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Low Velocity Performance of A Vortex-Shedding Anemometer

L. P. Purtell

Fluid Engineering Division
Center for Mechanical Engineering
and Process Technology
National Engineering Laboratory
National Bureau of Standards
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Task Report

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on
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Evaluation of the Behavior of Mine Anemometers in the NBS Low Velocity Calibration Facility

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Performance of a vortex-shedding anemometer is evaluated over the speed range of 58.1 feet per minute to 836 feet per minute. Tests on two units were performed in the NBS Low Velocity Airflow Facility which provides a uniform flow of low turbulence and utilizes a laser velocimeter as the velocity standard.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Airflow; anemometer; laser velocimeter; low velocity, mine ventilation; wind tunnel

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- FOREWORD -

This report was prepared by the National Bureau of Standards, Fluid Engineering Division, Washington, D. C. 20234, under USBM Contract Number H0166198. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of PM&SRC, With Dr. George H. Schnakenberg, Jr., acting as the Technical Project Officer. Mr. H. R. Eveland was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as part of this contract during the period February 28, 1978 to April 30, 1978. This report was submitted by the author December 1978.

LIST OF SYMBOLS

U	velocity measured by laser velocimeter
f	frequency indicated by anemometer under test
f_f	line segments fitted to U, f data
$\overline{U}$	group mean true velocity
$\overline{f}$	group mean indicated frequency
σ_f	standard deviation of f data from f_f
σ	standard deviation of f data expressed as true velocity
σ_c	σ adjusted for known variance in laser velocimeter measurements

LOW VELOCITY PERFORMANCE OF A VORTEX-SHEDDING ANEMOMETER

L. P. Purtell

1. INTRODUCTION

The National Bureau of Standards in order to meet the need for a calibration capability with adequate accuracy at low air velocities, i.e., below 500 feet per minute (fpm) undertook the development of a low-velocity calibration facility for wind speed measuring instruments which would provide a capability down to 3 meters per minute (approximately 10 fpm) with an accuracy of plus or minus one percent. It was a natural consequence therefore that when said facility became operational to undertake an evaluation of the state-of-the-art and to provide the information needed as to the reliability and performance of instrumentation for such measurement. Accordingly, a number of prototypes of various types of instruments for low velocity air measurements are undergoing test at NBS, and this report is concerned specifically with the results of one such test.

2. THE INSTRUMENT

The anemometer tested for this report (two units, serial numbers 48 and 49) is a commercially available instrument (J-TEC Associates, Incorporated, VA-216 Air Draft Sensor)[1] supplied for test by the U. S. Bureau of Mines. The instrument is approximately 12 x 4 x 5-1/2 inches in size (see Figure 1) and includes a probe head and the necessary electronics for operation. The probe head consists of a rod approximately 0.25 inches in diameter and 1.38 inches in length supported at the ends and oriented normal to the air stream. An ultrasonic transmitter and receiver pair located downstream of the cylinder detect the vortex street shed by the cylinder as an amplitude modulation of the ultrasonic signal. This modulation is converted by the electronics section to a pulse train (approximately a square wave signal) as an output. A frequency-to-voltage converter section also provides an analog output. Since the frequency of shedding of a vortex street is roughly proportional to velocity, the output signals can be used to measure the air velocity. A separate power supply is necessary to operate the instrument.

3. THE TESTS

The NBS Low Velocity Airflow Facility [1] used to test this instrument generates a low velocity air stream having a low turbulence intensity (less than 0.05%) and a large region of uniform flow (at least

[1] This particular instrument was selected as being representative of this type of anemometer and its selection does not represent an endorsement.

75 x 75 cm). A laser velocimeter is employed as a primary velocity standard. It is nonintrusive, has a linear response with velocity, and has good spatial resolution. Adequate sensitivity is obtained without the artificial seeding of scattering particles. Thus the difficulties and inconvenience associated with seeding and the possible effect of such seeding on the performance of the device under test are avoided.

Each anemometer was mounted with the probe head on the centerline of the tunnel test section one meter downstream of the entrance to the test section in a manner to minimize the effect of the support on the air stream around the anemometer (Figure 1). Since the anemometer itself modifies the airflow in the tunnel, the velocity should be measured at a location in the flow which has the same velocity in the presence of the anemometer as it does in the absence of the anemometer. The velocity upstream of the anemometer was measured to find the position where deceleration of the flow due to the presence of the anemometer was no longer detectable within the scatter of the measurement. These measurements were performed at the free-stream velocity of 990 fpm. As shown in a previous report [2] the variation of the ratio of the local velocity to the free stream velocity with distance upstream of the anemometer is independent of free-stream velocity. A distance of 35 cm upstream of the anemometer was chosen as the position for velocity measurement by the laser velocimeter. With no anemometer in the tunnel, variation in velocity is imperceptible over the distance traversed (35 cm).

The frequency of the anemometer output was recorded during the time interval required for the measurement by the laser velocimeter. Five separate test runs were made for each instrument, a run consisting of thirteen different velocities. The lowest velocities were limited by a minimum operating speed of 54.1 fpm for S/N 49 and 58.8 fpm for S/N 48. The data are presented in chronological order in Tables 1A to 1E and 2A to 2E for instruments with S/N 49 and 48 respectively.

4. TESTS RESULTS

Since a particular air speed in the wind tunnel cannot be exactly reset from run to run, scatter in the test data in the form of frequency against speed is distributed along a curve, thus prohibiting computing the standard deviation of the data from a simple average. Instead, deviations from a curve fit to the data were computed and the standard deviation approximated by the r.m.s. value of these deviations within a group. The groups are (fpm):

$U < 65$
$65 < U < 75$
$75 < U < 85$
$85 < U < 95$
$95 < U < 110$
$110 < U < 150$
$150 < U < 200$
$200 < U < 250$
$250 < U < 350$
$350 < U < 450$
$450 < U < 550$
$550 < U < 750$
$750 < U$

Since the groups of data are compact (small range of U within a group; see Figures 2 and 3), a straight line segment is used to approximate the curve within a group. The line segment passes through the point $(\bar{U},\bar{f})$, the group mean true velocity and the group mean frequency. The slope of the line segment is computed as the average of the slopes of two lines, both passing through $(\bar{U},\bar{f})$ of the group being considered, one line passing through the $(\bar{U},\bar{f})$ of the adjacent group <u>higher</u> in velocity, and one line passing through $(\bar{U},\bar{f})$ of the adjacent group <u>lower</u> in velocity. For the highest groups (U > 750) there is only one adjacent group, and thus the line segment for this highest group passes through $(\bar{U},\bar{f})$ of that adjacent group. The line segment for the lowest groups (U < 65 fpm) is similarly formed.

Designating the above line segments as f_f, the standard deviation, σ_f of the frequency, f, about the fitted segments is determined by squaring the differences between the f data and f_f, i.e., $[f\ (U) - f_f\ (U)]^2$. Since the data within the specified groups are reasonably compact, the mean of the squared differences within a group is taken as an estimate of the variance of f about f_f within that group and specified at that group's mean true velocity, $\bar{U}$. To convert this to a standard deviation in terms of true velocity, designated σ, each $\sigma_f\ (\bar{U})$ is divided by the slope (df_f/dU) of the line segment associated with the $\sigma_f(\bar{U})$. Note that this σ does not include the "scatter" in the U measurements (due to the inability to exactly reset wind tunnel to a specified speed), but does include the uncertainty in a particular laser velocimeter measurement. This uncertainty may be estimated from repeated measurements of velocity at a particular fan setting, thus also including any unsteadiness in the velocity, and is estimated as 0.001U for this report. A standard deviation, σ_c, corrected for the laser velocimeter uncertainty may thus be computed from

$$\sigma_c^2 = \sigma^2 - (0.001U)^2$$

for any given U. σ_f and $\sigma_f/\bar{f}$ are presented in Figures 4 through 7. σ and σ_c are presented in Figures 8 and 9 as velocity and in Figures 10 and 11 as percentage of $\bar{U}$. Since $\pm\ 2\sigma_f$ is extremely close to the 95 percent confidence interval for one measurement, curves of $\pm\ 2\sigma_f$ are also included in Figures 2 and 3 as dashed lines. The curves shown in each figure have been drawn for reference only.

5. DISCUSSION OF RESULTS

Since the primary output of this type of instrument ideally is a square wave with frequency related to the air speed, the analysis was concentrated on the measurements of that frequency directly rather than on the analog voltage output, since the latter merely reflects the quality of the frequency-to-voltage converter. The resolution in reading the frequency was always kept better than 0.1 percent to avoid affecting σ_f. The difference in the values of σ for the two units is not readily attributable to any known difference between the units; qualitatively the instruments performed the same.

The instruments in general performed with no erratic behavior. Some general comments concerning application of the instrument follow. With any measurement problem the instrument's capabilities should be matched to the required measurement.

This anemometer is intrusive, i.e., it must be placed in the flow.

This anemometer requires an outside source of power and either a frequency counter or a voltmeter.

Many other factors that can affect the suitability of an instrument for a particular application, such as turbulence or unsteadiness of the air stream, rough handling (shock and vibration), dirt and other environmental factors, time, orientation to the velocity and gravity vectors, etc., have not been tested herein but should be considered.

6. SUMMARY

The performance of a vortex-shedding anemometer (two units) has been evaluated at air speeds up to 836 fpm. Figures are presented showing the output frequency against true velocity and the standard deviation of repeated runs about the mean curves. The lowest velocities measurable were limited by a minimum operating speed of 54.1 fpm for one unit and 58.8 fpm for the other unit.

7. REFERENCES

1. L. P. Purtell and P. S. Klebanoff, The NBS Low velocity Airflow Facility, in preparation.

2. L. P. Purtell, Low Velocity Performance of a Bronze Bearing Vane Anemometer, NBSIR 78-1433.

Table 1A
J-Tec Type VA-216
S/N 49

Instrument Output Frequency Hz	Instrument Output Voltage volts	True Air Speed fpm
8.68	.132	60.3
10.9	.160	72.2
12.6	.182	81.0
14.6	.208	91.4
16.5	.233	100.6
22.7	.312	128
32.5	.44	170
46.9	.62	219
65.4	.88	284
83.2	1.12	374
110	1.48	492
147	1.95	649
187	2.45	835
242	3.20	1103
278	3.70	1290
318	4.20	1495

T = 21.3 to 21.6 °C

B = 752.4 mm Hg

Table 1B
J-Tec Type VA-216
S/N 49

Instrument Output Frequency Hz	Instrument Output Voltage volts	True Air Speed fpm
8.63	.126	60.8
10.5	.154	72.5
12.3	.175	81.6
15.0	.209	92.9
16.6	.229	100.8
22.9	.308	130
32.6	.44	172
46.9	.62	220
66.2	.86	284
84.0	1.13	375
112	1.49	492
148	1.95	647
186	2.50	833
245	3.20	1109
276	3.65	1293
320	4.15	1502

T = 22.5 °C

B = 752.7

Table 1C
J-Tec Type VA-216
S/N 49

Instrument Output Frequency Hz	Instrument Output Voltage volts	True Air Speed fpm
8.70	.130	61.6
10.8	.154	72.5
12.7	.180	81.6
14.9	.210	92.5
16.3	.226	100.2
23.0	.311	131
32.6	.43	171
47.4	.60	219
65.4	.86	285
84.0	1.13	375
112	1.48	492
147	1.96	648
186	2.47	834
245	3.21	1110
282	3.68	1298
318	4.16	1497

T = 22.5 to 22.8 °C

B = 752.8 mm Hg

Table 1D
J-Tec Type VA-216
S/N 49

Instrument Output Frequency Hz	Instrument Output Voltage volts	True Air Speed fpm
8.59	.126	59.8
10.6	.154	71.1
12.6	.175	80.5
14.8	.209	91.9
16.3	.227	100.4
22.7	.308	131
32.7	.43	171
46.7	.60	219
64.9	.86	286
82.6	1.12	374
110	1.48	493
148	1.97	648
189	2.46	835
243	3.20	1106
279	3.65	1286
316	4.19	1505

T = 22.8 to 23.0 °C

B = 752.8 mm Hg

Table 1E
J-Tec Type VA-216
S/N 49

Instrument Output Frequency Hz	Instrument Output Voltage volts	True Air Speed fpm
8.50	.126	59.5
10.8	.152	71.5
12.6	.177	80.9
14.9	.207	92.1
16.4	.226	100.2
23.3	.313	130
32.8	.43	172
46.5	.61	220
65.4	.84	284
83.3	1.12	375
110	1.48	490
147	1.96	648
188	2.47	836
244	3.20	1111
279	3.65	1292
320	4.12	1502

T = 23.2 to 23.4 °C

B = 751.3 mm Hg

Table 2A
J-Tec Type VA-216
S/N 48

Instrument Output Frequency, Hz	Instrument Output Voltage, volts	True Air Speed, fpm
8.61	.118	59.6
10.8	.146	71.0
12.6	.168	80.4
14.7	.195	92.0
16.3	.216	100.5
22.2	.29	130
30.8	.40	172
46.3	.60	220
59.5	.78	286
82.6	1.09	375
106.8	1.43	494
145.6	1.91	650
185.2	2.44	832

T = 23.1°C
B = 751.0 mm Hg

Table 2B
J-Tec Type VA-216
S/N 48

Instrument Output Frequency, Hz	Instrument Output Voltage, volts	True Air Speed, fpm
8.48	.116	58.1
10.7	.144	70.3
12.5	.166	80.2
15.0	.199	93.0
16.2	.215	99.5
22.2	.295	130
29.7	.39	170
46.1	.60	219
57.5	.76	285
82.0	1.09	375
105.7	1.42	494
144.5	1.92	649
186.2	2.45	835

T = 23.4°C
B = 751.2 mm Hg

Table 2C
J-Tec Type VA-216
S/N 48

Instrument Output Frequency, Hz	Instrument Output Voltage, volts	True Air Speed, fpm
8.65	.117	59.6
10.9	.147	71.9
12.7	.169	81.0
15.0	.198	92.9
16.4	.218	100.9
23.0	.29	130
29.2	.38	171
45.7	.60	220
57.8	.77	285
80.0	1.07	375
106.4	1.49	492
143.7	1.91	650
184.8	2.45	836

T = 23.7°C
B = 750.8 mm Hg

Table 2D
J-Tec Type VA-216
S/N 48

Instrument Output Frequency, Hz	Instrument Output Voltage, volts	True Air Speed, fpm
8.50	.119	63.5
10.6	.142	71.2
12.5	.166	80.1
14.7	.196	91.8
16.3	.217	100.2
21.5	.28	130
28.8	.38	170
45.2	.59	220
59.9	.78	284
78.1	1.04	375
107.0	1.40	492
143.5	1.90	647
186.2	2.44	834

T = 23.9°C
B = 750.2 mm Hg

Table 2E
J-Tec Type VA-216
S/N 48

Instrument Output Frequency, Hz	Instrument Output Voltage, volts	True Air Speed, fpm
8.40	.06	63.6
10.6	.142	70.4
12.4	.165	80.0
14.6	.195	91.1
16.2	.215	99.4
22.7	.30	130
27.9	.37	170
44.8	.59	219
60.2	.77	283
78.1	1.04	375
103.7	1.58	489
142.9	1.88	642
184.8	2.43	834

T = 24.2°C
B = 750.2 mm Hg

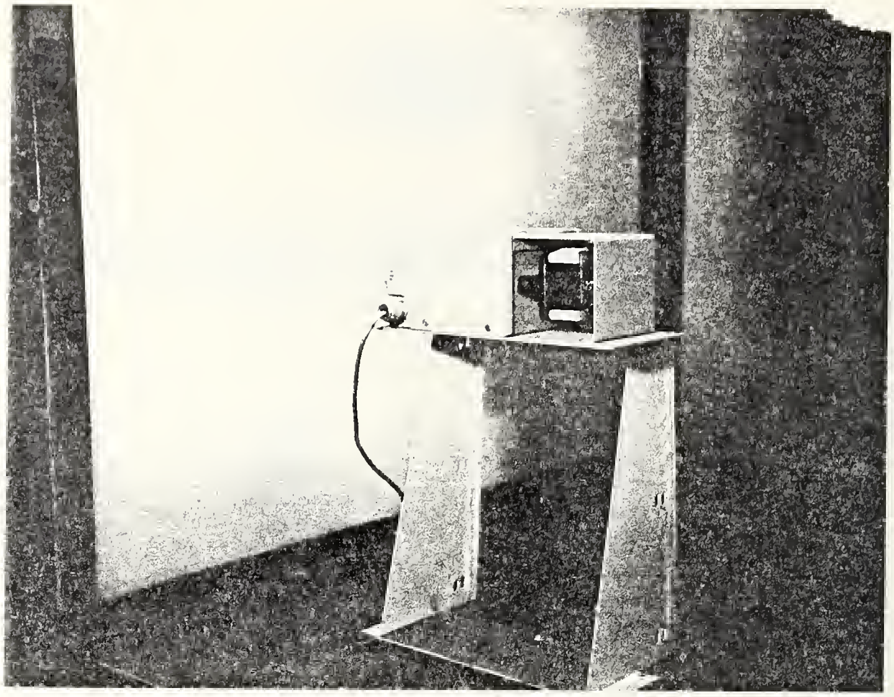

FIGURE 1. THE ANEMOMETER MOUNTED IN THE TUNNEL SHOWING METHOD OF SUPPORT (VIEWED LOOKING DOWNSTREAM).

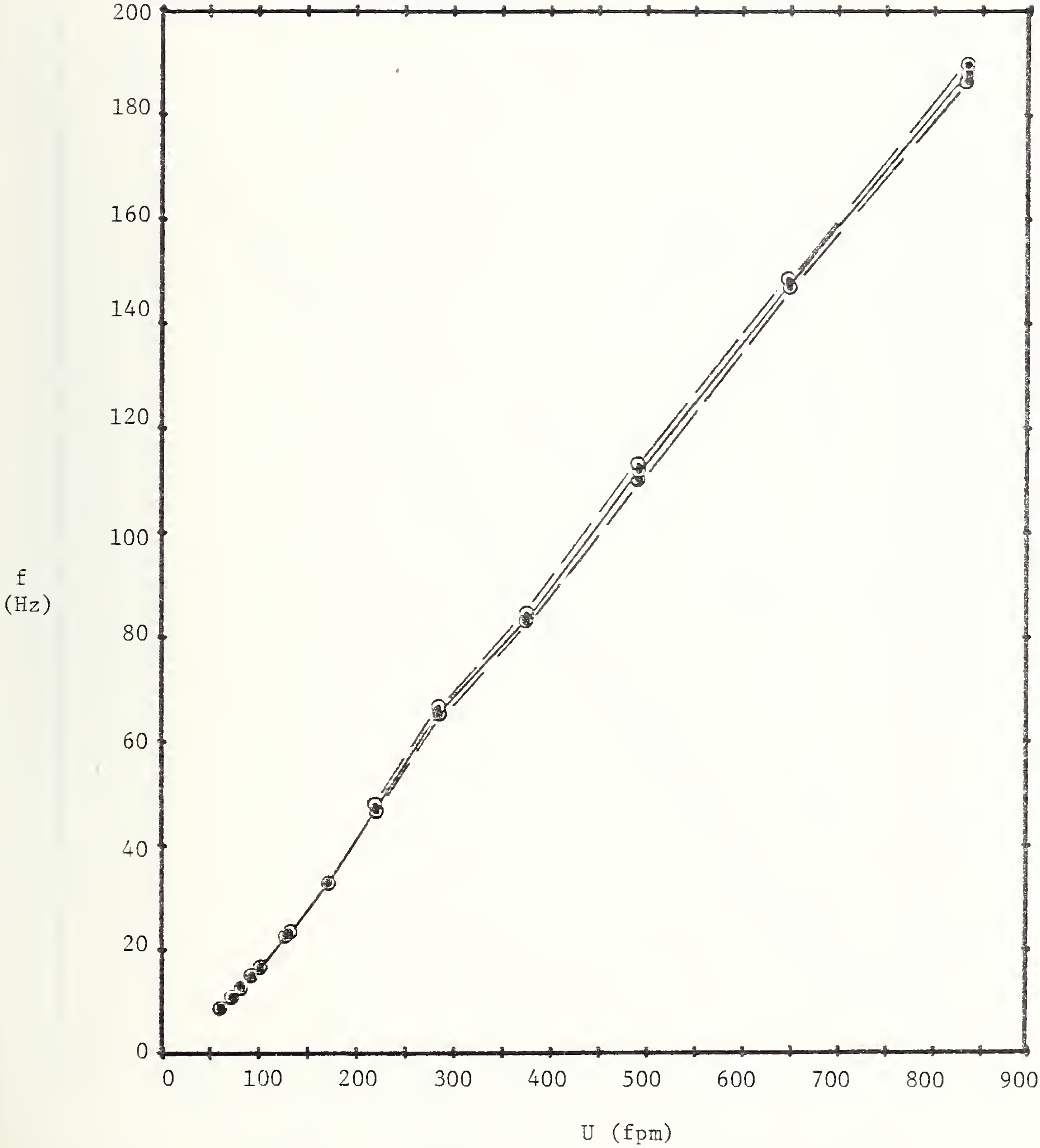

FIGURE 2. PULSE FREQUENCY VERSUS TRUE VELOCITY WITH $\pm 2\sigma_f$ CURVES. INSTRUMENT S/N 49.

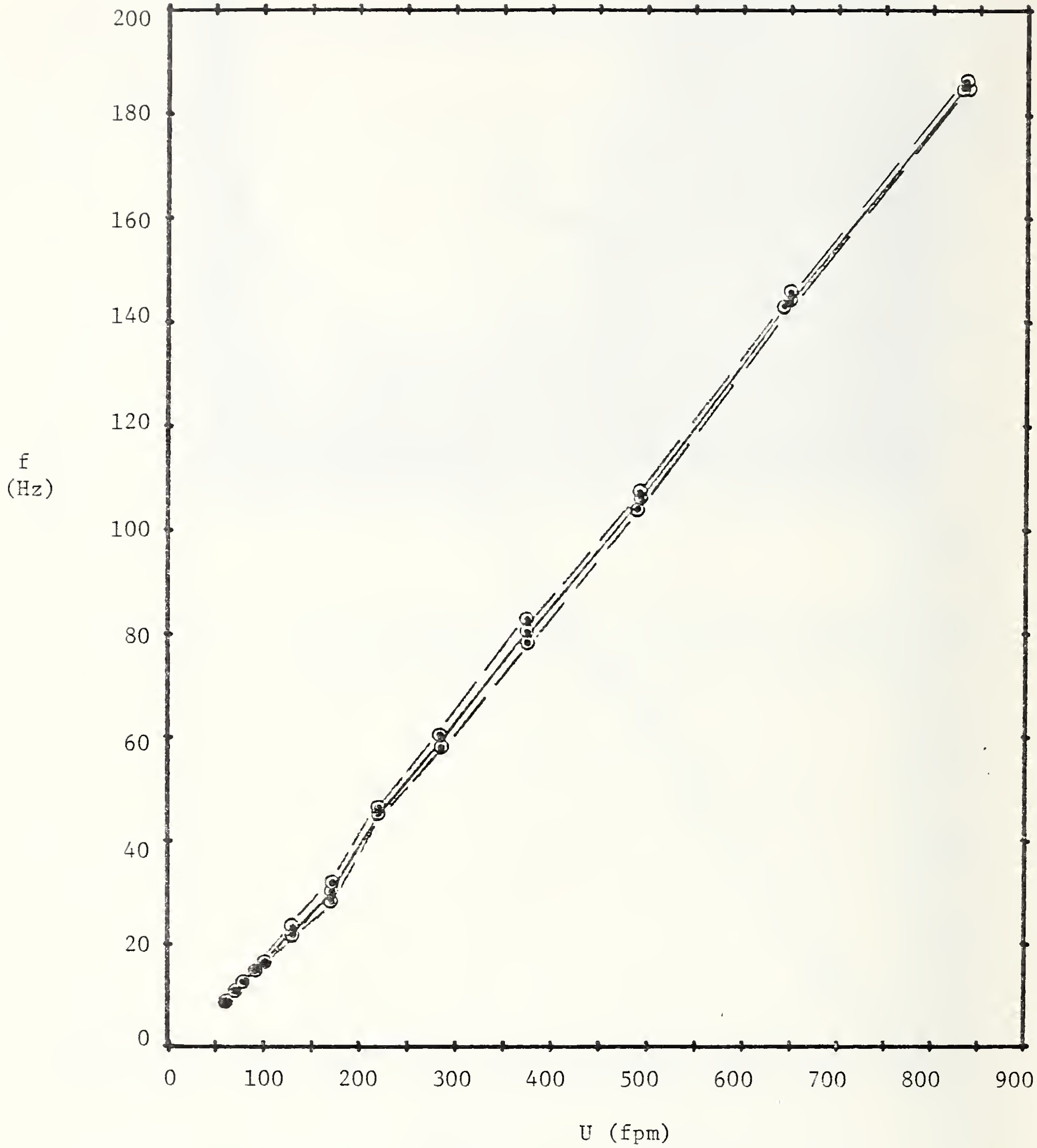

FIGURE 3. PULSE FREQUENCY VERSUS TRUE VELOCITY WITH $\pm 2\sigma_f$ CURVES. INSTRUMENT S/N 48.

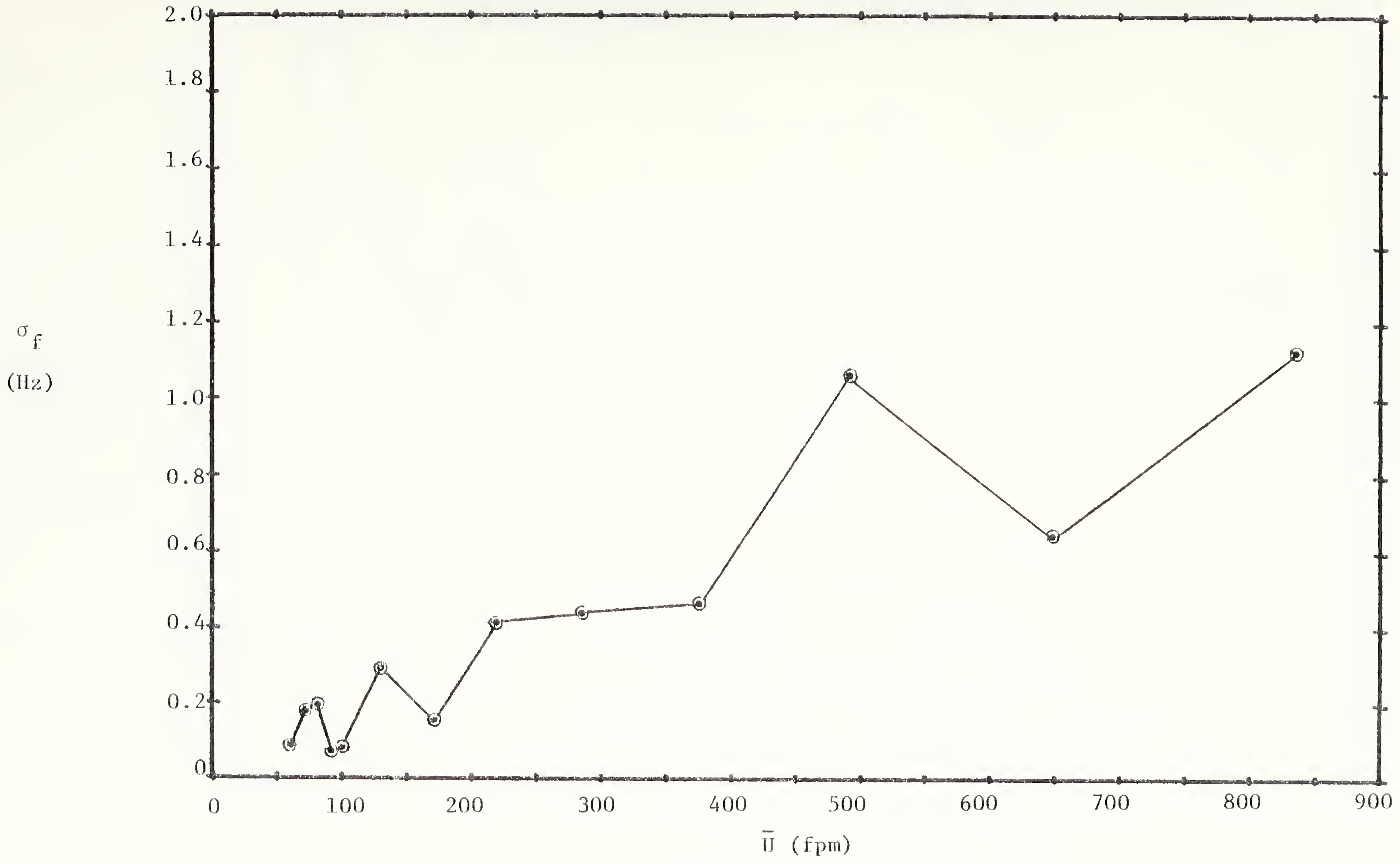

FIGURE 4. STANDARD DEVIATION OF PULSE FREQUENCY. INSTRUMENT S/N 49.

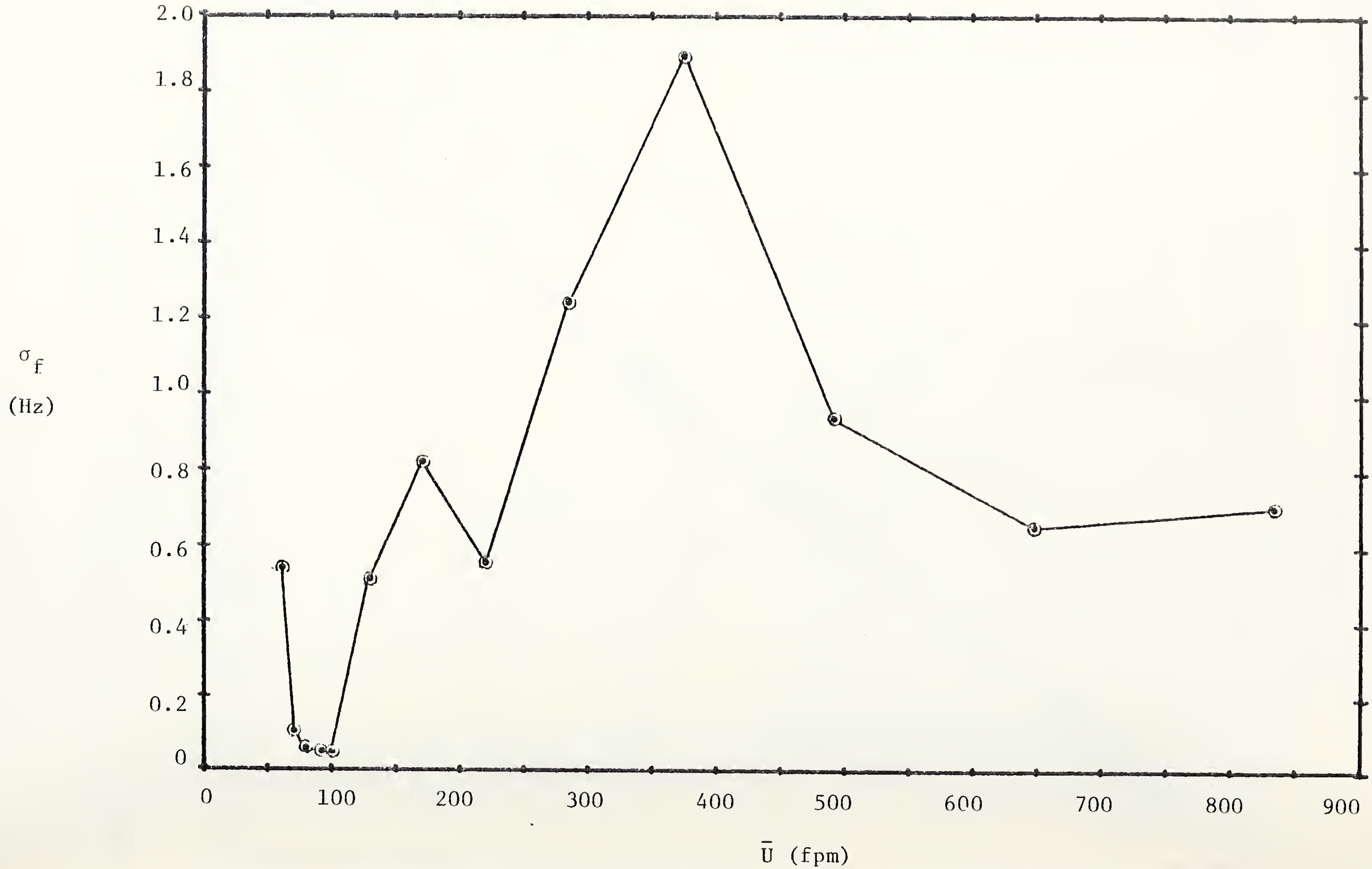

FIGURE 5. STANDARD DEVIATION OF PULSE FREQUENCY. INSTRUMENT S/N 48.

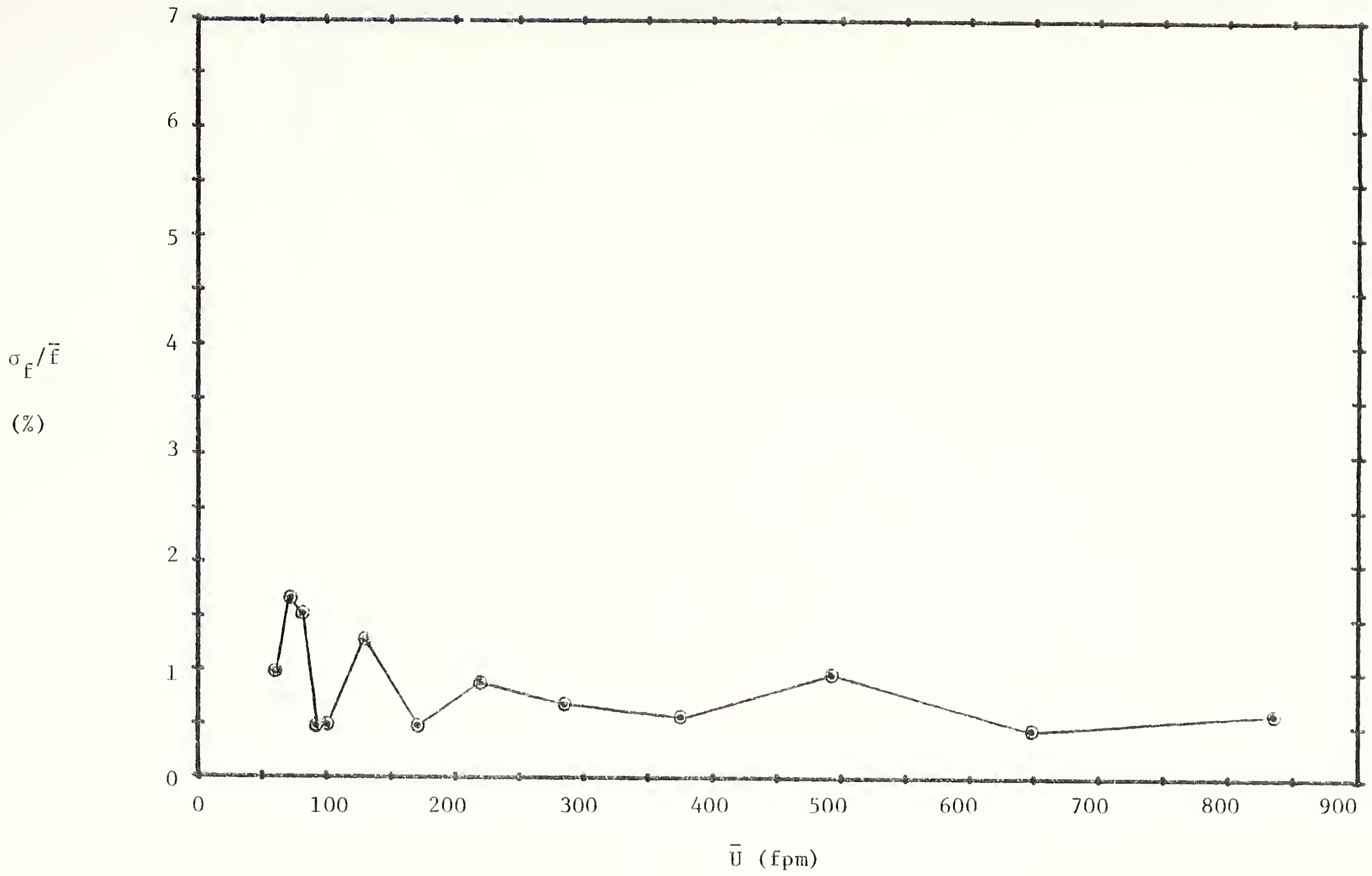

FIGURE 6. STANDARD DEVIATION OF PULSE FREQUENCY AS PERCENT OF GROUP MEAN FREQUENCY. INSTRUMENT S/N 49.

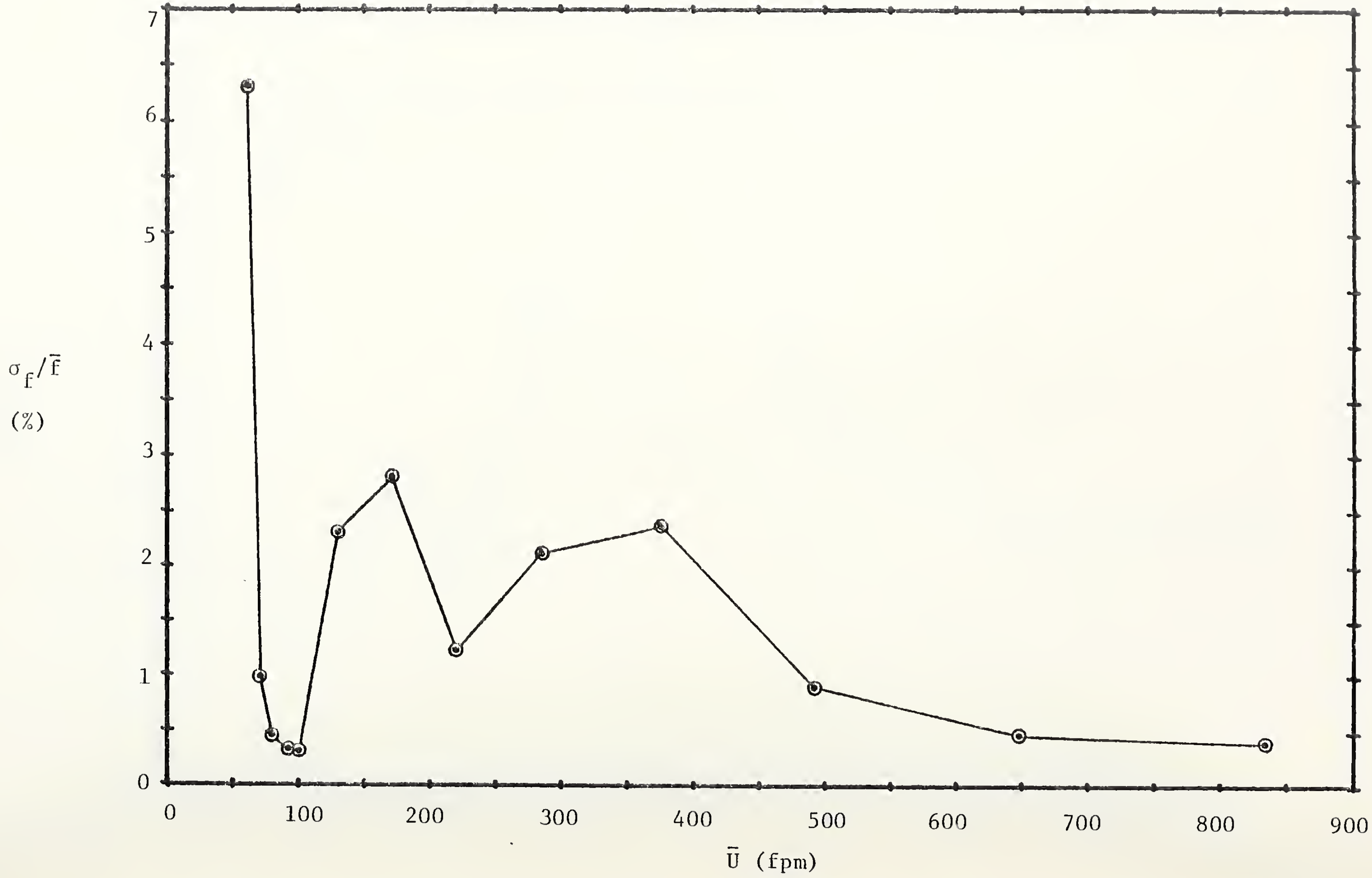

FIGURE 7. STANDARD DEVIATION OF PULSE FREQUENCY AS PERCENT OF GROUP MEAN FREQUENCY. INSTRUMENT S/N 48.

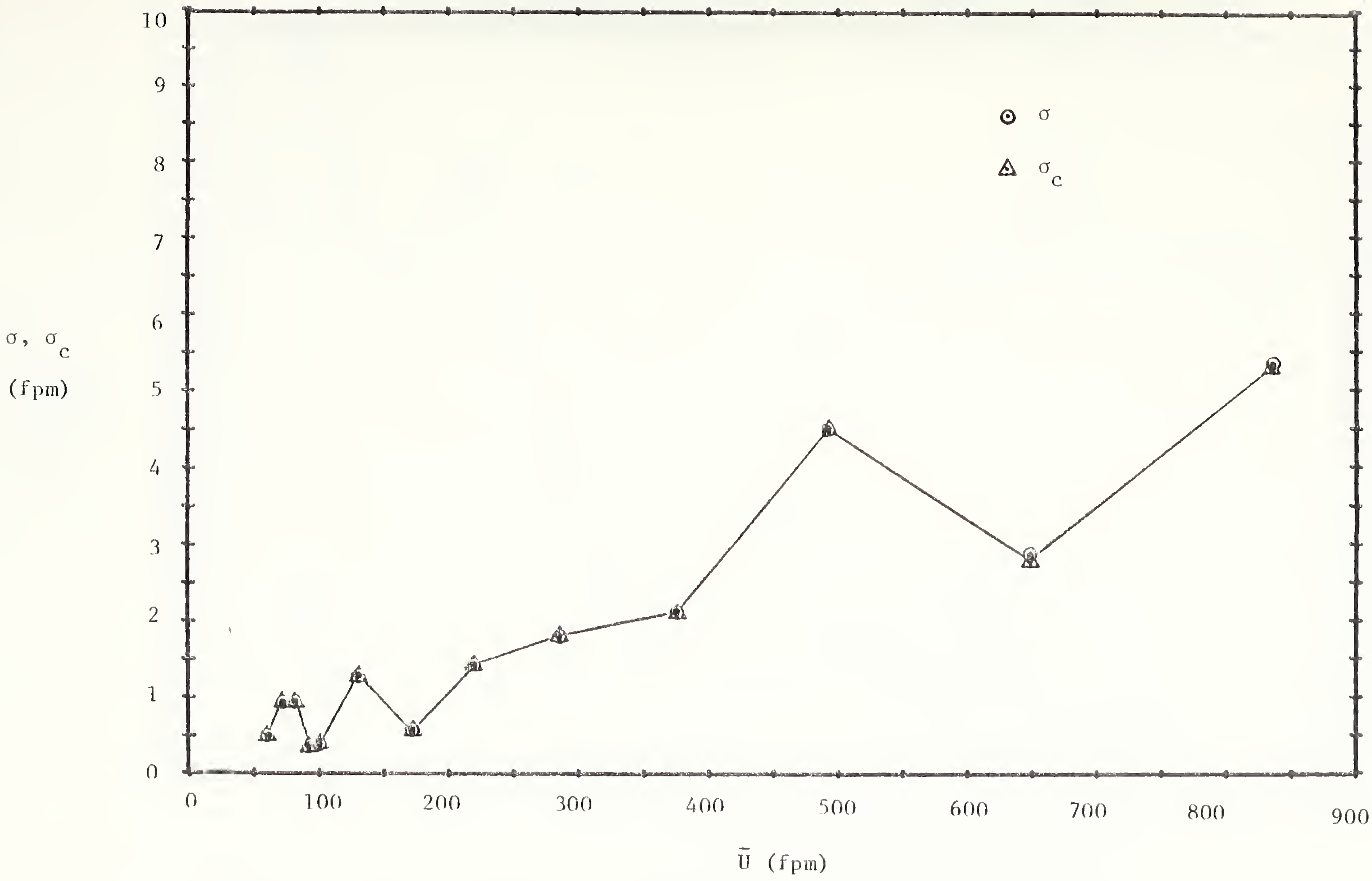

FIGURE 8. STANDARD DEVIATION, σ, AND CORRECTED STANDARD DEVIATION, σ_c, EXPRESSED AS EQUIVALENT TRUE VELOCITY. INSTRUMENT S/N 49.

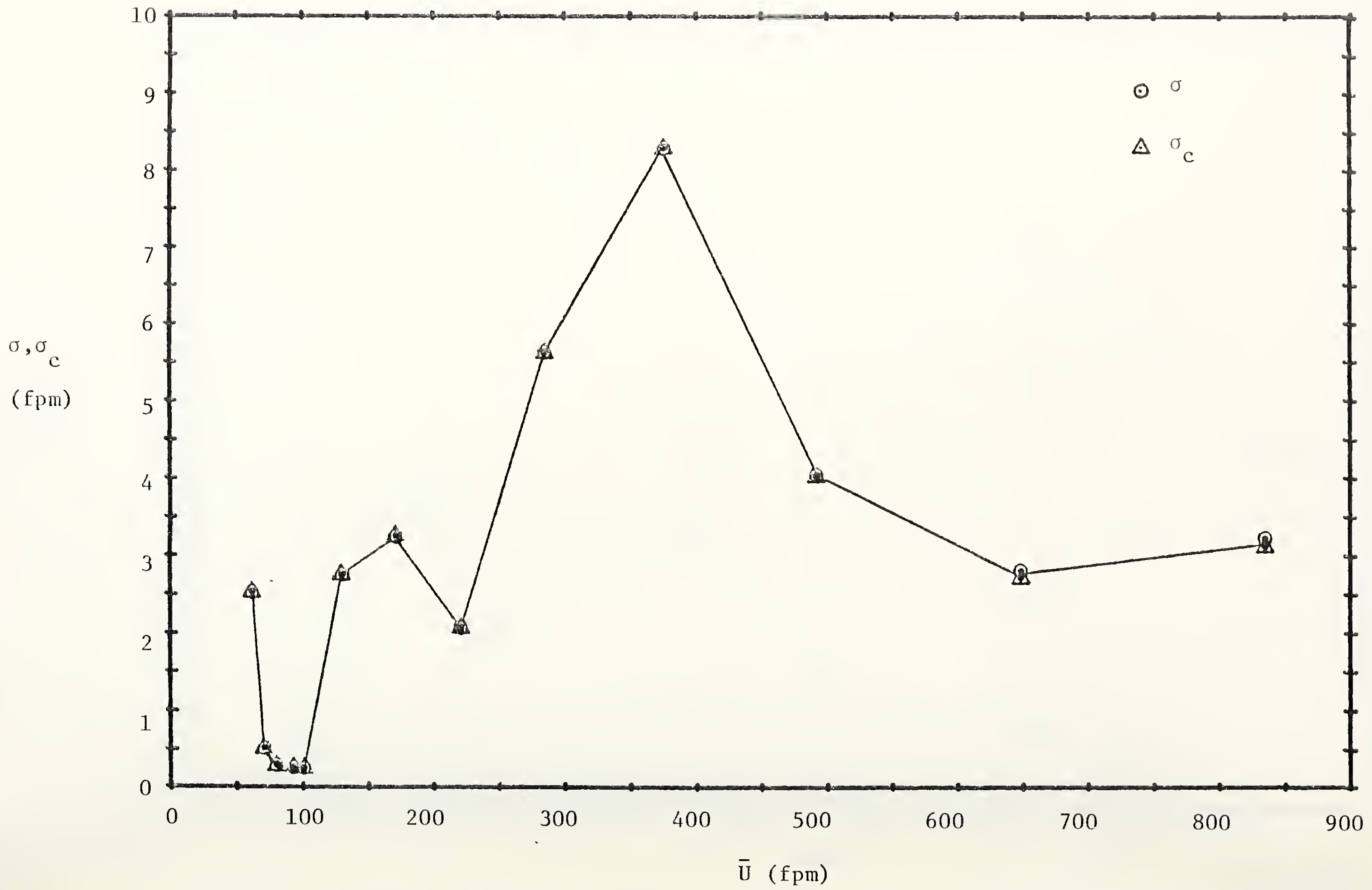

FIGURE 9. STANDARD DEVIATION, σ, AND CORRECTED STANDARD DEVIATION, σ_c, EXPRESSED AS EQUIVALENT TRUE VELOCITY. INSTRUMENT S/N 48.

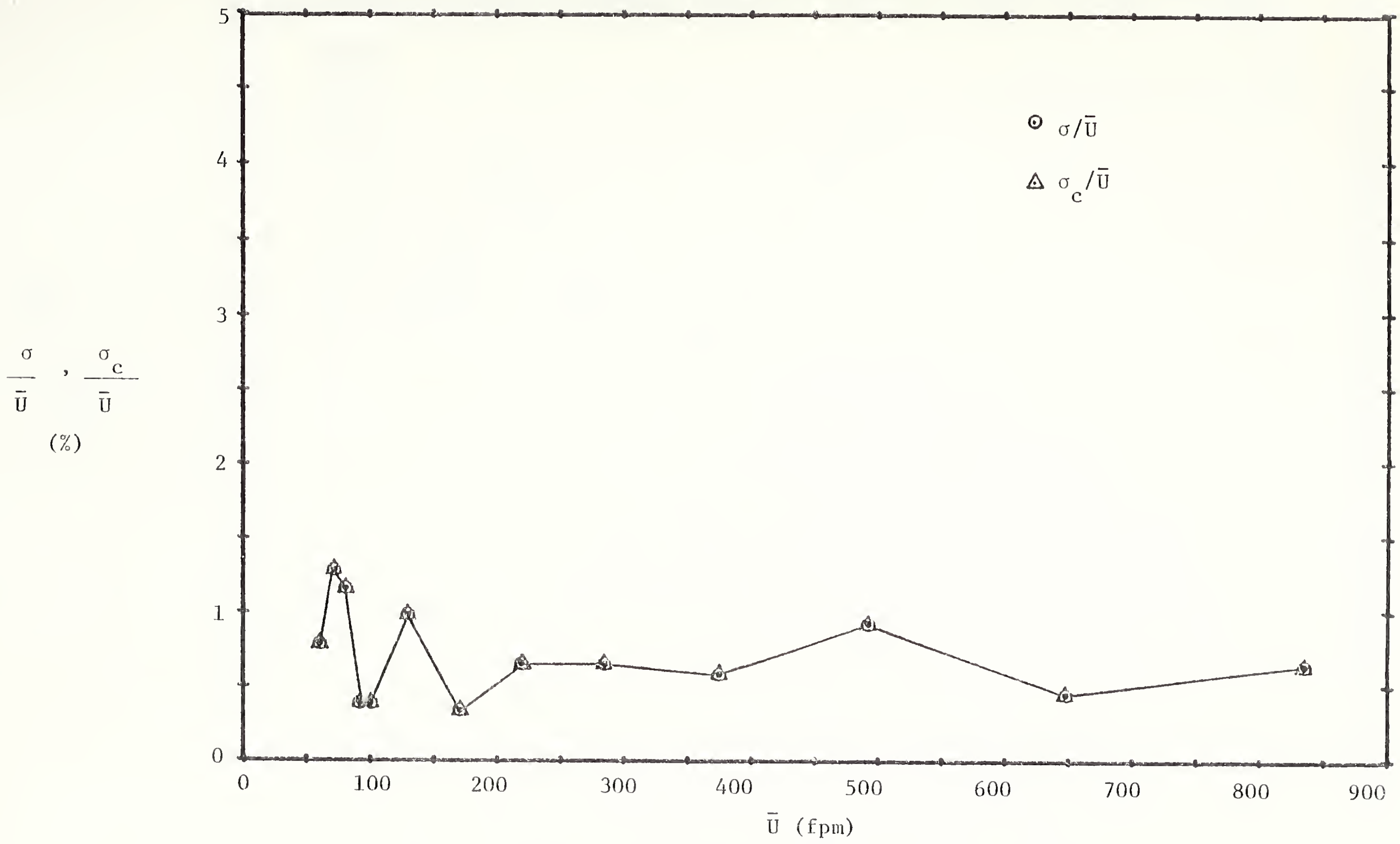

FIGURE 10. σ AND σ_c AS PERCENT OF GROUP MEAN VELOCITY. INSTRUMENT S/N 49.

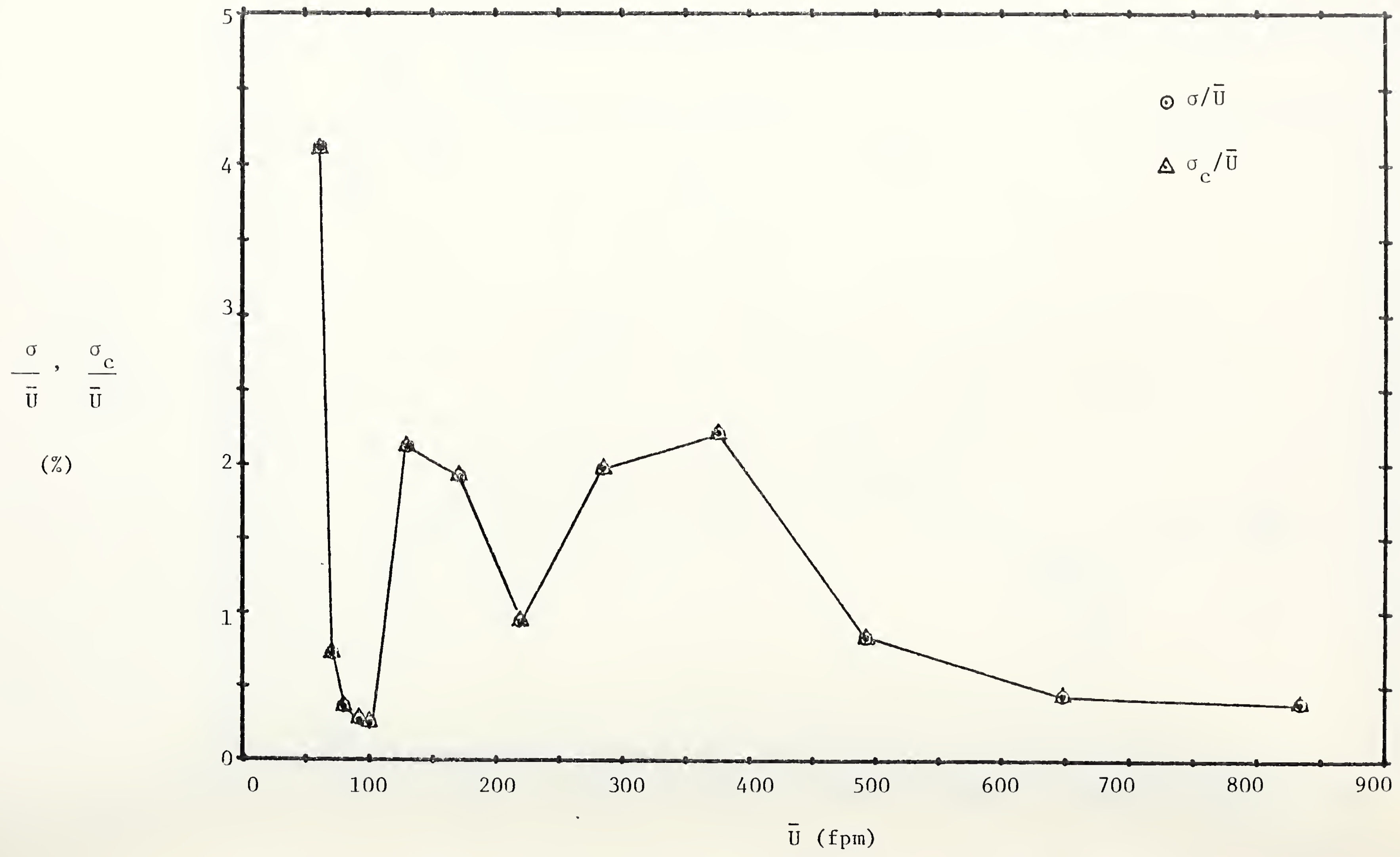

FIGURE 11. σ AND σ_c AS PERCENT OF GROUP MEAN VELOCITY. INSTRUMENT S/N 48.