Department of Mechanical Engineering
Cavitation and Multiphase Flow Laboratory
The University of Michigan

Report No. UMICH 014571-7-I (Internal)

WET STEAM TUNNEL: TRAILING EDGE OBSERVED

by

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(submitted in partial fulfillment of ME 490) - supervised by Prof. F. G. Hammitt
Mr. W. Kim

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I. INTRODUCTION

The problem of droplet erosion in low pressure stages of turbines continues to inspire the wet-steam flow research directed by Professor Hammitt. Last semester, under the direction of W. Kim, our attention focused on experimental film thickness measurements collected from four electrical conductivity guages installed on our model turbine blade. Oscilloscope readings and still photographs of the liquid film on the blade provided the basis for data analysis.

This semester our attention has shifted to observation of the liquid film breakup at the trailing edge of our model turbine blade. To aid in the observation of this liquid film break-up phenomenon, a Fastex camera and a high wattage lighting source were utilized to record this data on film. The Fastex camera runs at 5000 frames per second. About 40 films have been taken to date, each 100 ft. in length, and each recording an elasped time of about 1.6 sec.

II. DATA COLLECTION

Two major obstacles were encountered in the filming of the break-up phenomenon. These were focus and lighting. More than half the semester was spent adjusting equipment to arrive at proper filming conditions. An expensive stroboscope and sychronizing machine were ultimately abandoned for a simpler high wattage steady-state bulb which provided satisfactory lighting. Many lenses for the Fastex camera were tried in an attempt to produce satisfactory focus.

The major focusing improvement, however, was made by increasing the distance between the camera and the model blade by 1.5 inches. Once these lighting and focusing conditions were satisfactorily established, the filming procedure became a swift and simple repetition of loading, shooting, and unloading films.

III. DATA ANALYSIS - METHOD

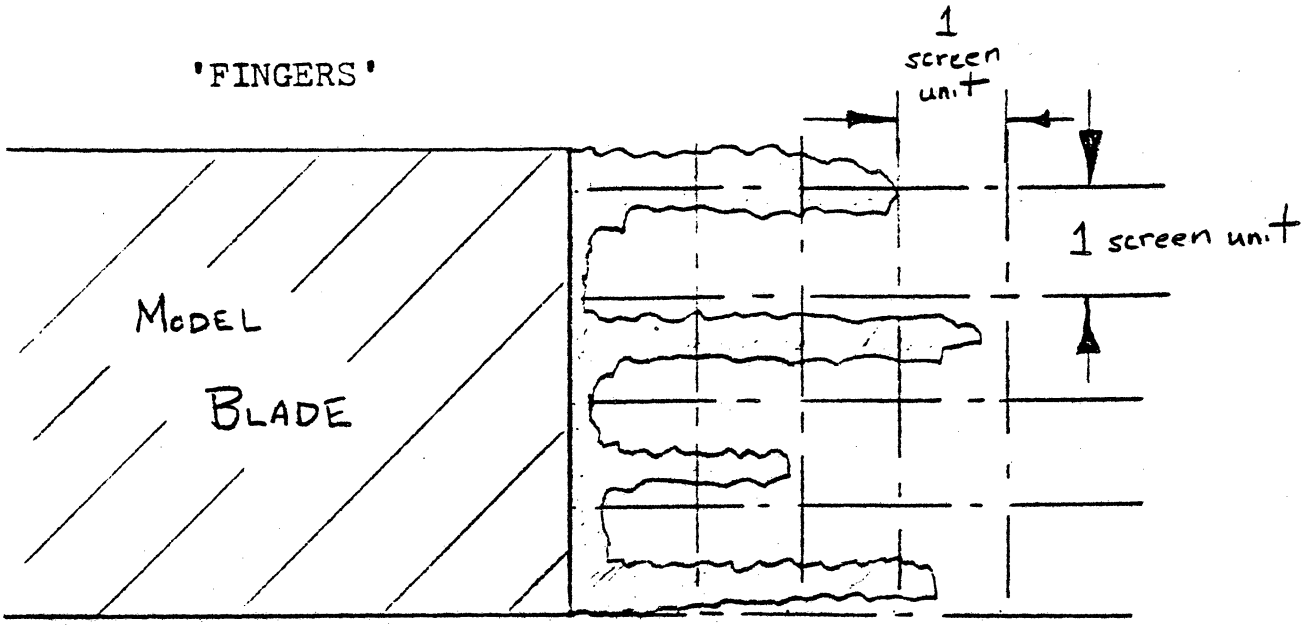
Showing the Fastex films on a 8mm movie projector provides an interesting visual account of the liquid film break-up phenomenon. However, it was found that serious data analysis must be done on a'film editor,' a device worked by hand, with the capability of reviewing the film frame by frame.

Initially the films were being analyzed one frame at a time with specific attention on the time duration of the liquid film break-up into droplets. Because of the enormous time required for this frame by frame analysis, a faster statistical approach for analysis was ultimately decided upon. In essence, this approach involved spot checking the film every 80 frames. This means each film was observed at 100 different data points, each point .016 seconds apart. The following section describes what type of data was collected.

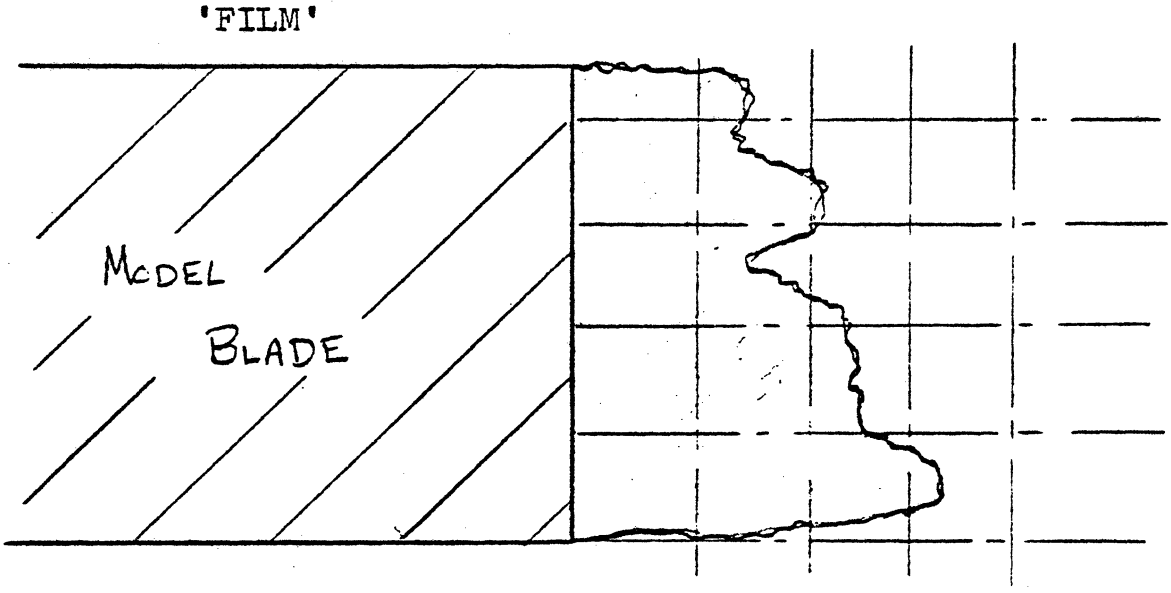
IV. DATA ANALYSIS - RESULTS

Two specific liquid film variations have been observed at the trailing edge of the blade. These have been defined as 'fingers' and 'film'. An illusration of each is the best method of describing these variations. The following illusration indicates that 'fingers' are just that, extensions

of liquid film originating at the trailing edge and strech-ing out to as much as 5 screen units.



On the other hand, a 'film' is a continuous sheet of water, again, originating at the trailing edge of the blade. The maximum width of a 'finger' has been defined as 0.5 screen units, therefore anything wider than that is termed a 'film.'



Units were marked on transparent plastic and then superimposed onto the screen of the film editor to provide

a relative means of measurement. An exact ratio of unit size to actual length is presently being established, but is not yet complete.

Having defined 'fingers' and 'film' our data at each 80 frames was recorded as follows. First it was determined which of the two trailing edge variations was being observed. If no liquid film was visible, the data sheet was marked 'negligible'. Secondly, the maximum length of either the 'fingers' or 'film' was recorded in terms of screen units. Thirdly, if the 'fingers' variation was observed, the number of fingers extending from the blade was recorded. Finally, the diameter of the closest droplet to the blade was recorded.

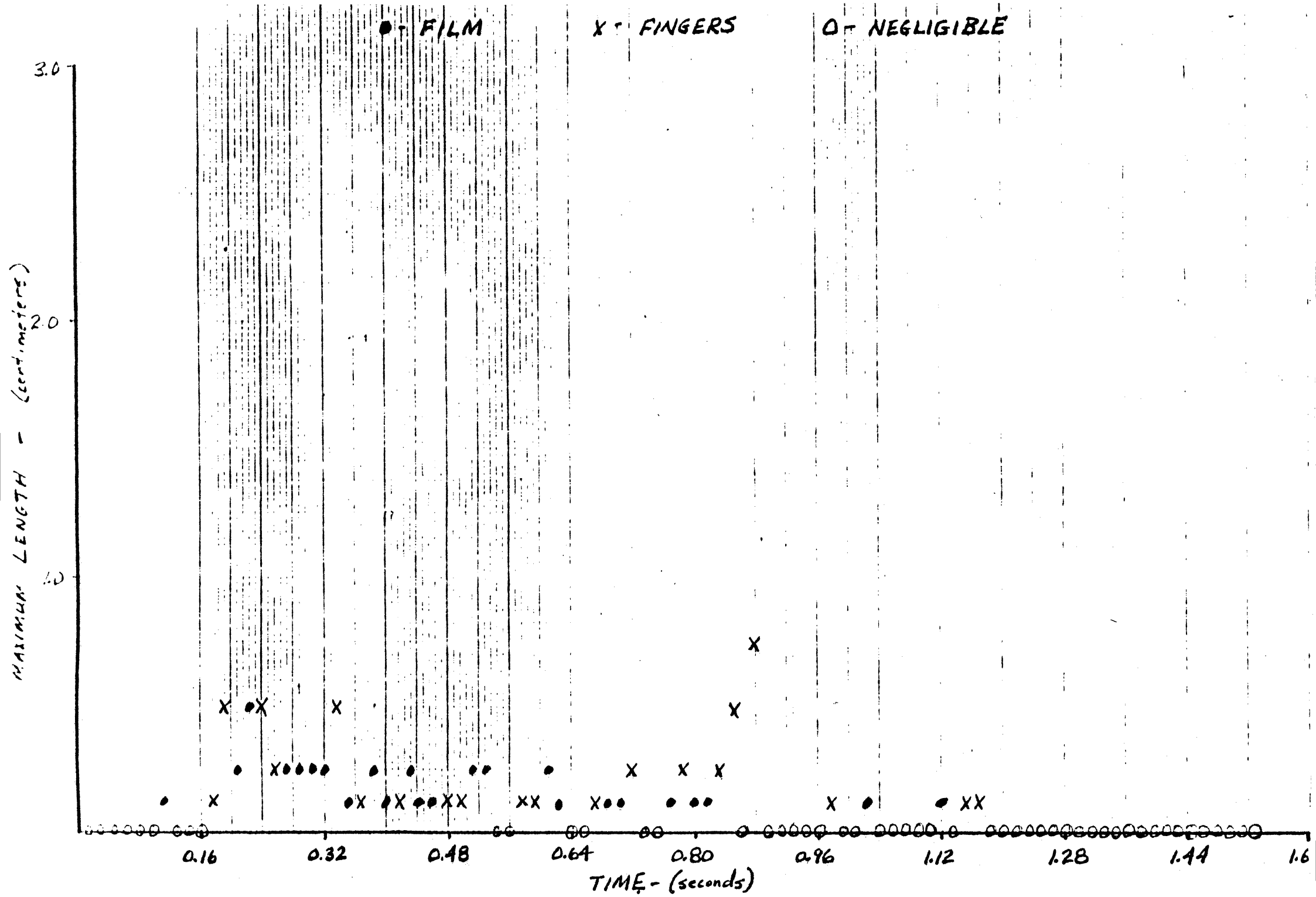
To date, 19 films have been analyzed. Graphs of the results follow this report. Appendix A contains the maximum length of the 'fingers' and 'film' variations observed for different liquid film flow rates and different steam velocities. Appendix B contains results of the number of fingers observed in the films and Appendix C contains the drop diameter data.

V. SUMMARY

More films must be analyzed before it is possible to detect whether or not patterns exist for trailing edge phenomenon under specific conditions. This report does not intend to draw any conclusions from these initial results; rather, it is a presentation of work done this semester.

APPENDIX A

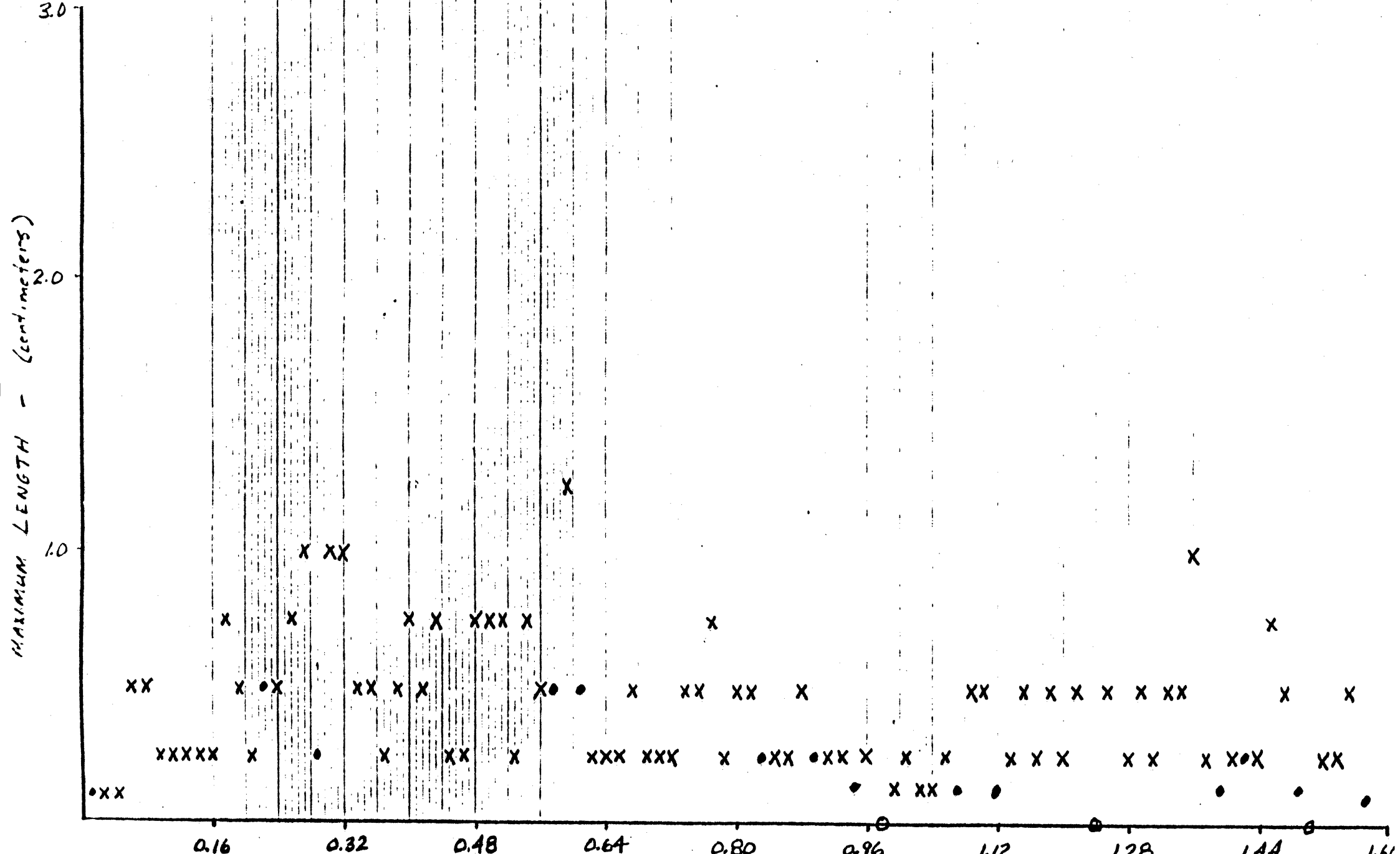
MAXIMUM FILM/FINGERS LENGTH VS. TIME

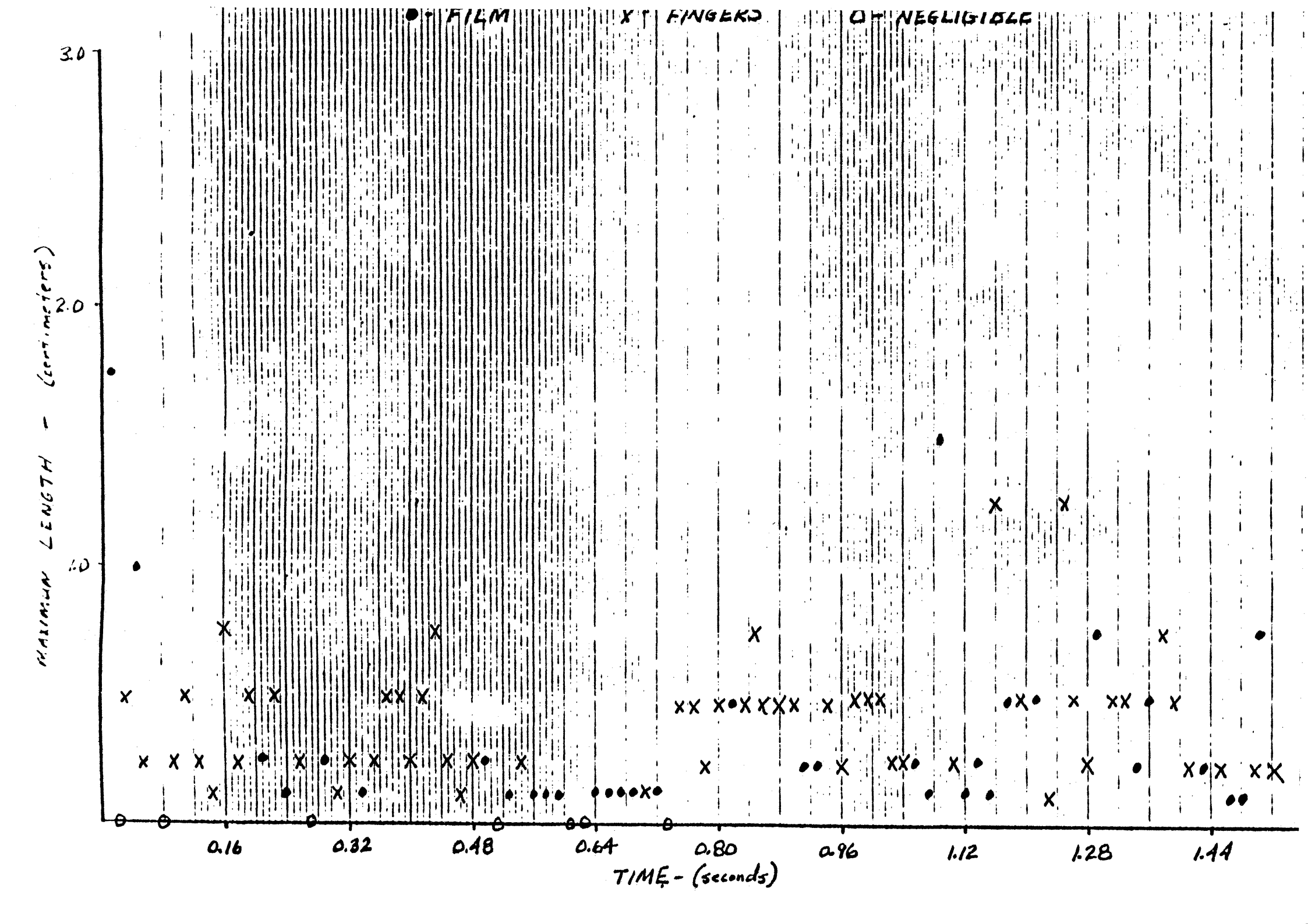

● - FILM
X - FINGERS
O - NEGLIGIBLE
3.0
2.0
1.0
MAXIMUM LENGTH - (centimeters)
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.6
TIME - (seconds)

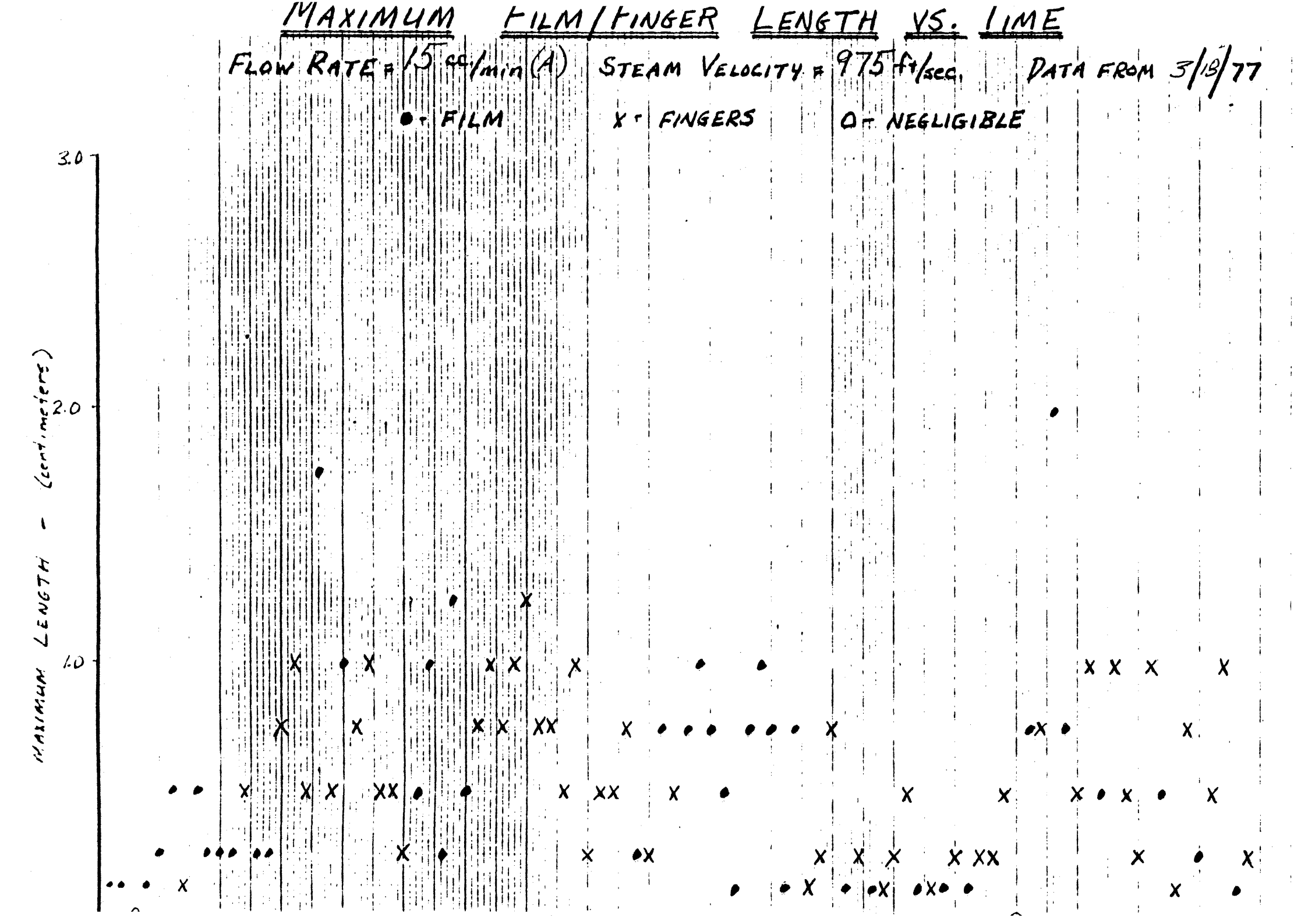
MAXIMUM FILM/FINGER LENGTH VS. TIME

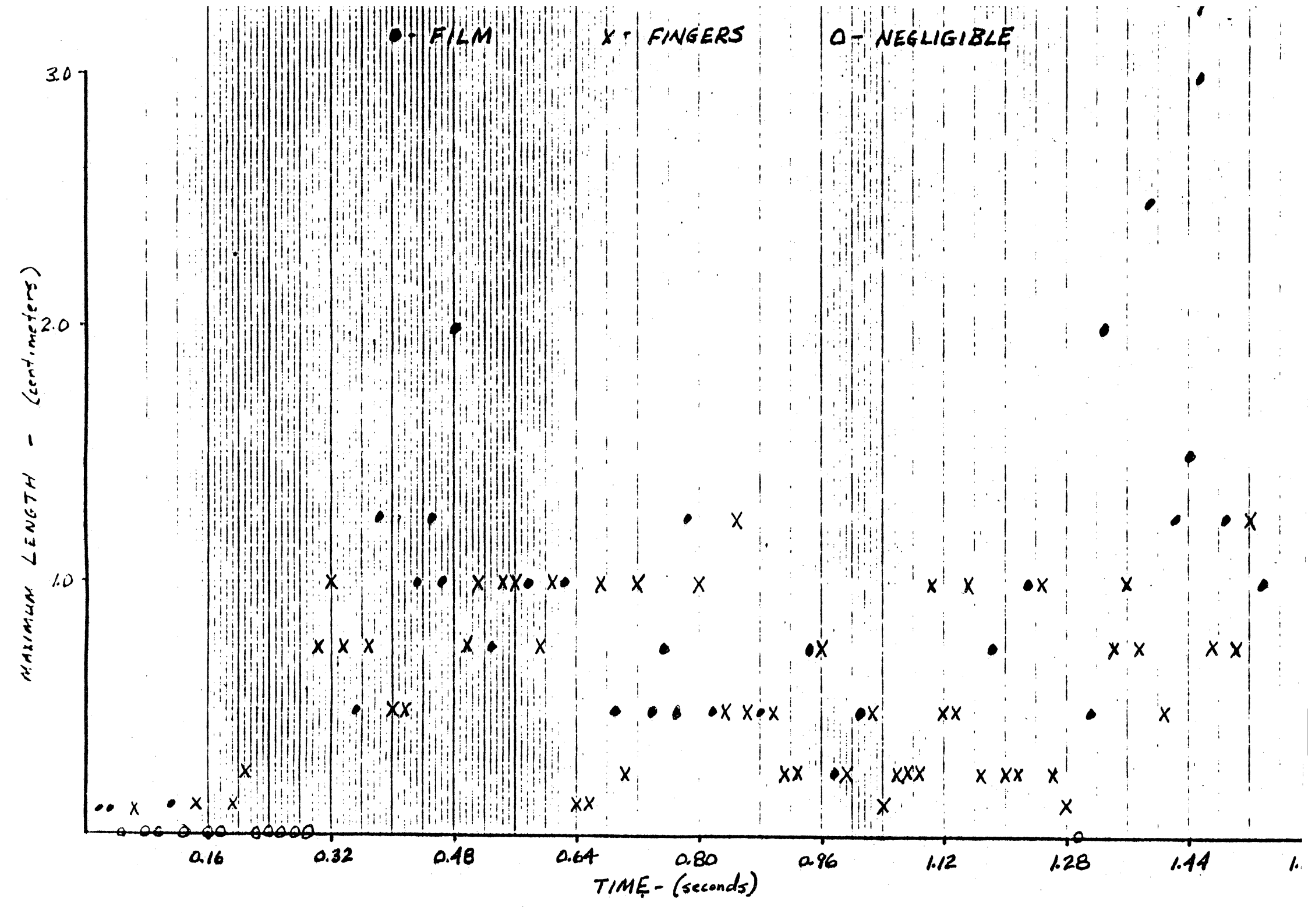
FLOW RATE = 10 cc/min (A) | STEAM VELOCITY = 975 ft/sec. | DATA FROM 3/18/77

● - FILM | X - FINGERS | O - NEGLIGIBLE




● - FILM
X - FINGERS
O - NEGLIGIBLE
3.0
2.0
1.0
MAXIMUM LENGTH - (centimeters)
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
TIME - (seconds)

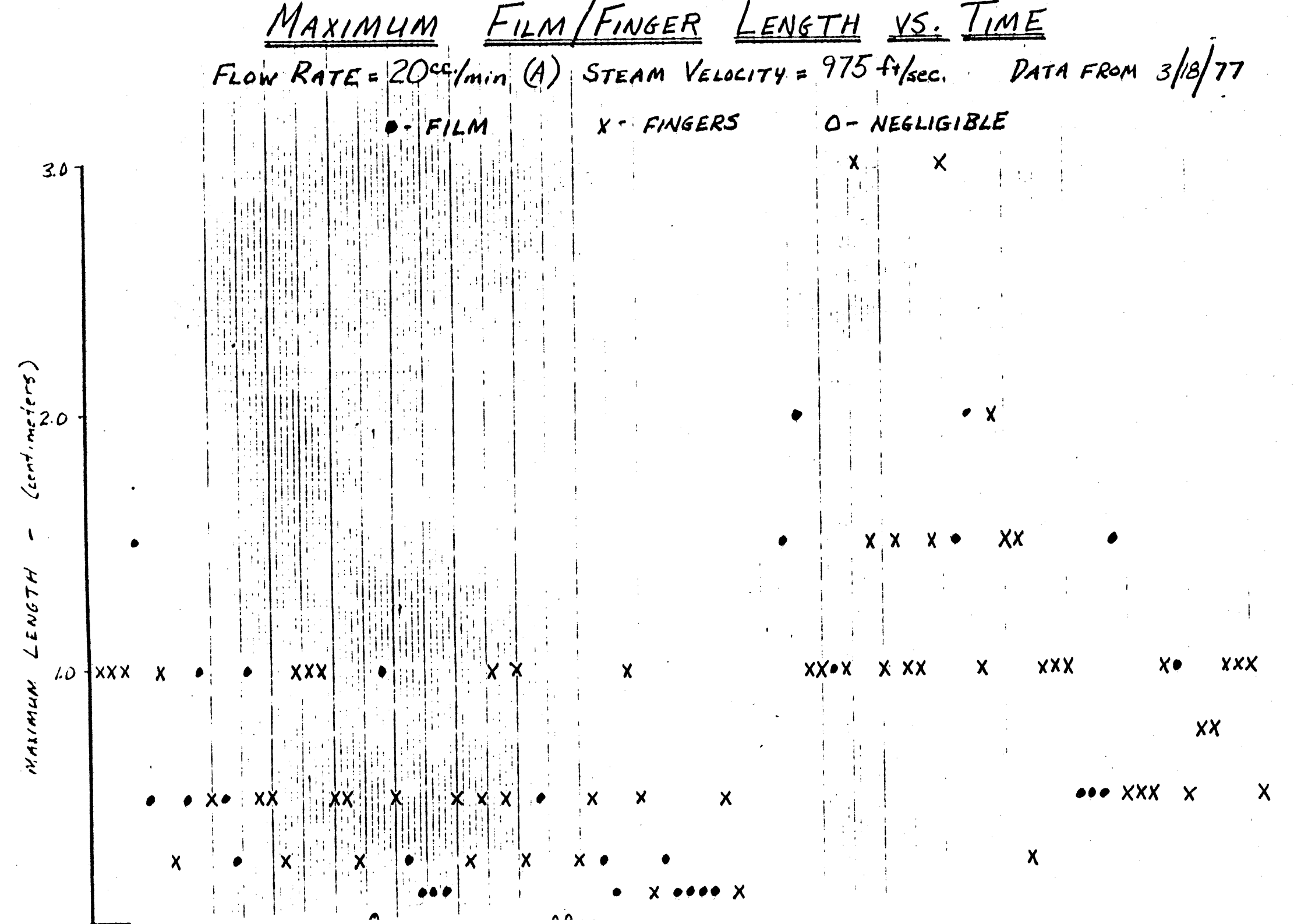

MAXIMUM FILM/FINGER LENGTH VS. LIME
FLOW RATE = 15 cc/min (A)
STEAM VELOCITY = 975 ft/sec.
DATA FROM 3/13/77
● - FILM
X - FINGERS
O - NEGLIGIBLE
MAXIMUM LENGTH - (CENTIMETERS)
3.0
2.0
1.0


● - FILM
X - FINGERS
O - NEGLIGIBLE
3.0
2.0
1.0
MAXIMUM LENGTH - (cent. meters)
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
TIME - (seconds)

MAXIMUM FILM/FINGER LENGTH VS. TIME

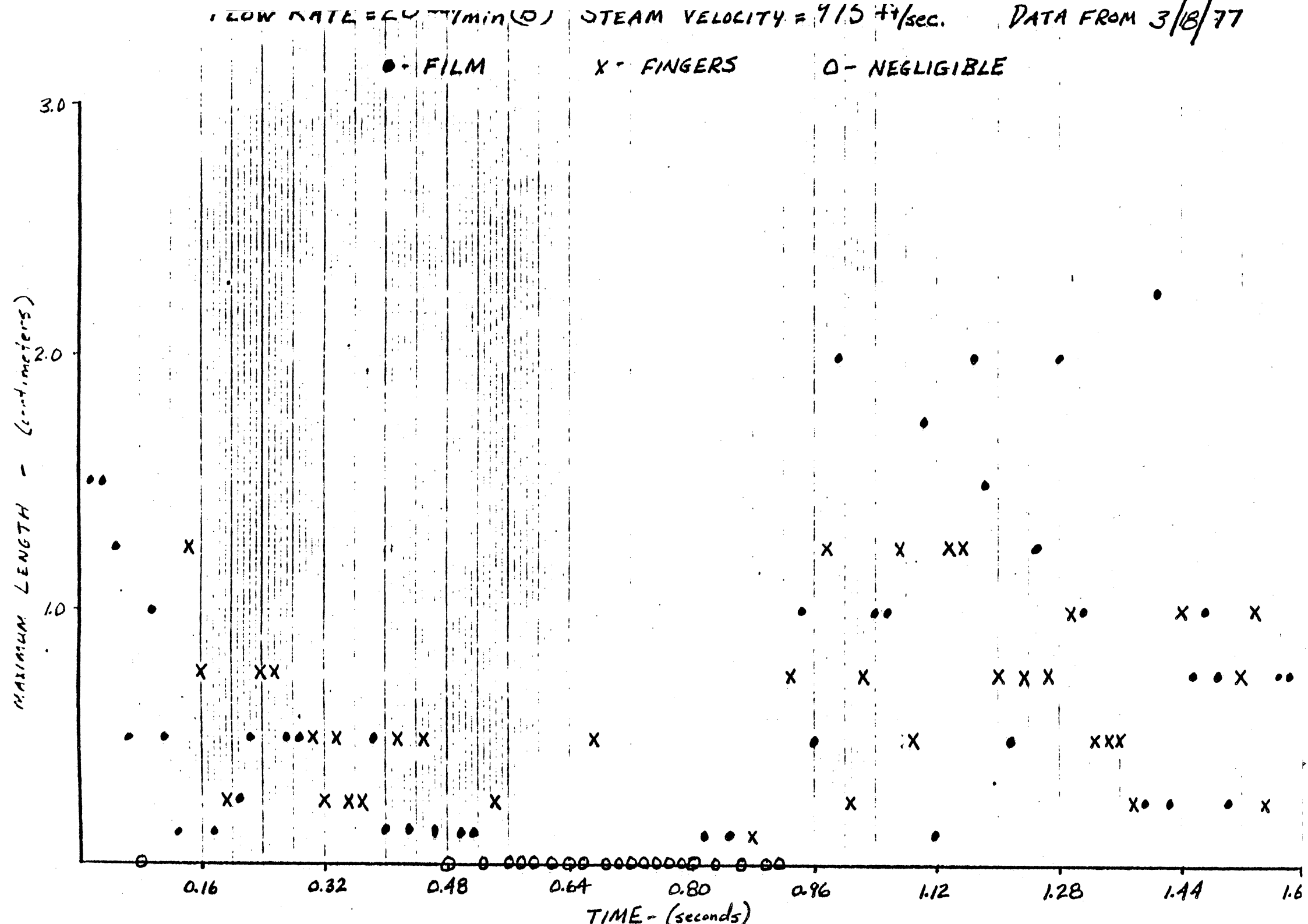
FLOW RATE = 20cc/min (A) STEAM VELOCITY = 975 ft/sec. DATA FROM 3/18/77

● - FILM X - FINGERS O - NEGLIGIBLE



FLOW RATE = [illegible] ml/min (0) STEAM VELOCITY = 915 ft/sec. DATA FROM 3/18/77

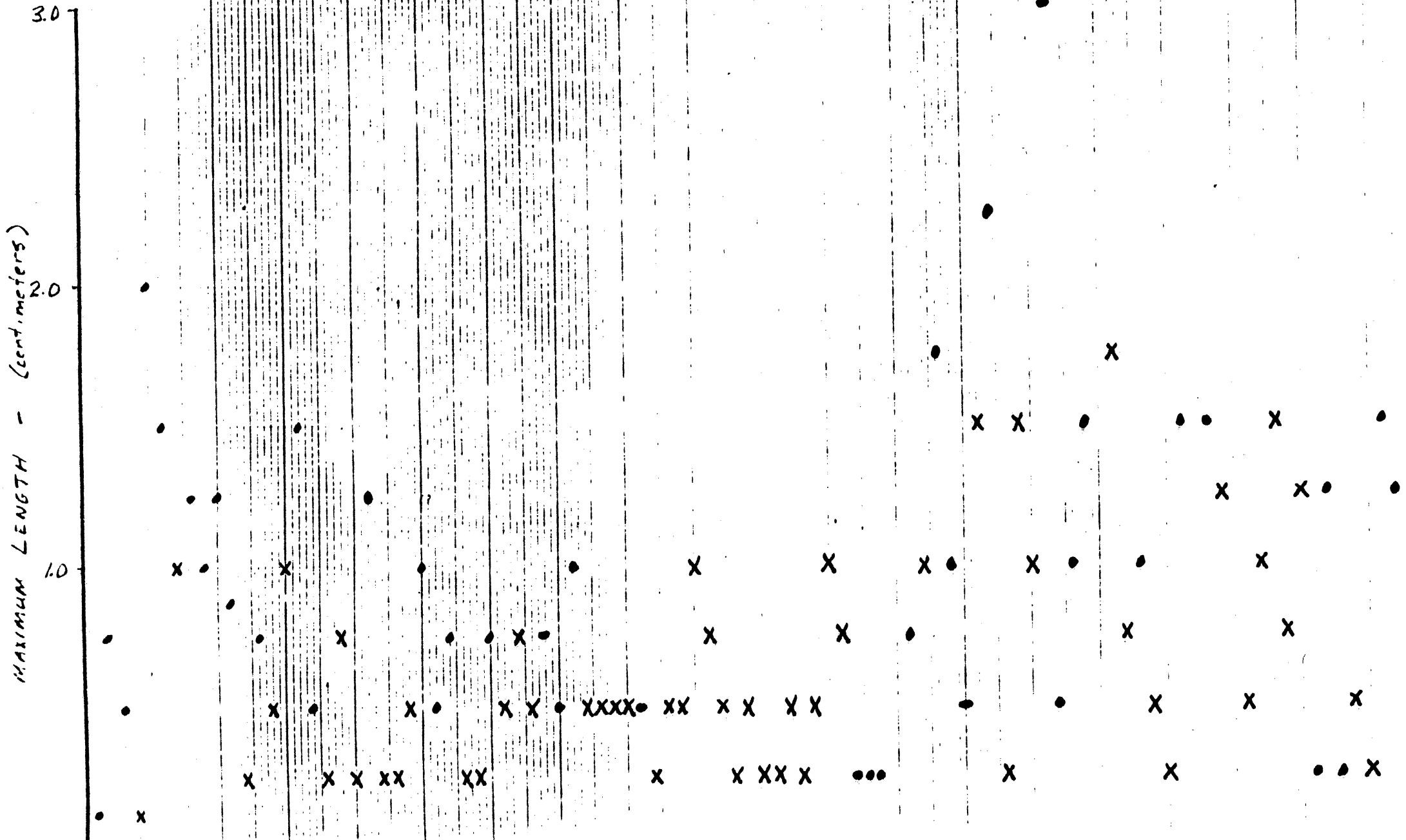
● - FILM X - FINGERS O - NEGLIGIBLE

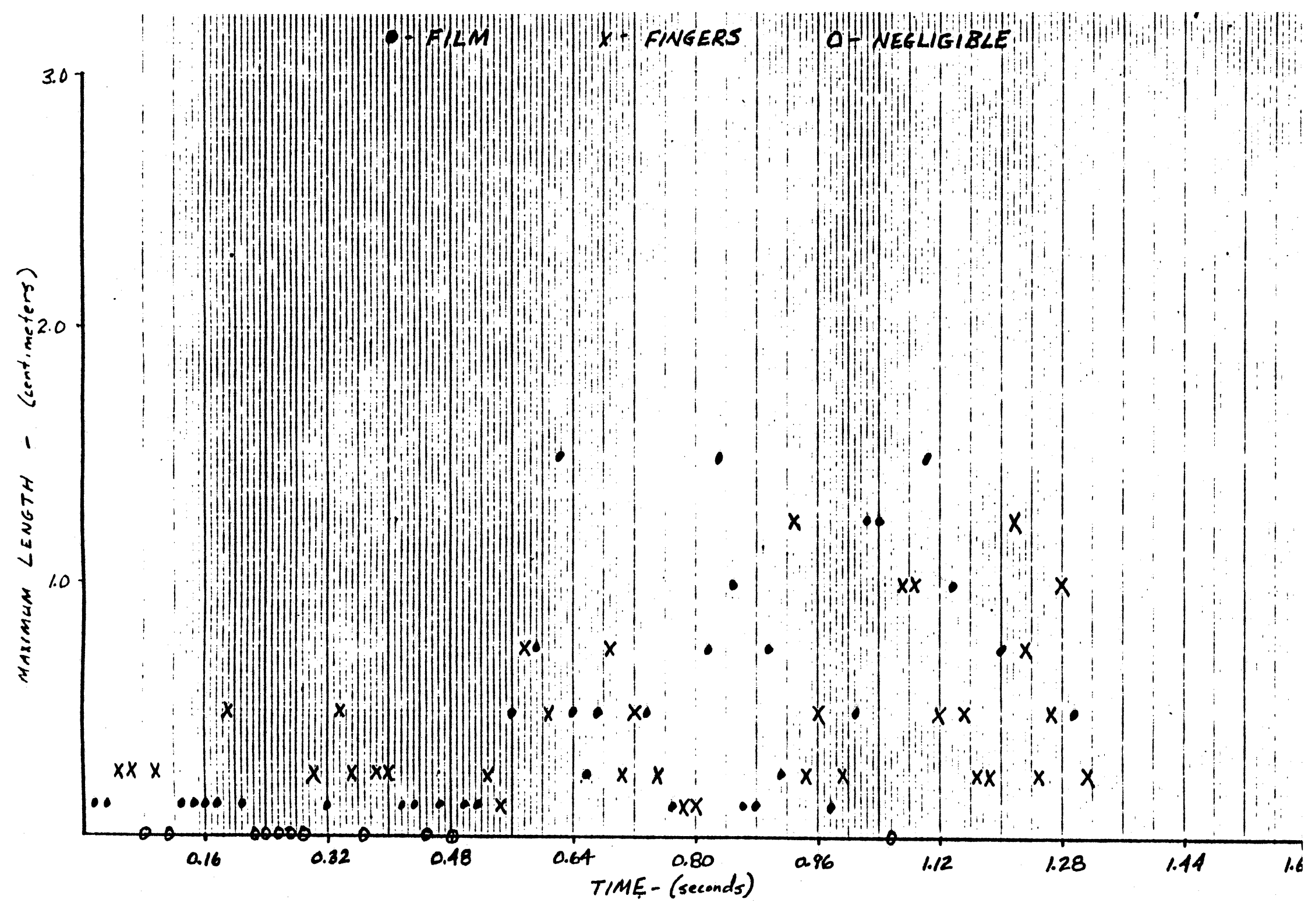


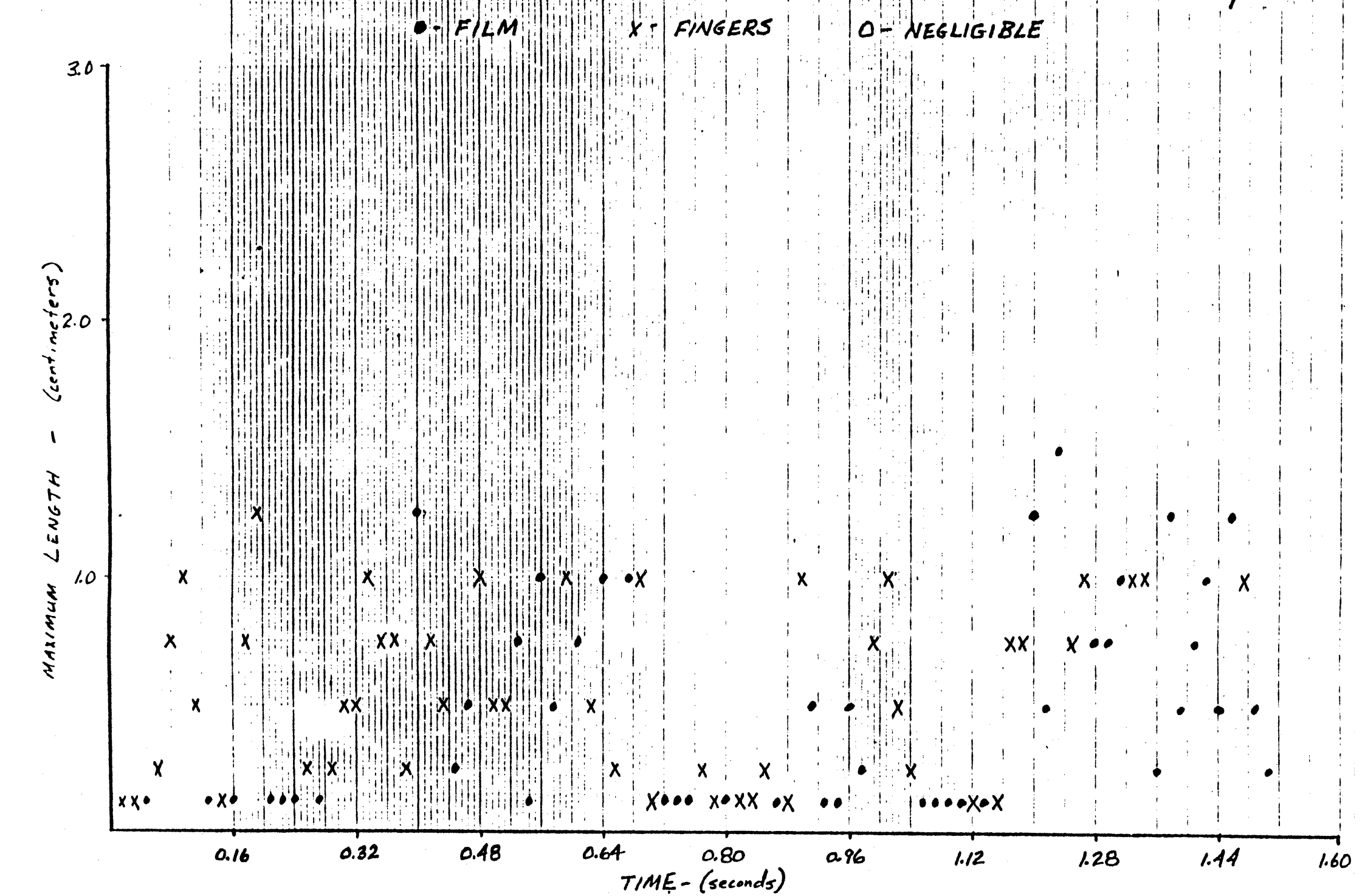
MAXIMUM FILM/FINGER LENGTH VS. TIME

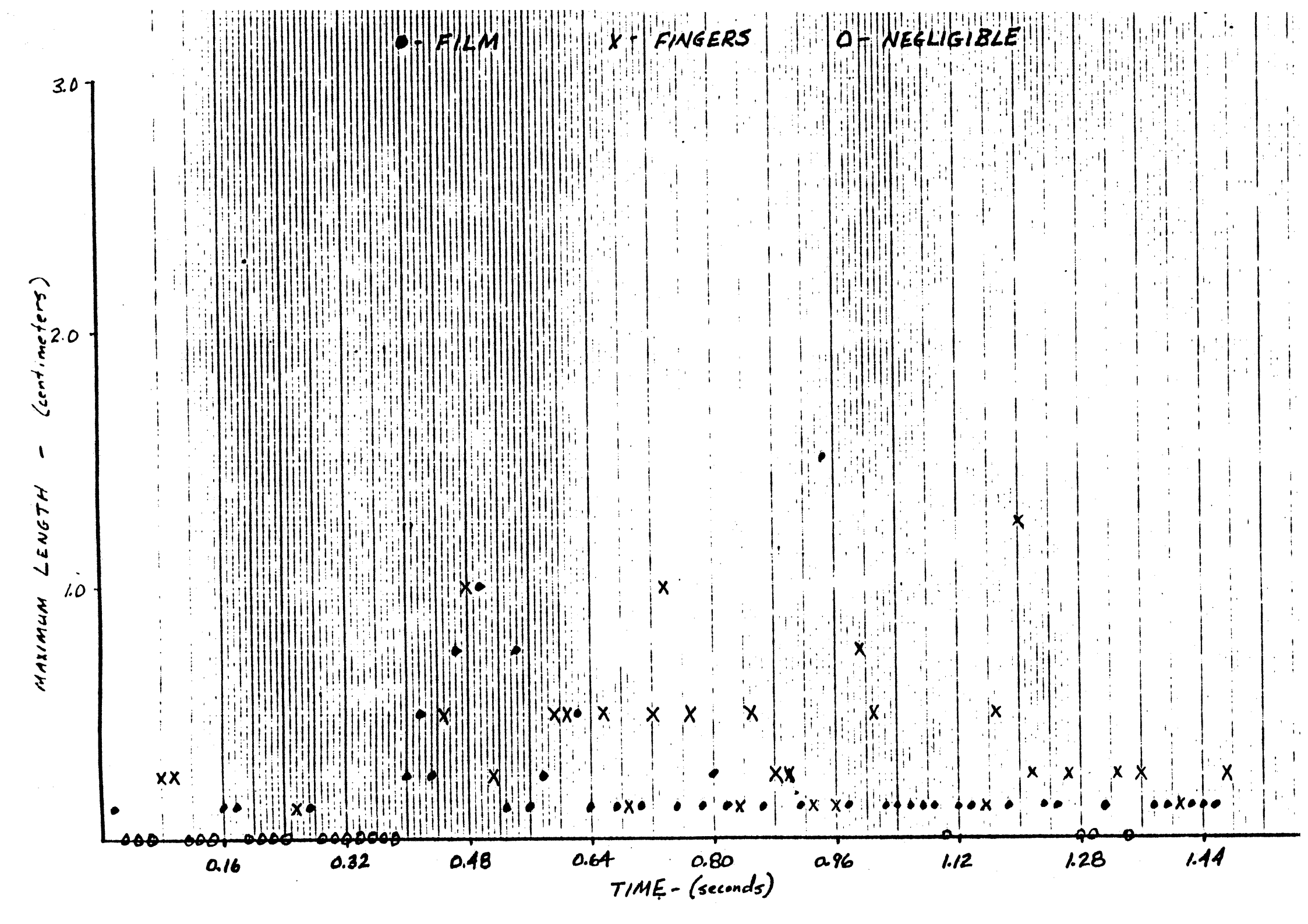
FLOW RATE = 30 cc/min (A) STEAM VELOCITY = 975 ft/sec. DATA FROM 3/18/77

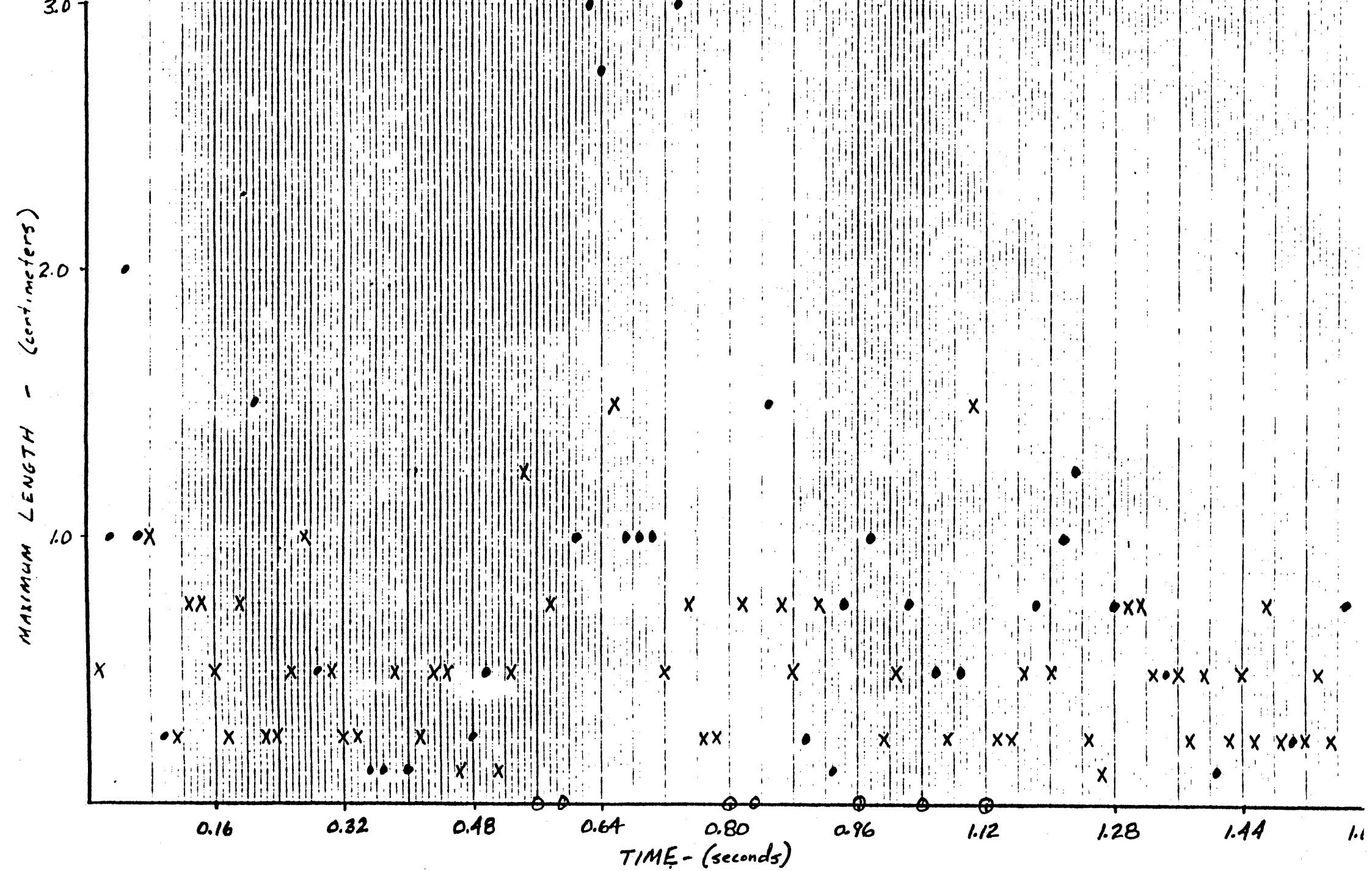
● - FILM X - FINGERS O - NEGLIGIBLE

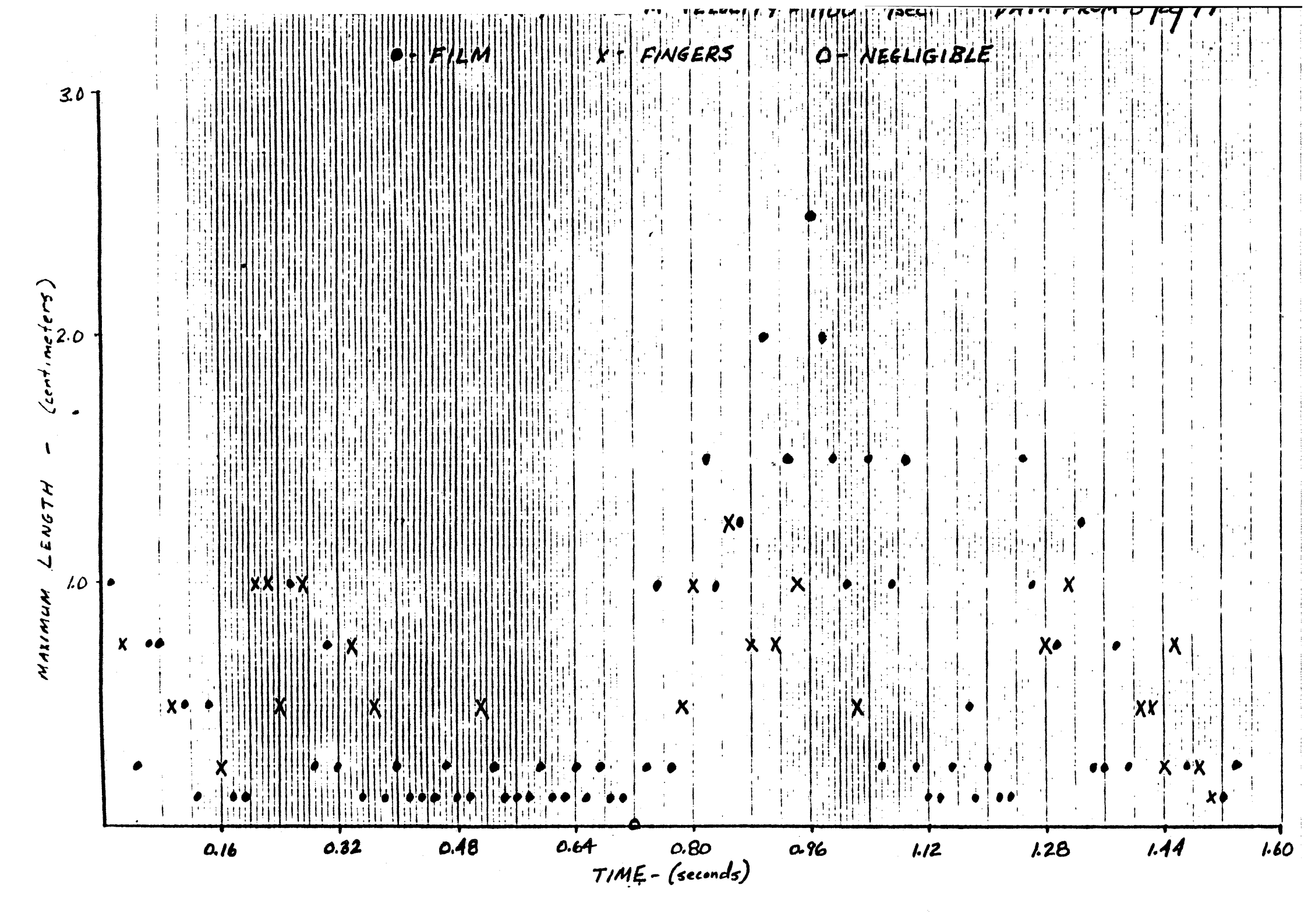


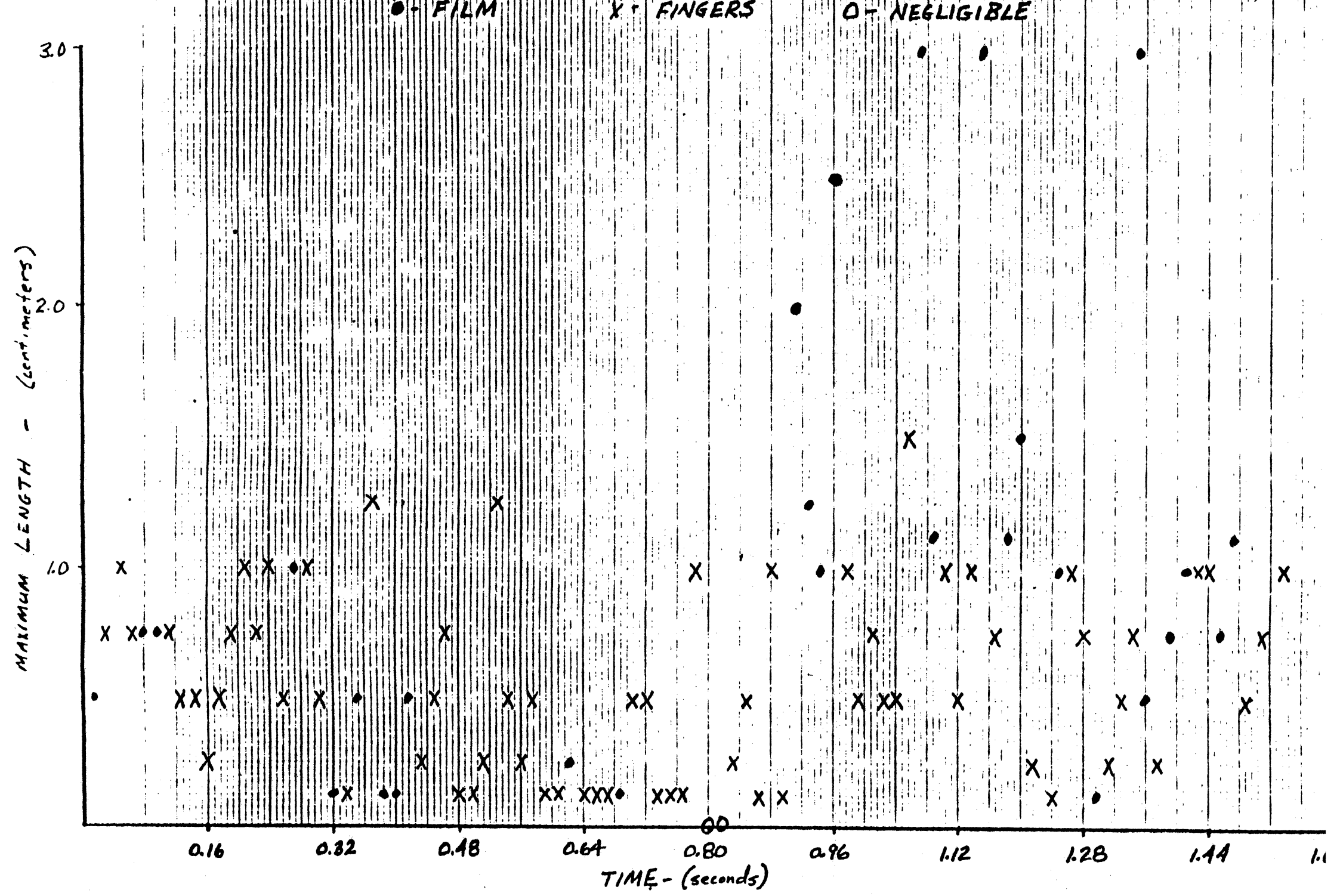

● - FILM
X - FINGERS
O - NEGLIGIBLE
3.0
2.0
1.0
MAXIMUM LENGTH - (centimeters)
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
TIME - (seconds)

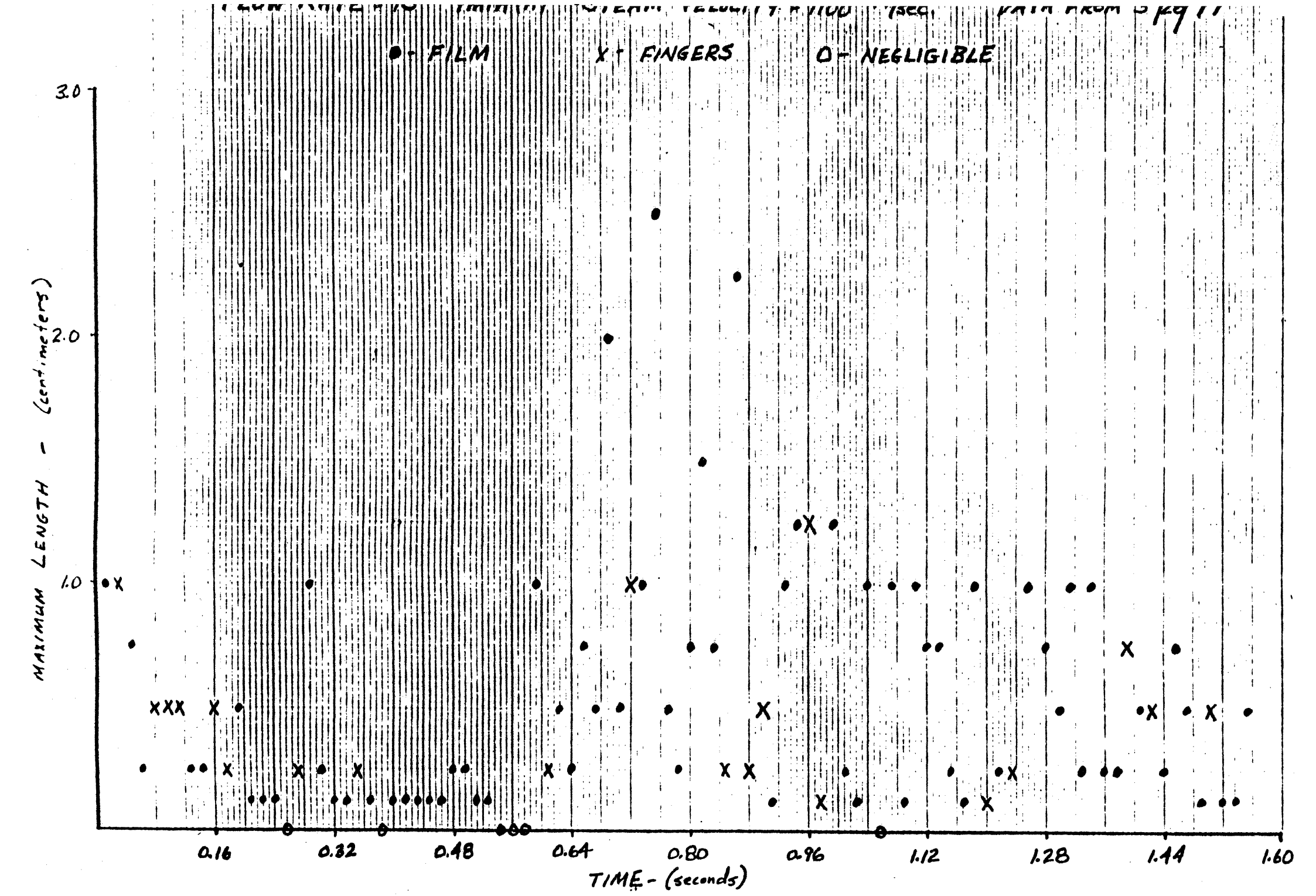

● - FILM
X - FINGERS
O - NEGLIGIBLE
3.0
2.0
1.0
MAXIMUM LENGTH - (centimeters)
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60
TIME - (seconds)

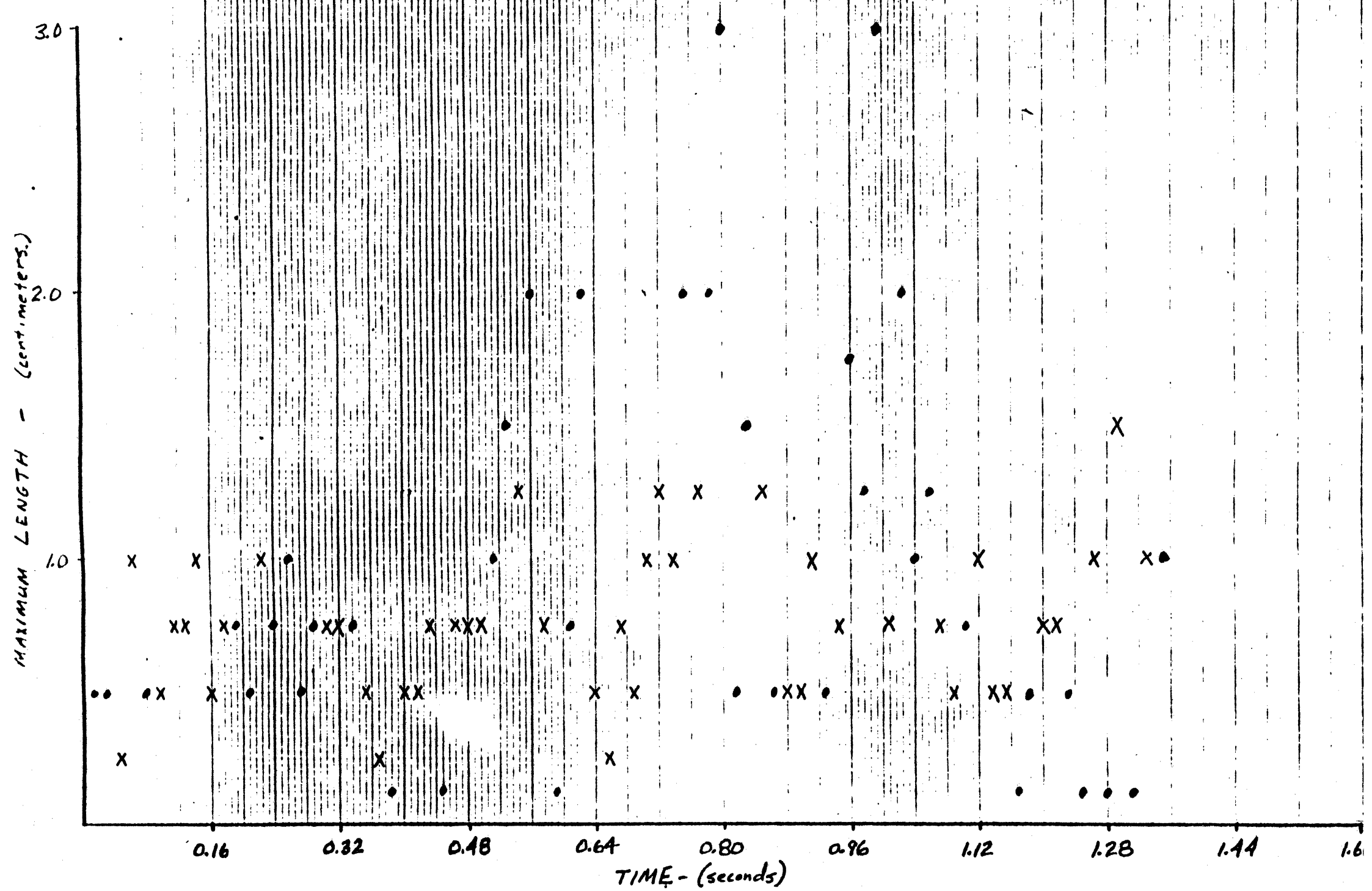

● - FILM
X - FINGERS
O - NEGLIGIBLE
3.0
2.0
1.0
MAXIMUM LENGTH - (centimeters)
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
TIME - (seconds)

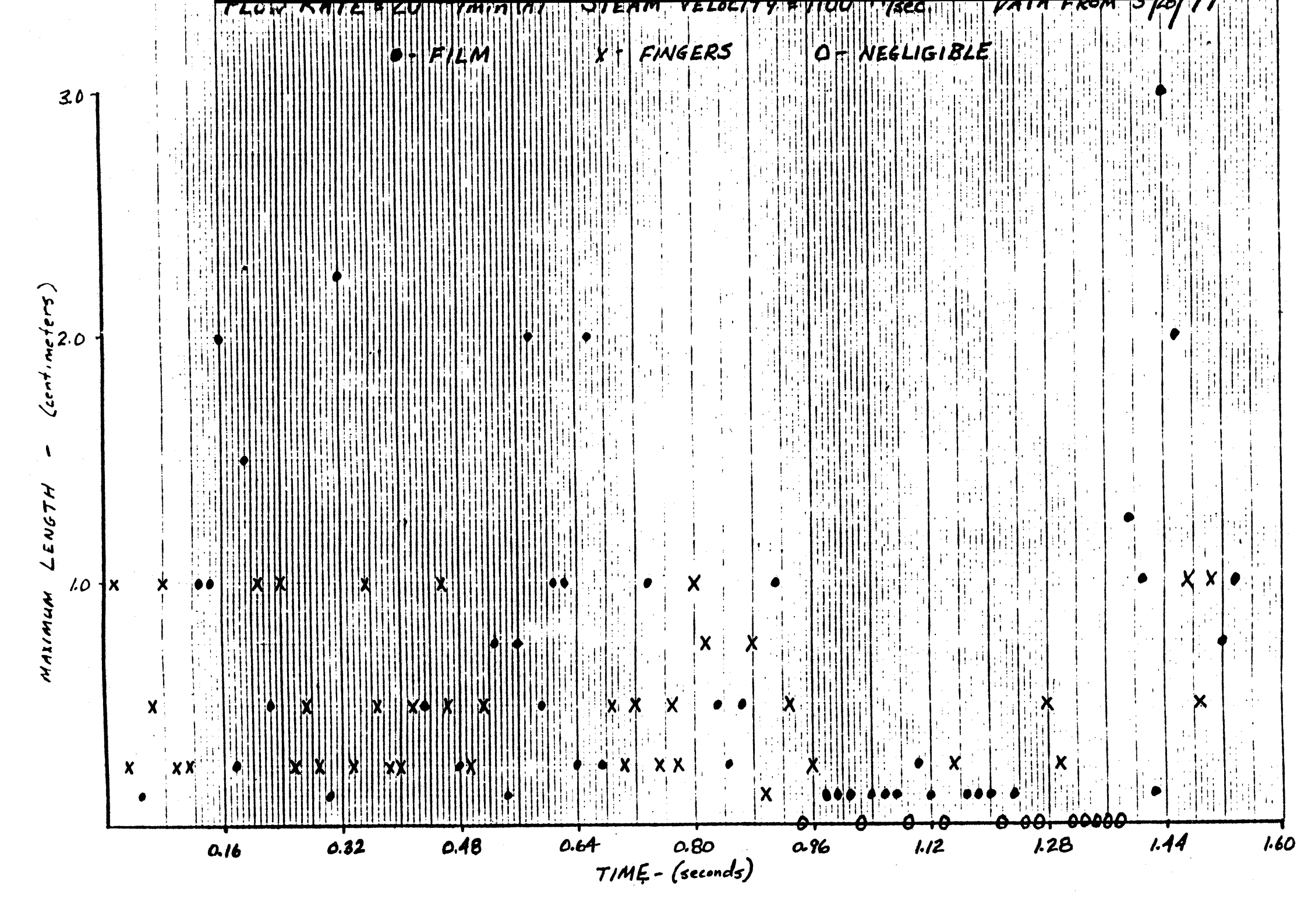

3.0
2.0
1.0
MAXIMUM LENGTH - (centimeters)
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
TIME - (seconds)

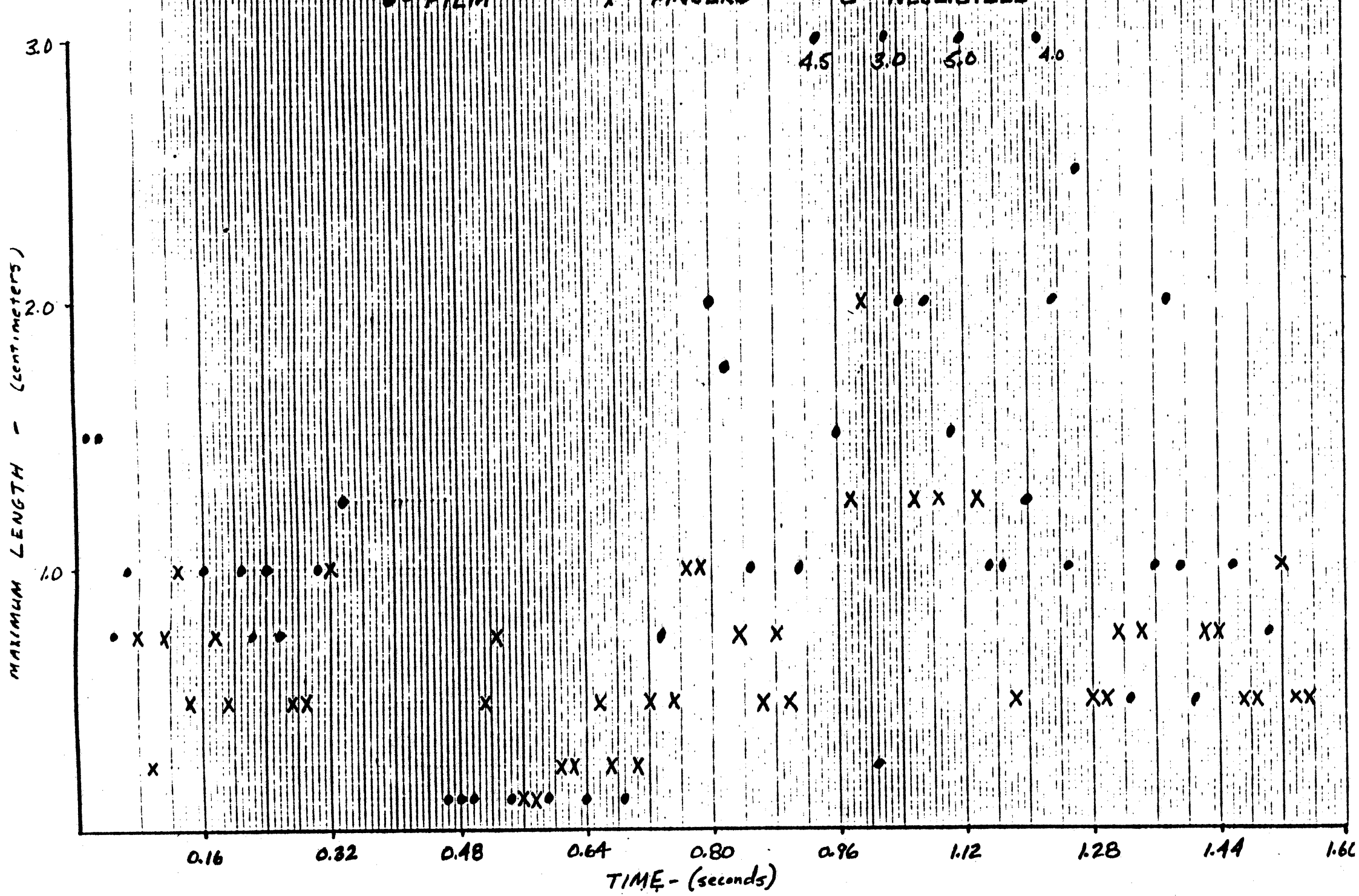

● - FILM
X - FINGERS
O - NEGLIGIBLE
3.0
2.0
1.0
MAXIMUM LENGTH - (centimeters)
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60
TIME - (seconds)

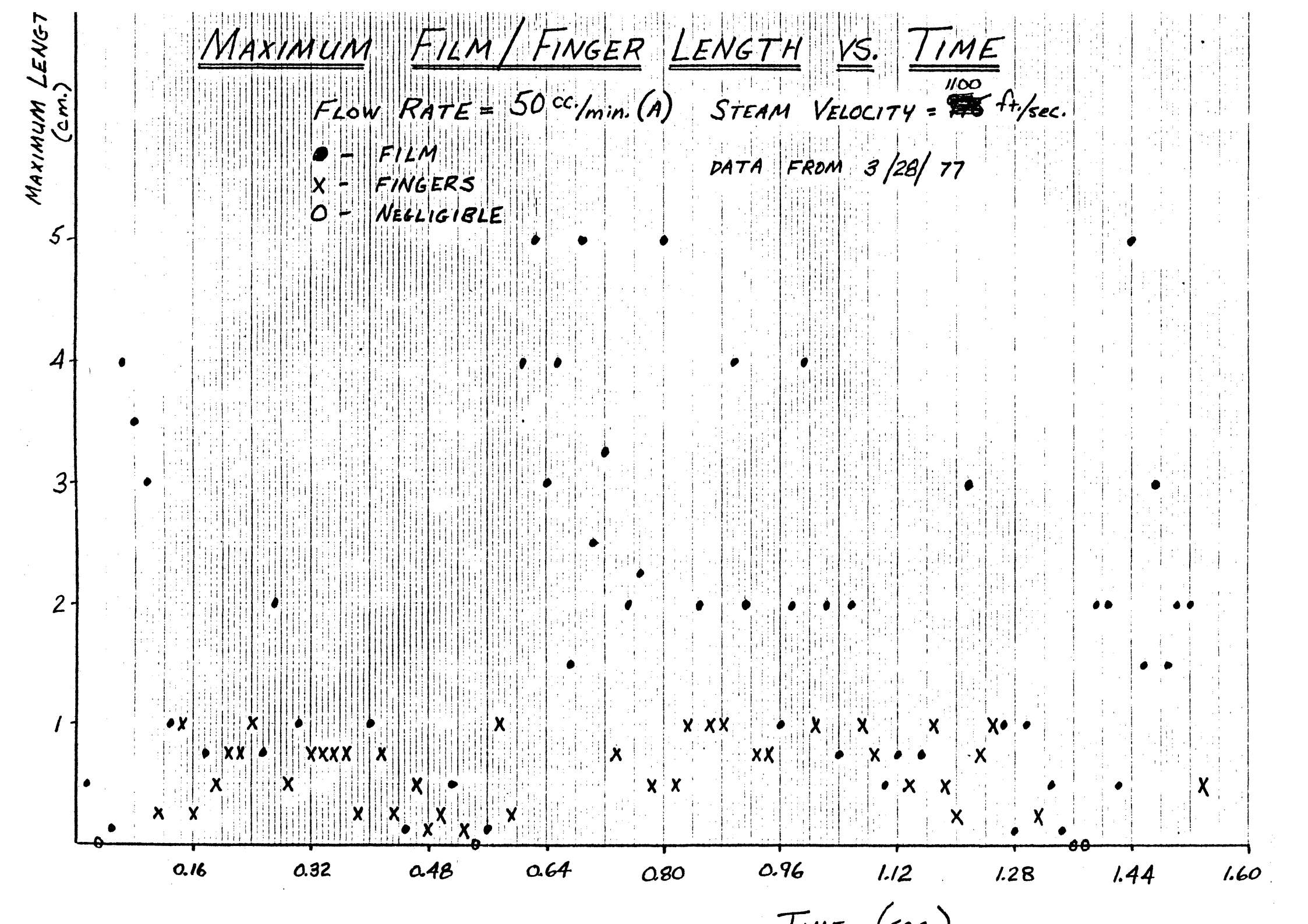

● - FILM
X - FINGERS
O - NEGLIGIBLE
3.0
2.0
1.0
MAXIMUM LENGTH - (cent. meters)
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
TIME - (seconds)


● - FILM
X - FINGERS
O - NEGLIGIBLE
3.0
2.0
1.0
MAXIMUM LENGTH - (centimeters)
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60
TIME - (seconds)


3.0
2.0
1.0
MAXIMUM LENGTH - (cent.meters.)
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
TIME - (seconds)


FLOW RATE = 20 gpm (?)
STEAM VELOCITY = 1100 ft/sec
DATA FROM 3/20/77
● - FILM
X - FINGERS
O - NEGLIGIBLE
MAXIMUM LENGTH - (cent.meters)
3.0
2.0
1.0
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60
TIME - (seconds)


4.5
3.0
5.0
4.0
3.0
2.0
1.0
MAXIMUM LENGTH - (centimeters)
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
TIME - (seconds)


MAXIMUM FILM / FINGER LENGTH VS. TIME
FLOW RATE = 50 cc./min. (A)
STEAM VELOCITY = 1100 ft./sec.
● - FILM
X - FINGERS
O - NEGLIGIBLE
DATA FROM 3/28/77
MAXIMUM LENGT (c.m.)
5
4
3
2
1
0
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60

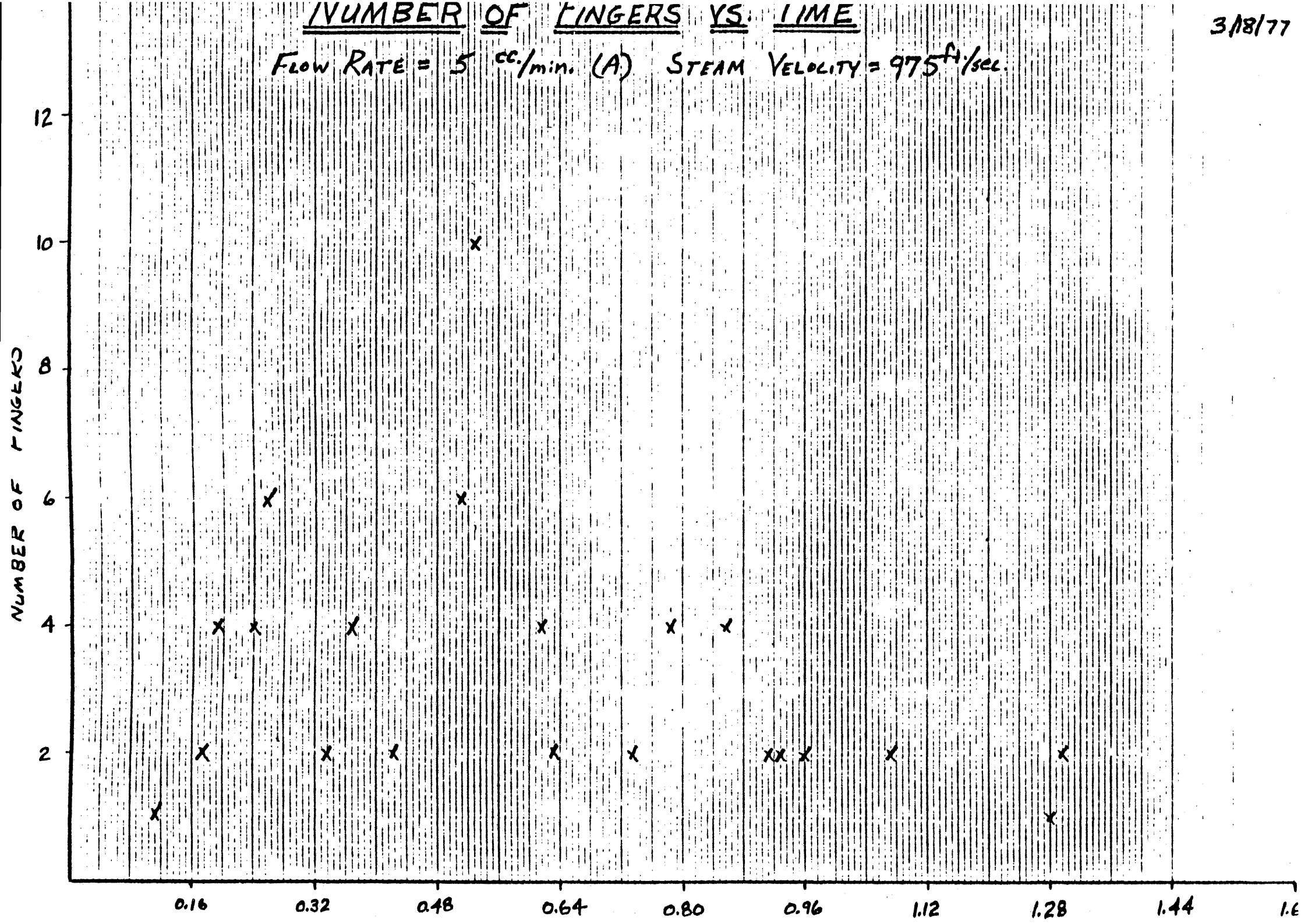
APPENDIX B

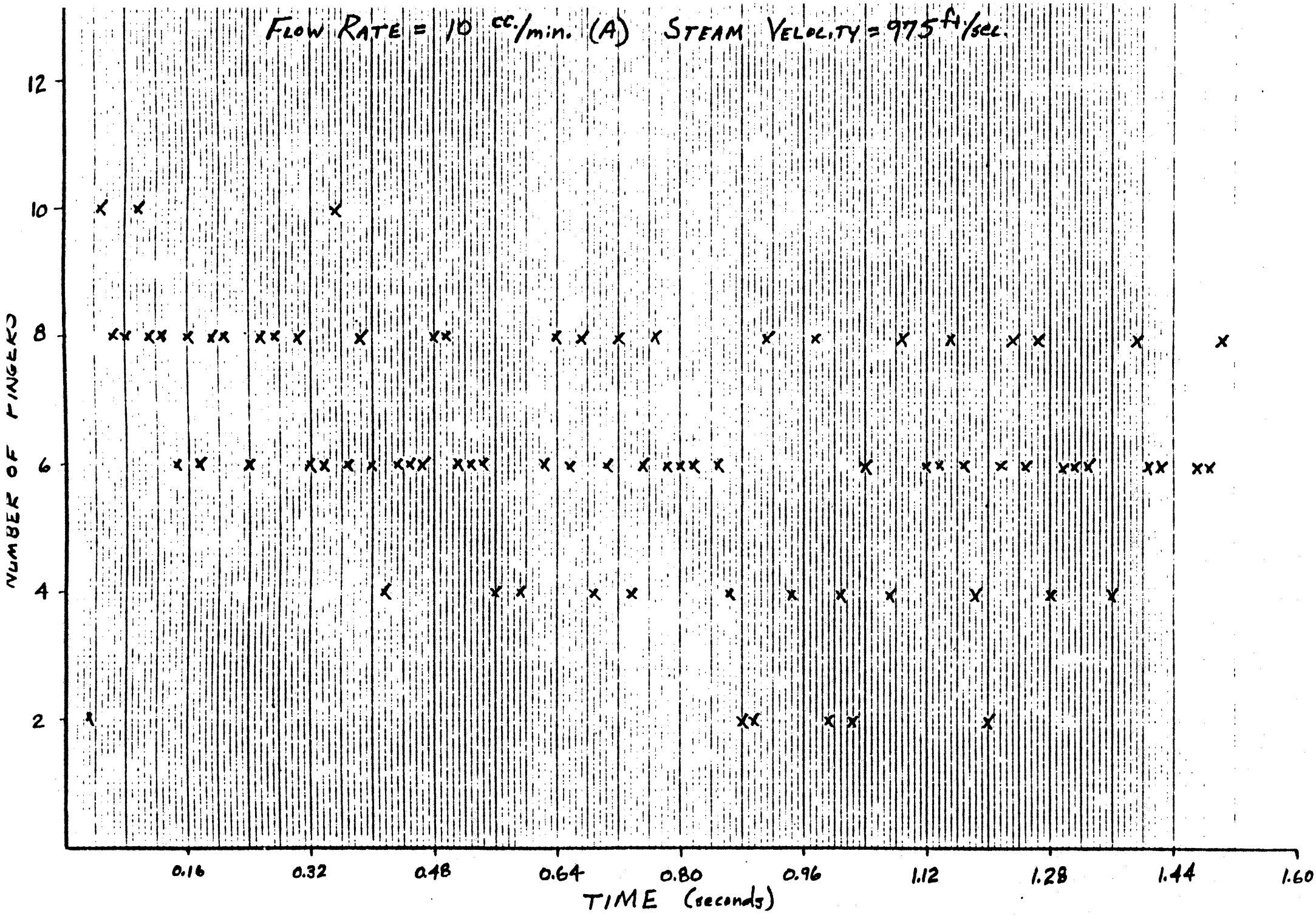
NUMBER OF FINGERS VS. TIME

NUMBER OF FINGERS VS. TIME

3/18/77

FLOW RATE = 5 cc./min. (A) STEAM VELOCITY = 975 ft/sec.

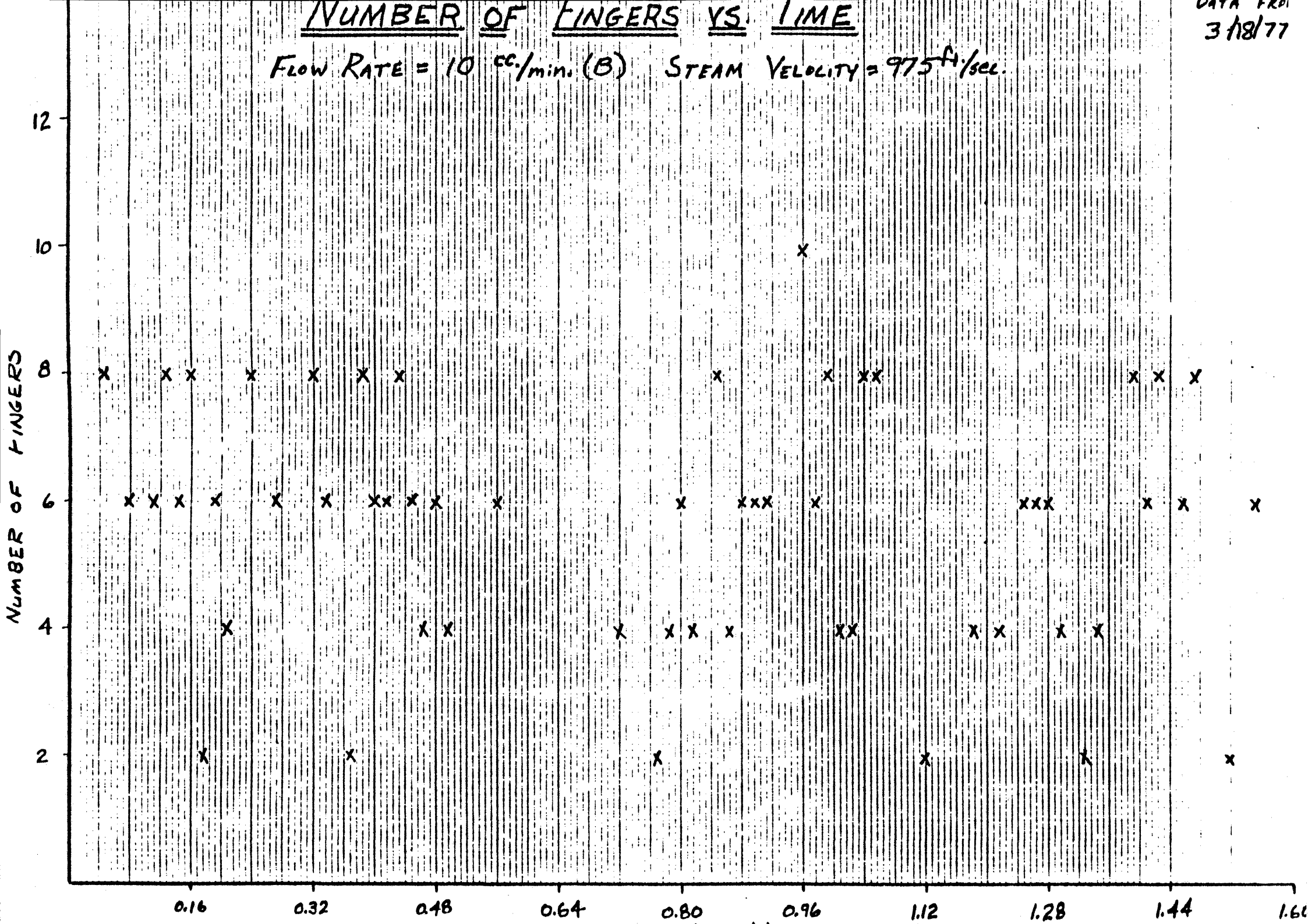



FLOW RATE = 10 cc./min. (A) STEAM VELOCITY = 975 ft/sec.
NUMBER OF FINGERS
12
10
8
6
4
2
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60
TIME (seconds)

NUMBER OF FINGERS VS. TIME

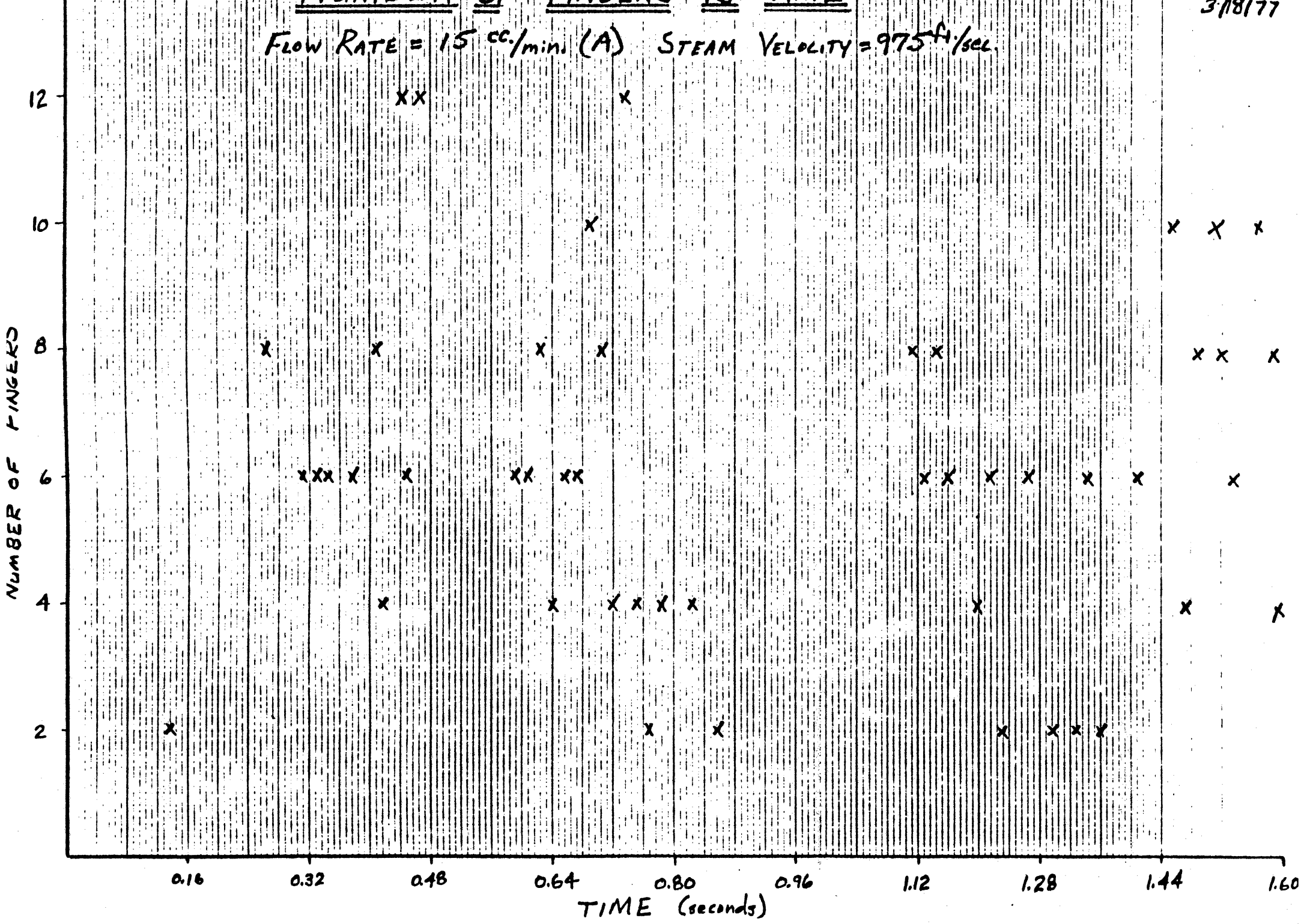
FLOW RATE = 10 cc./min. (B) STEAM VELOCITY = 975 ft./sec.

DATA FROM 3/18/77



3/18/77

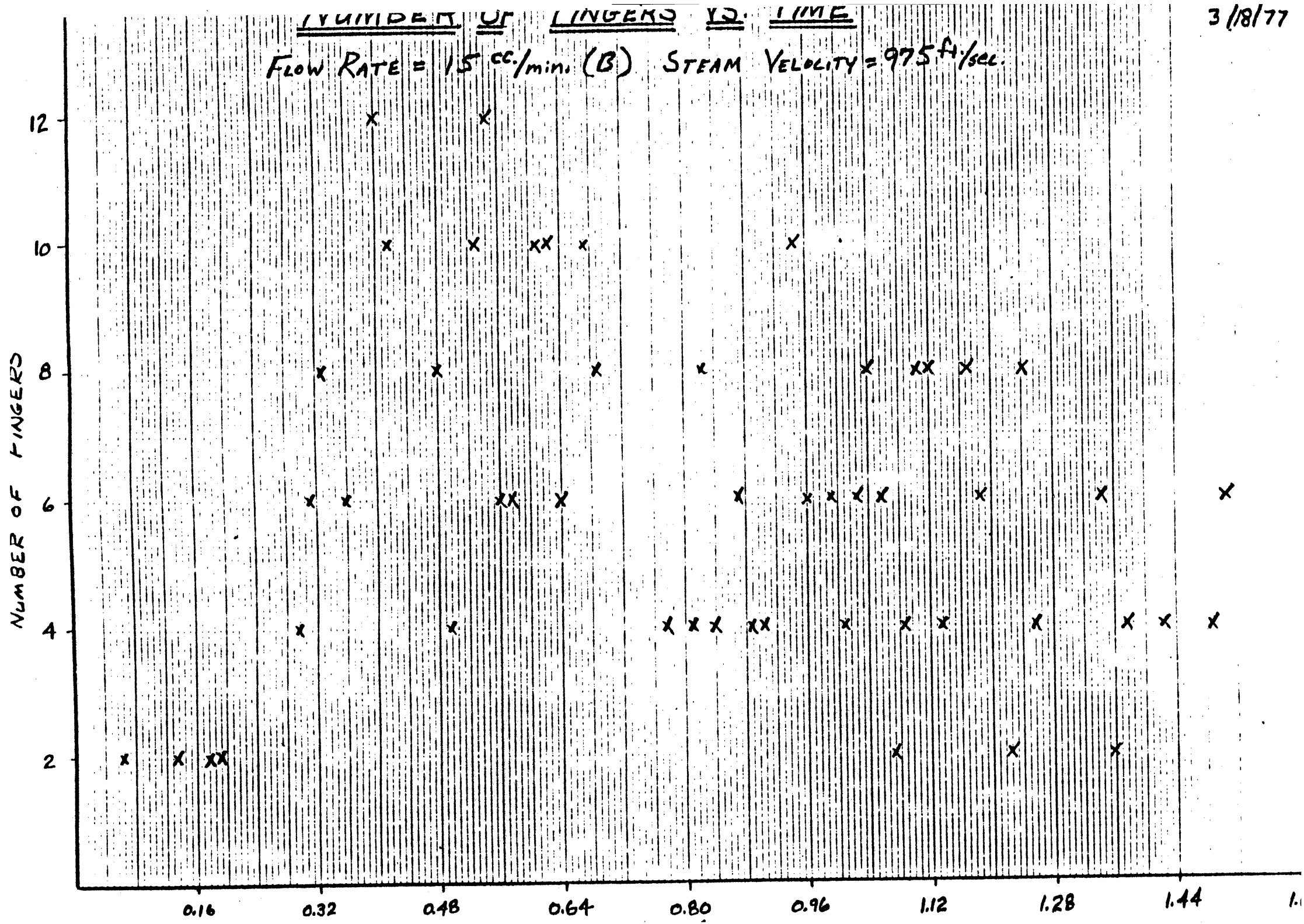
FLOW RATE = 15 cc./min. (A) STEAM VELOCITY = 975 ft./sec.

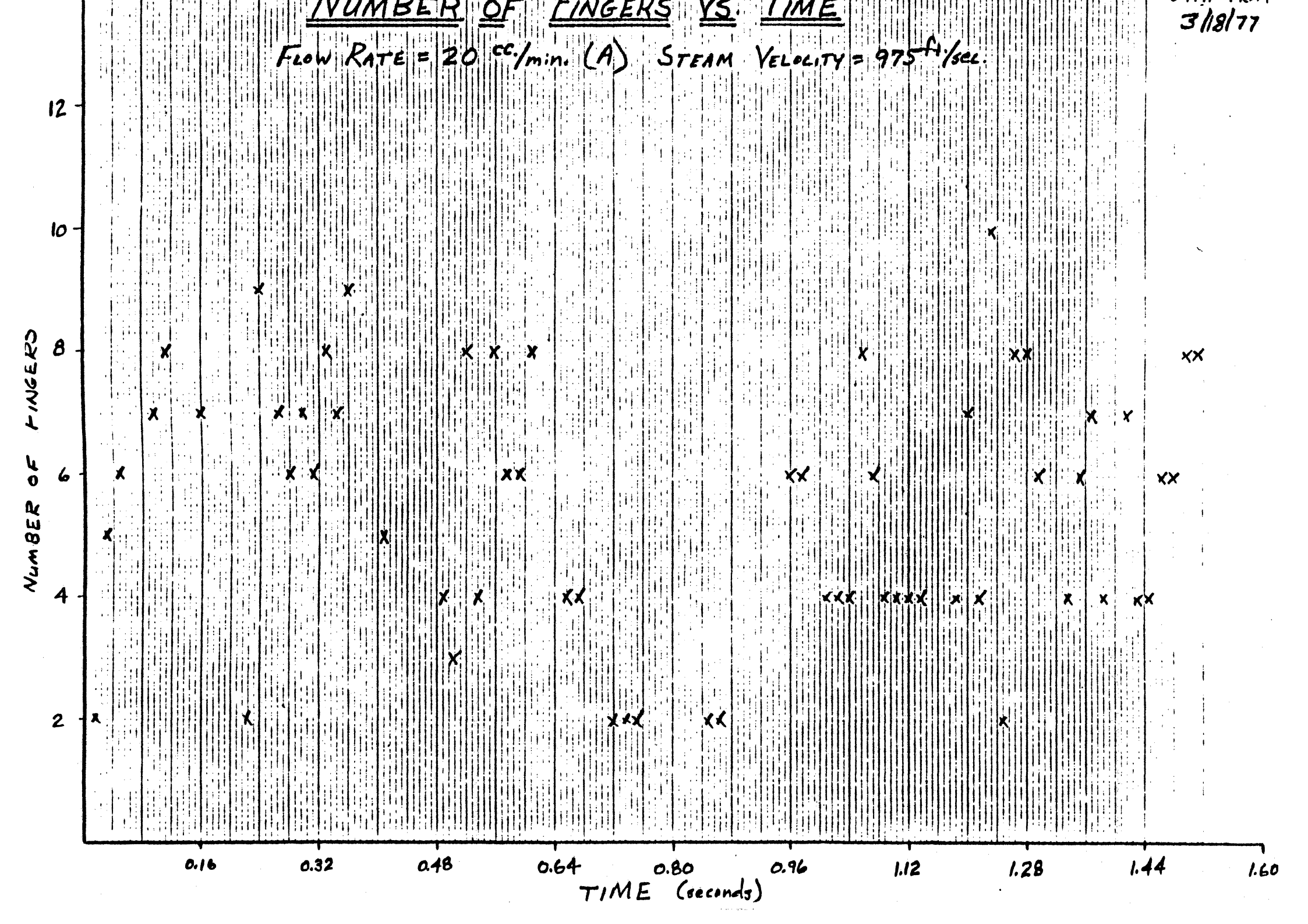


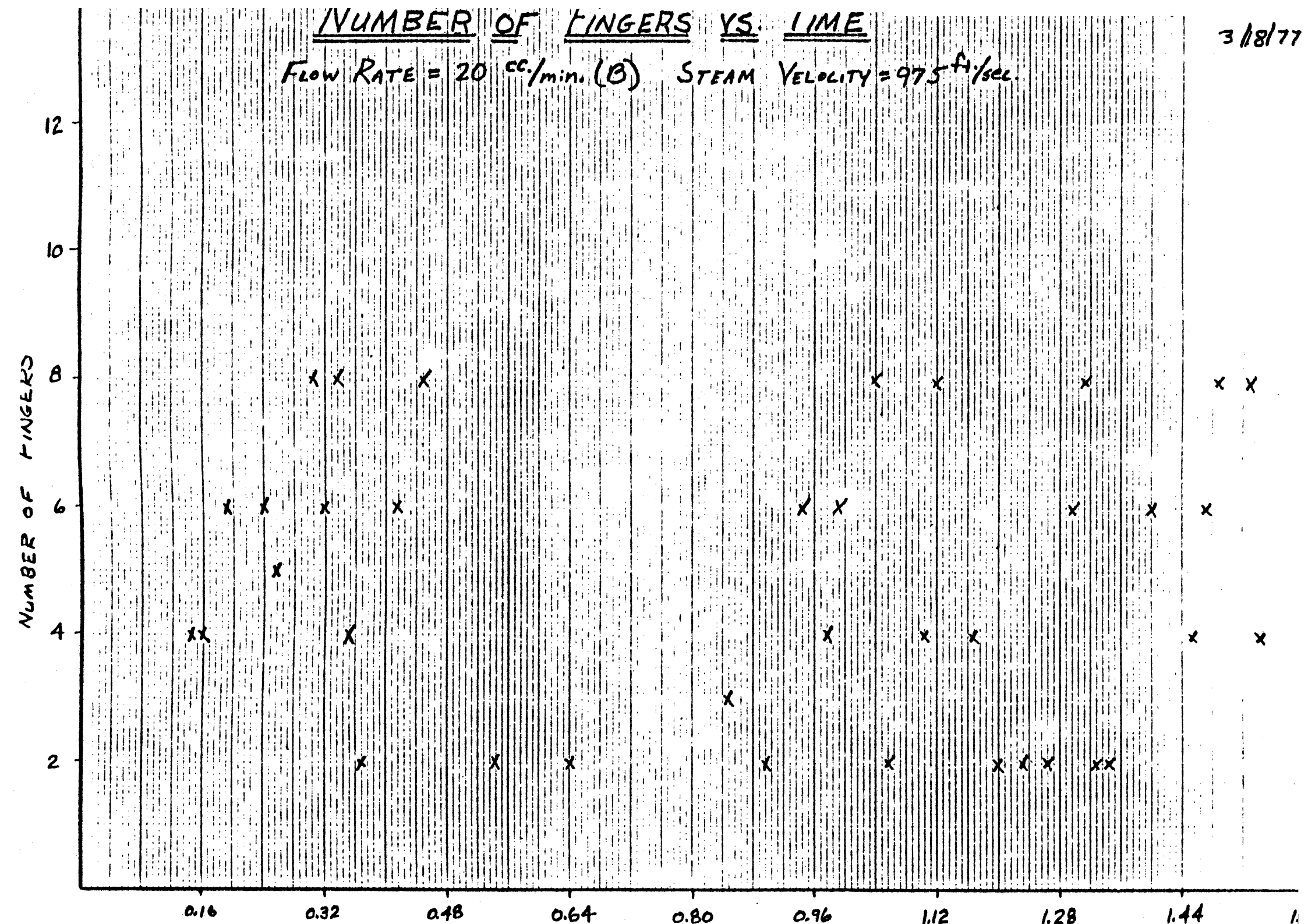
3/18/77

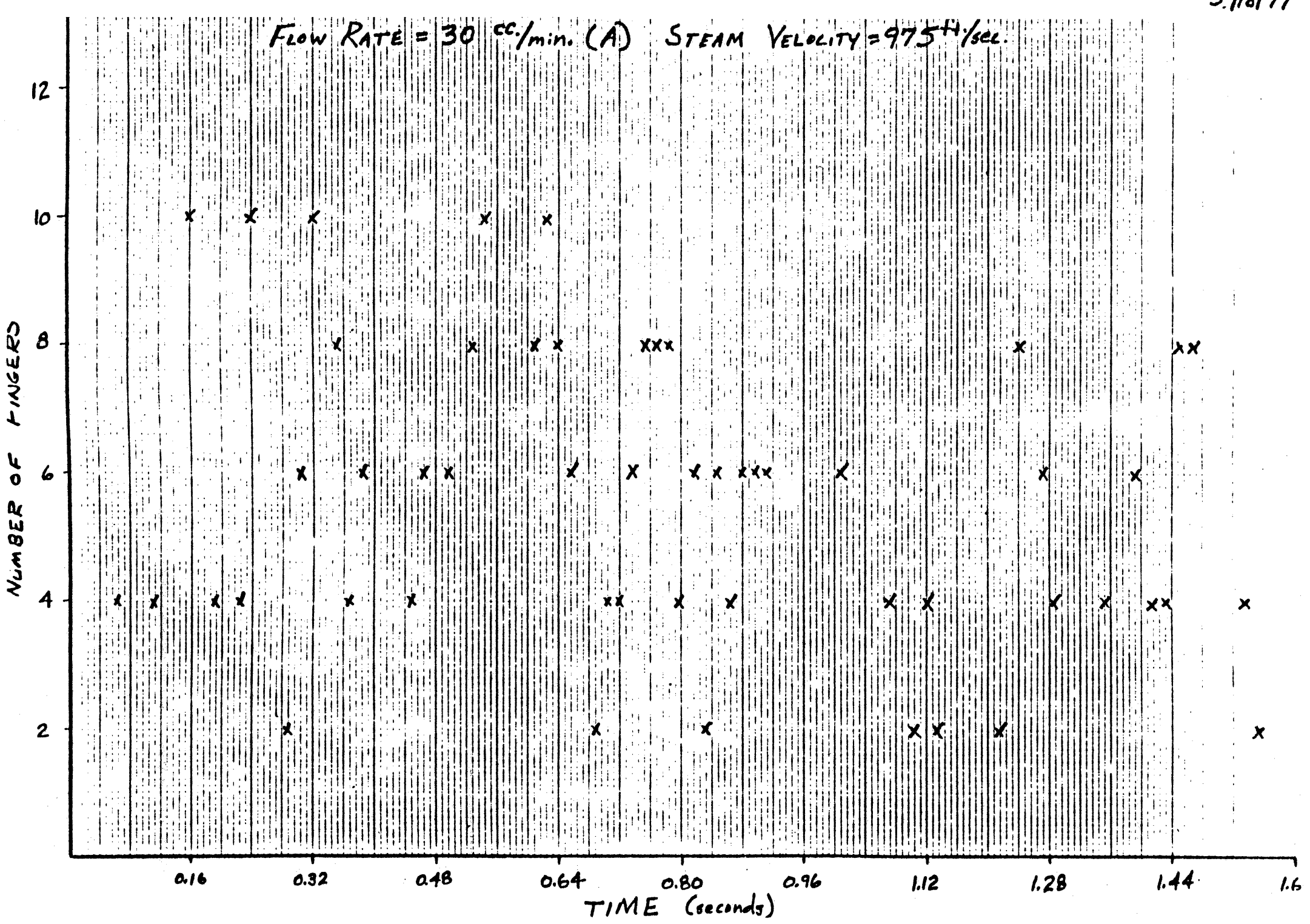
NUMBER OF FINGERS VS. TIME

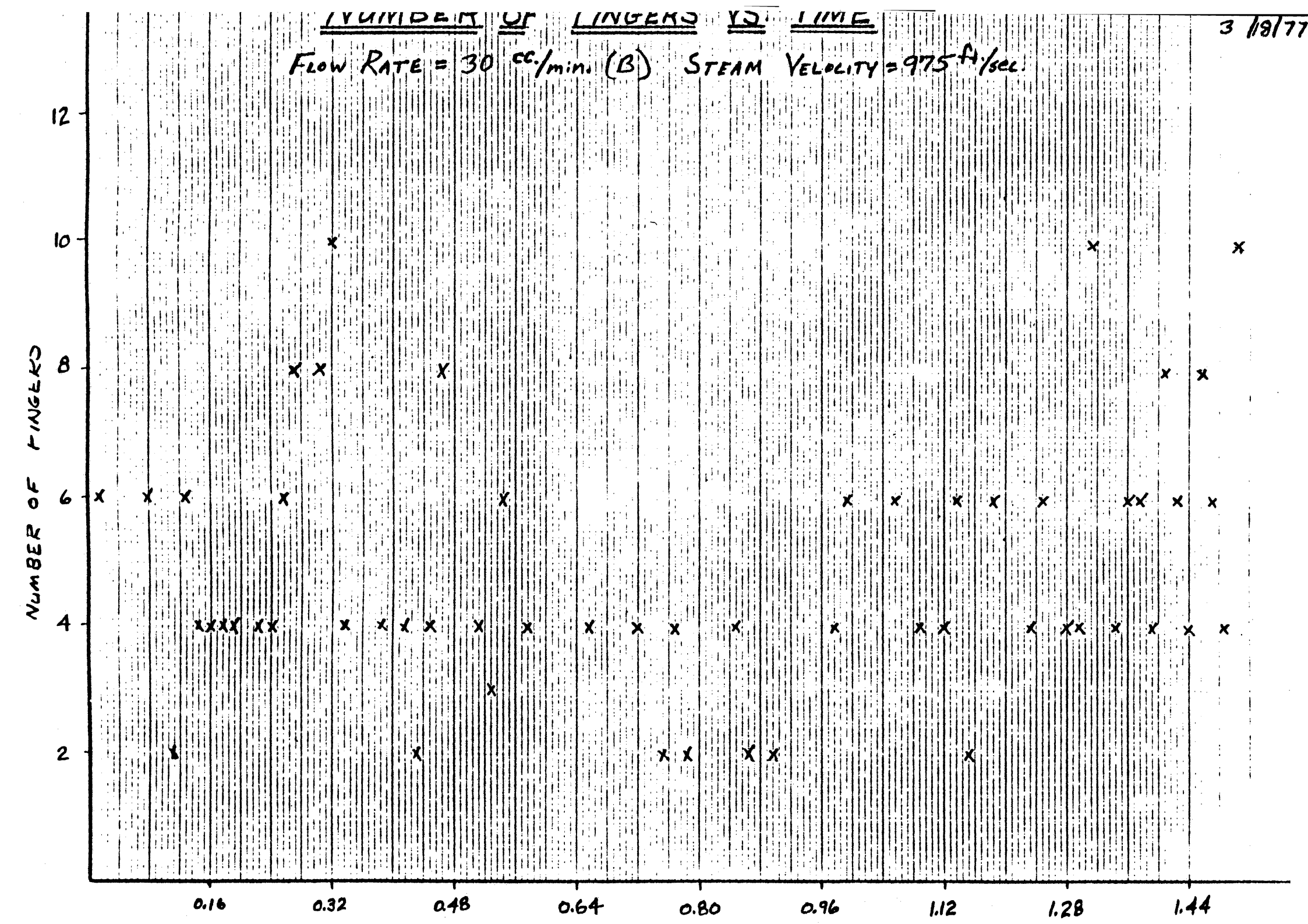
FLOW RATE = 15 cc./min. (B) STEAM VELOCITY = 975 ft./sec.

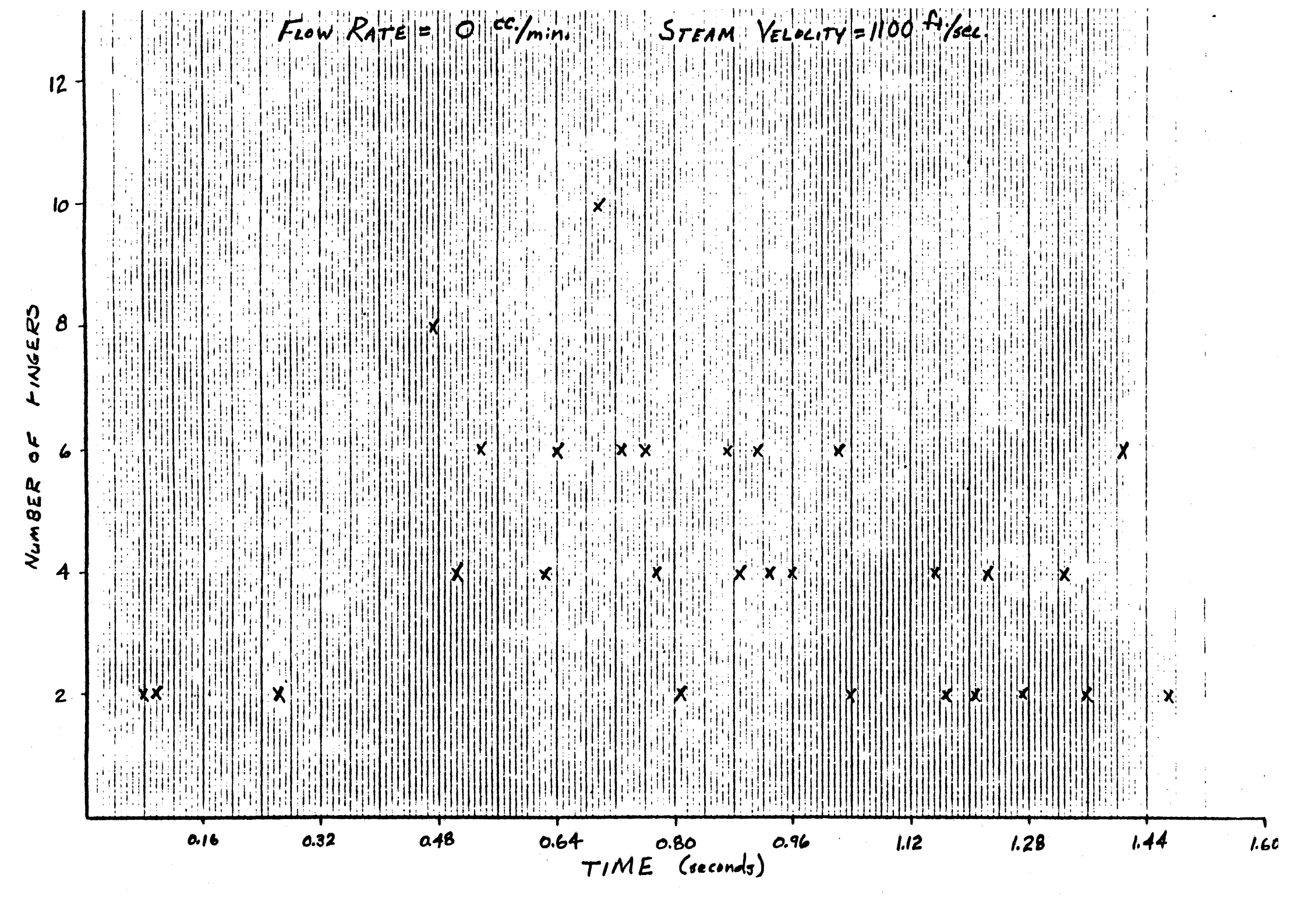


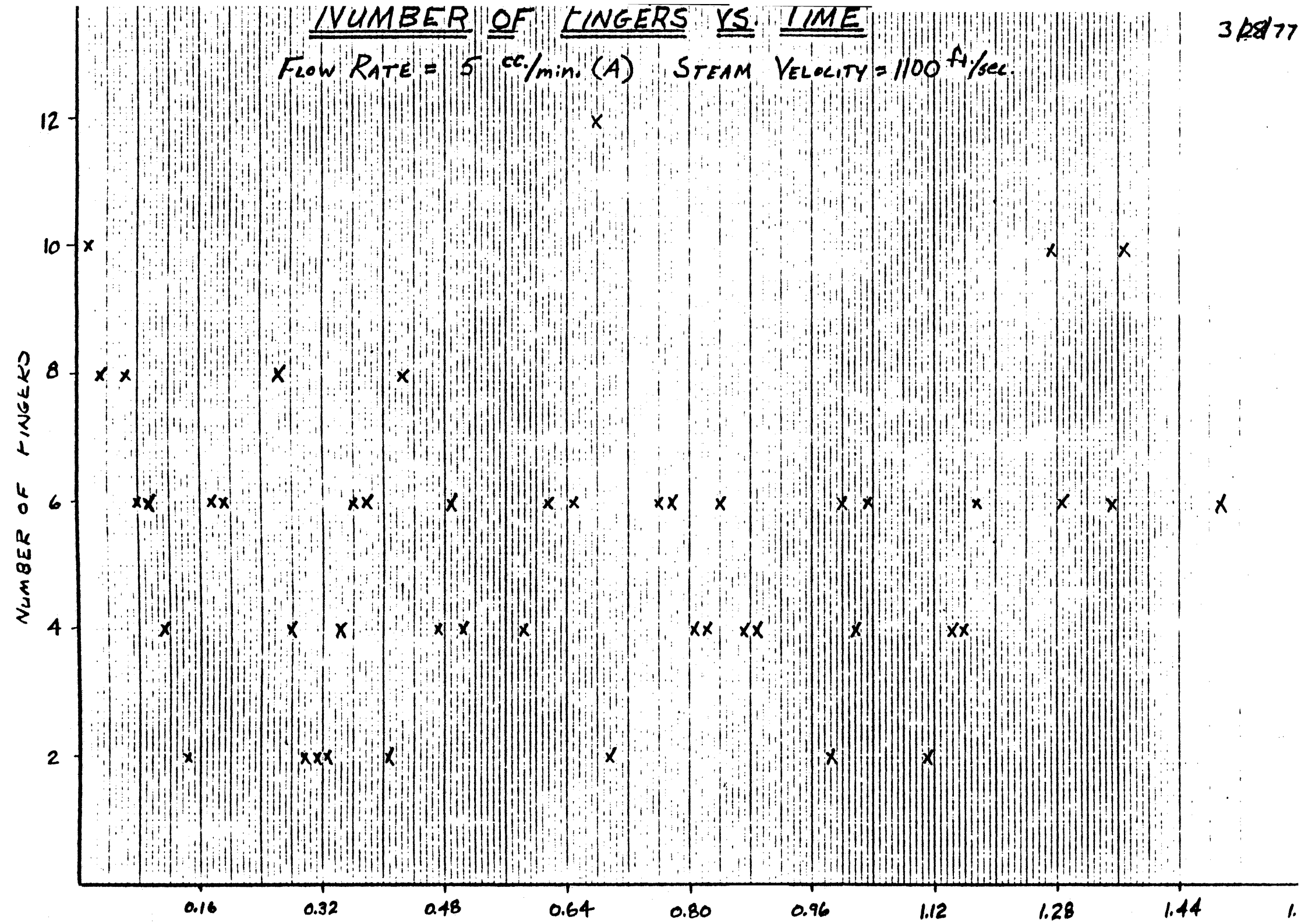

NUMBER OF FINGERS VS. TIME
FLOW RATE = 20 cc./min. (A) STEAM VELOCITY = 975 ft/sec.
3/18/77
NUMBER OF FINGERS
12
10
8
6
4
2
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60
TIME (seconds)

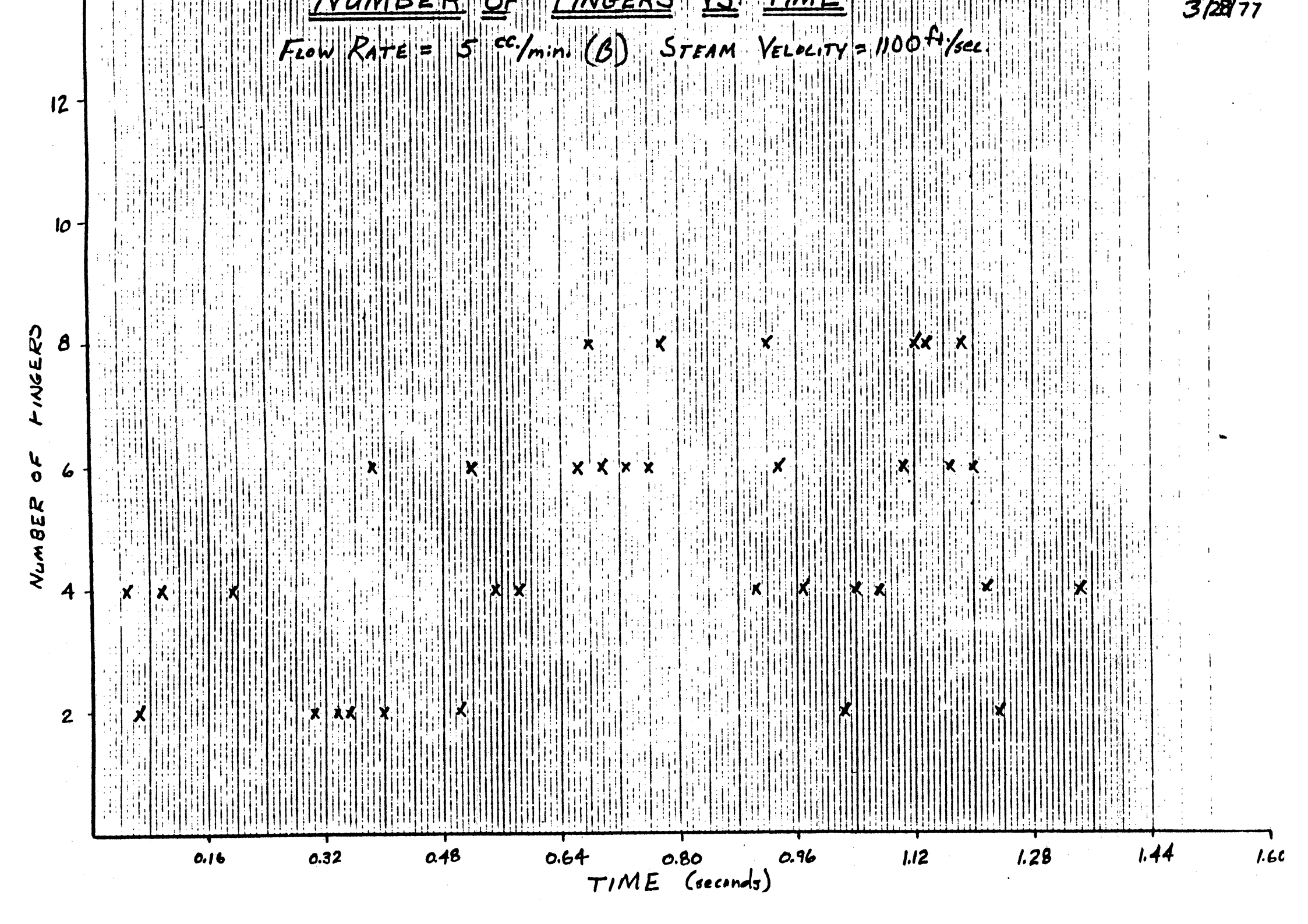

NUMBER OF FINGERS VS. TIME
FLOW RATE = 20 cc./min. (B) STEAM VELOCITY = 975 ft./sec.
3/18/77
NUMBER OF FINGERS
12
10
8
6
4
2
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44


FLOW RATE = 30 cc./min. (A) STEAM VELOCITY = 975 ft./sec.
NUMBER OF FINGERS
12
10
8
6
4
2
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.6
TIME (seconds)


NUMBER OF FINGERS VS. TIME
3/18/77
FLOW RATE = 30 cc./min. (B) STEAM VELOCITY = 975 ft/sec.
NUMBER OF FINGERS
12
10
8
6
4
2
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44


FLOW RATE = 0 cc./min.
STEAM VELOCITY = 1100 ft/sec.
NUMBER OF FINGERS
12
10
8
6
4
2
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60
TIME (seconds)

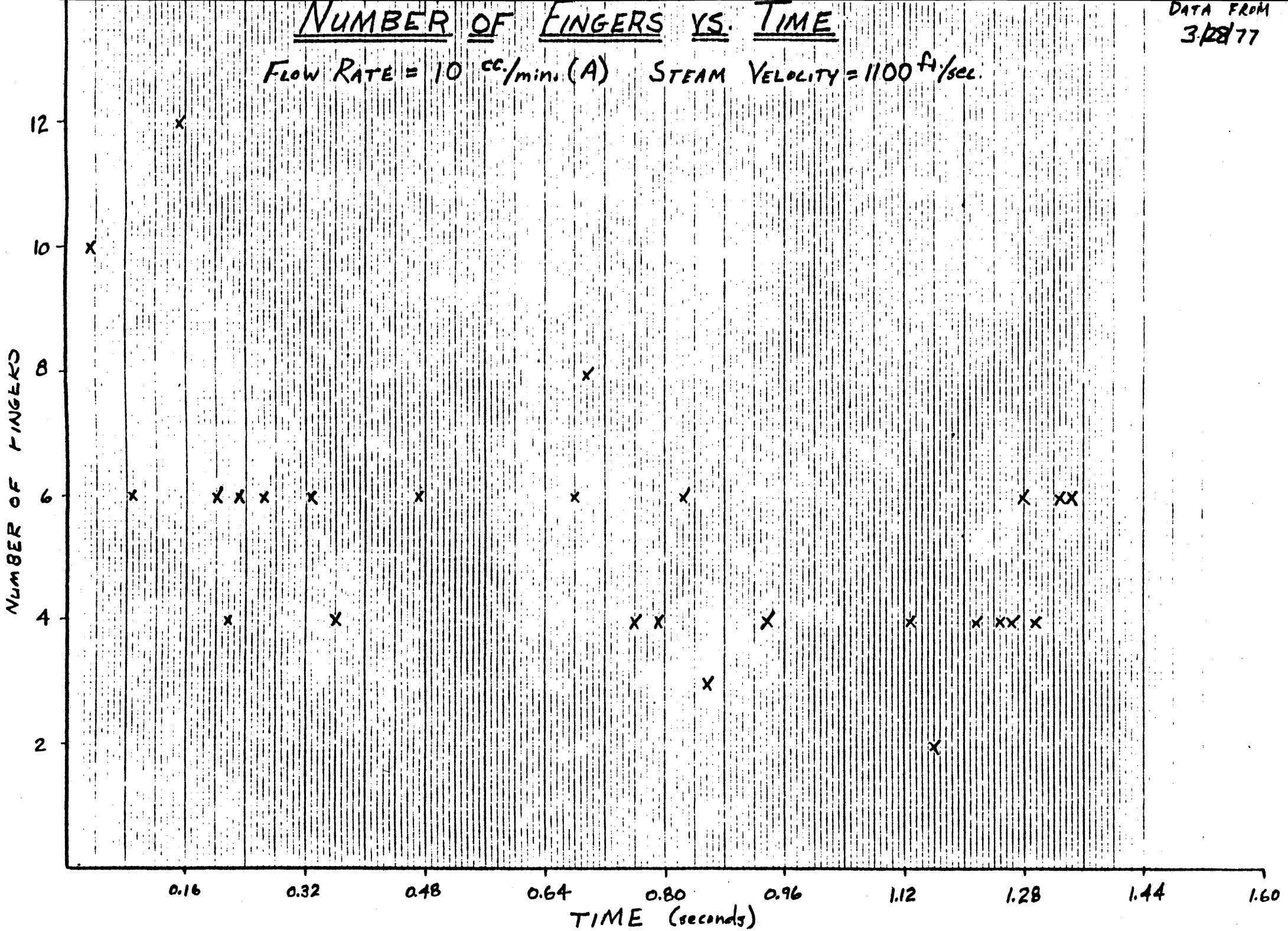

NUMBER OF FINGERS VS. TIME
FLOW RATE = 5 cc./min. (A) STEAM VELOCITY = 1100 ft./sec.
3/28/77
NUMBER OF FINGERS
12
10
8
6
4
2
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.

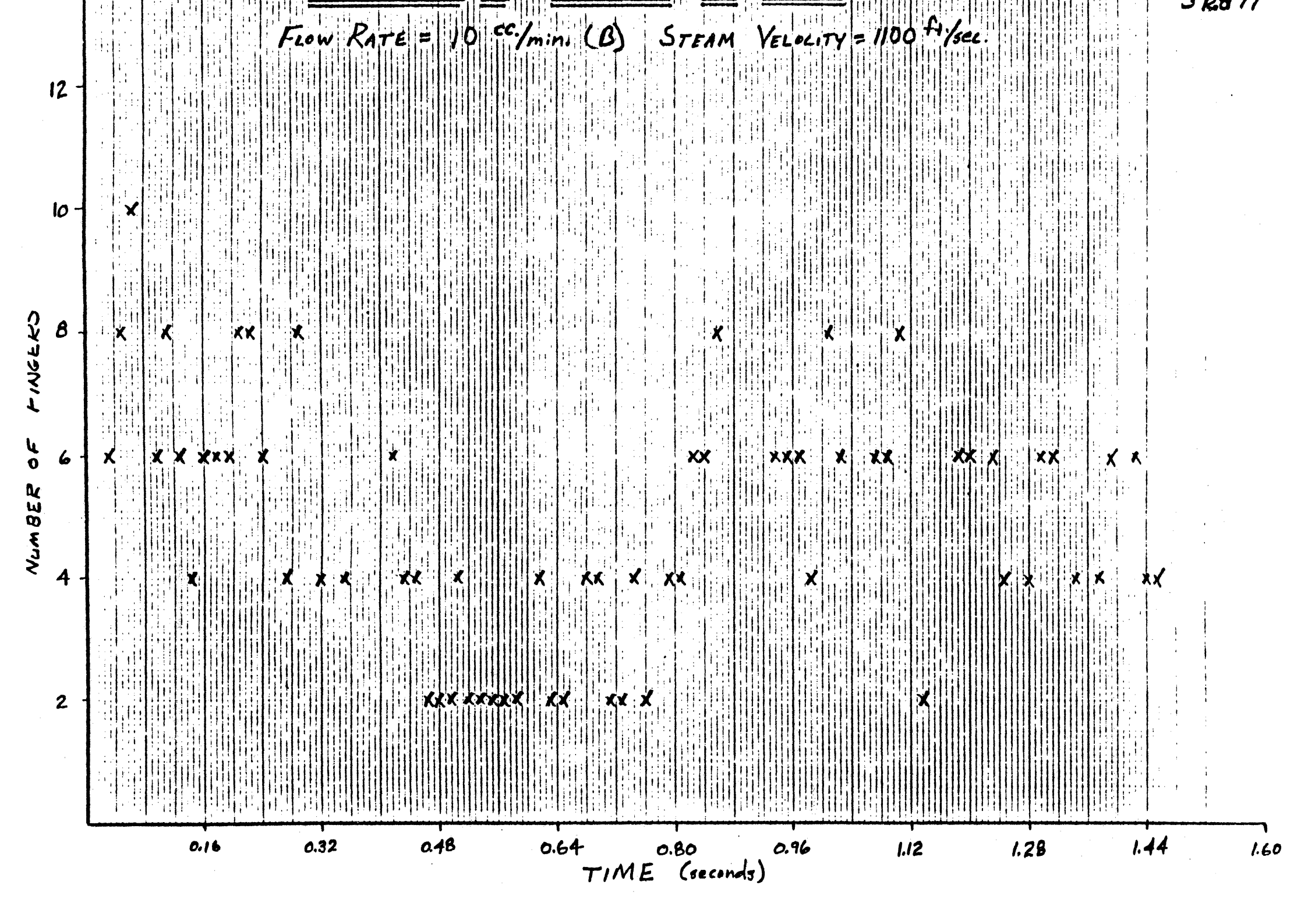

NUMBER OF FINGERS VS. TIME
3/28/77
FLOW RATE = 5 cc./min. (B) STEAM VELOCITY = 1100 ft./sec.
NUMBER OF FINGERS
2
4
6
8
10
12
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60
TIME (seconds)

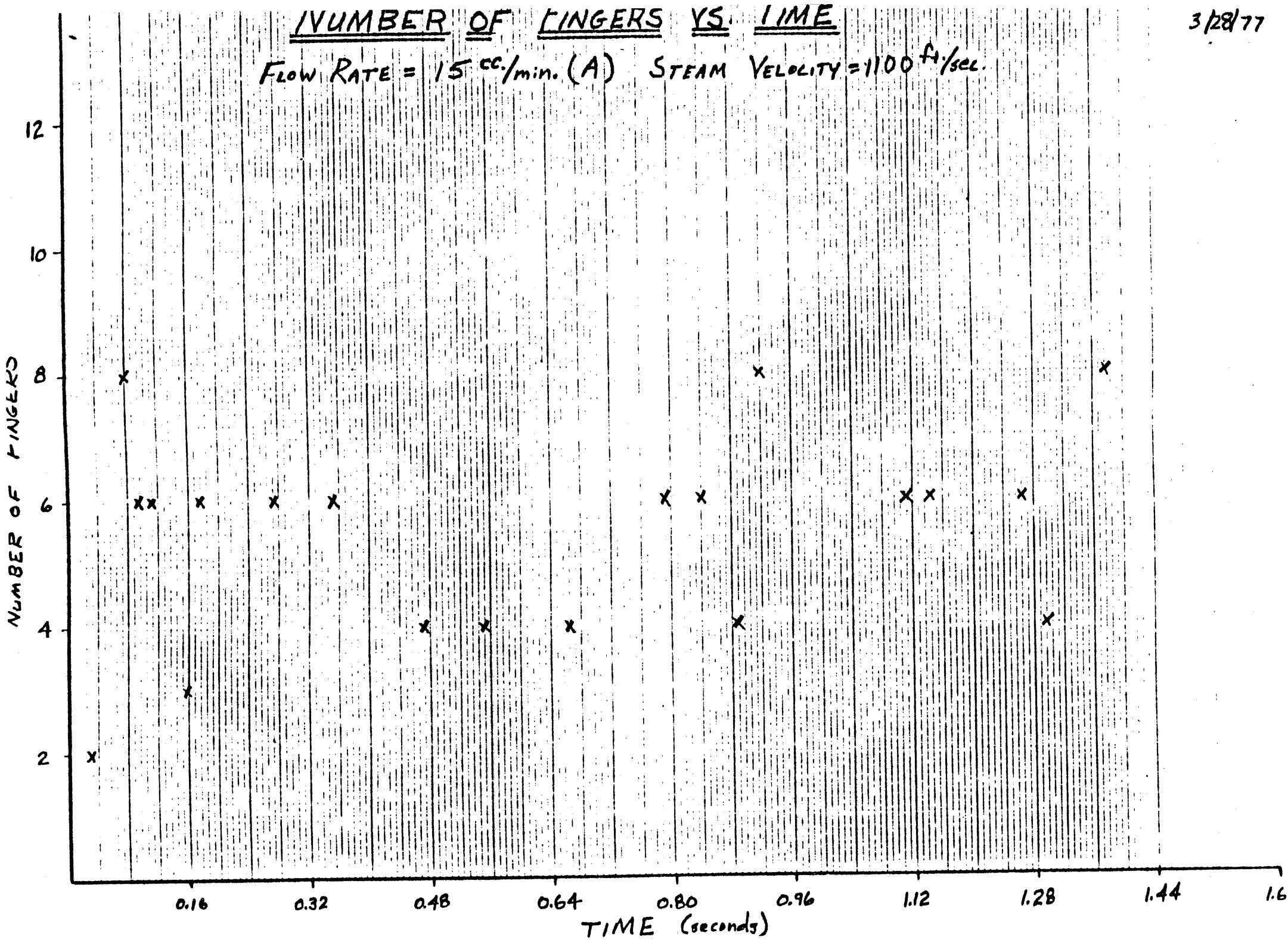
NUMBER OF FINGERS VS. TIME

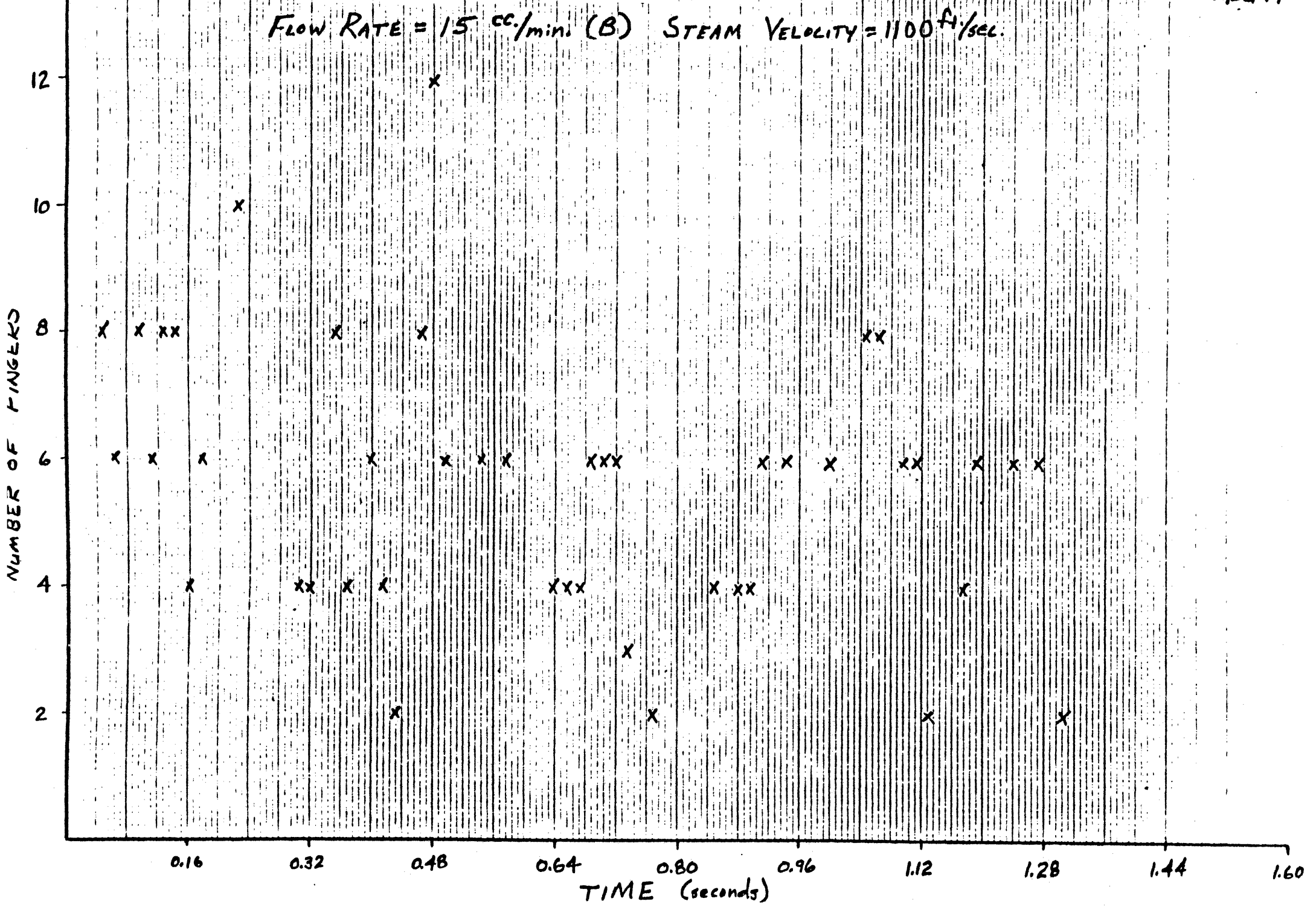
DATA FROM 3/28/77

FLOW RATE = 10 cc./min. (A) STEAM VELOCITY = 1100 ft/sec.




FLOW RATE = 10 cc./min. (B) STEAM VELOCITY = 1100 ft./sec.
NUMBER OF FINGERS
12
10
8
6
4
2
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60
TIME (seconds)

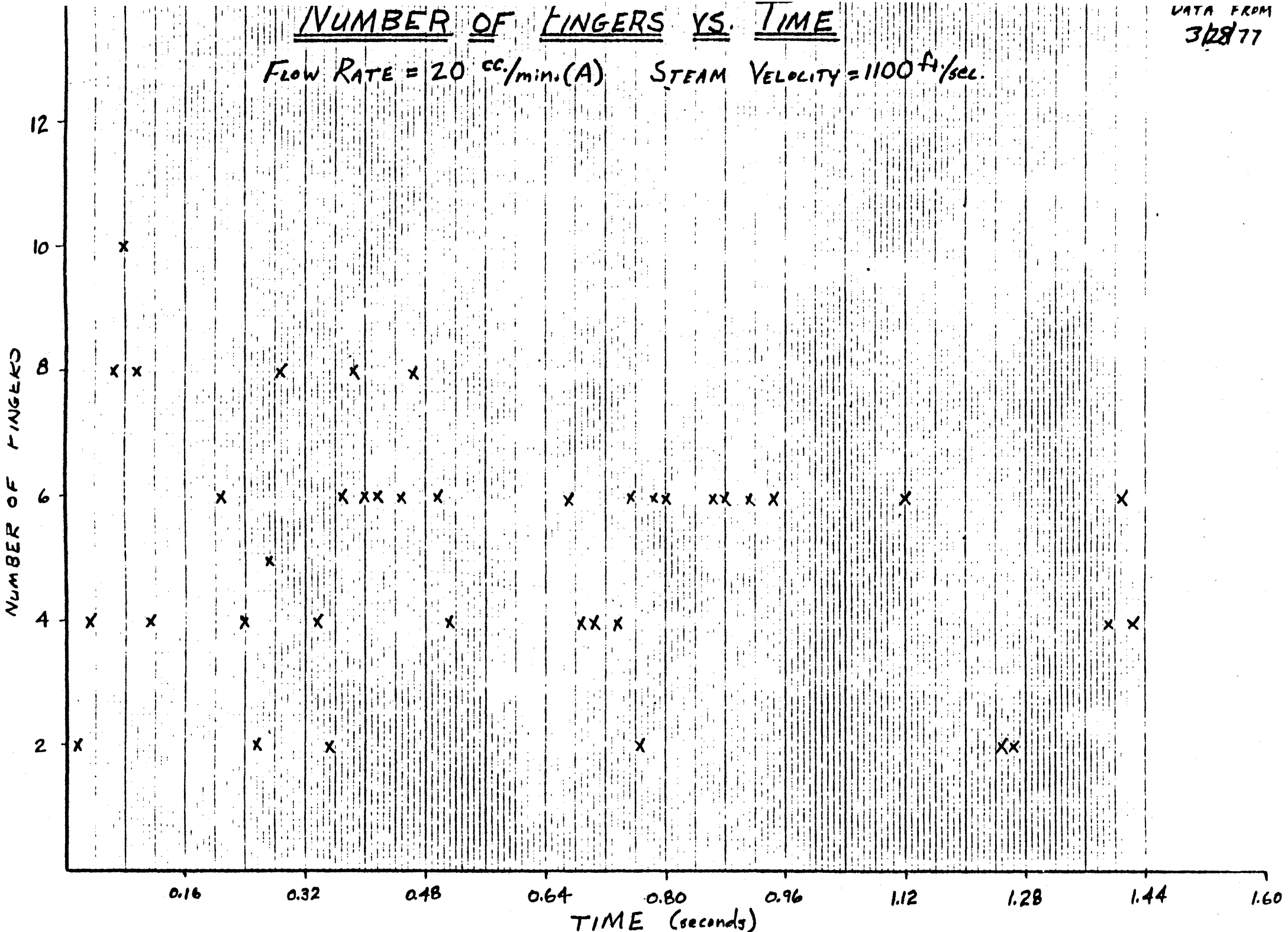

NUMBER OF FINGERS VS. TIME
3/28/77
FLOW RATE = 15 cc./min. (A) STEAM VELOCITY = 1100 ft./sec.
NUMBER OF FINGERS
12
10
8
6
4
2
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.6
TIME (seconds)

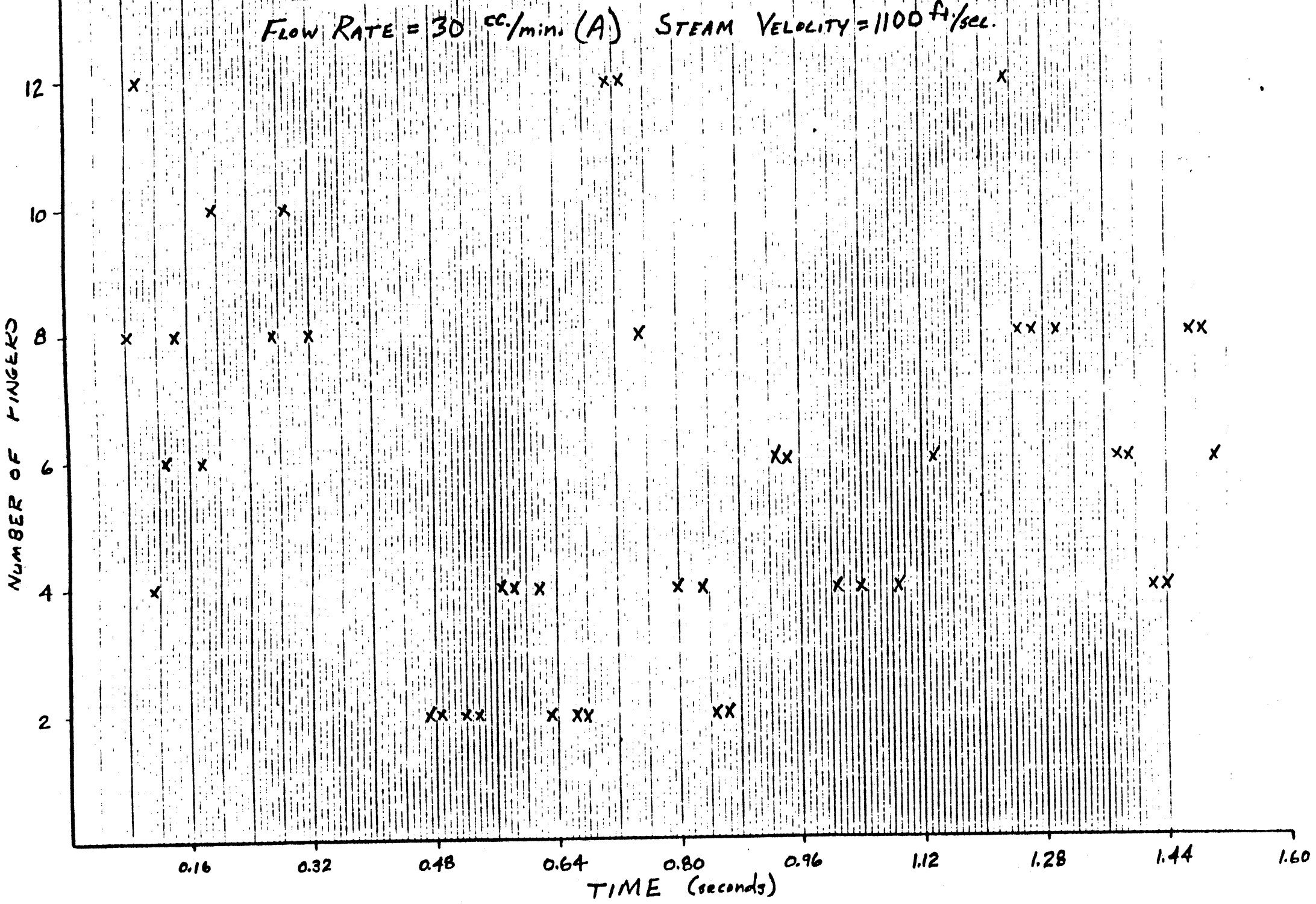

FLOW RATE = 15 cc./min. (B) STEAM VELOCITY = 1100 ft/sec.
NUMBER OF FINGERS
12
10
8
6
4
2
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60
TIME (seconds)

NUMBER OF FINGERS VS. TIME

DATA FROM 3/28/77

FLOW RATE = 20 cc./min.(A) STEAM VELOCITY = 1100 ft/sec.

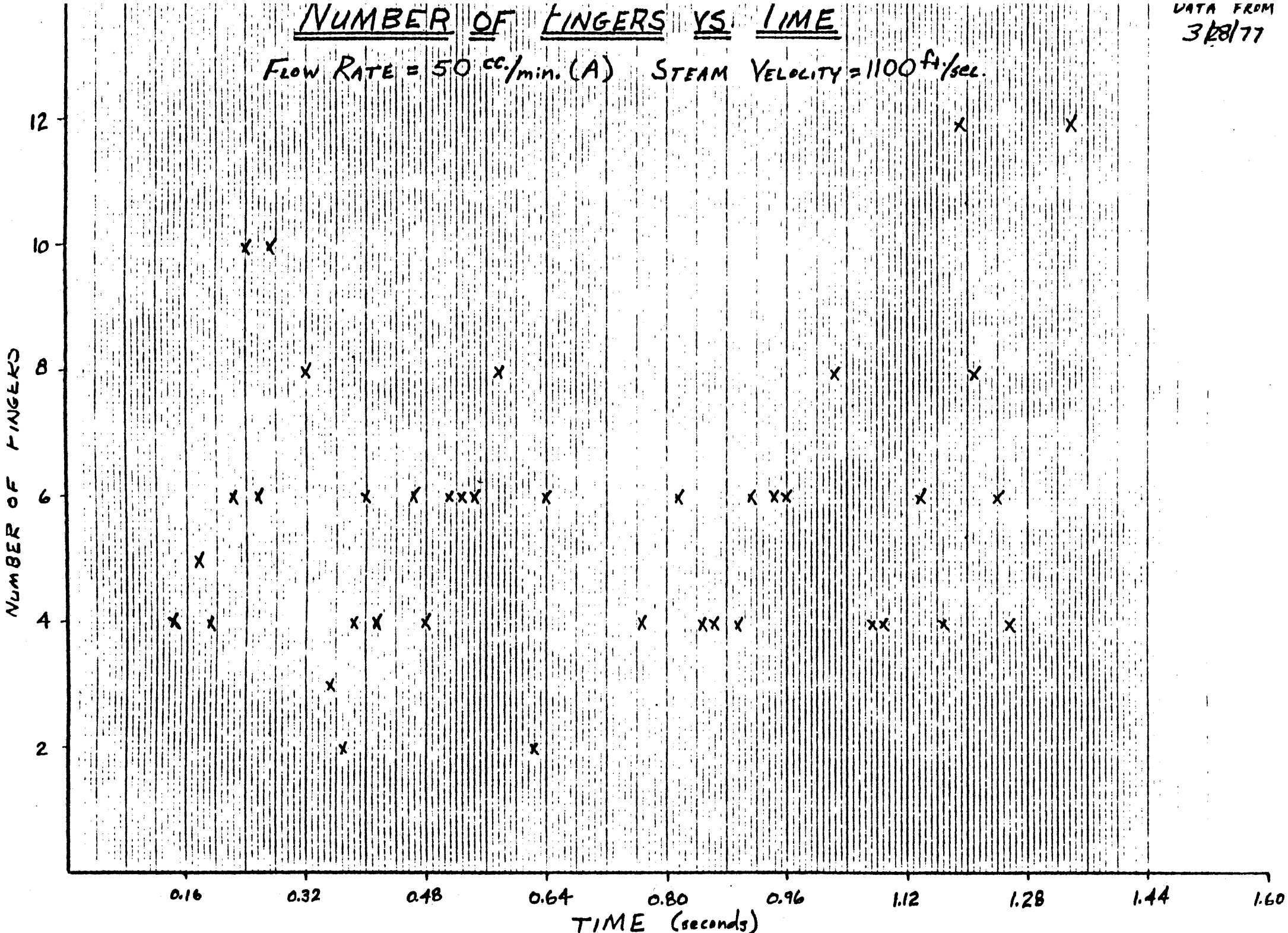



FLOW RATE = 30 cc./min. (A) STEAM VELOCITY = 1100 ft./sec.
NUMBER OF FINGERS
12
10
8
6
4
2
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60
TIME (seconds)

NUMBER OF FINGERS VS. TIME

DATA FROM 3/28/77

FLOW RATE = 50 cc./min. (A) STEAM VELOCITY = 1100 ft./sec.



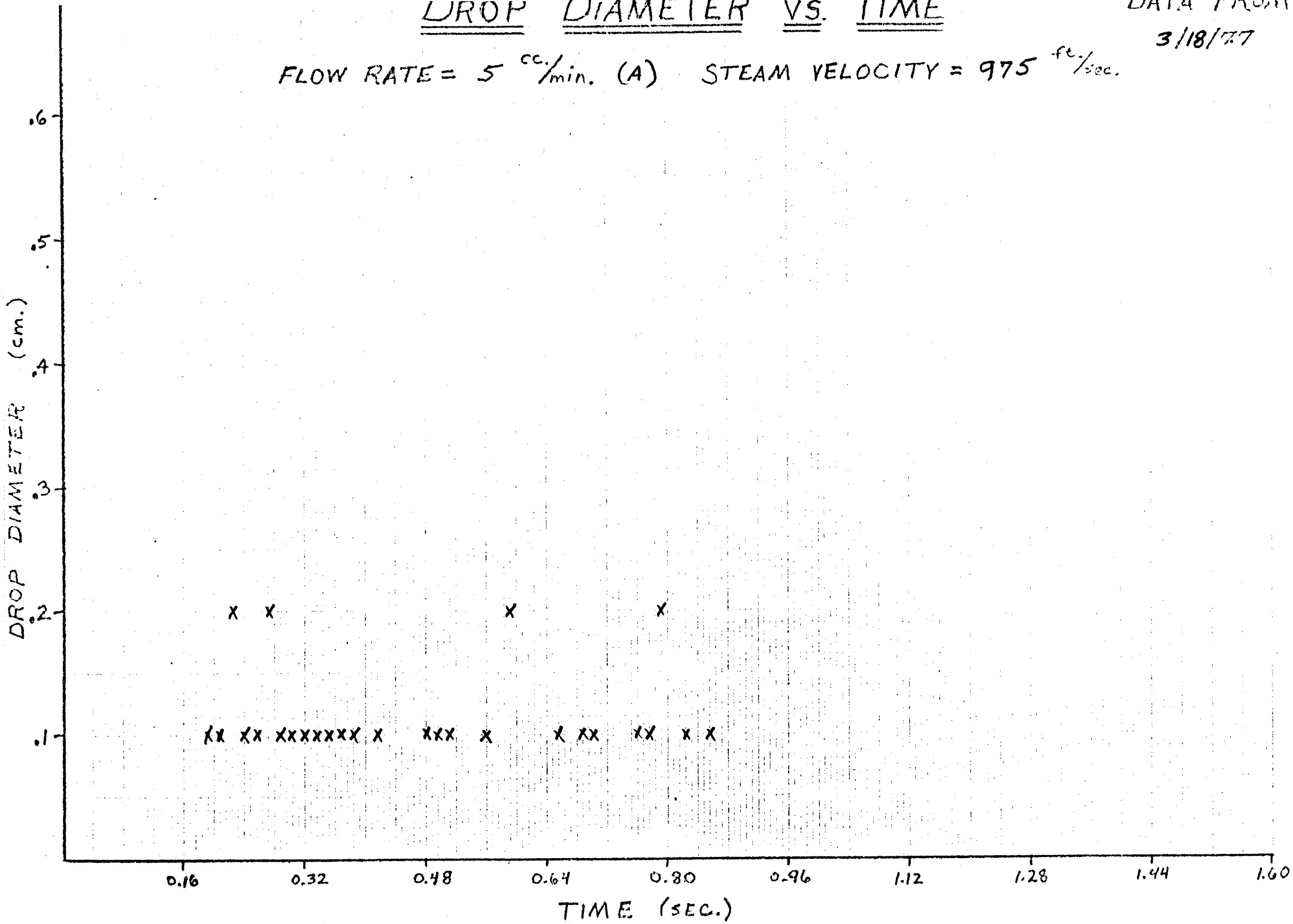
APPENDIX C

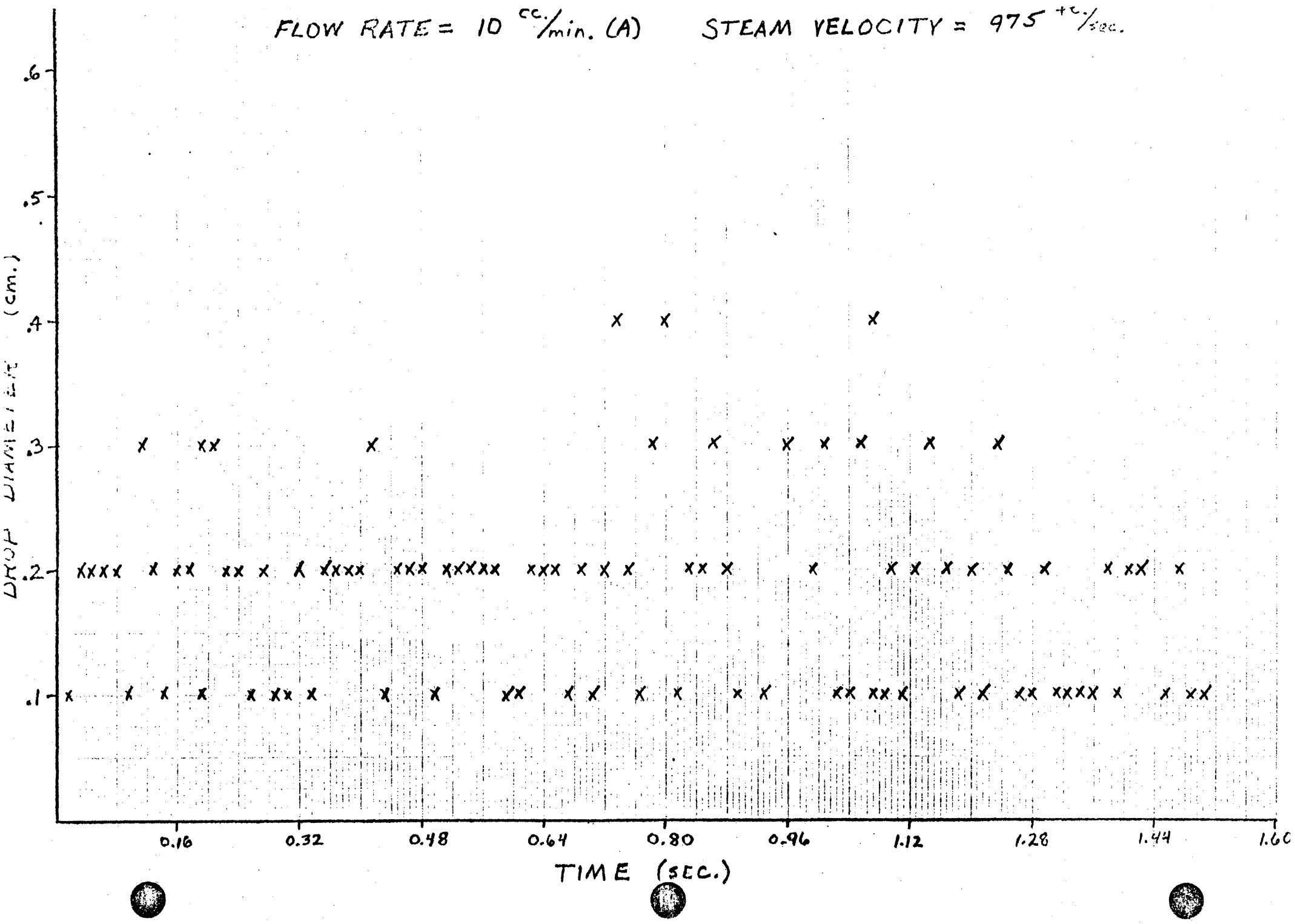
DROP DIAMETER VS. TIME

DROP DIAMETER VS. TIME

DATA FROM 3/18/77

FLOW RATE = 5 cc./min. (A) STEAM VELOCITY = 975 ft./sec.

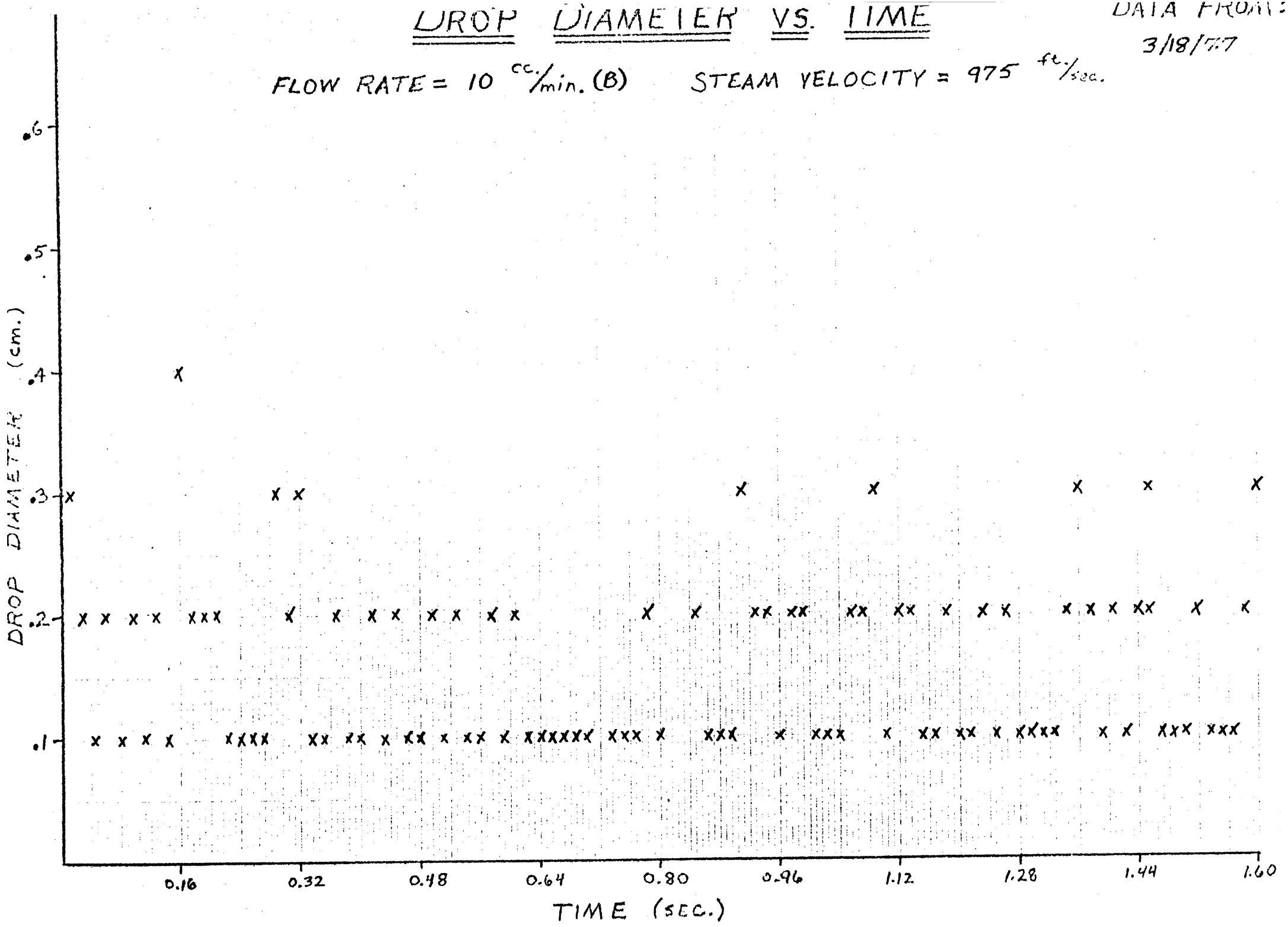



FLOW RATE = 10 cc./min. (A)
STEAM VELOCITY = 975 +c./sec.
.6
.5
.4
.3
.2
.1
DROP DIAMETER (cm.)
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60
TIME (SEC.)

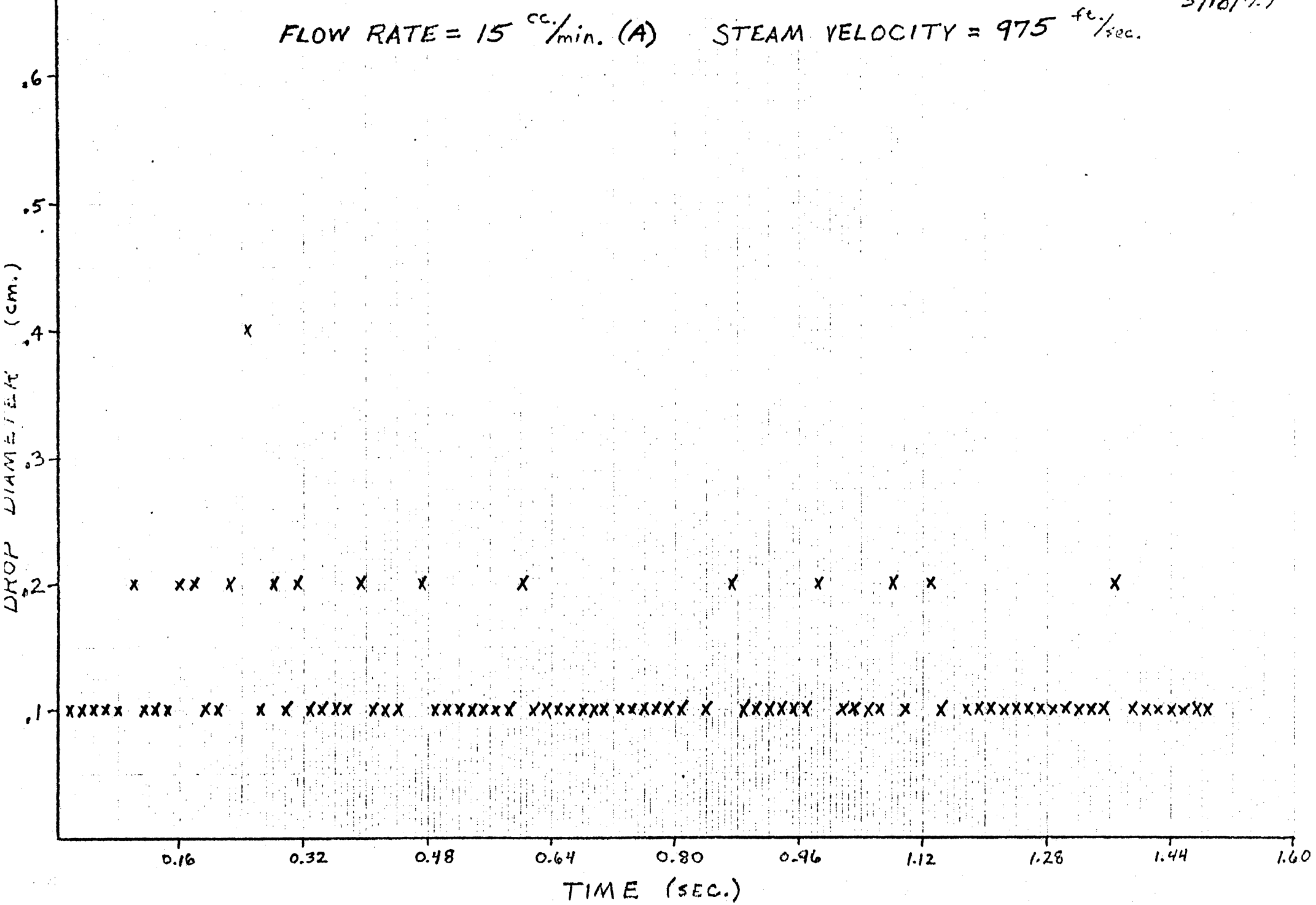
DROP DIAMETER VS. TIME

DATA FROM: 3/18/77

FLOW RATE = 10 cc./min. (B) STEAM VELOCITY = 975 ft./sec.



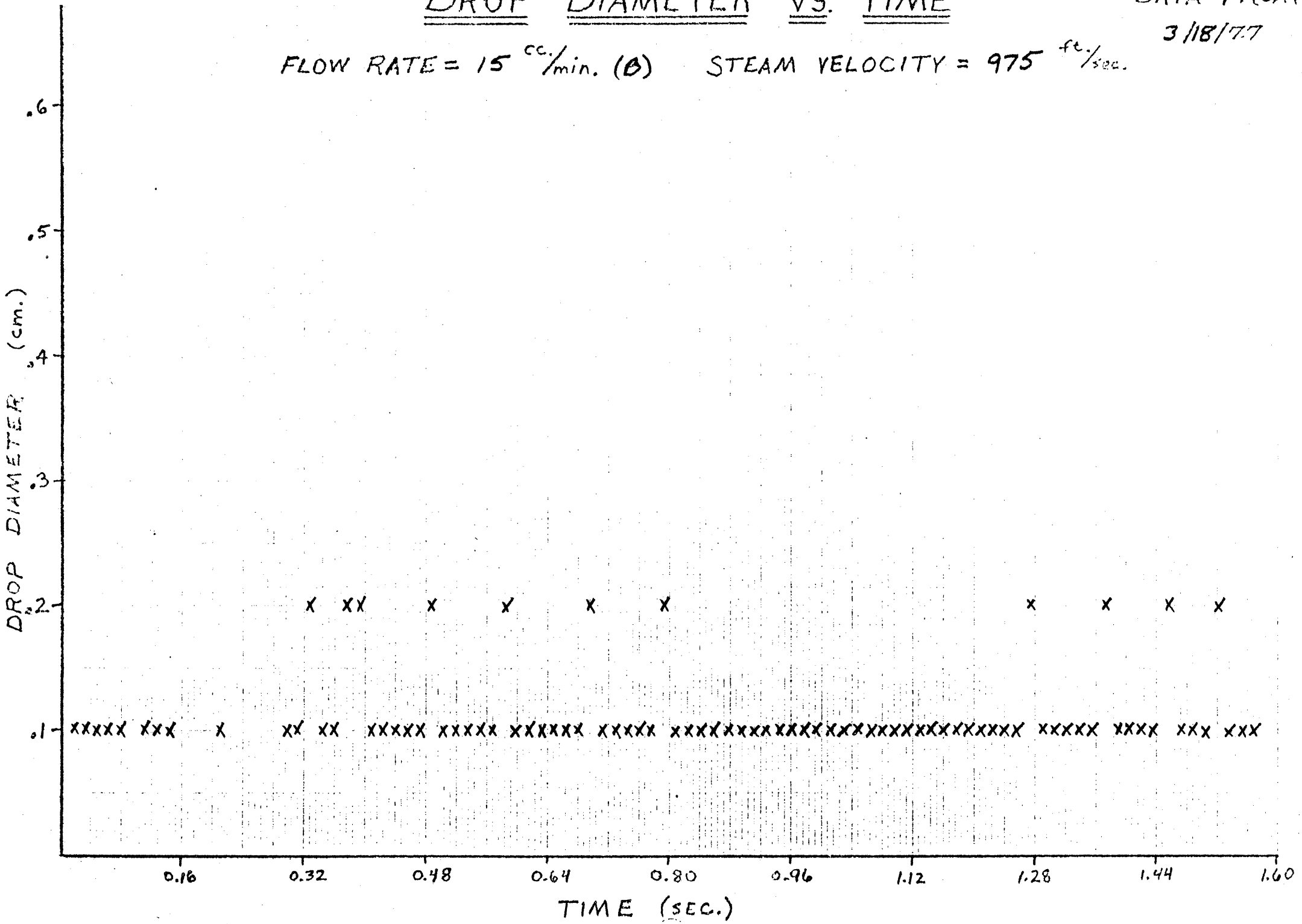
FLOW RATE = 15 cc./min. (A) STEAM VELOCITY = 975 ft./sec.



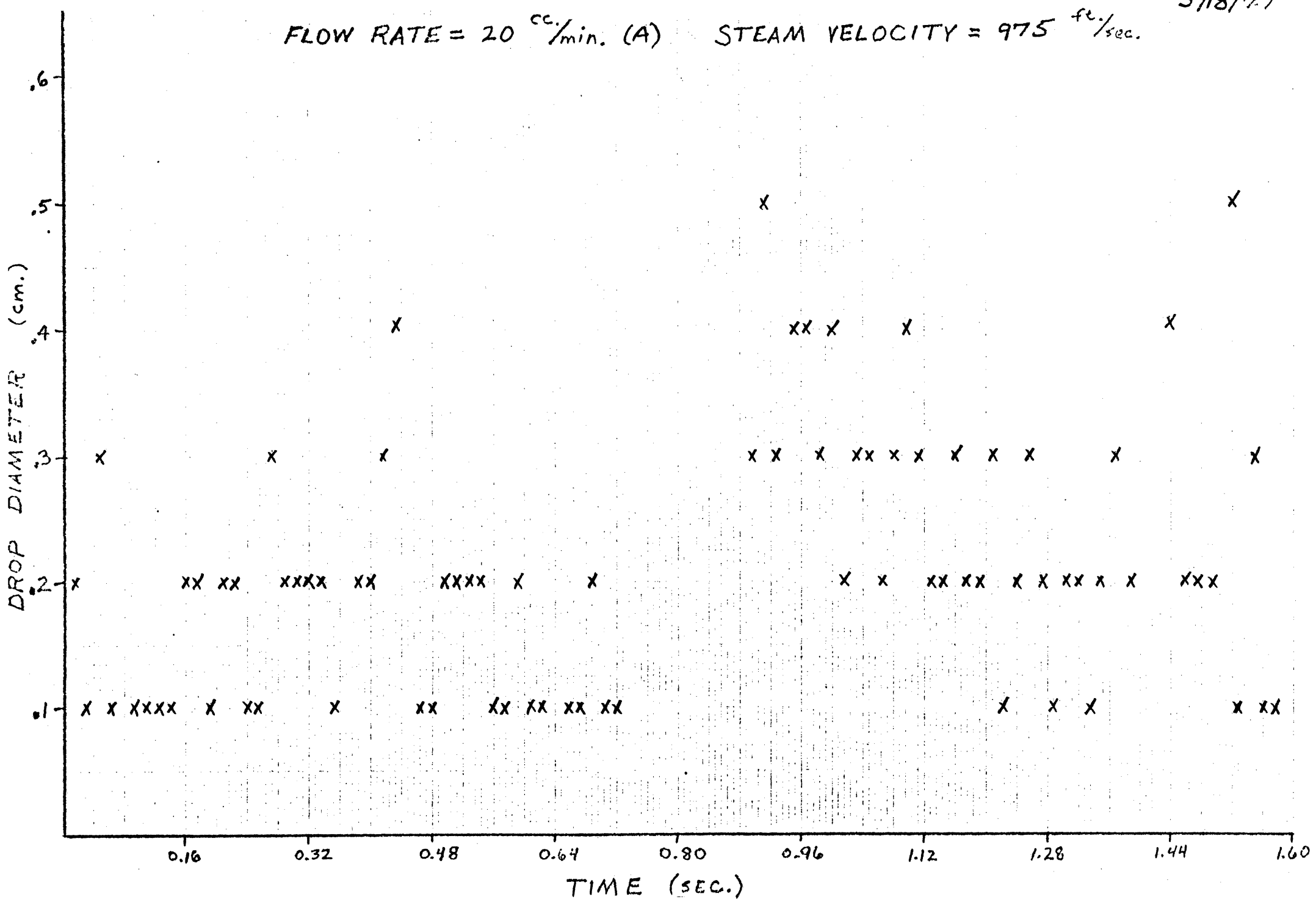
DROP DIAMETER VS. TIME

DATA FROM: 3/18/77

FLOW RATE = 15 cc./min. (B) STEAM VELOCITY = 975 ft./sec.



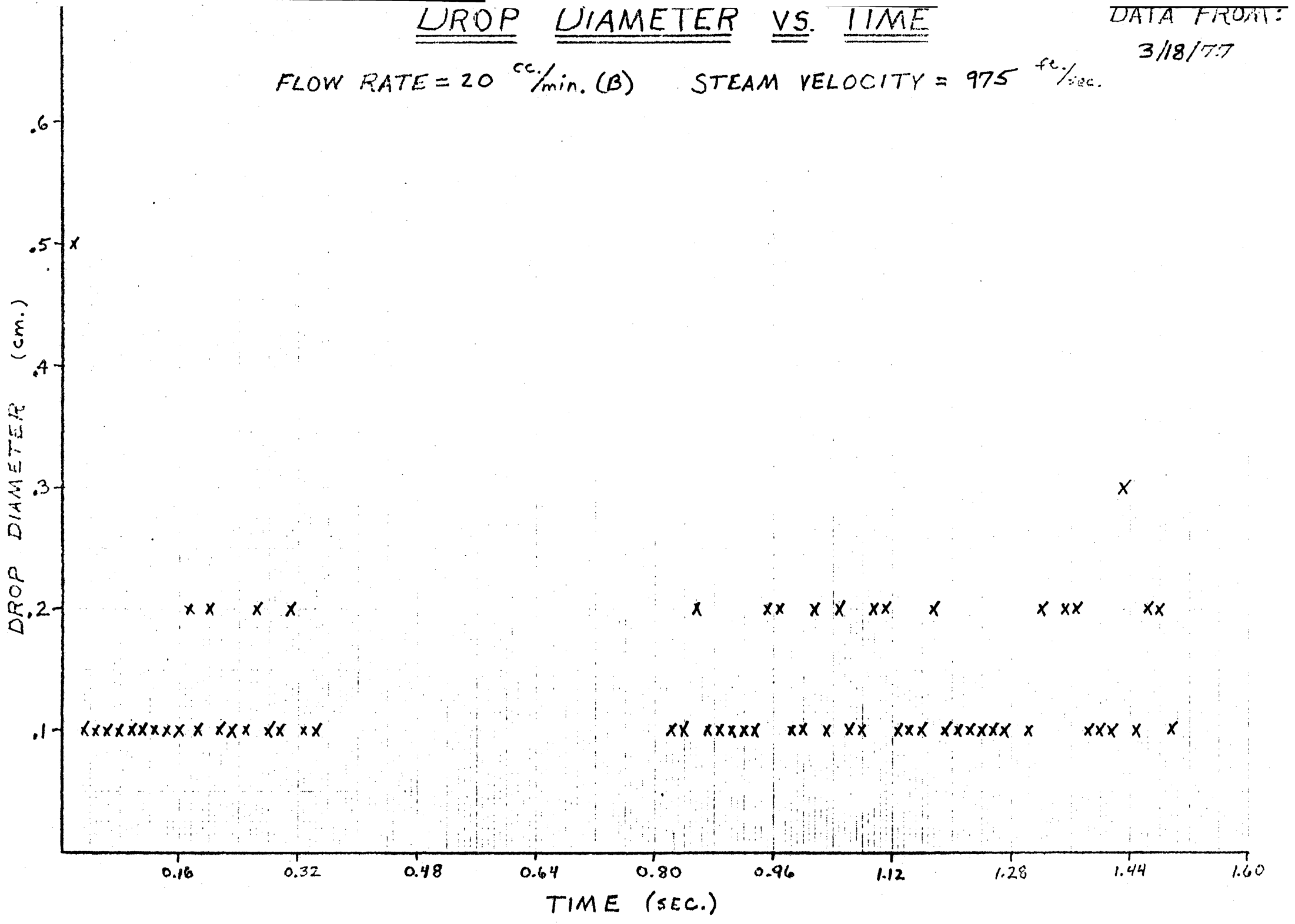
FLOW RATE = 20 cc./min. (A) STEAM VELOCITY = 975 ft./sec.



DROP DIAMETER VS. TIME

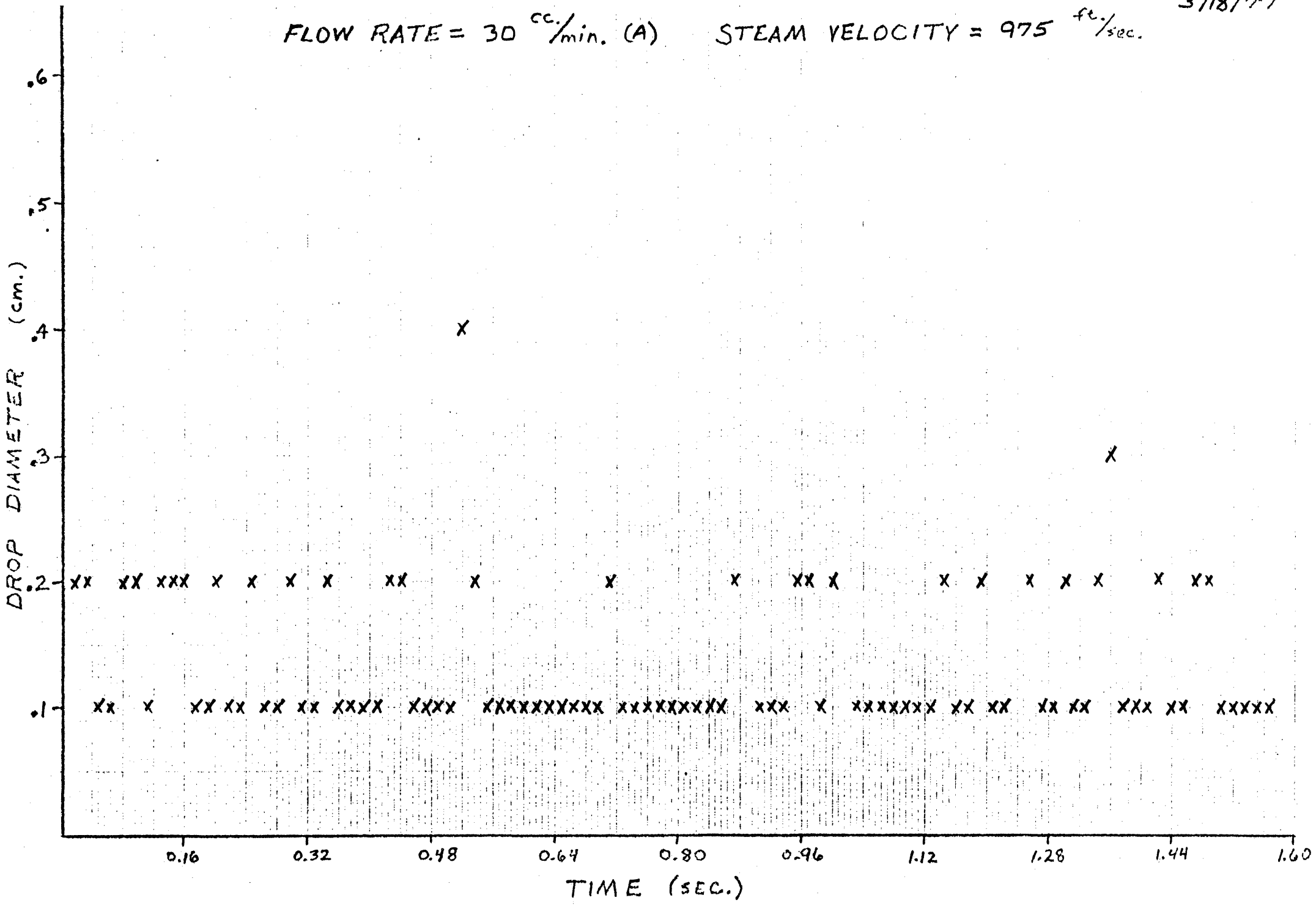
DATA FROM: 3/18/77

FLOW RATE = 20 cc./min. (B) STEAM VELOCITY = 975 ft./sec.



3/18/77

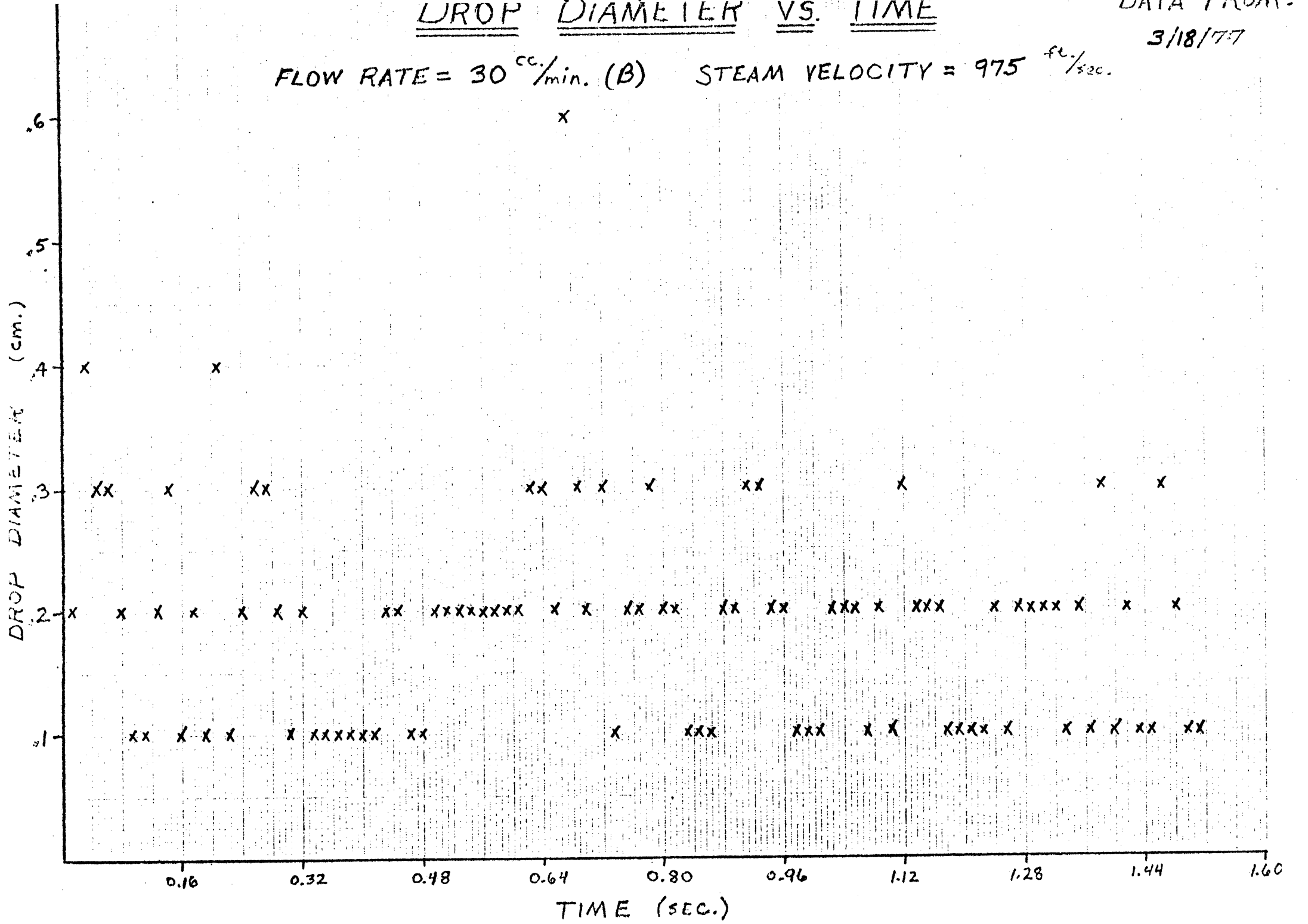
FLOW RATE = 30 cc./min. (A) STEAM VELOCITY = 975 ft./sec.



DROP DIAMETER VS. TIME

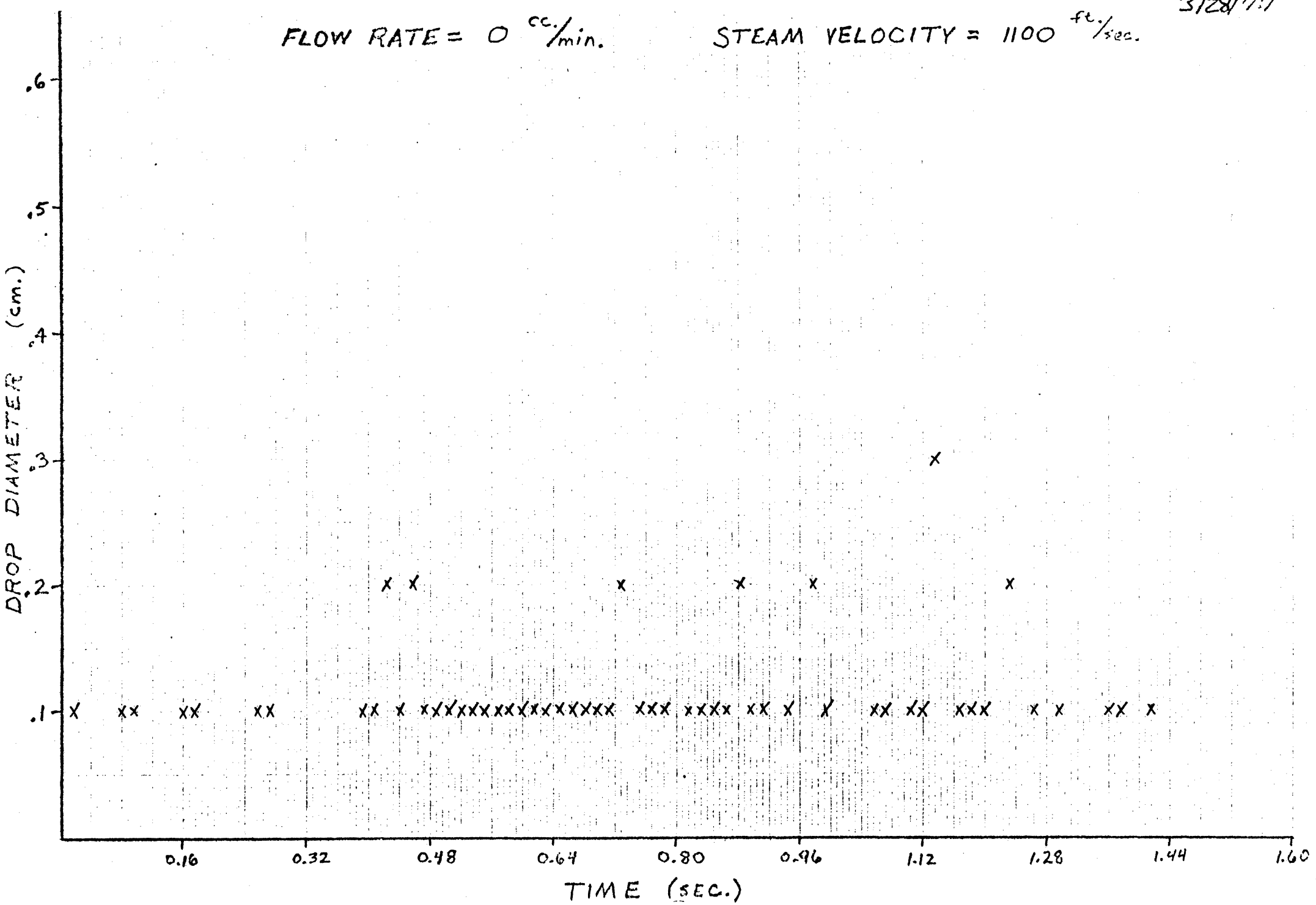
DATA FROM: 3/18/77

FLOW RATE = 30 cc./min. (B) STEAM VELOCITY = 975 ft./sec.



3128/7.1

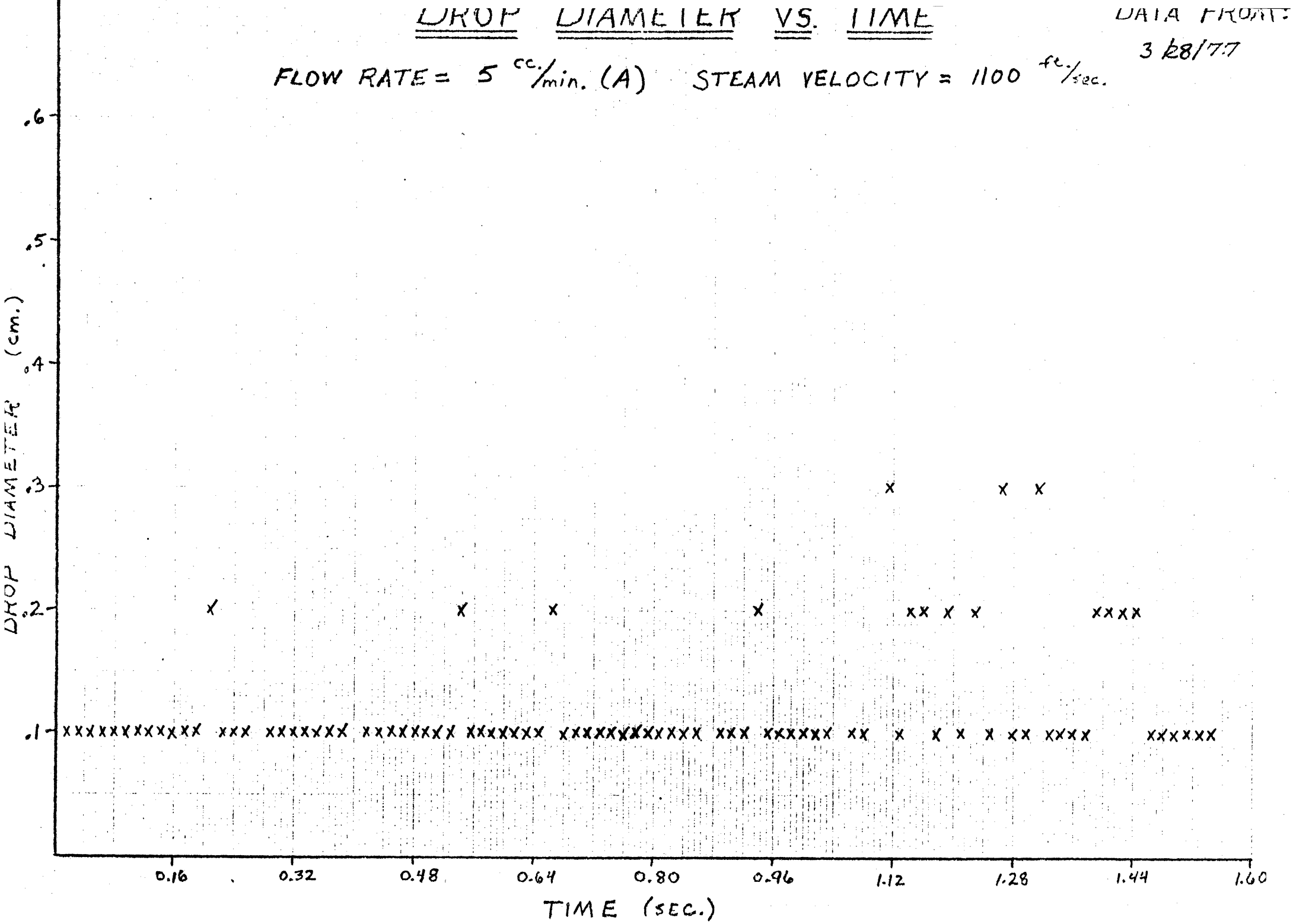
FLOW RATE = 0 cc./min. STEAM VELOCITY = 1100 ft./sec.



DROP DIAMETER VS. TIME

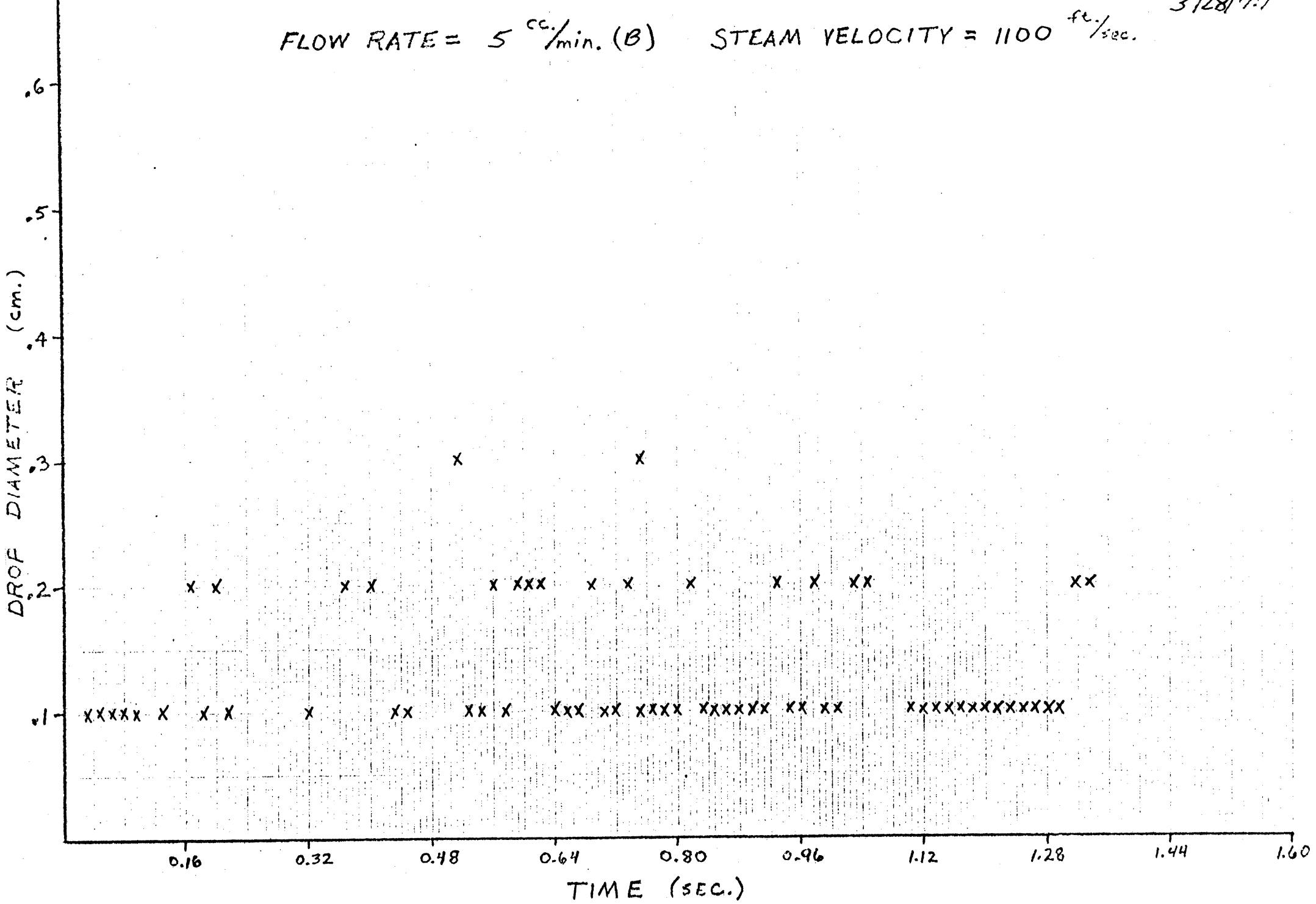
DATA FROM: 3/28/77

FLOW RATE = 5 cc./min. (A) STEAM VELOCITY = 1100 ft./sec.



3128/7.7

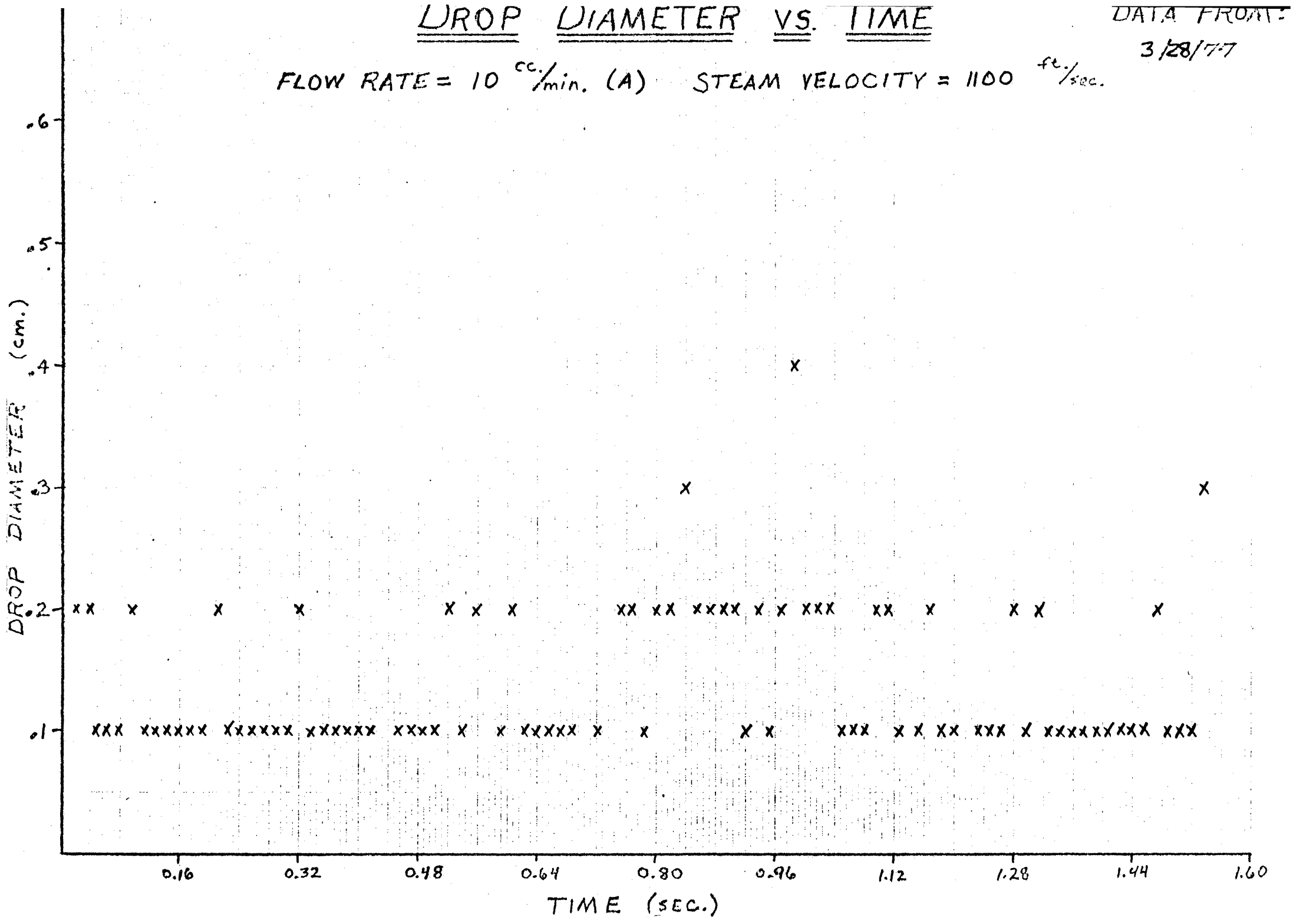
FLOW RATE = 5 cc./min. (B) STEAM VELOCITY = 1100 ft./sec.



DROP DIAMETER VS. TIME

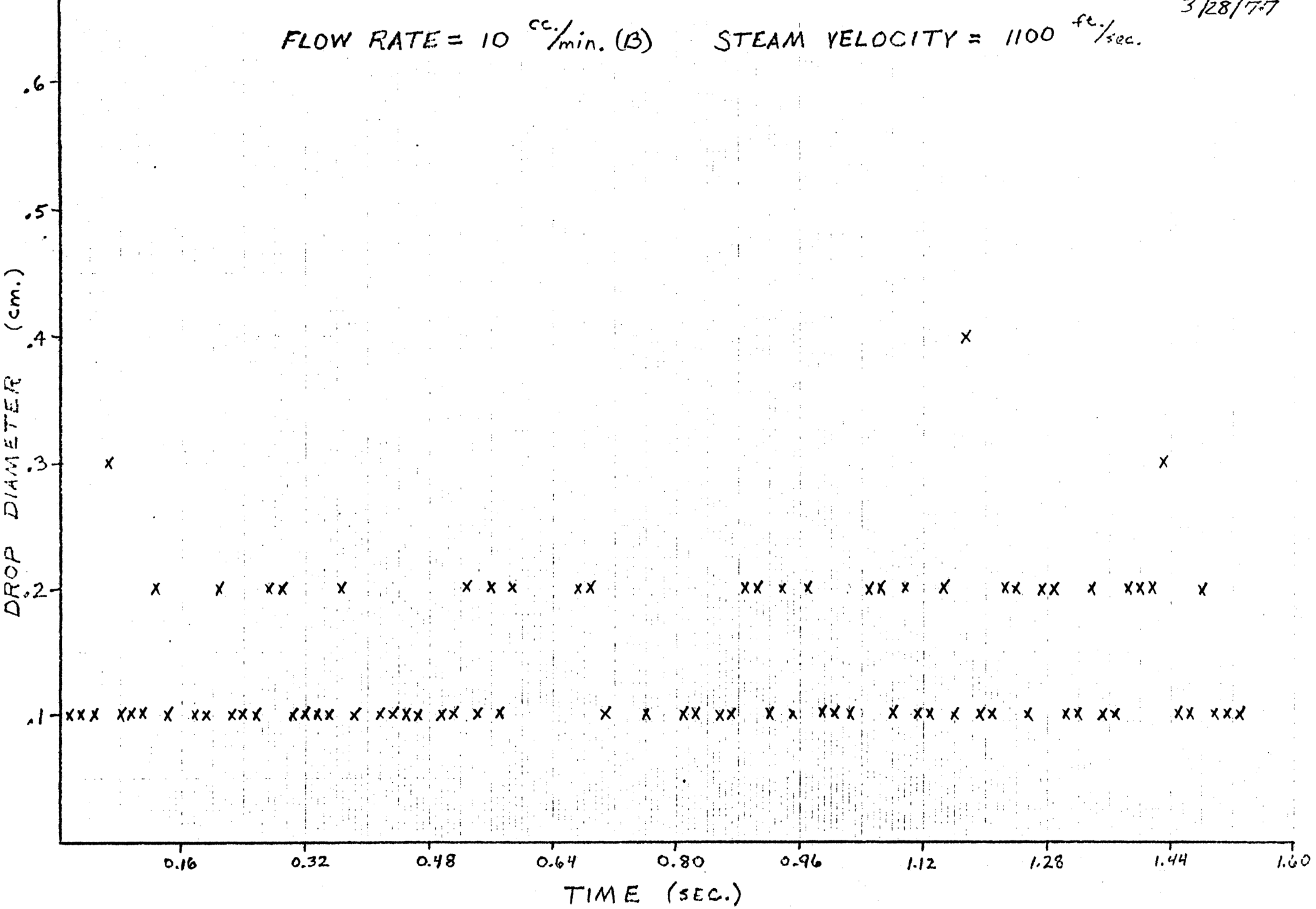
DATA FROM: 3/28/77

FLOW RATE = 10 cc./min. (A) STEAM VELOCITY = 1100 ft./sec.



3/28/77

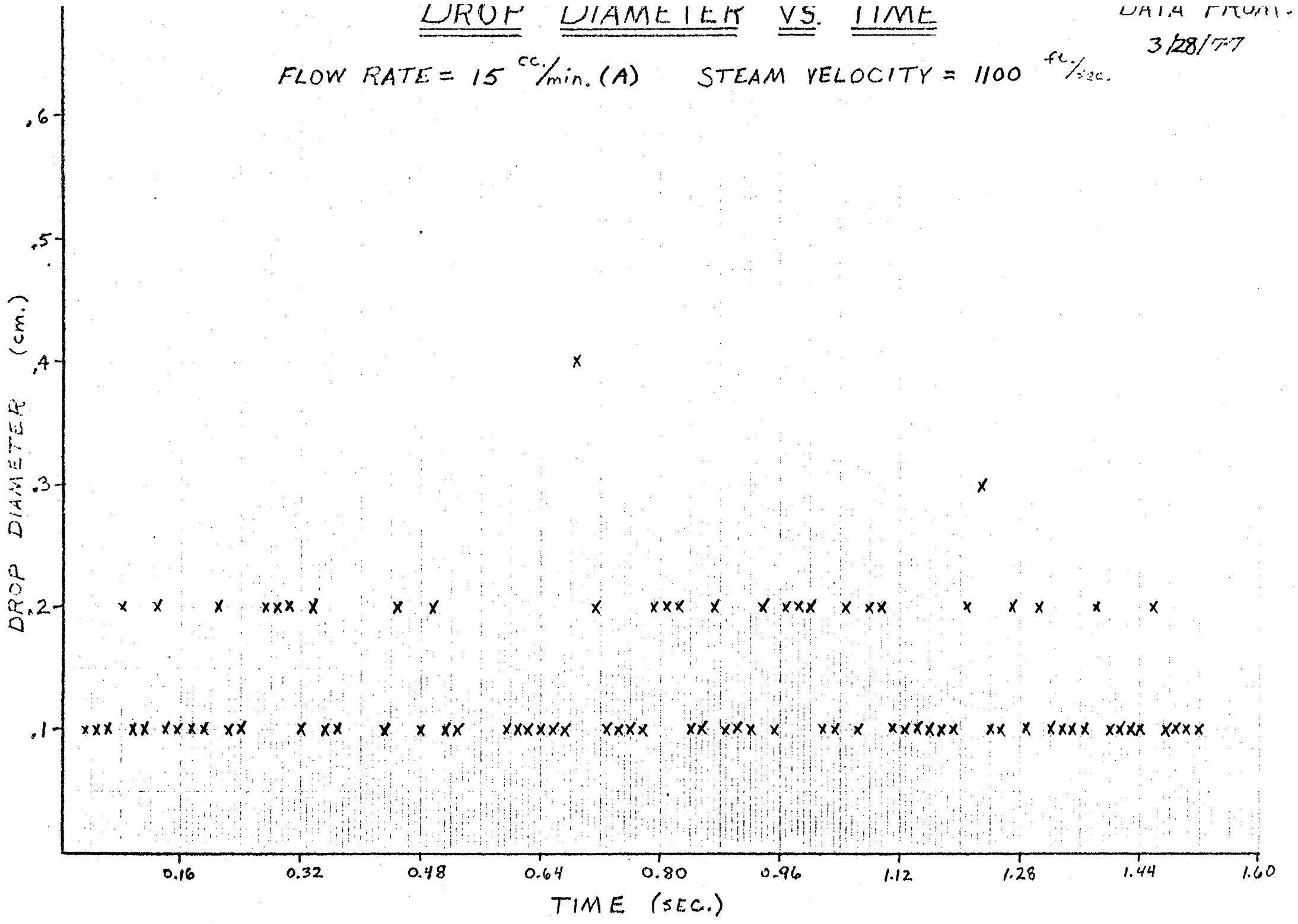
FLOW RATE = 10 cc./min. (B) STEAM VELOCITY = 1100 ft./sec.



DROP DIAMETER VS. TIME

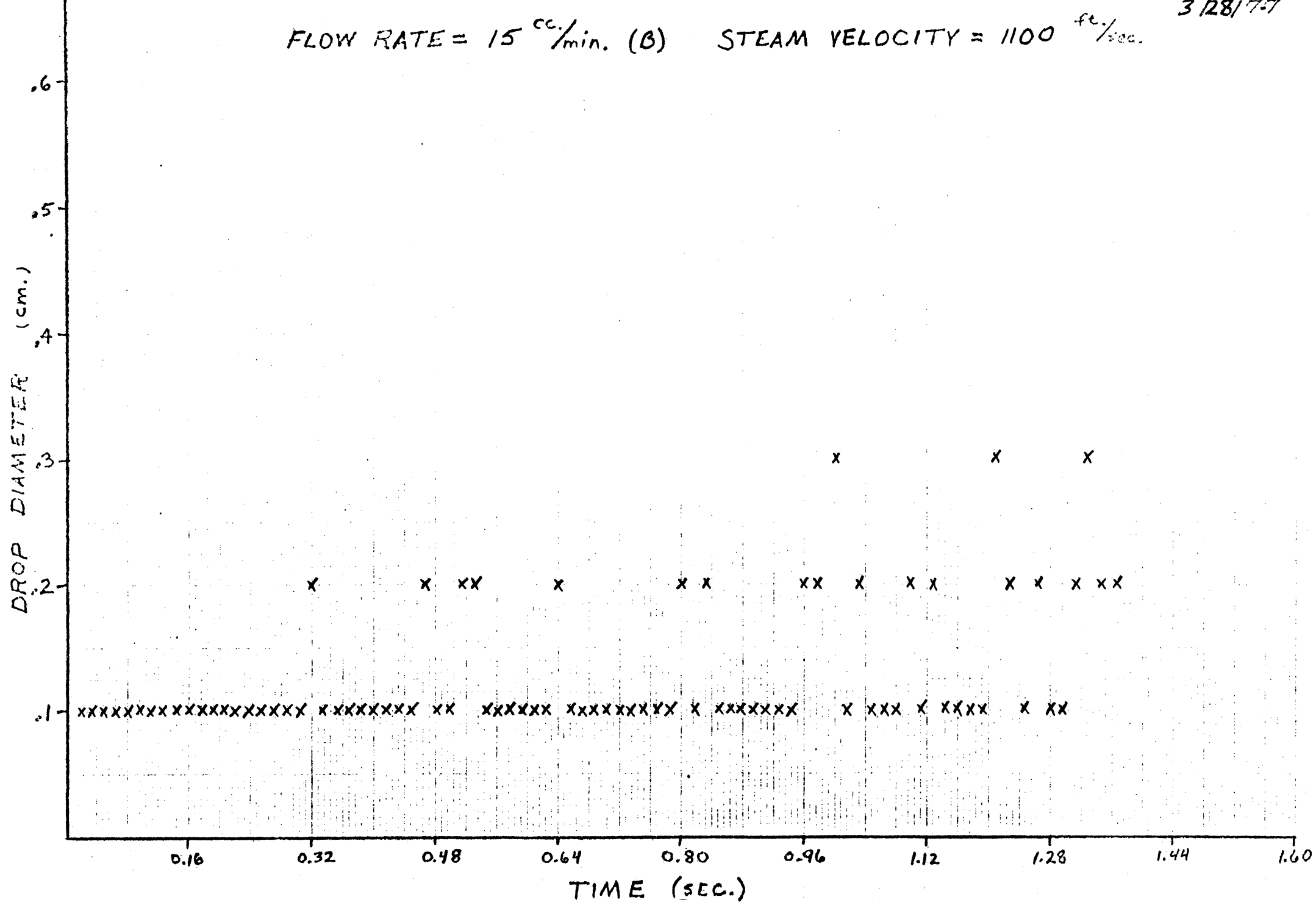
DATA FROM: 3/28/77

FLOW RATE = 15 cc./min. (A) STEAM VELOCITY = 1100 ft./sec.



3/28/77

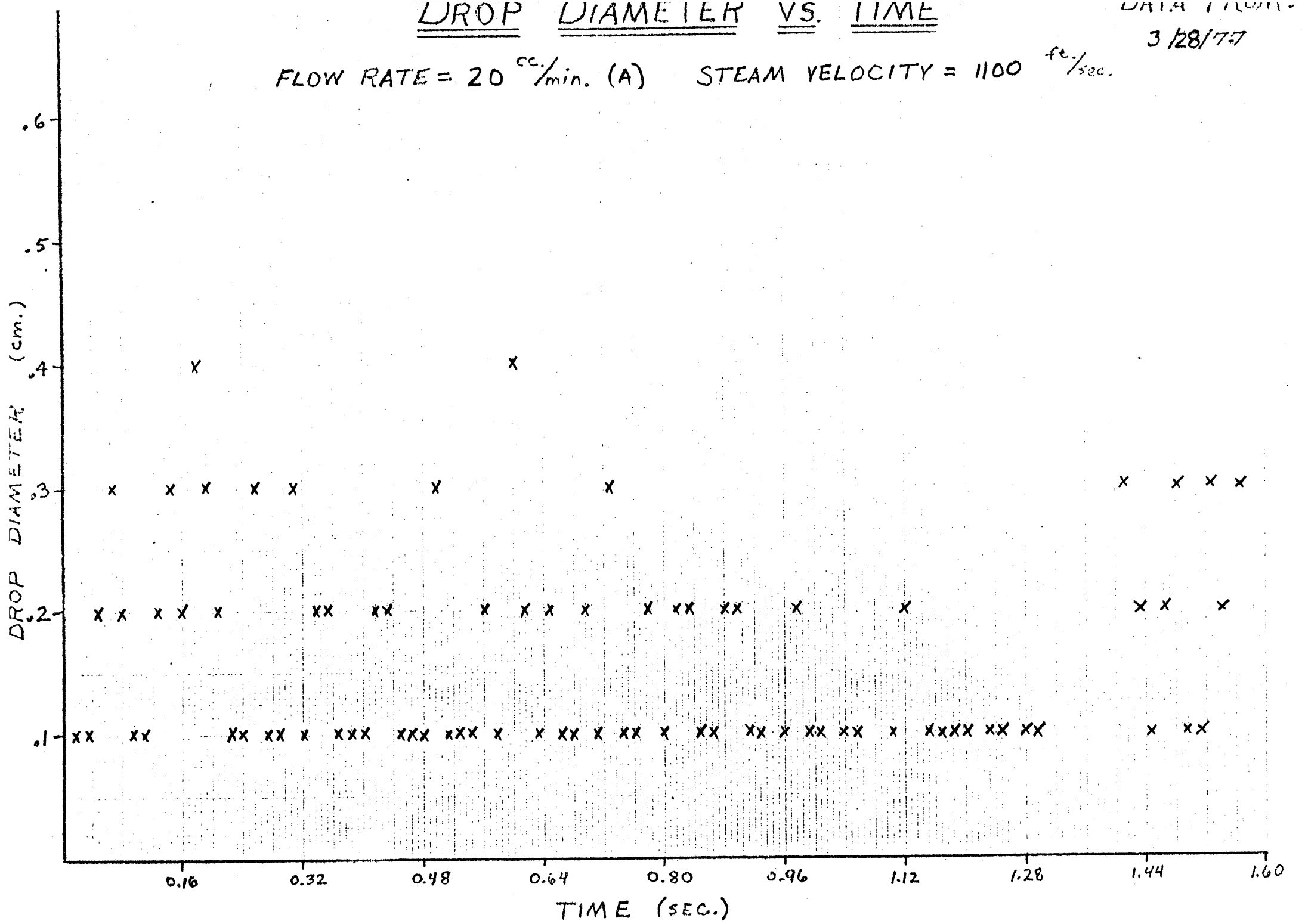
FLOW RATE = 15 cc./min. (B) STEAM VELOCITY = 1100 ft./sec.

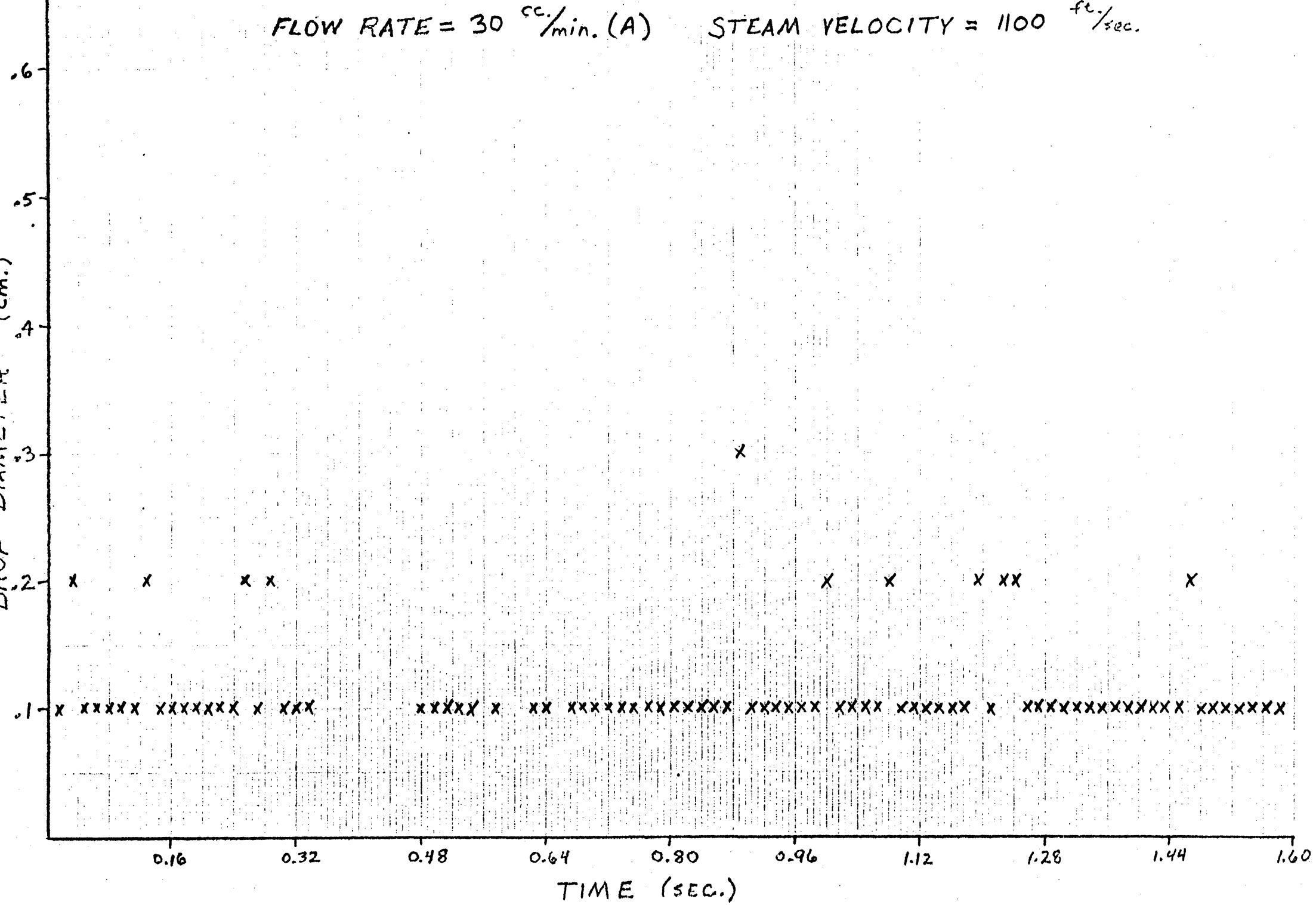


DROP DIAMETER VS. TIME

DATA FROM 3/28/77

FLOW RATE = 20 cc./min. (A) STEAM VELOCITY = 1100 ft./sec.




FLOW RATE = 30 cc./min. (A)
STEAM VELOCITY = 1100 ft./sec.
DROP DIAMETER (cm.)
.6
.5
.4
.3
.2
.1
0.16
0.32
0.48
0.64
0.80
0.96
1.12
1.28
1.44
1.60
TIME (SEC.)

DROP DIAMETER VS. TIME

DATA FROM: 3/28/77

FLOW RATE = 50 cc./min. (A) STEAM VELOCITY = 1100 ft./sec.