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Low Velocity Performance of a Heated Foil Anemometer

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National Bureau of Standards
Fluid Engineering Division
Washington, DC 20234

March 1979

Task Report

on

Contract No. H0166198

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

Prepared for

United States Department of the Interior
Bureau of Mines

DISCLAIMER NOTICE

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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 heated-foil anemometer is evaluated over the speed range of 16 to 140 feet per minute. The tests 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 October 15, 1978 to November 30, 1978. This report was submitted by the author March 1979.

LIST OF SYMBOLS

U	velocity measured by laser velocimeter
I	output indicated by anemometer under test, μa
U_{if}	line segments fitted to U, I data
$\bar{U}$	group mean true velocity
$\bar{I}$	group mean indicated output
σ_I	standard deviation of I data from U_{if}
σ	standard deviation of I data expressed as true velocity
σ_c	σ adjusted for known variance in laser velocimeter measurements
R_i	resolution of the instrument, μa
R	resolution expressed as true velocity

LOW VELOCITY PERFORMANCE OF A HEATED FOIL 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 is a prototype instrument (Thermogage, Inc., Air Velocity Meter)[1] intended for use as a portable anemometer. It was supplied for test by the U. S. Bureau of Mines. The instrument consists of a tube approximately 3/8 inch in diameter and 4.0 inches in length aligned with the flow, and a 5/8 inch diameter handle attached normal to the tube midway along its length (see Figure 1). A part of the wall of the tube is composed of a heat-conducting foil which has an electrically heated spot flanked upstream and downstream by temperature sensors. As air passes through the tube, the upstream sensor experiences a lower temperature than the downstream sensor, and this difference, converted to an electrical signal, is related to velocity. The instrument thus consists of this thermal transducer and an electronics module containing a line-voltage operated power supply, the necessary circuitry, and a micro-ammeter.

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 75 x 75 cm). A laser velocimeter is employed as a primary velocity

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

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.

The anemometer was mounted 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. Since this anemometer presents a smaller disturbance to the flow than some previously tested anemometers, e.g. [2], and since a distance upstream of 30 cm was found adequate for those tests, this same distance was chosen for the tests reported here. With no anemometer in the tunnel, variation in velocity along the centerline is imperceptible over the distance traversed (30 cm).

The output of the anemometer was recorded during the time interval required for the measurement by the laser velocimeter. Five separate test runs at ten different velocities were made for each speed range. The velocity was limited at the low end by instrument resolution to above approximately 16 fpm and at the high end by full scale at approximately 140 fpm. The data are presented in chronological order in Tables 1A to 1E.

4. TEST RESULTS

Since a particular air speed in the wind tunnel cannot be exactly reset from run to run, scatter in the test data 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):

$U < 21$	$60 < U < 80$
$21 < U < 25$	$80 < U < 90$
$25 < U < 32$	$90 < U < 110$
$32 < U < 45$	$110 < U < 130$
$45 < U < 60$	$130 < U <$

Since the groups of data are compact (small range of U within a group; see Figure 2), a straight line segment is used to approximate the curve within a group. The line segment passes through the point $(\bar{U},\bar{I})$, the group mean true velocity and the group mean indicated output. The slope of the line segment is computed as the average of the slopes of two lines, both passing through $(\bar{U},\bar{I})$ of the group being considered, one line passing through the $(\bar{U},\bar{I})$ of the adjacent group higher in velocity, and one line passing through $(\bar{U},\bar{I})$ of the adjacent group lower in velocity. For the highest group (U > 130) there is only one adjacent group, and thus the line segment for this highest group passes through $(\bar{U},\bar{I})$ of that adjacent group. The line segment for the lowest group (U < 21 fpm) is similarly formed.

Designating the above line segments as U_{if}, the standard deviation, σ_I of the indicated output, I, about the fitted segments is determined by squaring the differences between the I data and U_{if}, i.e., $[I(U) - U_{if}(U)]^2$. 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 I about U_{if} 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 $\sigma_I(\bar{U})$ is divided by the slope (dU_{if}/dU) of the line segment associated with the $\sigma_I(\bar{U})$. Note that this σ does not include the "scatter" in the U measurements (due to the inability to exactly reset the 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_I is presented in Figure 3 as current and in Figure 4 as percentage of $\bar{I}$. σ and σ_c are presented in Figure 5 as velocity and in Figure 6 as percentage of $\bar{U}$.

5. DISCUSSION OF RESULTS

Computing σ from measurements by an instrument having a scale with a resolution, R_i, much smaller than σ_I is a good procedure for determining repeatability of the instrument. If the resolution is large (poor) compared to σ_I (where σ_I is presumed known by some means independent of the scale being considered, say by a second scale with better resolution), the indicated σ may be much smaller than it should be. For a Gaussian distribution of errors it is assumed that σ_I may be adequately computed if the resolution is at most approximately twice σ_I. The resolution judged to be the best that can be read on the anemometer is ± 1 μa over the entire range.

As with the computed values of σ_I, these values of resolution, R_i were converted to equivalent values, R, in terms of true velocity by dividing by the slope (dU_{if}/dU). These latter values, divided by two, were then included in Figure 5 in units of velocity and in Figure 6 as percentage of $\overline{U}$. As may be seen in Figure 5, R/2 does indeed exceed σ for several of the measurements. Thus these particular values of σ should be taken with reservation and perhaps replaced by the values R/2. The performance of the instrument in these instances in terms of repeatability may exceed the quality of its resolution.

The instrument 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 AC power for operation.

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 heated foil anemometer has been evaluated at air speeds up to 140 fpm. Evaluation of the repeatability was found to involve considering the resolution of the instrument. Figures are presented showing the response of the instrument to air velocity and the standard deviation of repeated runs about the mean curves. The lowest velocities measurable were limited by resolution of the instrument to about 16 fpm.

7. REFERENCES

1. L. P. Purtell and P. S. Klebanoff, A Low Velocity Airflow Research and Calibration Facility, in preparation.

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

Table 1A

Thermogage Air Velocity Meter

Instrument Output, μa	True Air Speed, fpm
99	138.7
89	119.2
80	101.8
70	85.4
58	70.0
44	54.8
27	39.2
16	27.9
9	22.1
8	17.7

T = 22.2 °C
B = 752.8 mm Hg

Table 1B

Thermogage Air Velocity Meter

Instrument Output, μa	True Air Speed, fpm
100	138.7
91	119.1
81	102.7
70	86.4
58	69.8
45	54.7
26	37.5
18	30.4
11	23.4
7	15.8

T = 22.2 °C
B = 752.8 mm Hg

Table 1C

Thermogage Air Velocity Meter

Instrument Output, μa	True Air Speed, fpm
99	137.9
90	119.1
81	102.7
70	86.3
58	70.0
44	54.3
26	38.2
18	29.8
11	23.0
9	20.1

T = 22.2 °C
B = 752.8 mm Hg

Table 1D

Thermogage Air Velocity Meter

Instrument Output, μa	True Air Speed, fpm
100	138.6
90	118.9
81	101.8
71	86.5
58	69.5
43	53.6
24	35.6
17	28.7
12	23.6
8	19.4

T = 22.2 °C
B = 752.8 mm Hg

Table 1E

Thermogage Air Velocity Meter

Instrument Output, µa	True Air Speed, fpm
99	140.0
91	119.1
82	102.2
69	85.0
57	68.4
43	52.9
27	35.7
18	29.9
11	21.7
9	18.6

T = 22.0 °C
B = 752.8 mm Hg

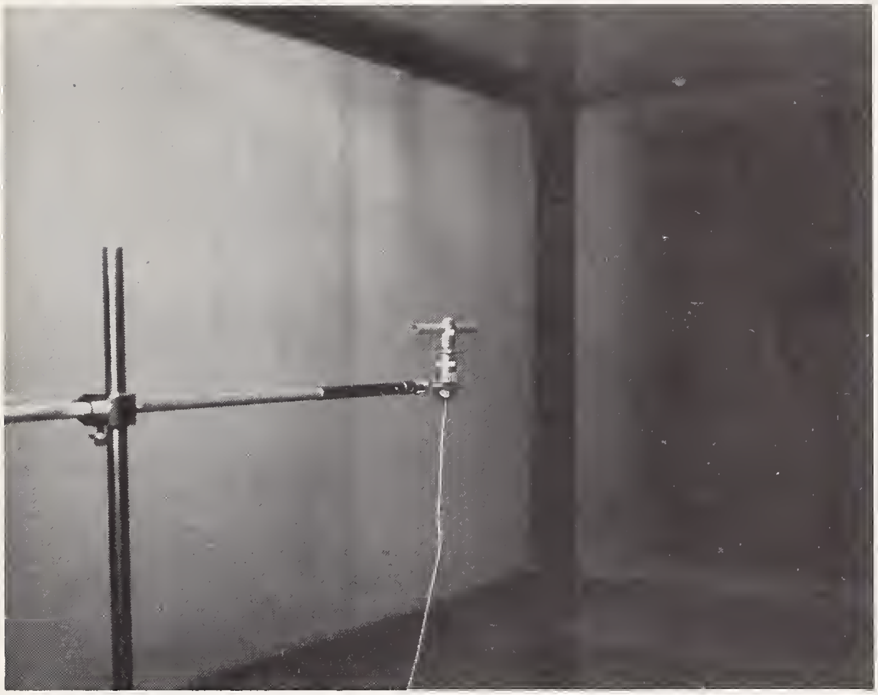

Figure 1. The anemometer mounted in the tunnel showing method of support.

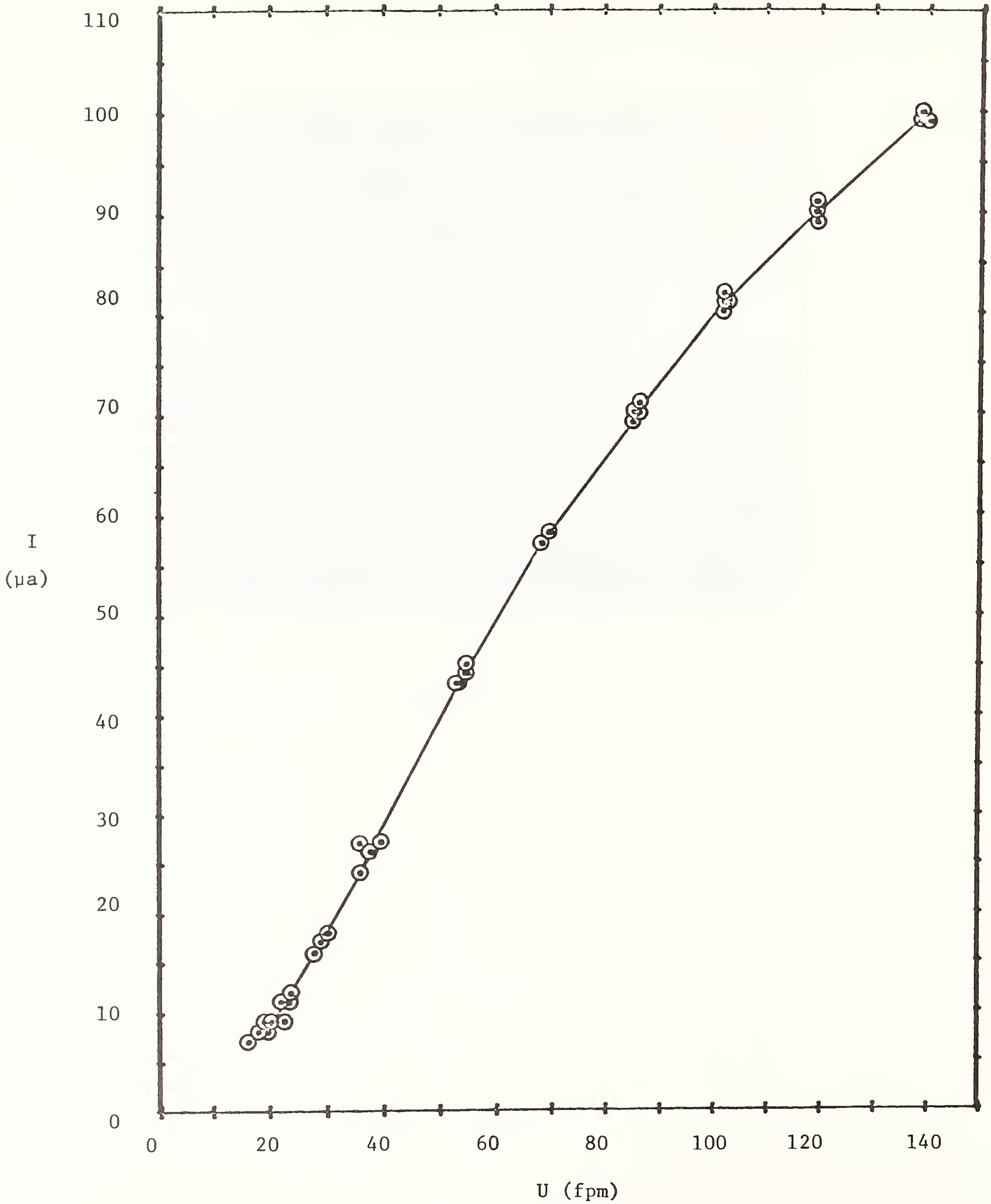

Figure 2. Output of instrument against velocity.

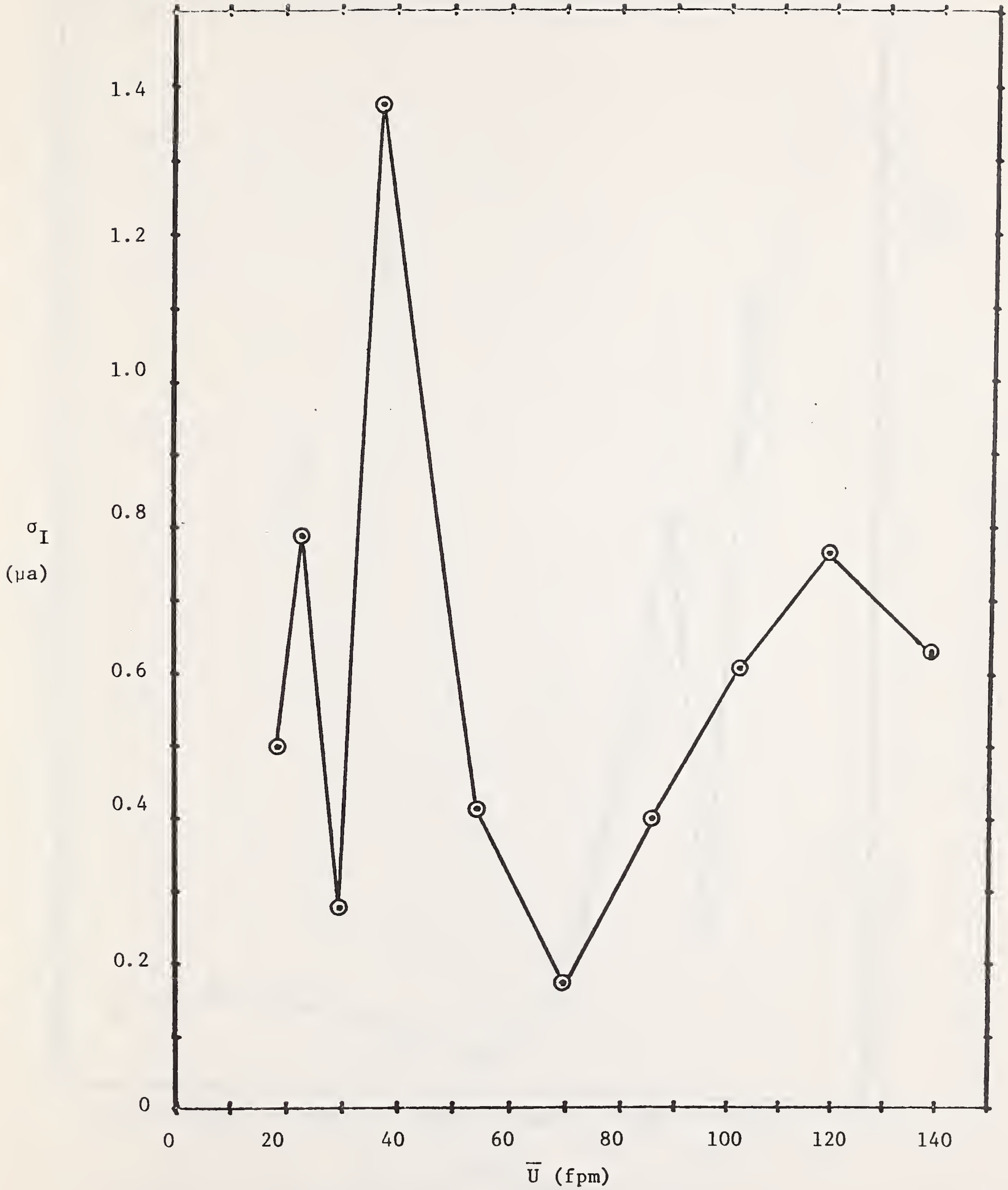

Figure 3. Standard deviation of instrument output against group mean velocity.

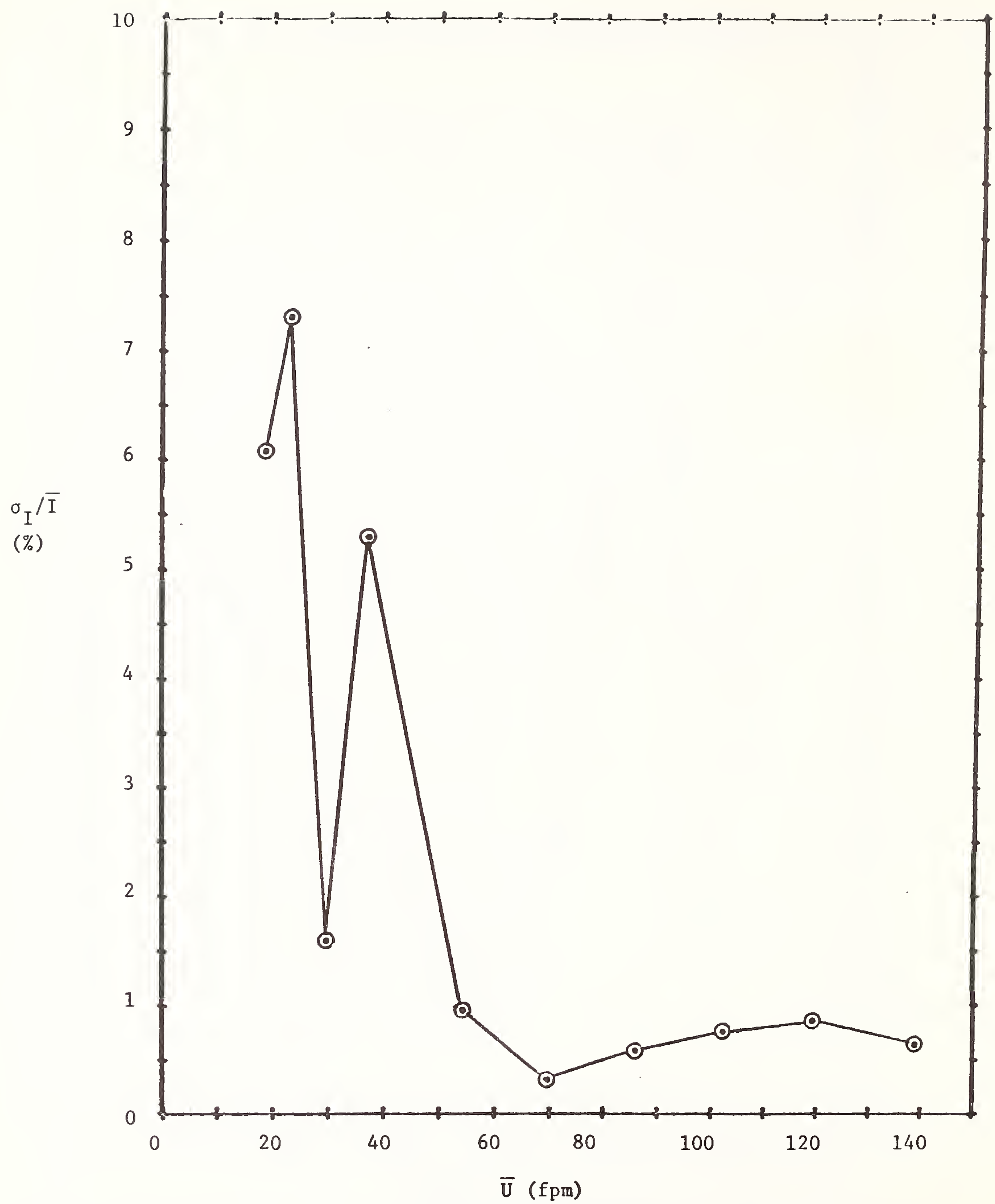

Figure 4. Standard deviation of instrument output as percent of instrument output.

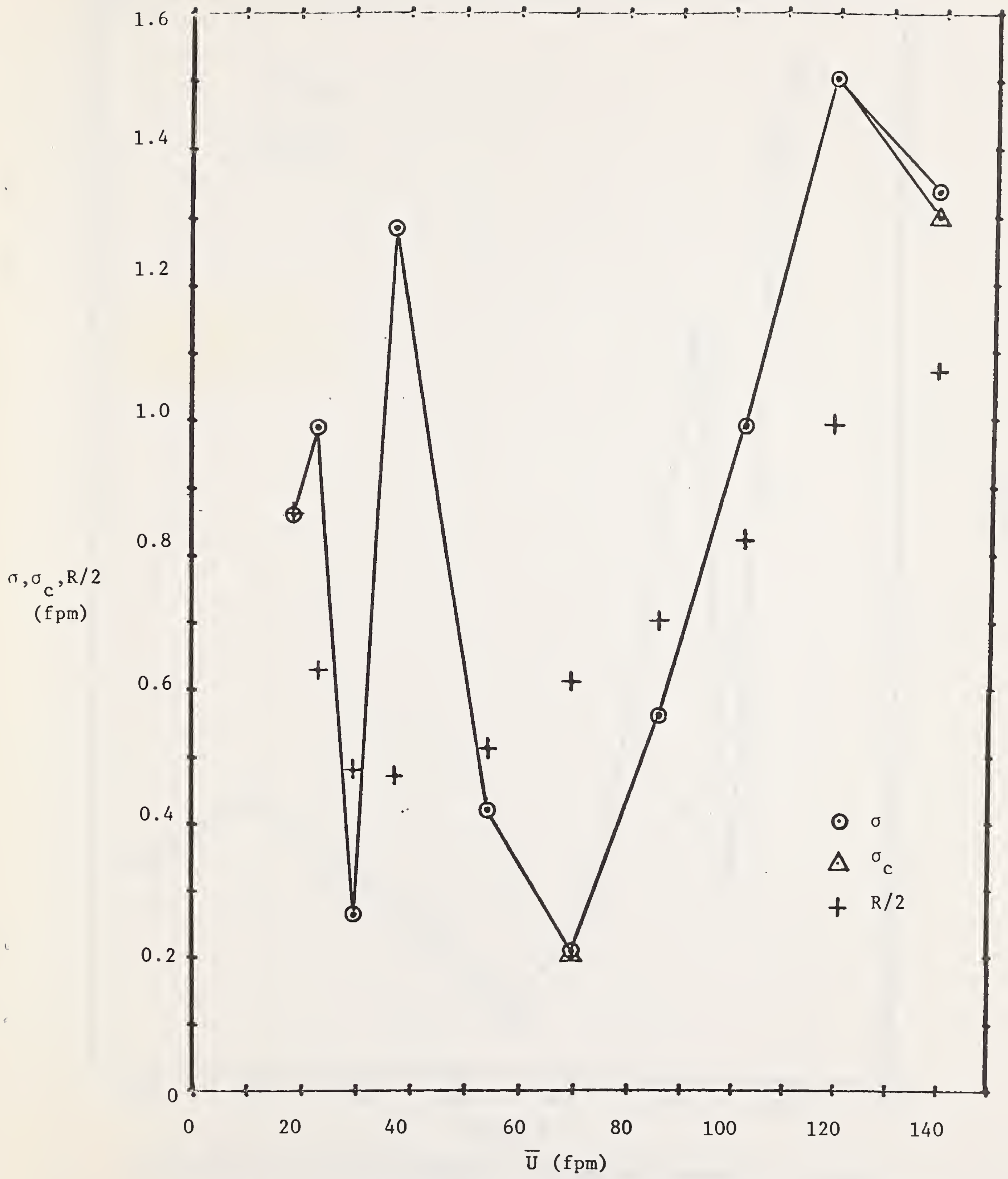

Figure 5. Standard deviation and corrected standard deviation in terms of velocity. R/2 noted.

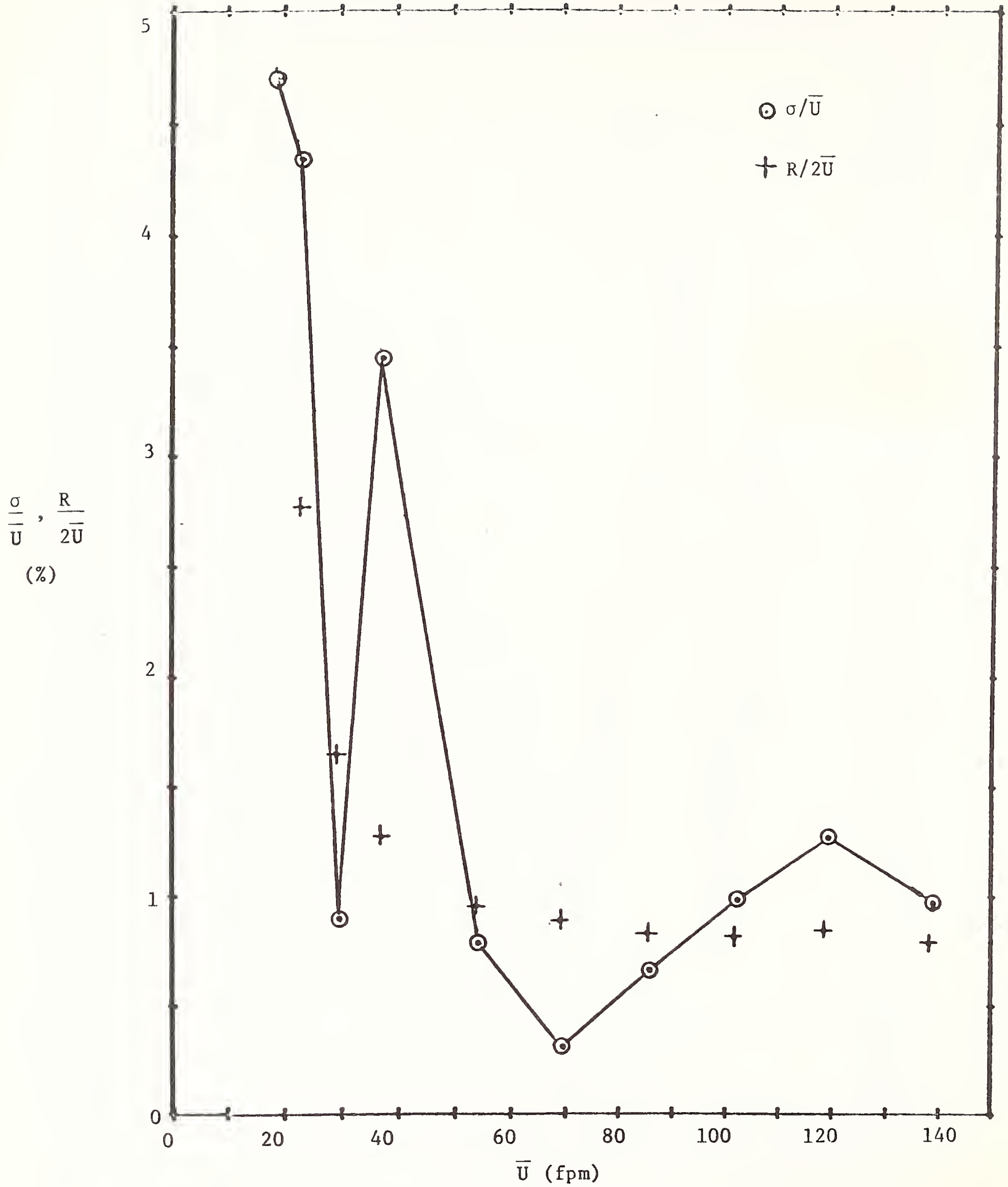

Figure 6. Standard deviation in terms of velocity as percent of group mean velocity. R/$2\overline{U}$ noted.