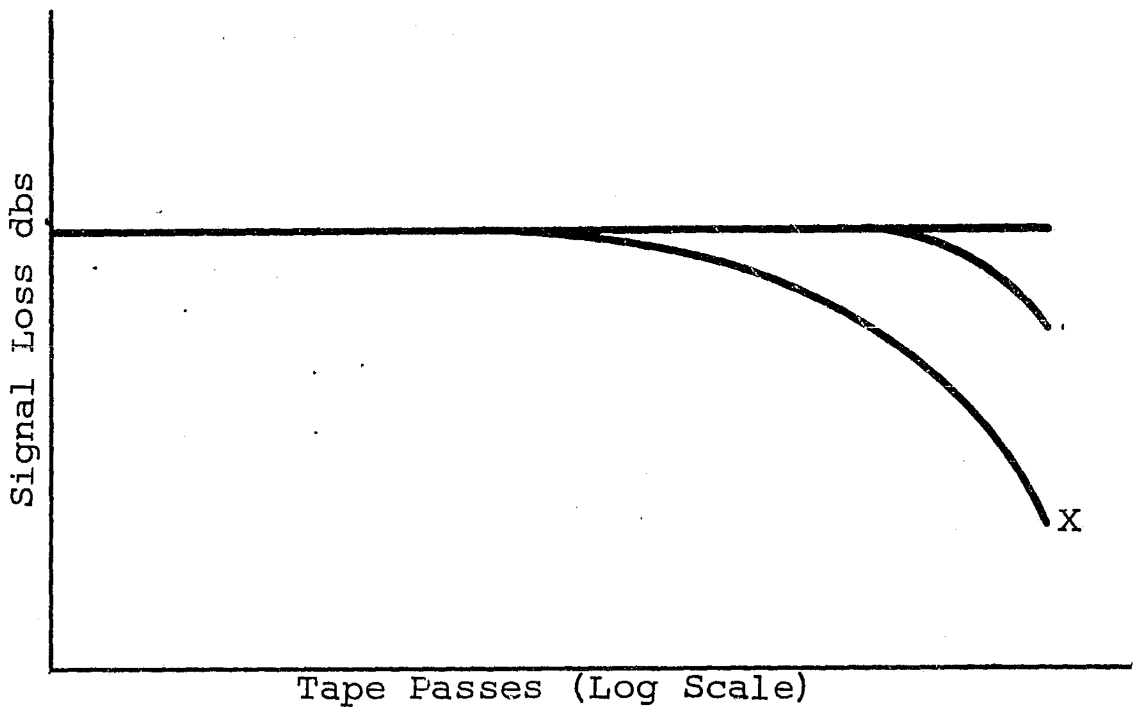


Fig. 9 SIGNAL LOSS TREND

Typical trend of signal loss results are shown above. In general, the condition of high wrap angle and high tension produced the greatest loss of signal for any head tape combination (X). Tape A also exhibited greater loss of signal at 2000 passes than tape B, this loss was attributed to oxide binder debris adhering to the magnetic heads. No substantial difference was noted between head types.

TEST RANKING TECHNIQUE

The loss in signal output after 2000 running passes was used to rank all tests one through twelve, where a higher ranking value signifies a greater signal loss.

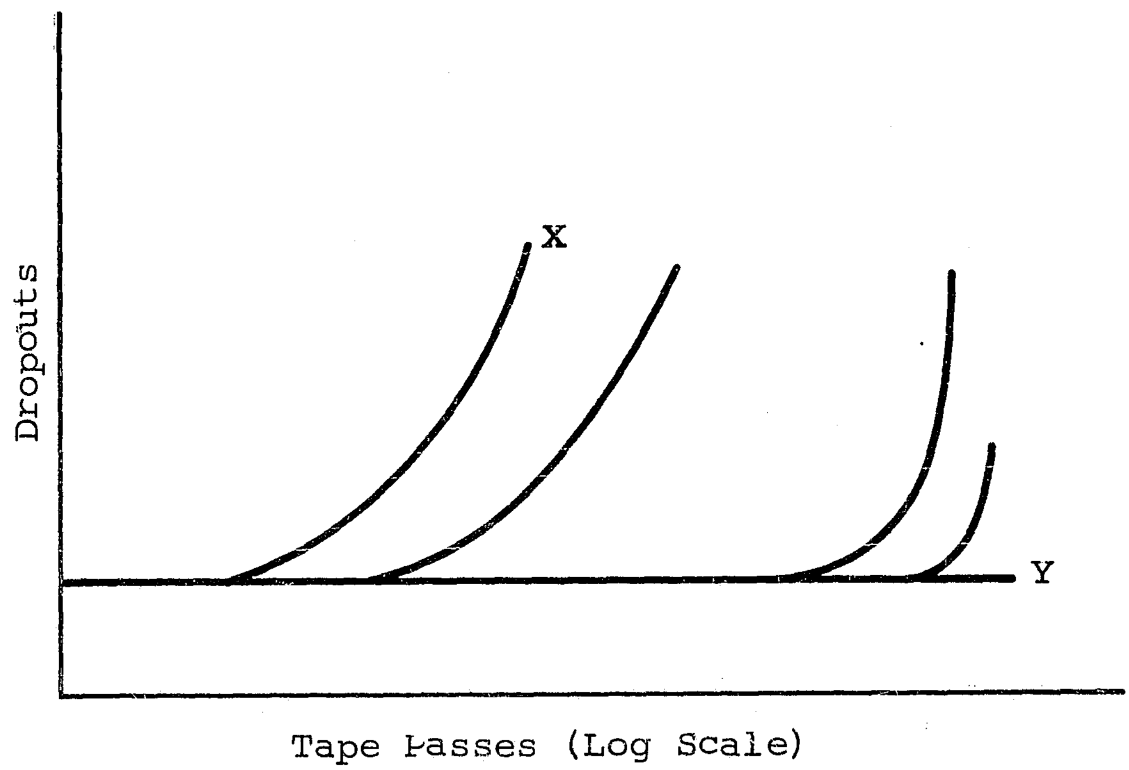


Fig. 10 DROPOUT COUNT TREND

Typical trend of dropout count results are shown above, where a sudden and marked increase was observed after a specific number of tape passes. This increase resulted from a repetitive disturbance in the signal output waveform indicating the start of stick slip. The order in which this increase occurred was directly related to the tape, the wrap angle/tension value and to a certain degree the type of recording head. In general, tape B readily exhibited this sudden increase (X) whereas tape A did not (Y). Results indicate that high wrap angles and tension resulted an early start to the disturbance, a reduction in tension extended the number of tape passes required to achieve this condition and a reduction in wrap angle proved even more effective in delaying the disturbance. The results also indicate that these disturbances occurred sooner when using soft faced heads.

TEST RANKING TECHNIQUES

The dropout curves were ranked in order one through twelve, where a higher ranking signifies an early start to the repetitive disturbance.

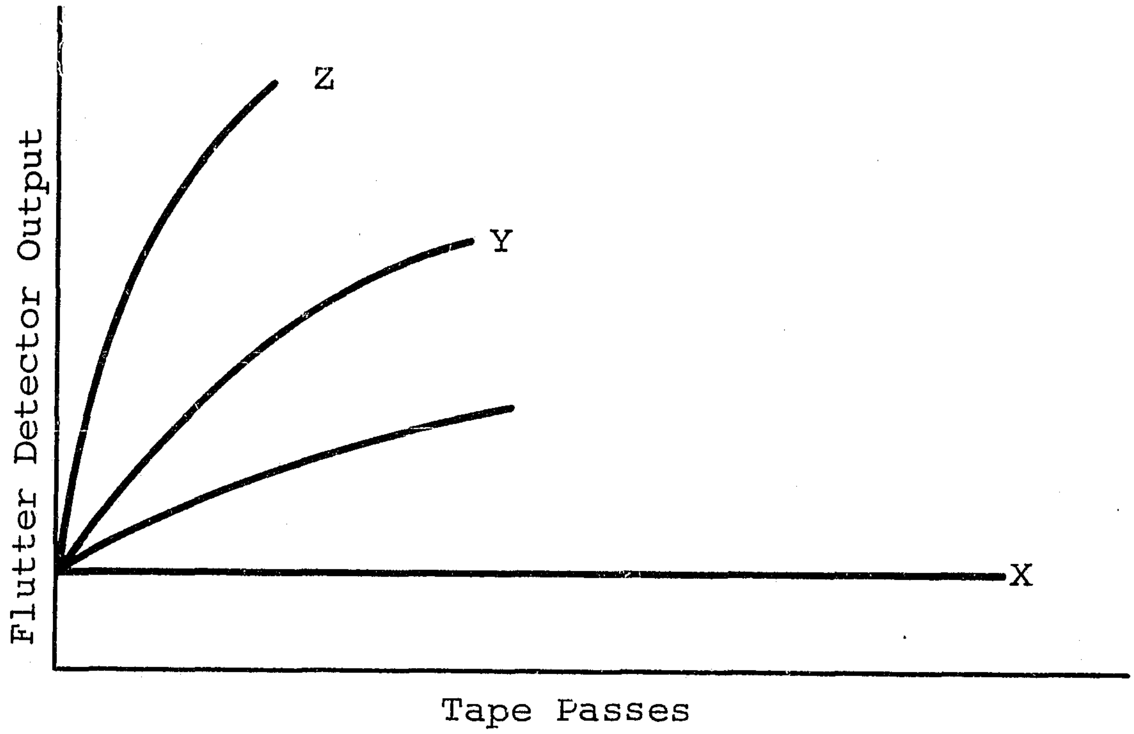


Fig. 11 FLUTTER TREND

Flutter characteristic measured while testing tape A proved constant over the measured 2000 running tape passes (X). Tape B, however, showed a marked increase in the value of flutter with increasing tape passes (Y, Z). The rate of increase proved to be extremely sensitive to the wrap angle/tension value. High values of wrap angle and tension resulted in characteristic (Z). In general, head type A exhibited a higher rate of flutter increase than head type B but this was not so apparent at low wrap angle values.

TEST RANKING TECHNIQUE

Test results were ranked one through twelve by measuring the rate of change of flutter after 200 running passes. The higher the measured slope the higher the ranking number.

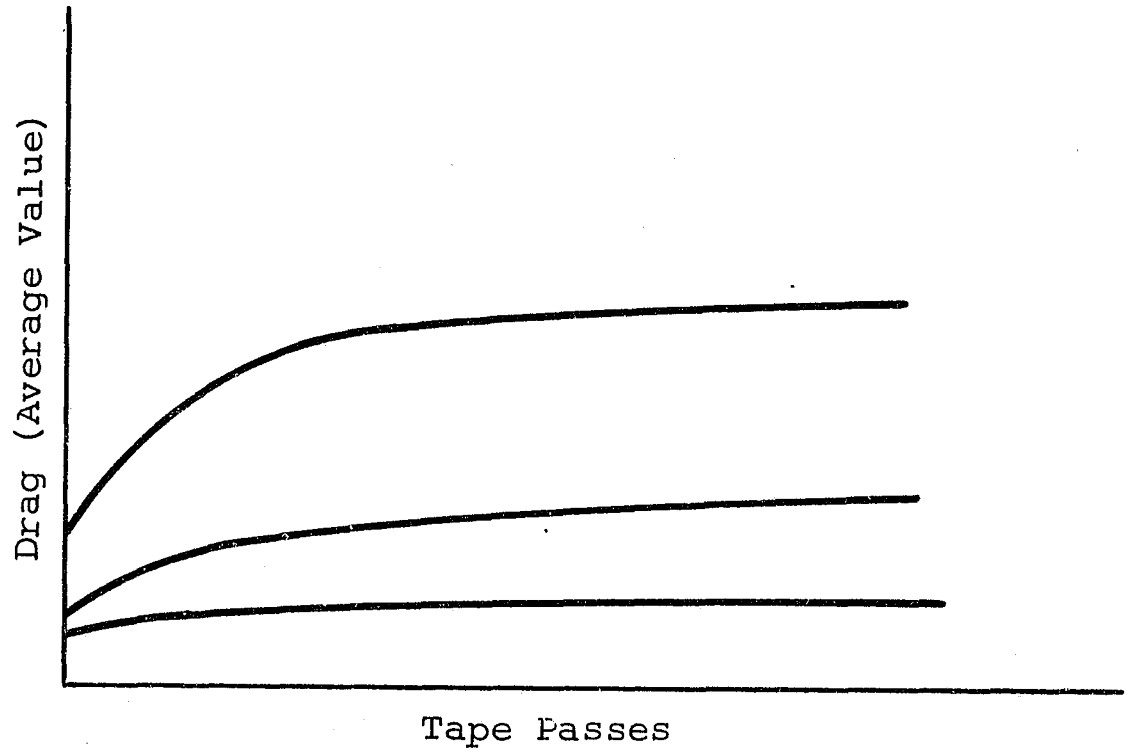


Fig. 12 HEAD TO TAPE DRAG TREND

Typical trends of the measured head to tape drag results are shown above. A rapid increase was followed in general by a leveling off to a fairly constant value. Results indicated that measured drag is directly related to the wrap angle/tension combination but independent of tape speed for the two values measured. While using tape B difference between head types were not substantial. However, with tape A distinct differences between head types were observed, head type B resulting in the minimum increase in drag.

TEST RANKING TECHNIQUE

The increase in drag from 0 to 2000 tape passes was measured and the results ranked one through twelve, where a higher ranking corresponded to a larger rate of increase of drag.

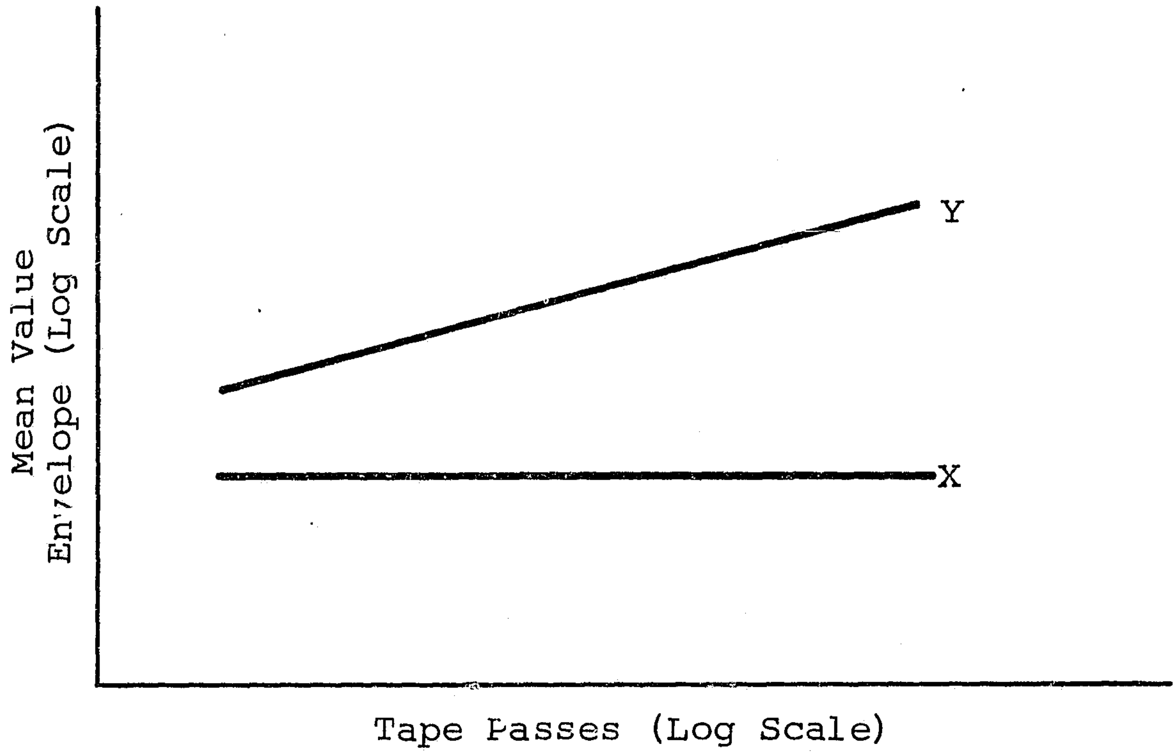


Fig. 13 ENVELOPE VARIATION TREND

Typical trend of the mean value of the output envelope is shown above. Variation of this value is directly related to the magnitude of signal disturbance experienced under stick' slip conditions. In general, tape A under most test conditions gave no indication of any substantial increase in the mean value of the output envelope (X). Tape B, however, always resulted in an increase (Y) with the number of tape passes. Correlation with the other test variables appeared complex.

TEST RANKING TECHNIQUE

The overall slope of the resulting curves were measured and ranked one through twelve where the higher ranking number corresponded to a higher value of slope. In addition, the magnitude of the signal envelope after 2000 tape passes was measured and also ranked one through twelve where a higher value corresponds to a higher ranking number.

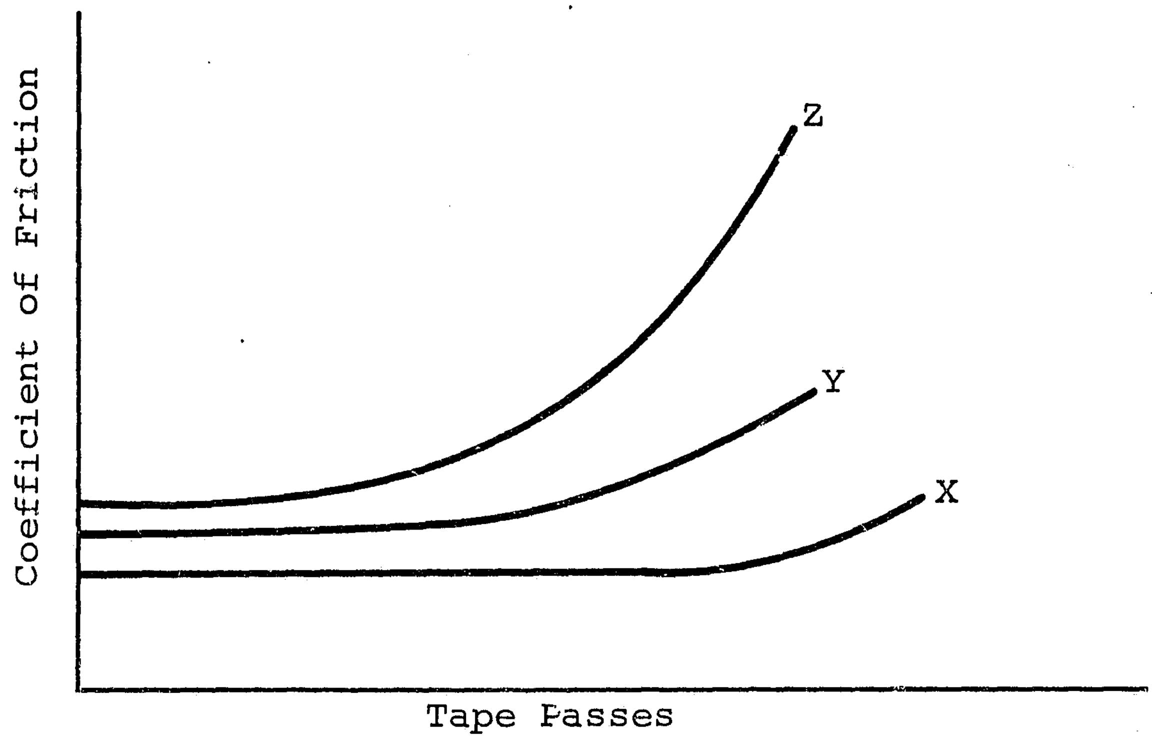


Fig. 14 TREND OF COEFFICIENT OF FRICTION

Typical trend of the change in the calculated value of the dynamic coefficient of friction is shown above. Initial values of the dynamic coefficient of friction for tape B appeared constant for either head type, however, for tape A initial differences were recorded between head types, the value for head type B being lower. After 2000 running tape passes the increase in the value of the coefficient of friction was smaller when using head type B. This applied to both tape types. In general the highest change in μg occurred for the highest wrap angle/tension combination, and when using tape A with head type A. Neither the original value of μg nor the change appears to correlate directly with the stick-slip capability of a system. More relavent to stick-slip is the rate of change between the static and dynamic values of the coefficient of friction.

4. Correlation of Test Variables

In an attempt to correlate these results a qualitative assessment was made of the previously displayed data. In the majority of cases such an assessment was undertaken by measuring the rate of change of each test variable with the number of tape passes. The exact procedure used is outlined on each of the previous trend curves. The results are summarized in Table II, where for each test combination, the individually ranked test variables are shown together with the rank sum and final rank order. Rank correlation coefficients of each test parameter against the final rank order is shown in Table III. An order of desirability for each test combination was then obtained by listing the twelve combinations in their final rank order as shown in Table IV. From this table, specific relationships can be observed for the test parameters by maintaining three of the parameters constant and determining the relative position, in rank order, for a change in one parameter only. Such an assessment of the major test variables follows:

Table II

RANKING ASSESSMENT OF TEST VARIABLES

Test No.	Parameters				Test Variables (Ranked 1 - 12)						Rank Sum	Final Rank Order
	Head	Tape	Wrap	Tension	Drag	Dropouts	Flutter	Output	Envelope (slope)	Envelope (magnitude)		
1	A	A	8	7	10	1	1	3	1	1	17	3
2	A	A	8	12	12	6	1	12	10	7	48	9
3	A	A	5	7	7	1	1	1	1	6	17	3
4	B	A	8	7	2	1	1	6	1	2	13	1
5	B	A	8	12	3	8	1	11	1	5	29	6
6	B	A	5	7	1	1	1	6	1	3	13	1
7	A	B	8	7	7	10	10	6	9	11	53	10
8	A	B	8	12	11	12	12	6	8	11	60	12
9	A	B	5	7	3	8	8	3	12	8	41	7
10	B	B	8	7	6	9	9	1	11	10	46	8
11	B	B	8	12	7	11	11	10	6	9	54	11
12	B	B	5	7	3	7	7	3	7	4	25	5

Table III

CORRELATION BETWEEN FINAL RANK ORDER
AND TEST VARIABLES

Rank Correlation (R) $= 1 - \frac{6\Sigma d^2}{n(n^2-1)}$ d = difference
n = number of samples

Final Rank Order	Drag		Dropouts		Flutter		Output		Envelope			
									Slope		Magnitude	
	Rank	d^2	Rank	d^2	Rank	d^2	Rank	d^2	Rank	d^2	Rank	d^2
3	10	49	1	4	1	4	3	0	1	4	1	4
9	12	9	6	9	1	64	12	9	10	1	7	4
3	7	16	1	4	1	4	1	4	1	4	6	9
1	2	1	1	0	1	0	6	25	1	0	2	1
6	3	9	8	4	1	25	11	25	1	25	5	1
1	1	0	1	0	1	0	6	25	1	0	3	4
10	7	9	10	0	10	0	6	16	9	1	11	1
12	11	1	12	0	12	0	6	36	8	16	11	1
7	3	16	7	0	8	1	3	16	12	25	8	1
8	6	4	9	1	9	1	1	49	11	9	10	4
11	7	16	11	0	11	0	10	1	6	25	9	4
5	3	4	1	4	7	4	3	4	7	4	4	1
$\Sigma d^2 =$		134		26		103		210		114		35
Rank Correlation =		0.53		0.91		0.604		0.27		0.60		0.88

Table IV

ORDER OF DESIRABILITY

Final Rank Order	Test No.	Parameters				Rank Sum	Observed Condition after 2000 Passes
		Head	Tape	Wrap	Tension		
1	6	HFH	A	5°	7	13	No Stick-Slip
2	4	HFH	A	8	7	13	No Stick-Slip
3	3	SFH	A	5	7	17	No Stick-Slip
4	1	SFH	A	8	7	17	No Stick-Slip
5	12	HFH	B	5	7	25	No Stick-Slip
6	5	HFH	A	8	12	29	Signal Loss
7	9	SFH	B	5	7	41	Stick-Slip
8	10	HFH	B	8	7	46	Stick-Slip
9	2	SFH	A	8	12	48	Signal Loss O/P Variation
10	7	SFH	B	8	7	53	Stick-Slip
11	11	HFH	B	8	12	54	Stick-Slip
12	8	SFH	B	8	12	60	Stick-Slip

a. Comparison of Head Type

Test No.	Head Type	Tape Type	Wrap Angle	Tension	Rank Order
6 3	B A	A	5	7	1 3
4 1	B A	A	8	7	2 4
5 2	B A	A	8	12	6 9
12 9	B A	B	5	7	5 7
10 7	B A	B	8	7	8 10
11 8	B A	B	8	12	11 12

Comparison of the above grouping clearly indicate that head type B (hard faced heads) has a higher degree of desirability than head type A (soft faced heads) for all conditions measured.

b. Comparison of Tape Type

Test No.	Head Type	Tape Type	Wrap Angle	Tension	Rank Order
6 12	B	A B	5	7	1 5
3 9	A	A B	5	7	3 7
4 10	B	A B	8	7	2 8
1 7	A	A B	8	7	4 10
5 11	B	A B	8	12	6 11
2 8	A	A B	8	12	9 12

Comparison of the above grouping indicates that tape type A has, in all cases, a lower ranking order; that is, a higher degree of desirability than tape type B. It should be noted that the difference in the numerical value of rank order for any one group is large indicating substantial differences between these two tape types.

c. Comparison of Wrap Angle

Test Type	Head Type	Tape Type	Wrap Angle	Tension	Rank Order
6 4	B	A	5 8	7	1 2
3 1	A	A	5 8	7	3 4
12 10	B	B	5 8	7	5 8
9 7	A	B	5 8	7	7 10

Comparison of the above grouping indicates that the lower wrap angle (5°) has a higher degree of desiribility than that of the higher wrap angle (8°). In general, results indicate that a change in the tape wrap angle is more significant in the reduction of signal disturbances than that of change in tension.

d. Comparison of Tension

Test Type	Head Type	Tape Type	Wrap Angle	Tension	Rank Order
4 5	B	A	8	7 12	2 6
1 2	A	A	8	7 12	4 9
10 11	B	B	8	7 12	8 11
7 8	A	B	8	7 12	10 12

In all the above cases it can be seen that a lower value of tape tension has a greater degree of desiribility in that this value appears lower in rank order than that of the higher value of tension.

e. <u>Comparison of Head Wear</u>

Throughout the Phase I testing program detailed measurements were made of each individual head profile both before and after each test sequence. The magnetic recording heads were refurbished only after tests had been completed on one head/tape combination. This allowed head wear to be measured for both each test condition and the total head wear after accumulating 6,000 tape passes. The instrument used throughout for this measurement was a Bendix Profilometer with a stylus force of 300 mg and a stylus radius of 0.001 inches. Detailed records are available for each case and the results are summarized below in Table V.

Table V

COMPARISON OF HEAD WEAR (MICROINCHES)

Test Condition		Tape Type A		Tape Type B	
Wrap	Tension	Head A	Head B	Head A	Head B
8°	7 oz	5	10	8	0
8°	12 oz	18	3	0.5	0
5°	7 oz	27	2.5	4.5	0
	TOTAL....	50	15.5	13	<2

It can be readily observed that head type B (hard faced head) wear considerably less than head type A (soft faced head) as expected. Tape type B also contributes to less head wear than tape type A, this can be attributed to its considerably higher lubrication content. Comparison between test conditions is not easily correlated. Attempts to relate measured head wear with either total radial force or total radial force per unit area proved difficult. However, the recommended combination of head B, tape A, wrap 5°, tension 7 oz resulted in 2.5 microinches of head wear for 2,000 tape passes which may be expressed 1.25×10^{3} inch per million feet of tape.

5. Summary

In summary it is clear from the results obtained that, the combination of head type B, tape type A, a wrap angle of 5°, and a tape tension of 7 oz gives the best degree of desirability from all other combinations measured. The degree of desirability is a qualitative measurement and is meant to express the lack of any undue head to tape disturbance.

Of the four basic test variables measured in the Phase I study, the choice of magnetic tape played the most significant role in the production of severe signal disturbances; this was to be expected, as the two types were selected from the prior knowledge of their stick-slip capability. The exact mechanisms relating to the early failure of tape type B are not clear, however, one significant parameter of this tape type is its high lubrication content which, it is thought, accentuates the formation of oxide binder debris.[1] No serious debris problems were encountered with this tape type during Phase I testing, however, these tests were conducted at ambient temperature where debris formation is minimized.

The apparent ease of tape B to readily exhibit a stick-slip condition was useful in the examination of tape type A. Within the constraints of the predetermined test conditions tape type A did not exhibit any severe stick-slip signal disturbance, however, some signal loss and signal output variation was experienced particularly at high wrap angle/tension conditions. In order to confirm this result, an auxiliary test was conducted with conditions identical to that of test No. 2 (head A, tape A, 8°, 12 oz) but with an extension in the number of tape passes up to 10,000. Again serious signal loss was experienced after 2,000 tape passes and beyond, this

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[1] R. J. Owen, Head/Tape Interface Study, Technical Report, Volume II, Contract No. NAS5-11622, IIT Research Institute, Chicago, Illinois, to be published.

was directly related to a build up of oxide-binder debris in the head to tape contact area. Following the analysis of the results obtained from this test it became apparent that a start of some form of signal disturbance could be identified in the output envelope characteristic. This was coupled with an increasing value of drag and an increase of the mean variation of the tape tension. Although stick-slip as observed with tape type B did not occur during this test with tape A, it is considered that conditions after 10,000 running passes were becoming critical at this high wrap angle/tension combination.

The next most significant test variable is considered to be the tape wrap angle. A comparison of the results achieved would indicate that a reduction in wrap angle significatnly reduces, or delays, the start of severe signal disturbances. The limiting factor in the reduction of this variable is simply that of ensuring intimate head to tape contact throughout mission life. The wrap angle tension product is, by first degree approximation, equal to the total radial force at the head/tape interface. A reduction in wrap angle may therefore necessitate a slight increase in overall tension to maintain good short wavelength response.

Of the two remaining test variables, head type and tape tension, both appear to have a similar significance. Head type B does, however, have an additional advantage of reduced wear which is not directly considered in these assessments; and a change in tape tension must be related to the wrap angle used. This is elaborated upon in the second section of this technical discussion under the Phase II investigation of boundary disturbances.

B. Boundary Disturbance Investigation

1. Introduction

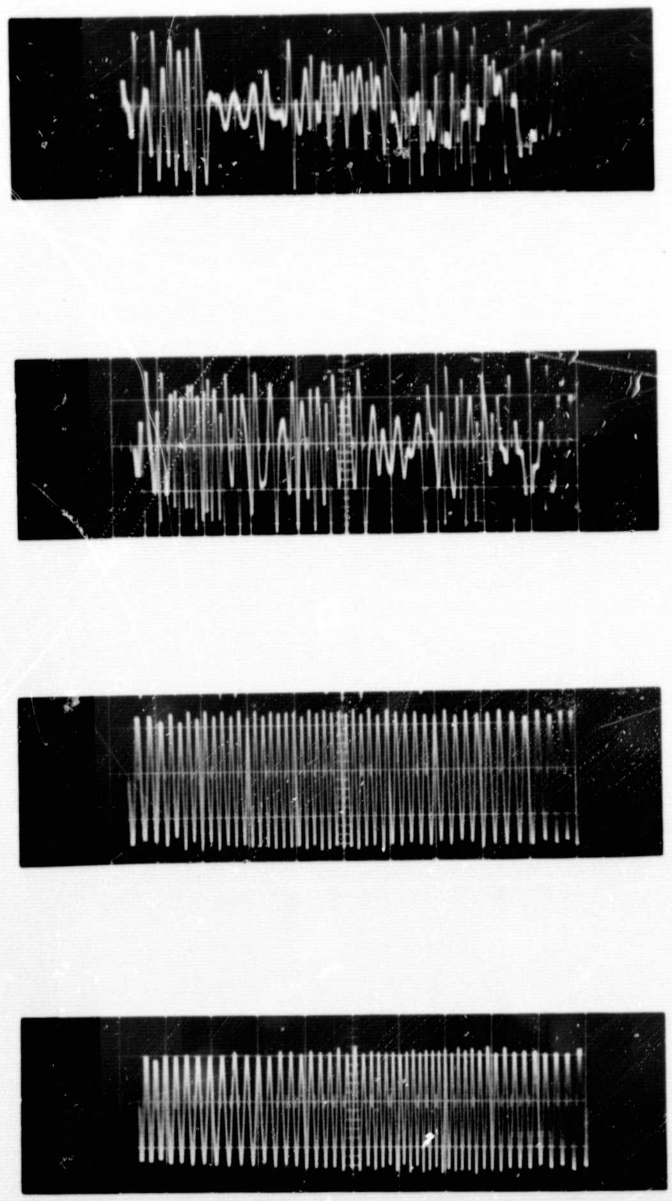
Constant monitoring of the reproduce output signal waveform was undertaken during Phase I in order to correlate any observed disturbance with the measured parameters. During one such test the change in output signal disturbance was recorded for various applied tape tensions. These are illustrated in Fig. 15. In order to supplement this result, additional tests were undertaken to observe the effect of changing the tape wrap angle while maintaining the tape tension constant. The results obtained are shown in Fig. 16 and clearly illustrate that a signal disturbance begins between 7° and 10° wrap angle. This experimental arrangement, in which only one recording head was used with tape guides symmetrically displaced either side, allowed us to further investigate the relationship between drag and tension for a variety of tape wrap angles. The initial results obtained are illustrated in Fig. 17 and substantiate the well known belt pulley relationship, (see Appendix A).

$$\frac{T_2}{T_0} = e^{\mu\theta}$$

Of specific interest to this program was the ability to superimpose on this data the locus of the disturbed/undisturbed signal output, Fig. 18. It was considered that the ability to predict such a disturbance boundary and its change with time, or mission life, with any degree of certainty would greatly enhance the designers ability in specifying conditions which at no time would produce a stick-slip condition.

Additional experimental determination was therefore carried out with specific objectives. First, the position and shape of this boundary disturbance was investigated and an attempt

DYNAMIC TENSION



8 oz.

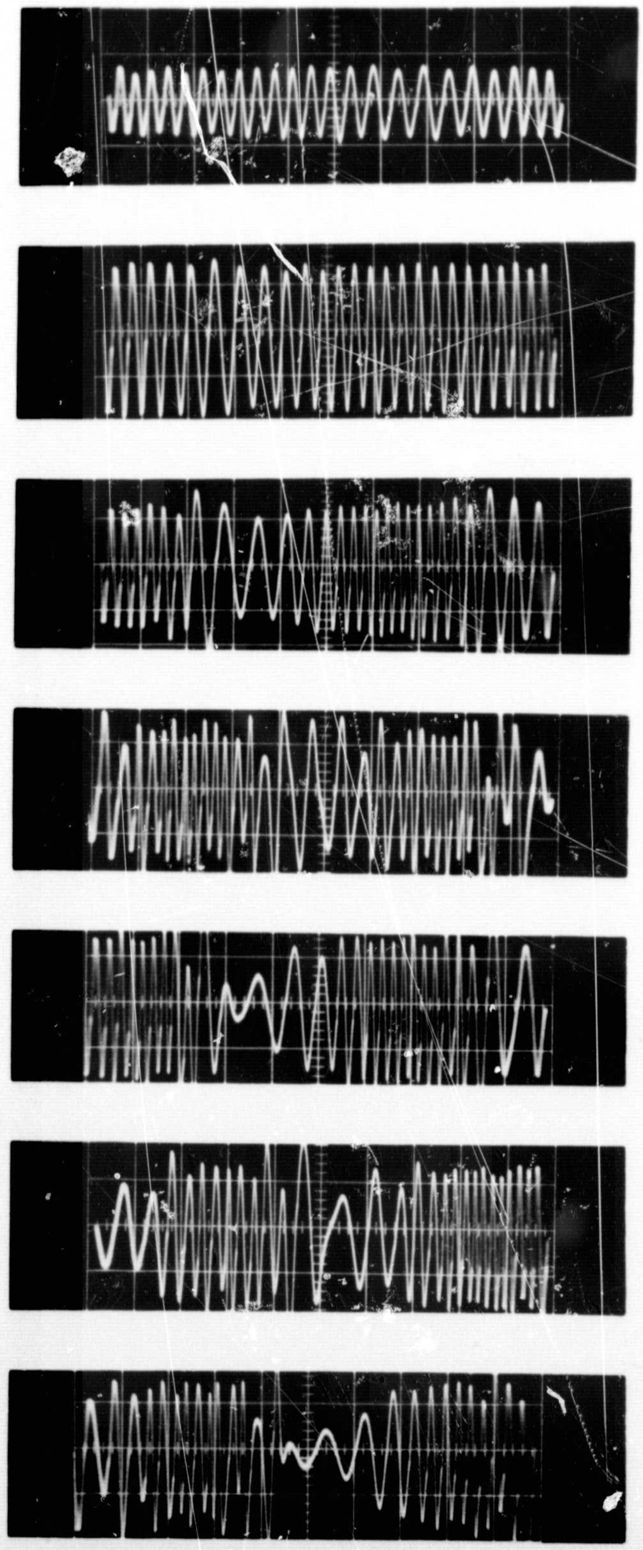
5 oz.

4 oz.

3 oz.

Fig. 15 OUTPUT SIGNAL FOR VARIOUS TAPE TENSIONS WITH A CONSTANT WRAP ANGLE OF 16°. TAPE SPEED 0.15 INCHES PER SECOND.

TOTAL WRAP ANGLE



0°

7°

10°

15°

20°

25°

30°

Fig.16 OUTPUT SIGNAL FOR VARIOUS WRAP ANGLES WITH A CONSTANT TENSION OF 12 oz. TAPE SPEED OF 0.15 INCHES PER SECOND.

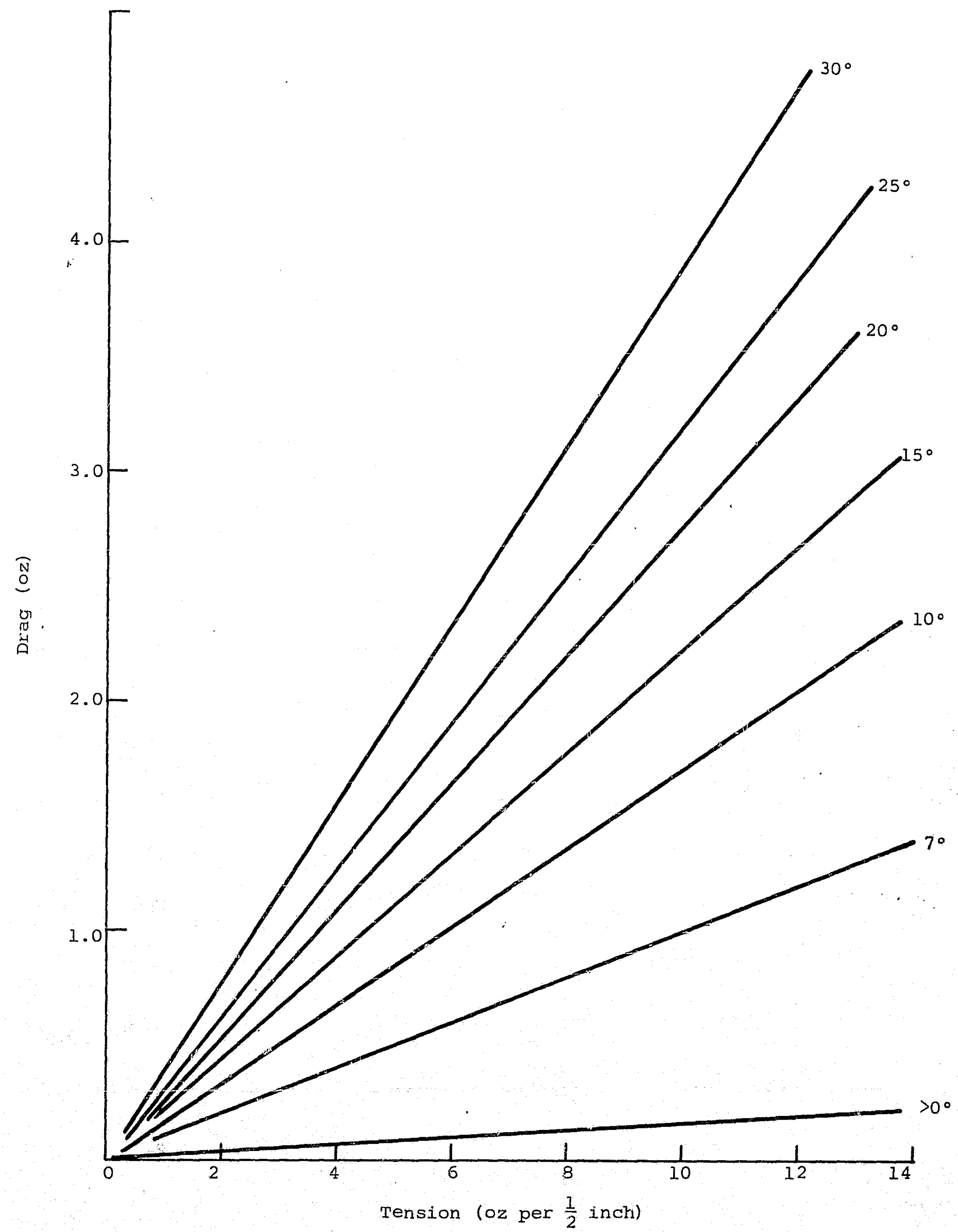


Fig. 17 RELATIONSHIP BETWEEN DYNAMIC TAPE TENSION AND DRAG FOR A VARIETY OF WRAP ANGLES MEASURED AT A REPRODUCE TAPE SPEED OF 0.15 INCHES PER SECOND

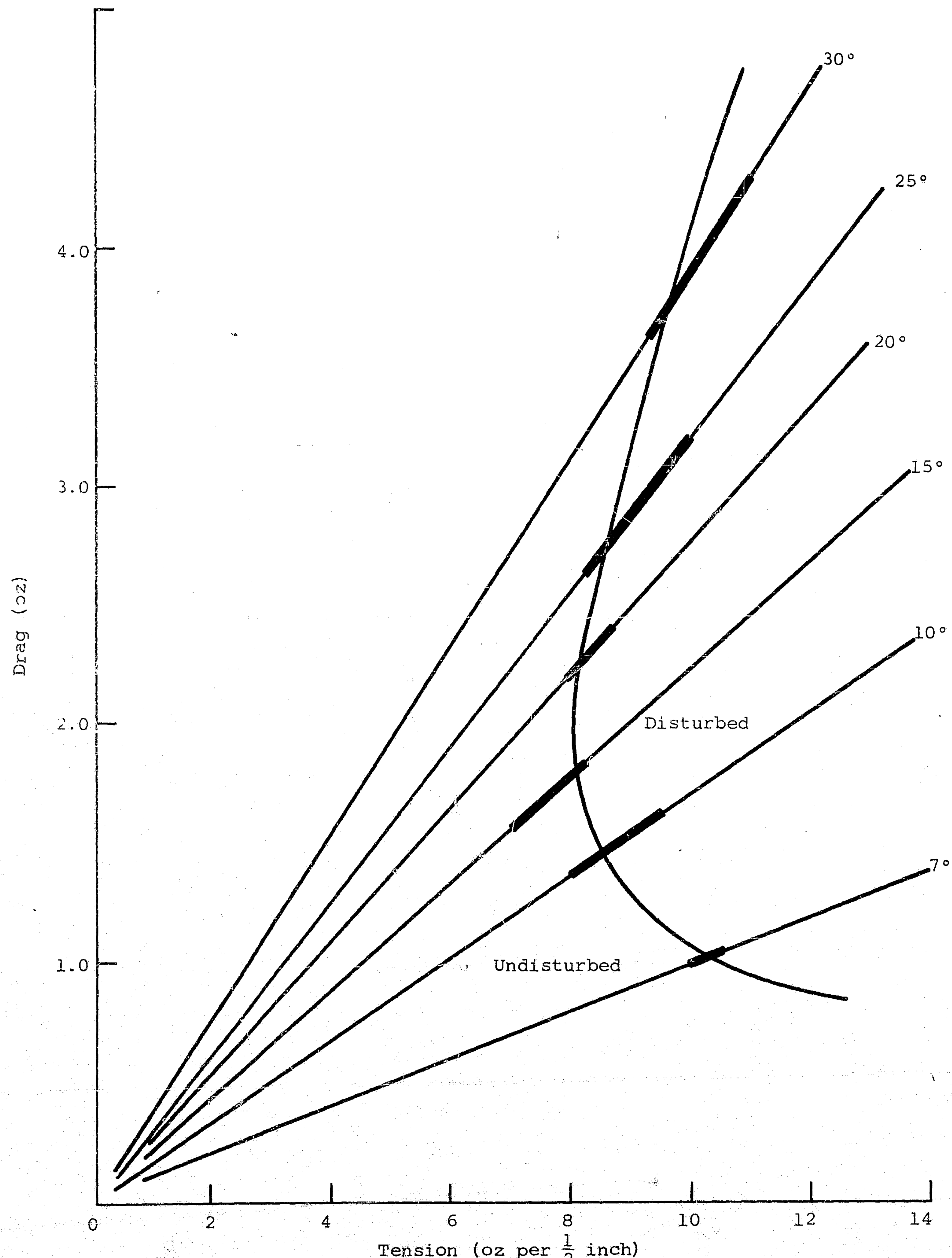


Fig. 18 THE RELATIVE POSITION OF THE DISTURBED AND UNDISTURBED AREAS OF OUTPUT SIGNAL, SHOWING THE LOCATION OF THE BOUNDARY LOCUS

made to relate its position to the test variables or other physical parameters associated with the head/tape interface. Second, the change in position with speed and number of tape passes was examined. The actual shape of the curves obtained which separated the disturbed from the undisturbed region appeared somewhat unusual as they indicated a non-linear relationship with the basic test variables. Initially it was thought that, except for values measured at low angles of wrap, the locus of the disturbed/undisturbed region approximated a constant radial force per unit area value. The nonconformity at low wrap angles was attributed to possible loss of signal output owing to poor head to tape contact. Unfortunately, subsequent testing coupled with an attempt to correlate these results with related theory failed to substantiate this argument. Assessments have been formulated in an attempt to relate these measured curves with conditions experienced at the head/tape interface and these are outlined later in the text.

2. Procedure

The test procedures used in the collection of the boundary disturbance data differed from that used during Phase I of this program and are therefore outlined. In order to allow ease in the continual adjustment of wrap angle only one reproduce head was used with precision rotating tape guides symmetrically displaced either side of the head (Fig. 19).

With the tape speed and tape wrap angle accurately set, the tape tension was then varied while monitoring drag and signal output. Assuming that the dynamic coefficient of friction remained constant this then allowed the test to move along a constant $\mu\theta$ load line (Fig. 17) while observing any signal disturbance experienced at the head/tape interface. In such a way it was, therefore, possible to precisely determine the point at which a serious signal disturbance

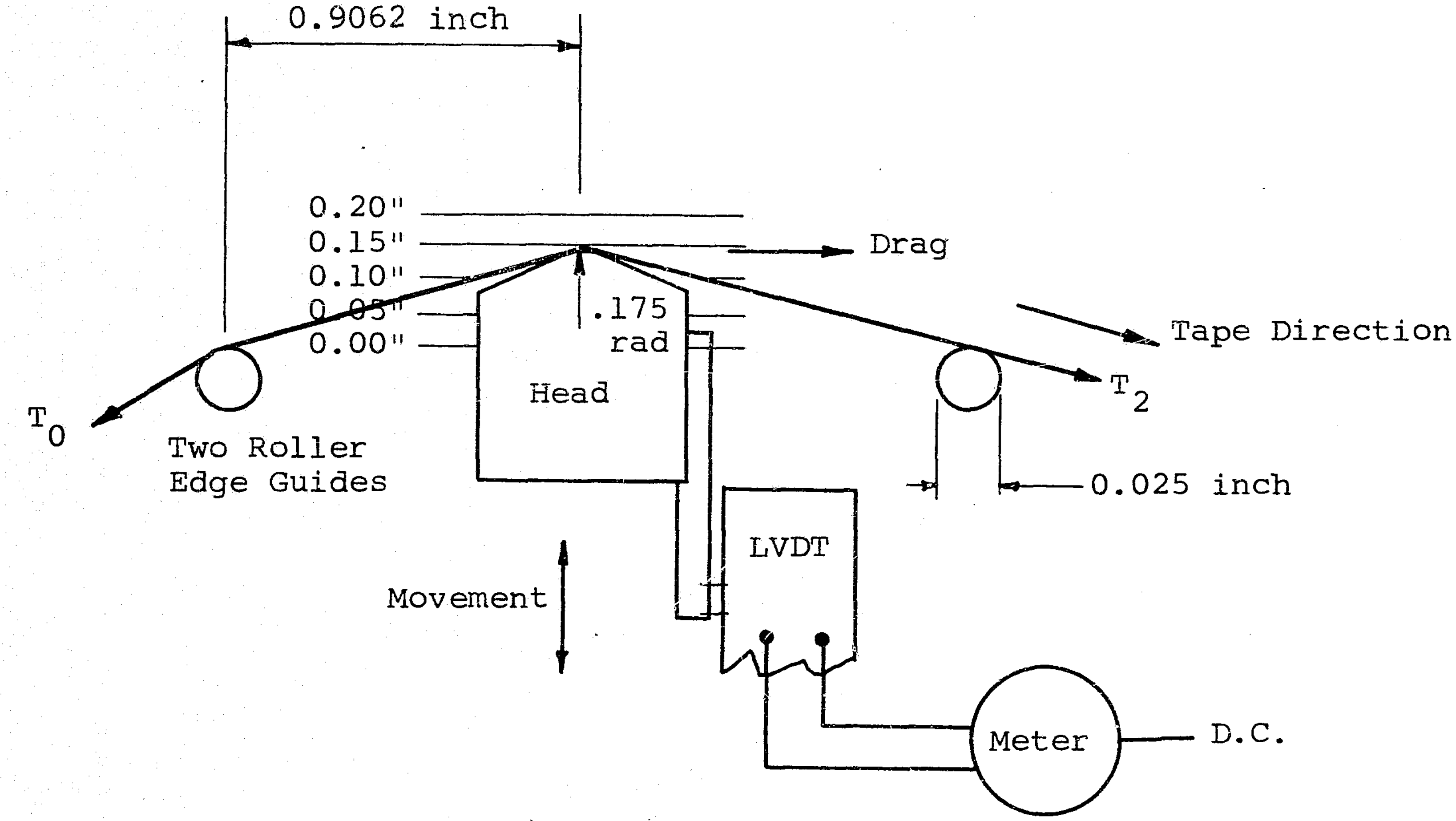


Fig. 19 SCHEMATIC LAYOUT OF SINGLE HEAD SYSTEM SHOWING SYMMETRICAL RELATIONSHIP OF ROTATING EDGE TAPE GUIDES

appeared. This same procedure was repeated for a variety of tape wrap angles thereby defining a boundary at which signal disturbances occurred.

This initial procedure was later modified in an attempt to incorporate two recording heads into the system. However, in doing so, the method used in measuring drag had to be changed from that using an LVDT device attached to the recording head, to that of measuring differential tension. Following this change, it was found that the tensiometers themselves introduced values of drag of sufficient magnitude to make measurements of drag difficult. Modifications were carried out to reduce the inherent drag of these devices so allowing differential tension to be used, but the results obtained using this system proved unreliable and finally the system was restored to that originally described. It was this instrumented one head system that was therefore used for a more detailed analysis of the disturbance boundary position. Tests were conducted using different tape types, recording heads, and most important, tapes which had been subjected to various degrees of cycling at 19.4 inches per second.

3. Results

In general it was found that both tape A and unused tape B when subjected to this test did not exhibit any form of measurable stick-slip disturbance, therefore, subsequent tests concentrate on used Tape B where boundary disturbances were readily plotted. Measurements were made after 10,000, 1,000, and 200 tape passes at 19.4 inches per second. After 10,000 tape passes the stick-slip condition of tape B was so extreme that severe capstan slippage occurred and undisturbed regions proved difficult to measure even at low angles of wrap and tension. After 1,000 and 200 tape passes respectively the disturbed/undisturbed boundary fell more within the measurement regimes and allowed a variety of measurements to be made at various reproduce tape speeds, namely, 0.16, 0.52, 0.75, and 0.90 inches per second. The magnetic recording heads used throughout were type B, this was mainly to insure compatibility with the earlier measurements.

The results shown in Fig. 20 display the disturbed/undisturbed boundaries for four reproduce speeds after subjecting the tape to 200 running passes at 19.4 inches per second. It is interesting to note that the general shape of these loci agrees with the earlier data in that at higher values of wrap angle the tension value required to induce a signal disturbance remains constant or slightly increases. Such an effect has proved difficult to explain. At low values of wrap angle the disturbance boundary tends to follow a constant value of drag and this part of the curve does appear to fit published theory[2] and is explained later. After 1,000 running passes at 19.4 inches per second the disturbance boundaries appears as shown in Fig. 21. It can be seen that although the general shape appears as before the loci have moved and appear quite congested at low tape speeds, a fact which substantiated the problems experienced after 10,000 running tape passes.

This movement of the disturbed/undisturbed boundary dependent upon the condition of the magnetic tape is considered to be very important in that, once a boundary condition has been determined for a specific tape type it should be possible to predict an operating area in which no stick-slip disturbance would occur over a predetermined mission life. In analyzing the results obtained during this investigation, emphasis was placed on attempting to relate both the shape and position of these curves with specific parameters including tape tension,

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[2] Steinhorst, W. Elastic Longitudinal Vibrations in Recording Tapes Especially with Stick-Slip Excitation, Feinwerktechnik, Volume 70, No. 4, pp. 172-184, April 1966.

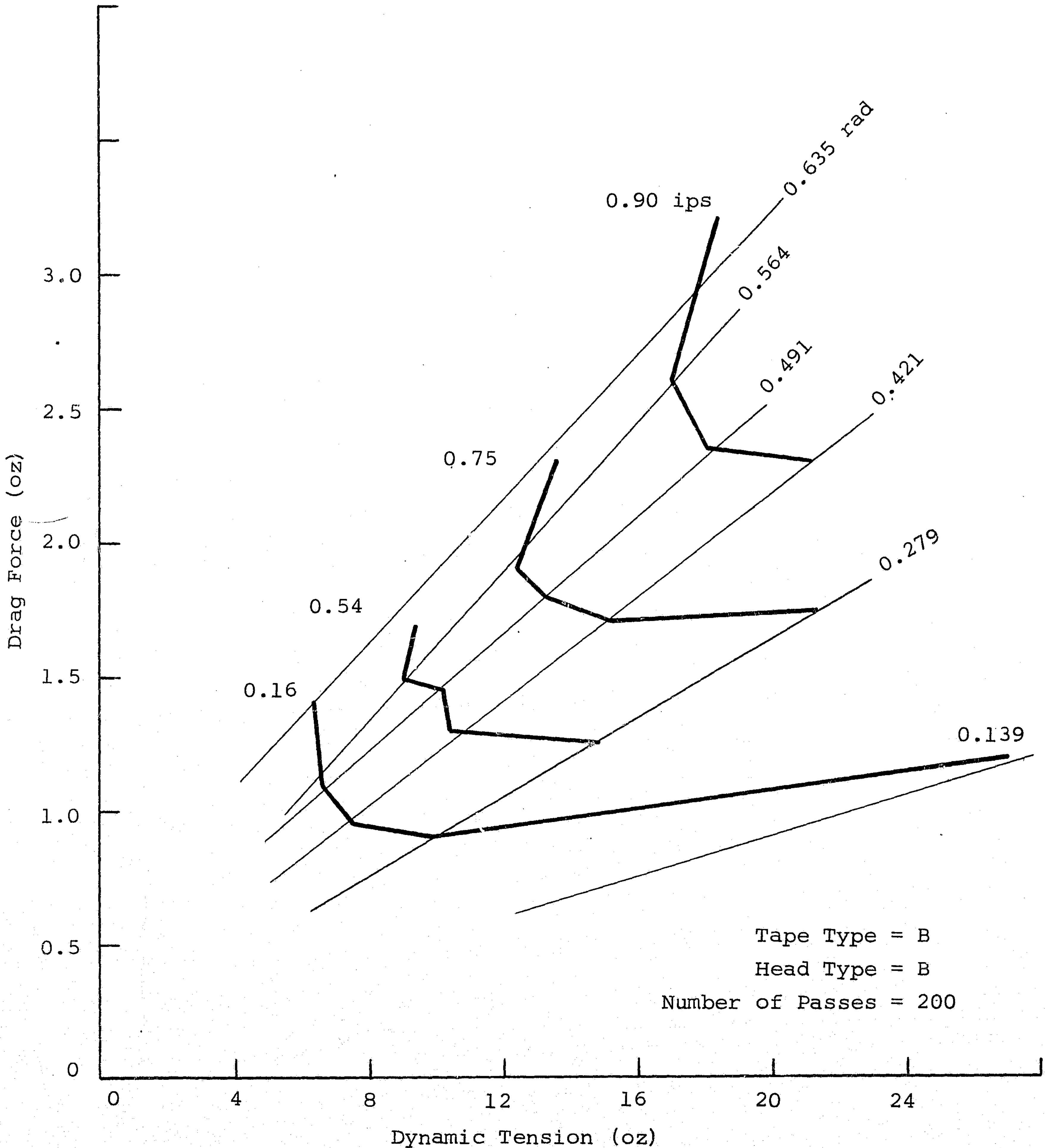

Fig. 20 POSITION OF THE DISTURBED/UNDISTURBED BOUNDARIES AFTER 200 RUNNING PASSES AT FOUR DIFFERENT REPRODUCE TAPE SPEED

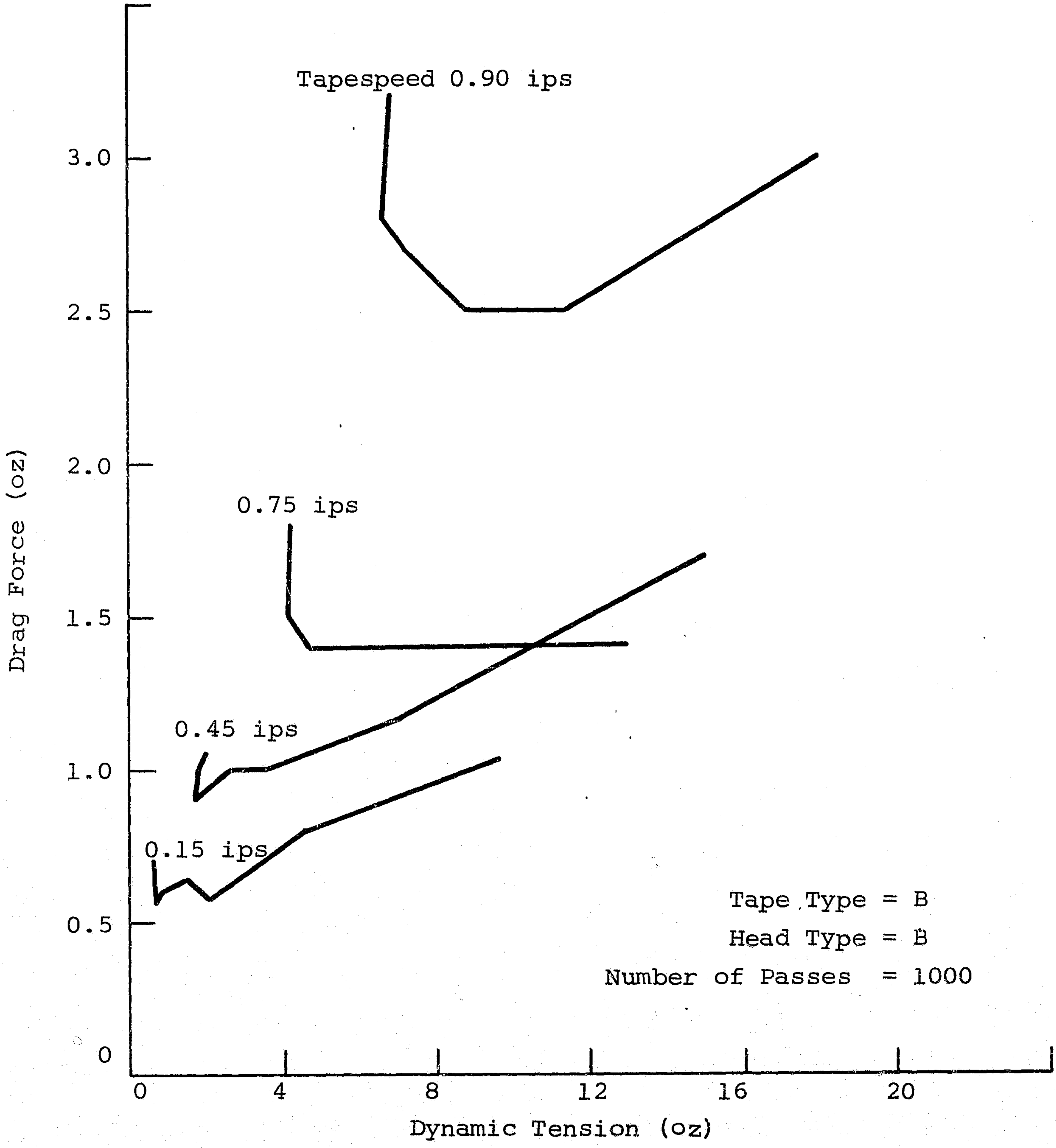

Fig. 21 POSITION OF THE DISTURBED/UNDISTURBED BOUNDARIES AFTER 1000 RUNNING PASSES AT FOUR DIFFERENT REPRODUCE TAPE SPEEDS

drag, wrap angle, normal force, coefficient of friction, and tape speed.

4. Analysis of Results

Although a full and complete analysis was not possible within the scope of this phase of the program, an attempt was made to relate a few of the basic test variables to the measured results. Initial analysis centered around the relationship between tape speed and the value of tape tension at the disturbance point for a fixed value of wrap angle. This relationship with tape speed is illustrated for both 200 and 1,000 tape passes in Figs. 22 and 23. In each case the value of tape tension for a fixed wrap angle is plotted against critical speed, that is, the speed at which a severe signal disturbance appears. It can be clearly seen that this relationship, as measured, is non-linear but interesting similarities in the curves are evident. The curves appear to approximate the following relationship

$$T_0 \propto \frac{1}{\theta} \cdot f\ (V_{CR})$$

the product of tension and wrap angle was therefore plotted against the hyperbolic cosine of critical tape speed as shown in Fig. 23.

The resultant straight line indicates a relationship

$$T_0 = \frac{k}{\theta}(\cosh V_{CR})^N \qquad (1)$$

where for 200 tape passes K = 2.7 and n = 3 for comparison Fig. 24 shows the relationship

$$T_0 = \frac{2.7}{\theta}\ (\cosh V_{CR})^3 \quad \text{for various values of } \theta$$

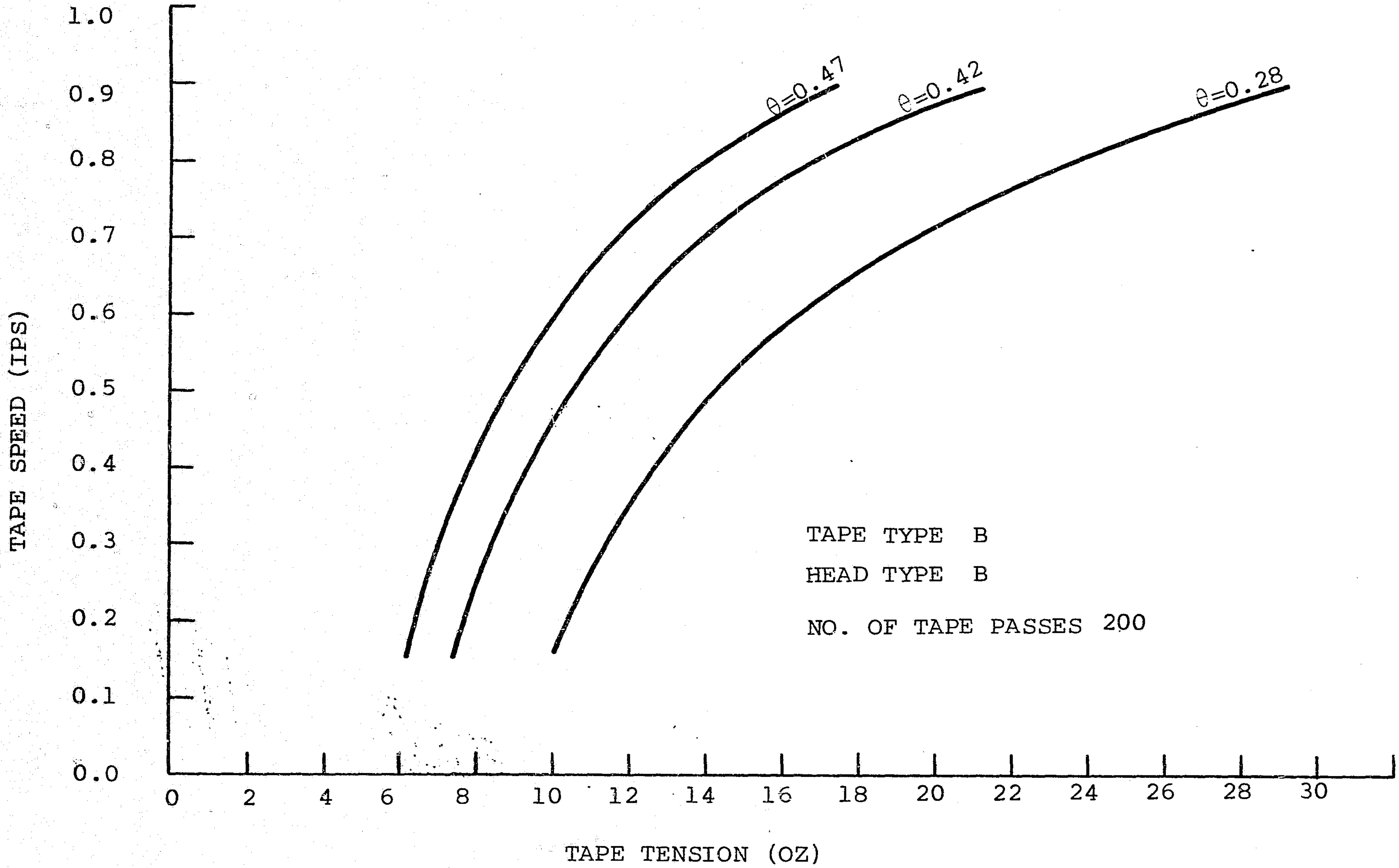

Fig.22 RELATIONSHIP BETWEEN THE TAPE SPEED AND TAPE TENSION AT A DISTURBANCE POINT, FOR A CONSTANT WRAP ANGLE AFTER 200 RUNNING TAPE PASSES

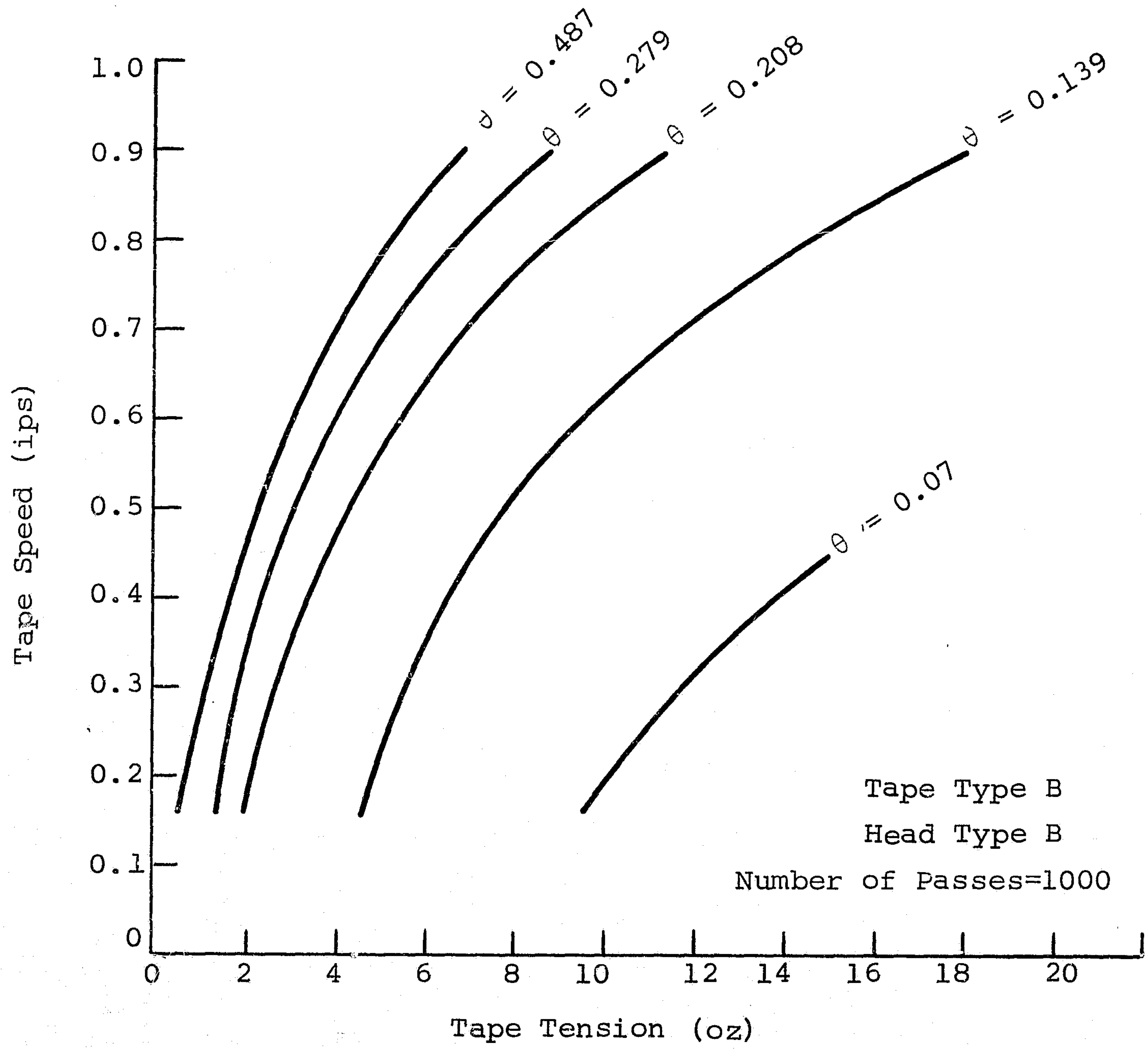

Fig. 23 RELATIONSHIP BETWEEN THE TAPE SPEED AND TAPE TENSION AT A DISTURBANCE POINT, FOR A CONSTANT WRAP ANGLE AFTER 1000 RUNNING PASSES

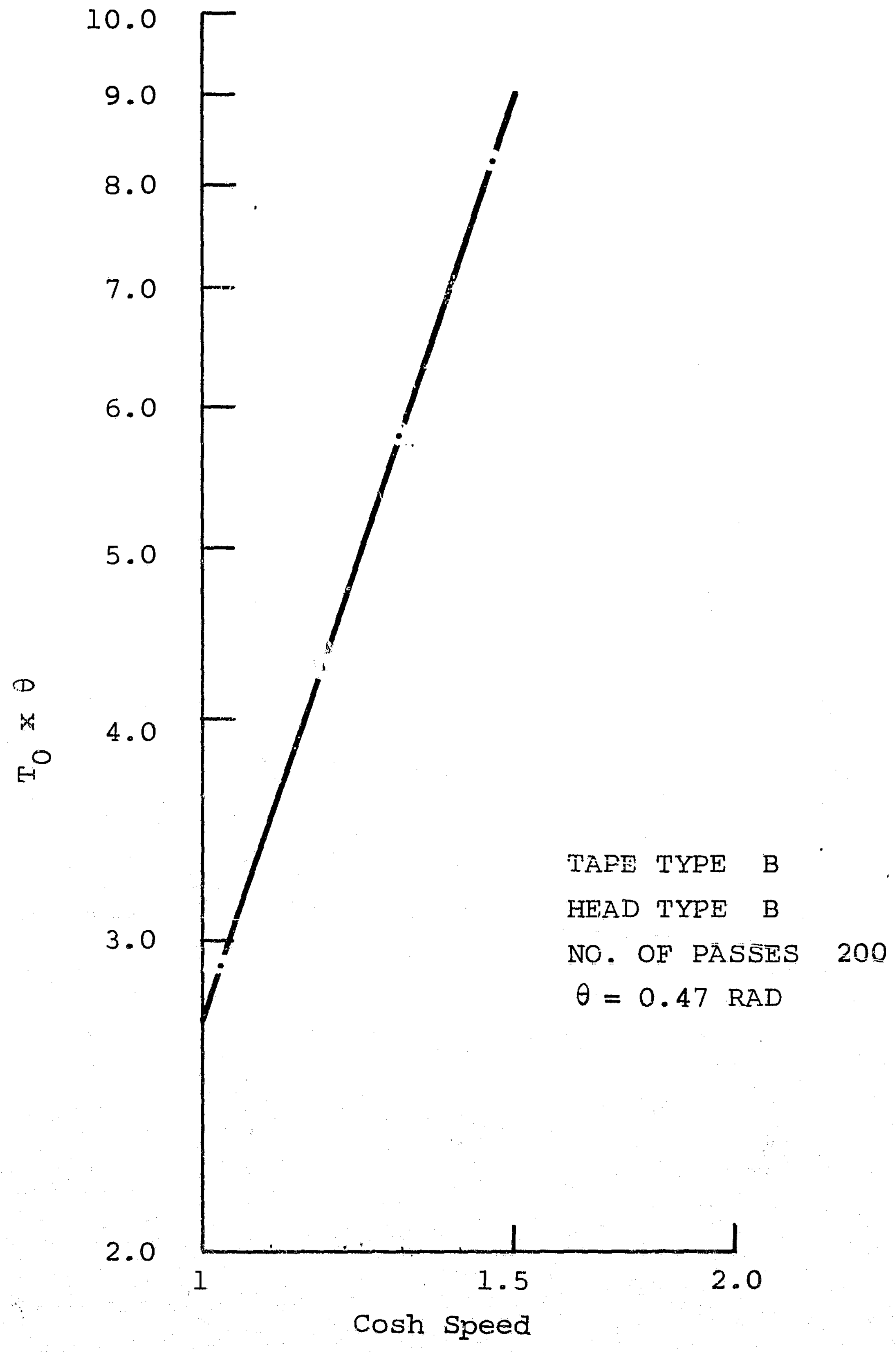

Fig.24 RELATIONSHIP BETWEEN THE TENSION/WRAP ANGLE PRODUCT AND THE HYPERBOLIC COSINE OF TAPE SPEED

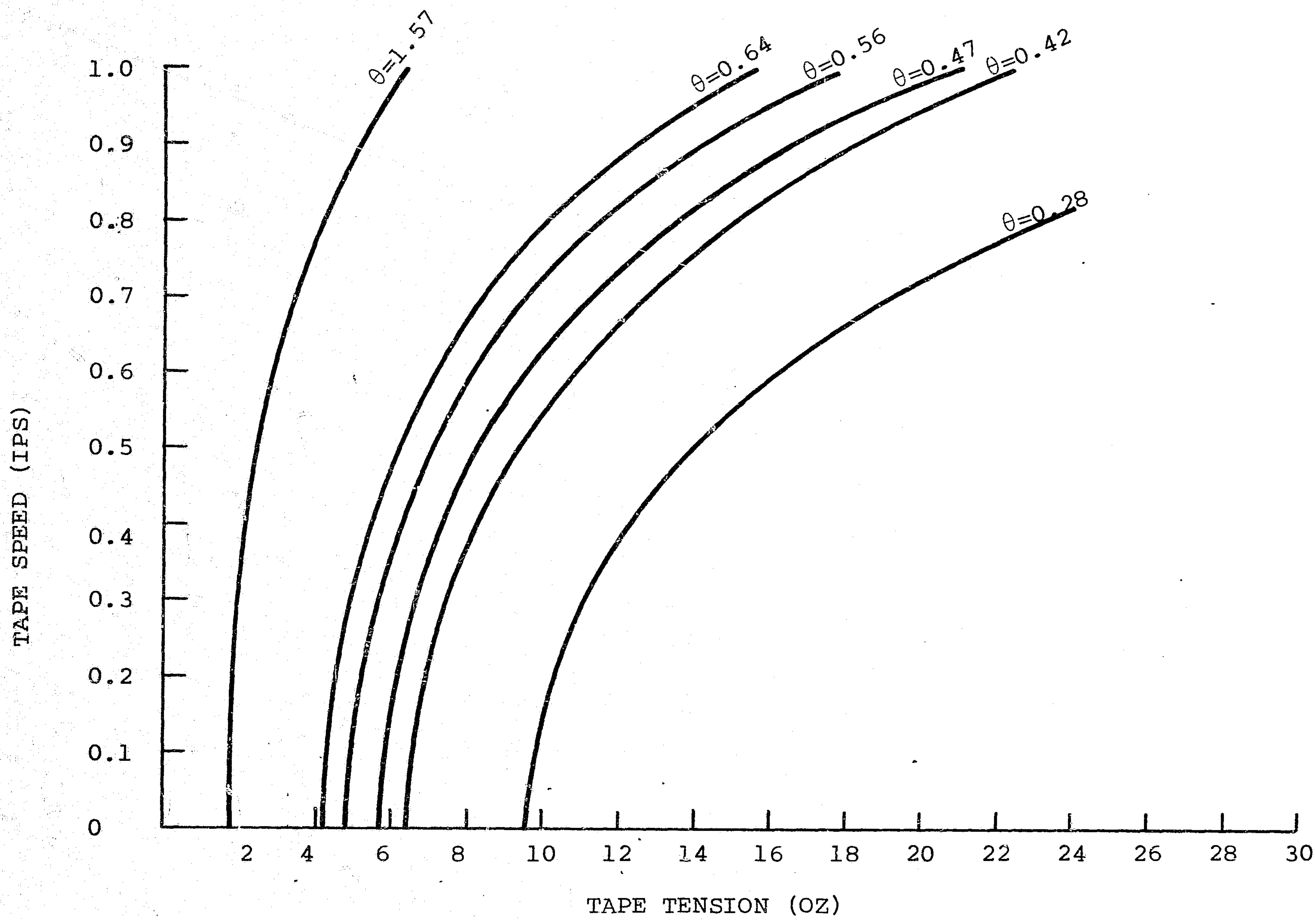

Fig.25 THEORETICAL PLOT OF TAPE SPEED AGAINST TAPE TENSION

$$T_0 = \frac{2.7}{\theta} (\cosh S)^3$$

The ability to correlate this exponential relationship to previously published data has proved difficult. An equation for a critical boundary velocity has been observed by W. Steinhorst W. Steinhorst[2] where he combines the restraint that a gross increase in head to tape coupling occurs at zero tape to head velocity, with the equations of dynamic equilibrium and the standard belt pulley relationship. This analytical approach results in the following equation which he experimentally verifies.

$$V_{CR} = \frac{(e^{\mu_s \vartheta} - e^{\mu_g \vartheta}) T_0}{E_s w b} \sqrt{\frac{E_D}{\rho}} \qquad (2)$$

where

μ_s = static coefficient of friction

μ_g = kinetic coefficient of friction

T_0 = tape tension

E_s = modulus of elasticity

w = tape width

b = tape thickness

$E_D = \frac{E_s (1-\nu)}{(1+\nu)(1-2\nu)}$

ν = Poissons' ratio

ρ = density

ϑ = total wrap angle

This relationship can be essentially expressed as follows:

$$V_{CR} = (e^{\mu_s \theta} - e^{\mu_s \theta})\ T_0 \times K$$

where K is a constant associated with the tape type

It can be further simplified for small values of μ and θ to

$$V_{CR} = (\mu_s - \mu_g)\theta \times T_0 \times K \qquad (3)$$

Assuming that $(\mu_s - \mu_g)$ remains constant then a linear relationship between the critical velocity and the tape tension results. Typical curves are shown in Fig. 26.

A comparison is shown in Fig. 27, for the same wrap angle, there appears to be substantial differences in the relationship between critical speed and tape tension. A review of the referenced paper, however, indicates that the technique used to measure the critical speed for various tape tensions was to weight a stationary piece of tape which had been placed over a rotating mu-metal post. Such a system would very quickly subject the tape to a large number of equivalent tape passes which would explain the steepness of the plotted curve. Steinhorst does point out that his experiments were limited to a symmetrical case and that such conditions are rarely satisfied in tape recorders, he further adds that the introduction of more than one friction spot result is a superposition of disturbances coming from either end which may lead to fast temporary changes in the elastic deflection of the magnetic tape. Other factors to which regenerative amplifications of the elastic vibrations in magnetic tape are related include:

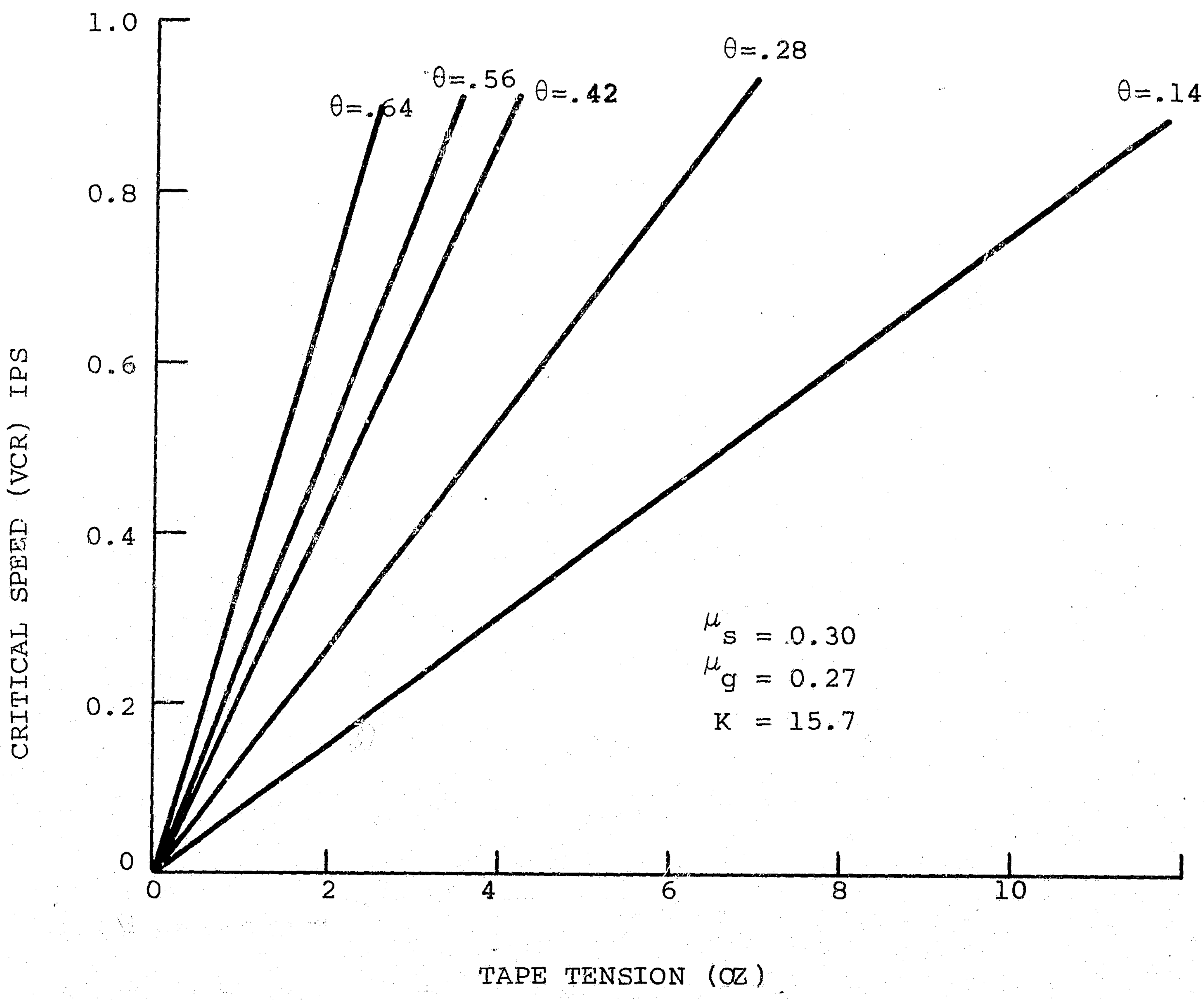

Fig.26 THEORETICAL RELATIONSHIP BETWEEN CRITICAL TAPE SPEED AND TAPE TENSION

$$VCR = (e^{\mu_s \theta} - e^{\mu_g \theta}) \times T \times K$$

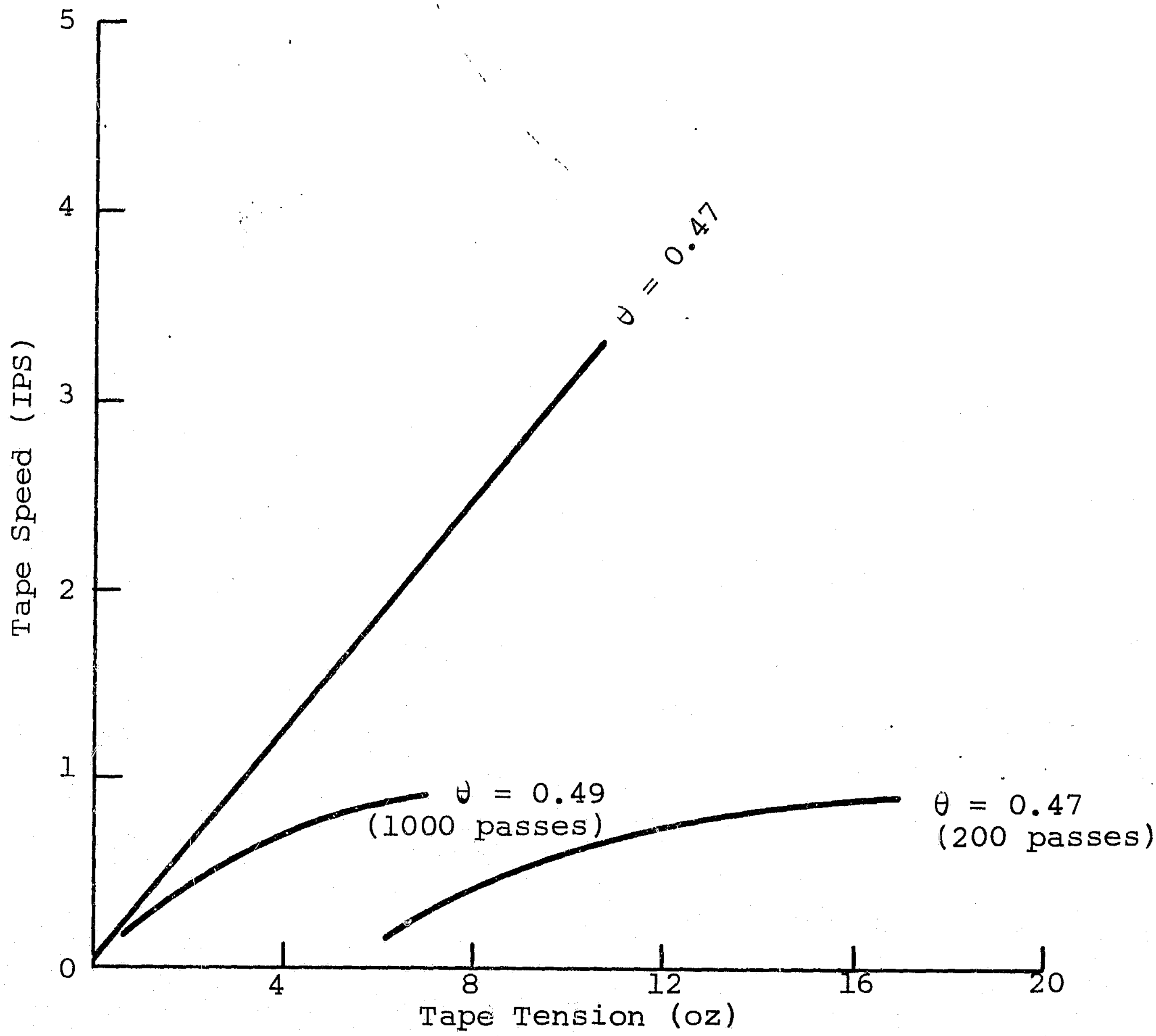

Fig. 27 COMPARISON OF TAPE SPEED/TAPE TENSION RELATIONSHIP MEASURED DURING PHASE II EFFORT WITH THAT OF PUBLISHED DATA

- Variation in the dynamic coefficient of friction
- Disturbances of the static coefficient of friction due to debris deposits
- Variations in the cross sectional area of the magnetic tape
- Variable modulus of elasticity at different locations on the tape
- Inbalance and impact of rotating guide elements in the tape path

All of these, of course, related to an actual system and certainly the change in the frictional coefficient was experienced during this Phase II testing. One particular test tape exhibited gross variations of its stick-slip capability along its relatively short length of 52 inches. Optical inspection revealed no obvious differences along its length, but it is thought that the variations which occurred near the splicing area were due to injected oxide binder debris which would seriously affect the frictional coefficients.

If we take the critical speed relationships as formulated by Steinhorst and make the following two assumptions, namely,

a. If a disturbance was experimentally observed, then the tape speed at the time of the disturbance was either the critical velocity or in excess of the critical velocity.

b. That if the tape velocity is maintained constant, then values of critical tension could be evaluated for various values of wrap angle.

Then if a value of the constant (k) associated with the physical parameters of the magnetic tape is evaluated,

$$k = \frac{1}{E_s \, w \cdot b} \sqrt{\frac{E_D}{P}} \qquad (4)$$

$$= 20.4$$

where

$E_s = 672 \times 10^3$ psi

$w = 0.5$ inches

$b = 0.001$ inches

$\rho = .0542$ pound inches^3

$\nu = 0.45$

Then substituting one data point from the experimental disturbance curve the equation

$$V_{CR} = (e^{\mu_s \vartheta} - e^{\mu_s \vartheta}) \; T_0 \cdot k$$

can be rearranged and solved for the critical value of tension for various wrap angles at a constant speed of 0.15 inches per second. This is illustrated in Fig. 28 and, therefore, represents a theoretical disturbance boundary. Comparison with Phase II experimental data indicates an agreement for low values of wrap angle where the curve approximates a value of constant drag. For higher values of wrap the curves appear unrelated and continued data analysis has failed to explain this anomaly.

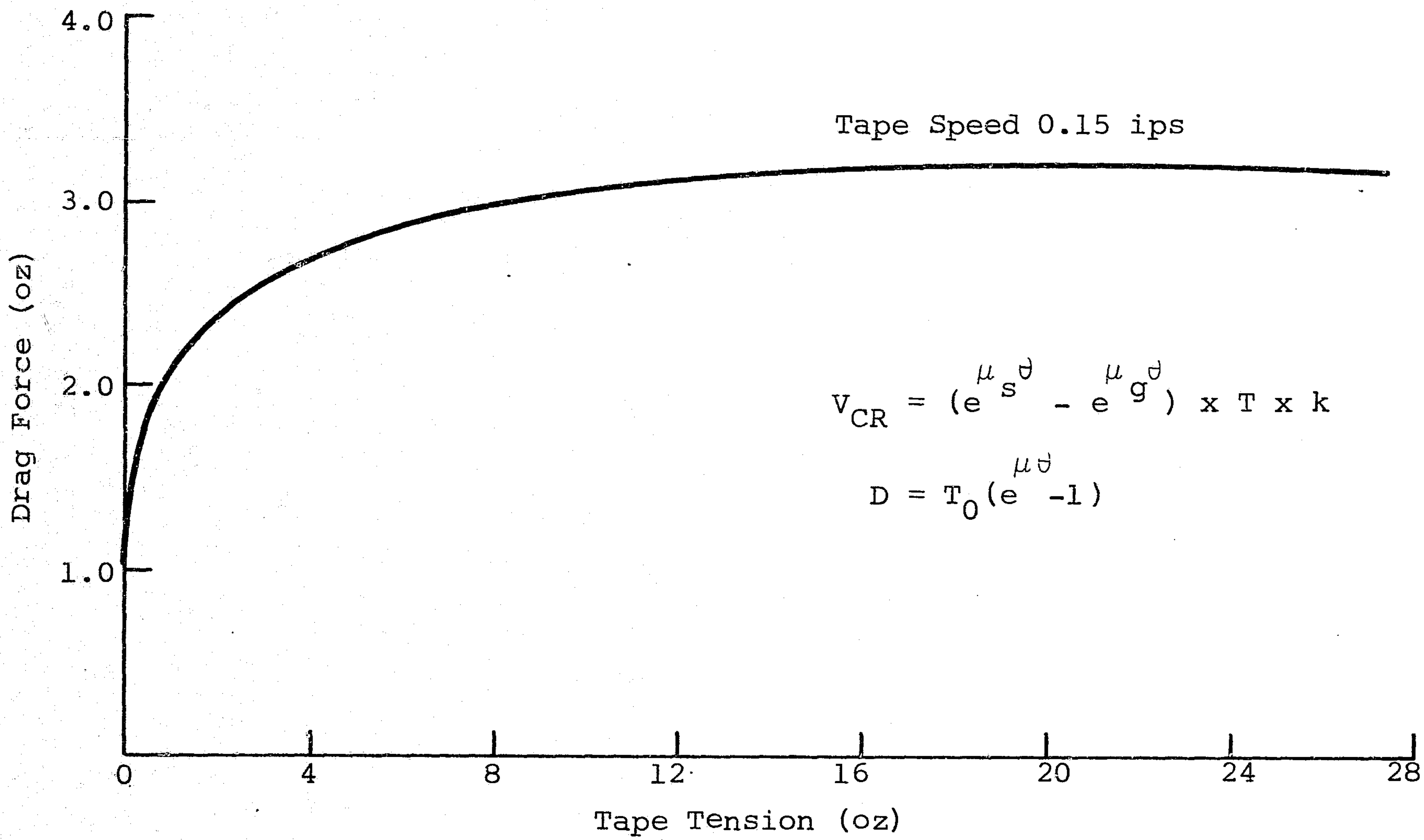

Fig. 28 THEORETICAL DETERMINATION OF A BOUNDARY DISTURBANCE CURVE GENERATED BY MAINTAINING V_{CR} CONSTANT AND SOLVING FOR TENSION

In an attempt to correlate the measured data independently of the number of tape passes, the boundary disturbance curves were plotted in the form shown in Fig. 29. Here the ratio of drag to tension at a disturbance point is plotted against tension. The drag tension ratio can be shown to approximately equal the $\mu\theta$ product. So these curves represent the relationship between the $\mu\theta$ product and the tape tension for data measured at several reproduce tape speeds.

Of particular interest is that the resulting curves appear to be somewhat independent of tape passes. For example, the solid line at 0.15 inches per second represent data measured after 200 running passes while the broken line represents data at the same speed after 2,000 running tape passes. This also applies to the measurements made at 0.9 inches per second. An increase in the number of tape passes certainly changes the value of the coefficient of friction between the head and the tape and, therefore, the $\mu\theta$ product, but it does not appear to laterally displace the overall curve. Unfortunately, the quantity of data is too limited to be able to formulate firm conclusions.

5. Summary of Results

In summarizing, we have shown that an attempt to relate a change in total wrap angle to the disturbance of the output signal leads to an interesting experimental technique which allows the generation of boundary disturbance curves. It proved difficult to obtain such curves for tape type A and unused tape type B, but used tape type B allowed a variety of curves to be examined for several reproduce tape speeds. Movement of the boundary disturbance loci occurred for both a change in tape speed and a change in the number of tape passes. Analysis of the results indicate a complex relationship between critical speed and tape tension of the form

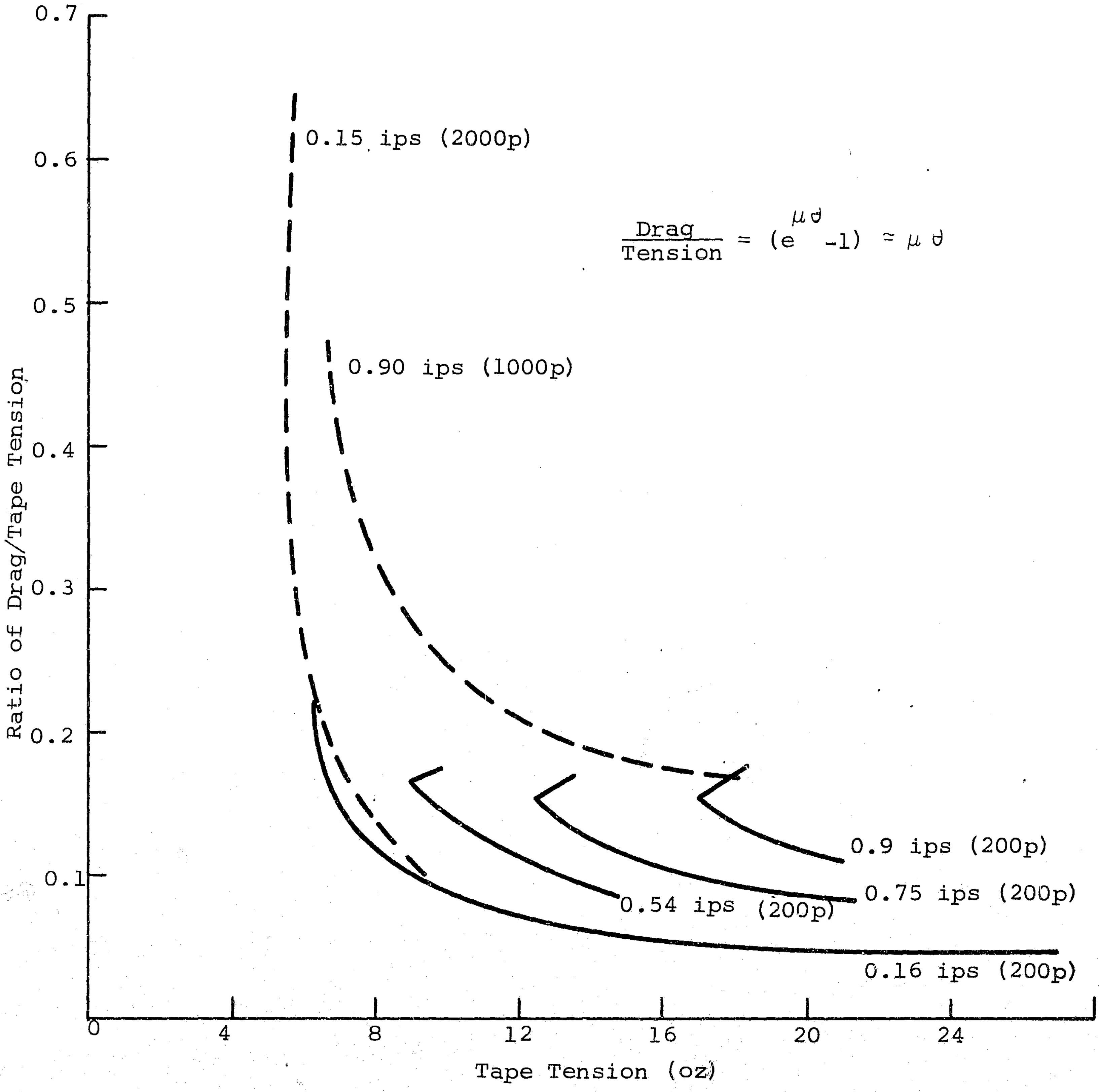

Fig. 29 RELATIONSHIP BETWEEN TAPE TENSION AND THE $\mu\vartheta$ PRODUCT FOR VARIOUS TAPE SPEEDS AND NUMBER OF PASSES

$$T_0 = \frac{k}{\theta} (\cosh V_{CR})^N$$

Such a result did not align itself with previously published data and this may be related to the difference in experimental procedure, as well as other factors which were outlined. A theoretical boundary disturbance was generated which showed correlation to the measured results for low values of wrap angle but proved to be dissimilar at higher values. An attempt to relate the results obtained in a manner independent of the number of tape passes was shown, although firm conclusion could not be formulated. Overall, an interesting relationship between the tape speed at which a disturbance occurs and that of tape tension/wrap angle combination has been shown, this relationship does not appear to be linear for the number of tape passes used during these tests, but its possible use is elaborated upon in Section III of this report.

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

In conclusion we feel that the overall objectives of both phases of this study program were successfully achieved in that a greater understanding of the stick-slip phenomena was obtained. To ensure that severe signal disturbances are not experienced the most desirable combination would appear to be head type B, tape type A, 5° wrap angle, and 7.0 oz tape tension. Within the limits of the test variables chosen, the magnetic tape appeared to be the most significant contributor to stick-slip, followed by the wrap angle, the tape tension, and the head type. Tape speed also played an important role in the production of signal disturbances.

Once the tape type has been determined the recommended procedure would be to minimize the total tape wrap angle and then increase the tape tension to obtain the necessary total radial force for the system. This assures intimate head to tape contact and therefore minimum short wavelength losses. The choice of magnetic head would appear from the results to favor the hard faced head type. Results of other studies[1] substantiate this finding; such studies reveal that the choice of head bracket material is also important and that although aluminum is preferred over that of brass, a harder bracket material is desirable in negating the products of wear.

Phase II activities proved extremely valuable in the generation of well defined boundary disturbance loci. The results allowed greater insight into the relationship between the tape tension and the speed at which a disturbance occurred, namely, the critical velocity. If we generalize these results and rearrange the coordinate axes to allow the vector quantity of velocity to shown bidirectionally on the abscissa (Fig. 30). Then if we assume that a change in direction of tape travel

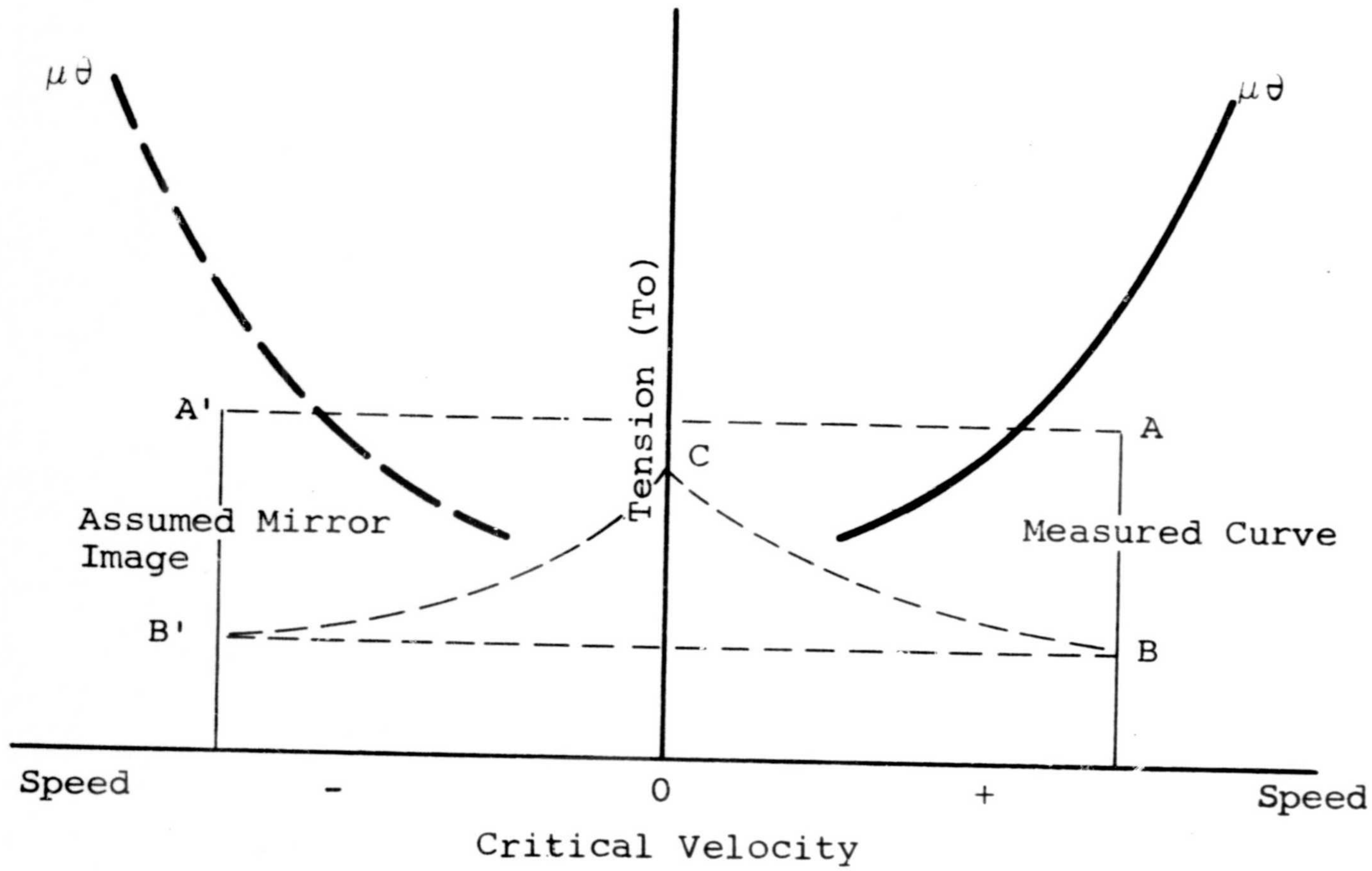

Fig. 30 GENERALIZED RELATIONSHIP BETWEEN CRITICAL VELOCITY AND TAPE TENSION FOR BIDIRECTIONAL OPERATION

across a symmetrical head arrangement while maintaining the speed constant would not unduly alter the position of a measured disturbance point, then a mirror image curve shown in Fig. 29 would result.

Unfortunately, critical velocity at zero tape speed can not be defined but the trend of this curve would appear to indicate that as the tape speed approaches zero, the tension required for disturbance approaches some constant value. This constant value of tension itself approaches zero only after the tape has been subjected to a large number of tape passes. If we assume that all magnetic tapes conform to this generalized curve and that only specific values on the axis are different, it is interesting to postulate the effect of bidirectional operation with regard to this generalized critical velocity curve.

Assume that a transport is operating in the positive direction of speed, at some defined tension level, which places its operating point at A. If the transports speed is now changed to the opposite direction without a change in tape tension the operating point will move from A to A'. In doing so the speed will fall momentarily to zero and the operating point will move through a critical area (that is the tape speed will fall to and below the critical velocity). If the transport conditions are adjusted so that the operating point is B rather than A, it can be seen that, assuming there is no change in the value of tape tension, the operating point will not pass through the critical area when the tape direction is reversed. Such an operating point (B to B') will remain safe only for a specific number of tape passes, for as it has already been pointed out, as the number of tape passes increase the overall critical velocity curve moves downward towards the origin.

Another interesting example is the case of certain types of tape transports which exhibit an increase in tension during the tapes change in direction. In this case we can show that the operating point B moves to B' via C and therefore passes through the critical area. One could anticipate, therefore, a higher probability of stick slip occurring in a region where the tape is subjected to either higher tension values or where the tape direction is changed.

Such a postulation and the use of a critical velocity diagram does not totally explain the occurance of the stick-slip phenomena, but we feel that its use as a design tool could prove of interest. Certainly the shape of this curve at tape speeds much less than 0.15 ips is worthy of investigation; especially for tape types which are being used or may be used for future missions.

A recommended procedure for such an investigation would be to maximize the critical parameters that relate to a severe signal disturbance, namely,

- o Tape speed
- o Wrap angle
- o Tape tension
- o Coefficient of static and dynamic friction
- o Head material

A reproduce tape speed well below the 0.15 inches per second used during this study is recommended. Although actual testing would preferably be carried out on a breadboard model DSST transport, IITRI has at this time a modified loop machine capable of operating at speeds in the order of 0.01 ips. Use of this machine would allow initial low speed determinations to be made using any tape type selected by JPL engineers.

This report has also indicated what may be a critical value of the $\mu\theta$ product, therefore, knowing the value of the dynamic coefficient of friction of the tape type a set value of wrap angle could easily be determined to optimize the stick slip capability. Similarly, past experience will dictate the value of tape tension. It would appear from the analysis of results of this current study that large differences between the dynamic and static coefficients of friction are necessary in order to produce stick-slip. Change of this parameter, if not control, may be achieved by running the tape at slew speed. Although such a condition is easily achieved with tape B with only a few hundred tape passes at 19.4 inches per second, we feel confident that a similar condition can be promoted with any tape type by drastically increasing the number of tape passes -- a parameter easily achieved using the present loop machines. Finally, the head material and head radii relate to both the normal force and frictional forces present at the head/tape interface, in this case we would recommend use of the existing soft faced 0.190 inch radii heads (type A) currently in our possession.

In conclusion we feel that the determination of a stick-slip boundary condition with any chosen tape type is feasible by maximizing the critical parameters related to this head tape disturbance. Such a technique, if successful, would prove invaluable as an additional tape selection mechanism, as well as aiding in the design of tape recorder systems where extremely low tape speeds are used both for recording or the reproduction of data.

APPENDIX A

MATHEMATICAL RELATIONSHIPS

Consider a small element at the head tape contact surface as shown in Fig. A1

where

T = tension

ΔT = increase in tension over element

$\Delta\theta$ = small elemental angle

ΔF_R = radial force

ΔF_T = tangential force

and resolve the forces radially and tangentially, we have

a) Radially

$$\Delta F_R = T \sin \frac{\Delta\theta}{2} + (T + \Delta T) \sin \frac{\Delta\theta}{2}$$

$$= 2T \sin \frac{\Delta\theta}{2} + \Delta T \sin \frac{\Delta\theta}{2}$$

if ΔT and $\Delta\theta$ are small, then $\sin \frac{\Delta\theta}{2} = \frac{\Delta\theta}{2}$ and their product can be ignored, then

$$\Delta F_R = T\Delta\theta \qquad \text{(A-1)}$$

b) Tangentially

$$\Delta F_T = (T + \Delta T) \cos \frac{\Delta\theta}{2} - T \cos \frac{\Delta\theta}{2}$$

if $\frac{\Delta\theta}{2}$ is small then $\cos \frac{\Delta\theta}{2} = 1$, then

$$\Delta F_T = \Delta T$$

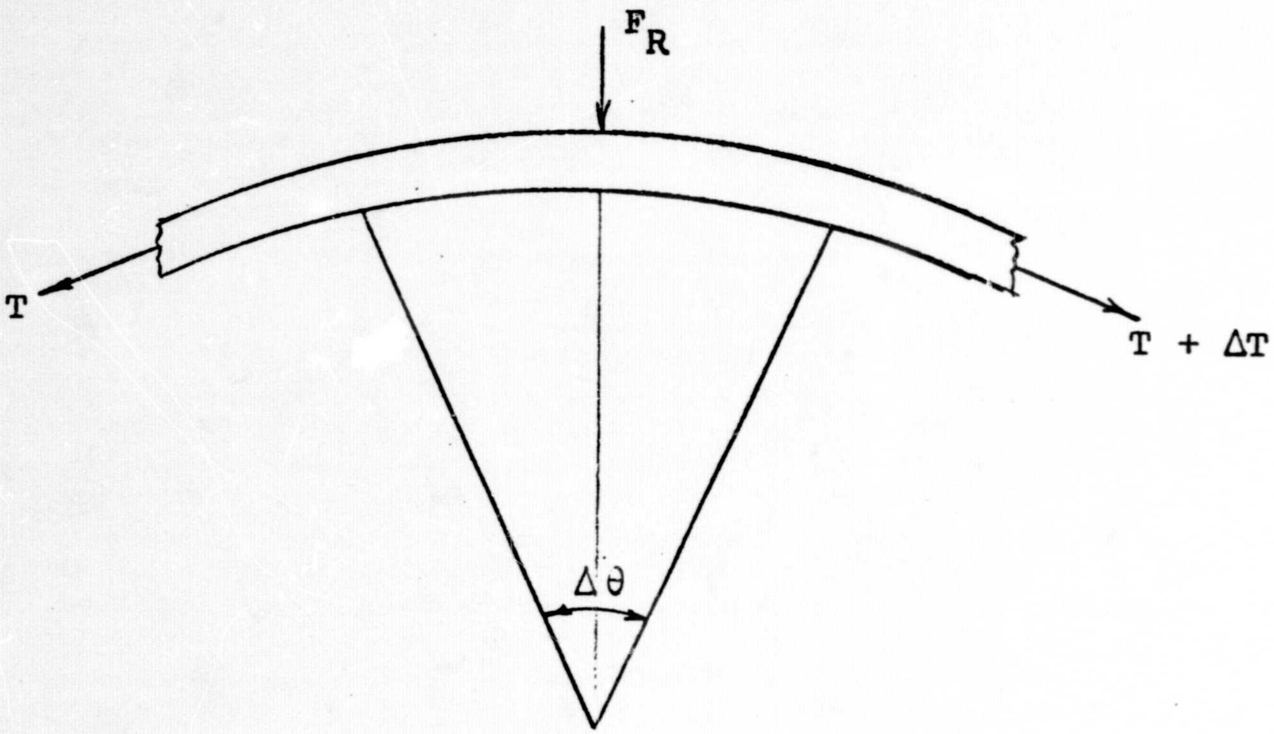

Fig. A-1 INCREMENTAL HEAD AND TAPE CONTACT AREA

If we assume that μ_g = the dynamic coefficient of friction, then by definition

$$\mu_g = \frac{\Delta F_T}{\Delta F_R} \quad \text{(A-2)}$$

therefore,

$$\Delta F_R = \frac{\Delta T}{\mu_g} \quad \text{(A-3)}$$

insertion in equation (A-1) and rearranging, we get

$$\frac{\Delta T}{T} = \mu_g \Delta\theta$$

therefore

$$\int_{T_0}^{T_1} \frac{dt}{T} = \mu_g \int_0^{\theta_T} d\theta$$

where T_1 is the tension at θ_T Total

$$\Big[\ln T\Big]_{T_0}^{T_1} = \mu_g \Big[\theta\Big]_0^{\theta_T}$$

or

$$\ln \frac{T_1}{T_0} = \mu_g \theta_T$$

and

$$\frac{T_1}{T_0} = e^{\mu g} \cdot \theta_T \qquad \text{(A-4)}$$

Experimental results obtained during Phase I substantiate this relationship

Now using the result of equation (A-4) and substituting into equation (A-1), we have

$$\Delta F_R = T\Delta\theta \qquad \text{but } T = f\ (\theta)$$

$$\text{where } T = T_0 e^{\mu\theta}$$

therefore

$$\Delta F_R = T_0 e^{\mu\theta} \cdot \Delta\theta$$

or

$$\int_0^T F_R = T_0 \int_0^{\theta_T} e^{\mu\theta} \cdot d\theta$$

$$F_{R_T} = T_0 \left[\frac{e^{\mu\theta}}{\mu}\right]_0^{\theta_T}$$

Total radial force

$$F_{R_T} = \frac{T_0}{\mu}\,(e^{\mu\vartheta} - 1) \qquad \text{(A-5)}$$

If the total radial force per unit area $= \overline{P}$, then

$$\overline{P} = \frac{T_0}{\mu r w \vartheta}\,(e^{\mu\vartheta} - 1) \qquad \text{(A-6)}$$

where

r = head radius

w = tape width

<u>Approximations</u>

For small values of $\mu\vartheta$ product

$$e^{\mu\vartheta} \simeq 1 + \mu\vartheta$$

therefore

$$\text{Total radial force} = \frac{T_0(e^{\mu\vartheta} - 1)}{\mu} \simeq T_0\vartheta \qquad \text{(A-7)}$$

$$\text{Total radial force per unit area} = \frac{T_0(e^{\mu\vartheta} - 1)}{\mu . rw\vartheta} \simeq \frac{T_0}{rw} \qquad \text{(A-8)}$$

$$\text{Drag} = T_0(e^{\mu\vartheta} - 1) \simeq T_0\mu\vartheta \qquad \text{(A-9)}$$