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Low Velocity Performance of a Compact Impact-Deflection Anemometer

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National Bureau of Standards
Fluid Engineering Division
Washington, D.C. 20234

September 1978

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

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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 compact impact-deflection anemometer is evaluated over the speed range of 50.8 to 716 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; performance; 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 September 1, 1977 to November 30, 1977. This report was submitted by the author September 1978.

LIST OF SYMBOLS

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

LOW VELOCITY PERFORMANCE OF A COMPACT IMPACT-DEFLECTION 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 commercially available instrument (Alnor Instrument Company, Velometer Jr., Type 8100)[1] used in the mining industry and elsewhere as a portable anemometer. It was supplied for test by the U. S. Mining Enforcement and Safety Administration at the request of the U. S. Bureau of Mines. The instrument is ap approximately 3.25 x 4 x 1.5 inches in size (see Figure 1) and contains entrance and exit ports for the air on the upstream and downstream surfaces respectively. The air stream inside the instrument impacts and deflects a small vane linked to a meter indicator. The entrance port is adjustable (two sizes) providing two ranges of velocity measurement, 50 to 200 fpm and 100 to 800 fpm, referred to herein as the low and high ranges respectively. The instrument is a one piece, self contained unit not requiring power or other devices for operation.

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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.

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 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. The velocity upstream of the anemometer on the centerline 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 (Figure 2). These measurements were performed at a free-stream velocity of 205 fpm. As shown in a previous report [2] the variation of the ratio of the local velocity to the free stream velocity with distance of the anemometer is independent of free-stream velocity. A distance of 30 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 along the centerline is imperceptible over the distance traversed (30cm).

The air speed indicated by the anemometer was recorded during the time interval required for the measurement by the laser velocimeter. If fluctuations of the dial indicator were noticeable their magnitude was estimated and recorded. Five separate test runs were made for each speed range, a run consisting of seven different velocities for the low range and ten for the high range. The lowest velocities were limited by instrument resolution and are 53.0 fpm for the low range and 50.8 fpm for the high range. The data are presented chronological order in Tables 1A to 1E and 2A to 2E for the low and high ranges respectively.

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

Low Range (fpm)	High Range (fpm)
$U < 60$	$U < 60$
$60 < U < 80$	$60 < U < 100$
$80 < U << 100$	$100 < U < 120$
$100 < U < 130$	$120 < U < 180$
$130 < U < 150$	$180 < U < 250$
$150 < U < 180$	$250 < U < 350$
$180 < U$	$350 < U < 450$
	$450 < U < 550$
	$550 < U < 650$
	$650 < U$

Since the groups of data are compact (small range of U within a group; see Figures 3 and 4), a straight line segment is used to approximate the curve within a group. The line segment passes through the point $(\bar{U},\bar{U}_i)$, the group mean true velocity and the group mean indicated velocity. The slope of the line segment is computed as the average of the slopes of two lines, both passing through $(\bar{U},\bar{U}_i)$ of the group being considered, one line passing through the $(\bar{U},\bar{U}_i)$ of the adjacent group higher in velocity, and one line passing through $(\bar{U},\bar{U}_i)$ of the adjacent group lower in velocity. For the highest groups ($U > 180$ and 650 fpm) there is only one adjacent group, and thus the line segment for this highest group passes through $(\bar{U},\bar{U}_i)$ of that adjacent group. The line segment for the lowest groups ($U < 60$ fpm) is similarly formed.

Designating the above line segments as U_{if}, the standard deviation, σ_i of the indicated velocity, U_i, about the fitted segments is determined by squaring the differences between the U_i data and U_{if}, i.e., $[U_i(U) - U_{if}(U)]^2$. 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 U_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 σ_i $(\bar{U})$ is divided by the slope (dU_{if}/dU) of the line segment associated with the σ_i ($\overline{U}$). 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 and σ_c are presented in Figures 5 and 6 as velocity and in Figures 7 and 8 as percentage of $\overline{U}$. Since $\pm 2\sigma_c$ is extremely close to the 95 percent confidence interval for one measurement, curves of $\pm 2\sigma_c$ are also included in Figures 3 and 4 as dashed lines.

The actual differences between the true and indicated velocities, $U - U_i$, are presented in Figures 9 and 10 and as a percentage of U in Figures 11 and 12. The curves shown in each figure have been drawn for reference only.

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 following values of resolution were judged to be the best that can be read on the anemometer tested:

Low Range

$50 < U_i < 100$ fpm, R_i = 1/5 division or 2 fpm

$100 < U_i < 200$ fpm, R_i = 1/10 division or 1 fpm

High Range

$100 < U_i < 600$ fpm, R_i = 1/5 division or 5 fpm

$600 < U_i < 800$ fpm, R_i = 1/10 division or 2.5 fpm

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 Figures 5 and 6 in units of velocity and in Figures 7 and 8 as percentage of $\overline{U}$. As may be seen in Figures 5 and 6, 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. Fluctuations of the dial indicator during a reading were generally below ± 1 or 2 fpm, but for the high range, the fluctuations at $\overline{U}$ = 715 fpm were as large as ± 25 fpm diminishing to near zero below 600 fpm. As evidenced by Figure 6, though, these fluctuations did not result in an exceedingly large σ. 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 is entirely mechanical and does not require an outside source of power.

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 compact, low speed, impact-deflection anemometer has been evaluated at air speeds up to 716 fpm. Evaluation of the repeatability of measurements was found to involve consideration of the resolution of the instrument. Figures are presented showing the deviation of indicated velocity from true velocity and the standard deviation of repeated runs about the mean curves. The lowest velocities measurable were limited by resolution of the instrument and were 53.0 fpm for the low range and 50.8 fpm for the high range.

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
Alnor Velometer Jr.
Low Range

Indicated Air Speed, fpm	True Air Speed, fpm
205	204.7
172	166.4
148	141.1
122	116.3
100	93.0
80	70.6
62	53.0

T = 26.9 °C
B = 747.5 mm Hg

Table 1B
Alnor Velometer Jr.
Low Range

Indicated Air Speed, fpm	True Air Speed, fpm
205	204.6
170	165.8
146	141.6
122	118.0
100	94.9
78	70.3
60	53.2

T = 26.9 °C
B = 747.5 mm Hg

Table 1C
Alnor Velometer Jr.
Low Range

Indicated Air Speed, fpm	True Air Speed, fpm
200	204.2
170	166.6
148	142.1
120	117.0
100	92.7
80	70.7
62	53.3

T = 26.9 °C
B = 747.5 mm Hg

Table 1D
Alnor Velometer Jr.
Low Range

Indicated Air Speed, fpm	True Air Speed, fpm
205	204.7
170	166.3
146	141.1
120	116.4
100	92.9
80	69.5
62	53.4

T = 26.9 °C
B = 747.5 mm Hg

Table 1E
Alnor Velometer Jr.
Low Range

Indicated Air Speed, fpm	True Air Speed, fpm
205	204.6
170	166.2
146	141.3
122	117.5
102	93.6
80	70.1
62	53.4

T = 27.0 °C
B = 747.5 mm Hg

Table 2A
Alnor Velometer Jr.
High Range

Indicated Air Speed, fpm	True Air Speed, fpm
775	712.8
600	608.5
525	503.1
480	399.0
420	296.1
300	192.2
230	142.0
195	117.2
160	93.5
100	50.8

T = 26.9 °C
B = 747.5 mm Hg

Table 2B
Alnor Velometer Jr.
High Range

Indicated Air Speed, fpm	True Air Speed, fpm
800	714.7
610	608.8
525	504.2
485	400.0
420	296.5
300	192.4
230	141.7
195	117.4
160	93.3
105	52.5

T = 26.9 °C
B = 747.5 mm Hg

Table 2C
Alnor Velometer Jr.
High Range

Indicated Air Speed, fpm	True Air Speed, fpm
800	714.2
610	609.7
530	504.9
480	399.3
420	296.9
300	191.8
210	140.3
180	117.4
150	93.0
100	53.3

T = 26.9 °C
B = 747.5 mm Hg

Table 2D
Alnor Velometer Jr.
High Range

Indicated Air Speed, fpm	True Air Speed, fpm
800	715.9
610	609.4
530	504.4
480	400.2
415	296.9
300	192.5
230	141.5
195	116.9
160	93.4
100	52.8

T = 26.9 °C
B = 747.5 mm Hg

Table 2E
Alnor Velometer Jr.
High Range

Indicated Air Speed, fpm	True Air Speed, fpm
800	715.7
625	610.6
530	504.6
480	399.0
420	296.3
300	191.5
225	141.0
195	115.4
160	92.3
100	54.4

T = 27.0 °C
B = 747.5 mm Hg

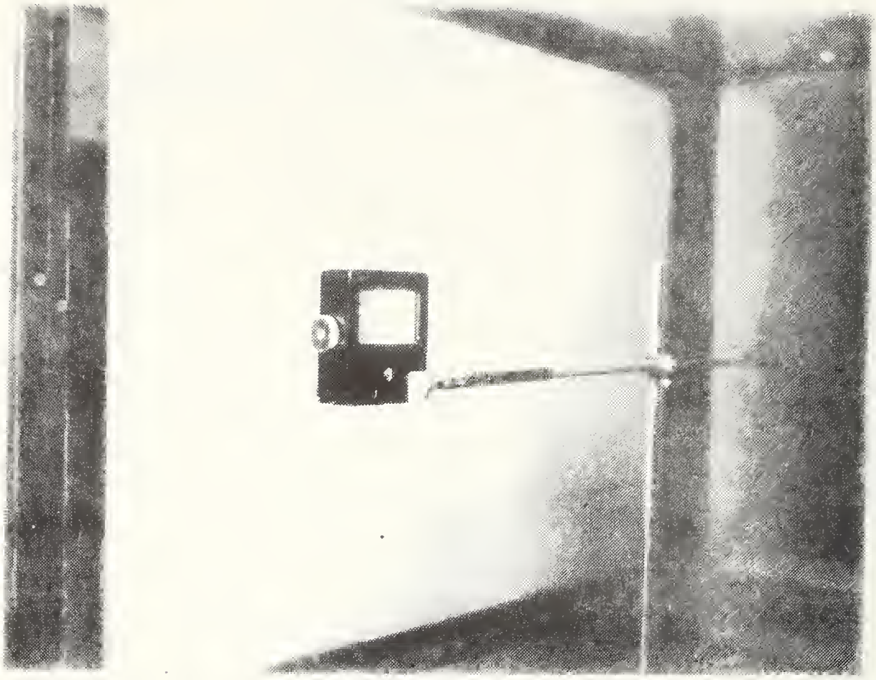

FIGURE 1. THE ANEMOMETER MOUNTED IN THE TUNNEL SHOWING METHOD OF SUPPORT (VIEWED LOOKING DOWNSTREAM).

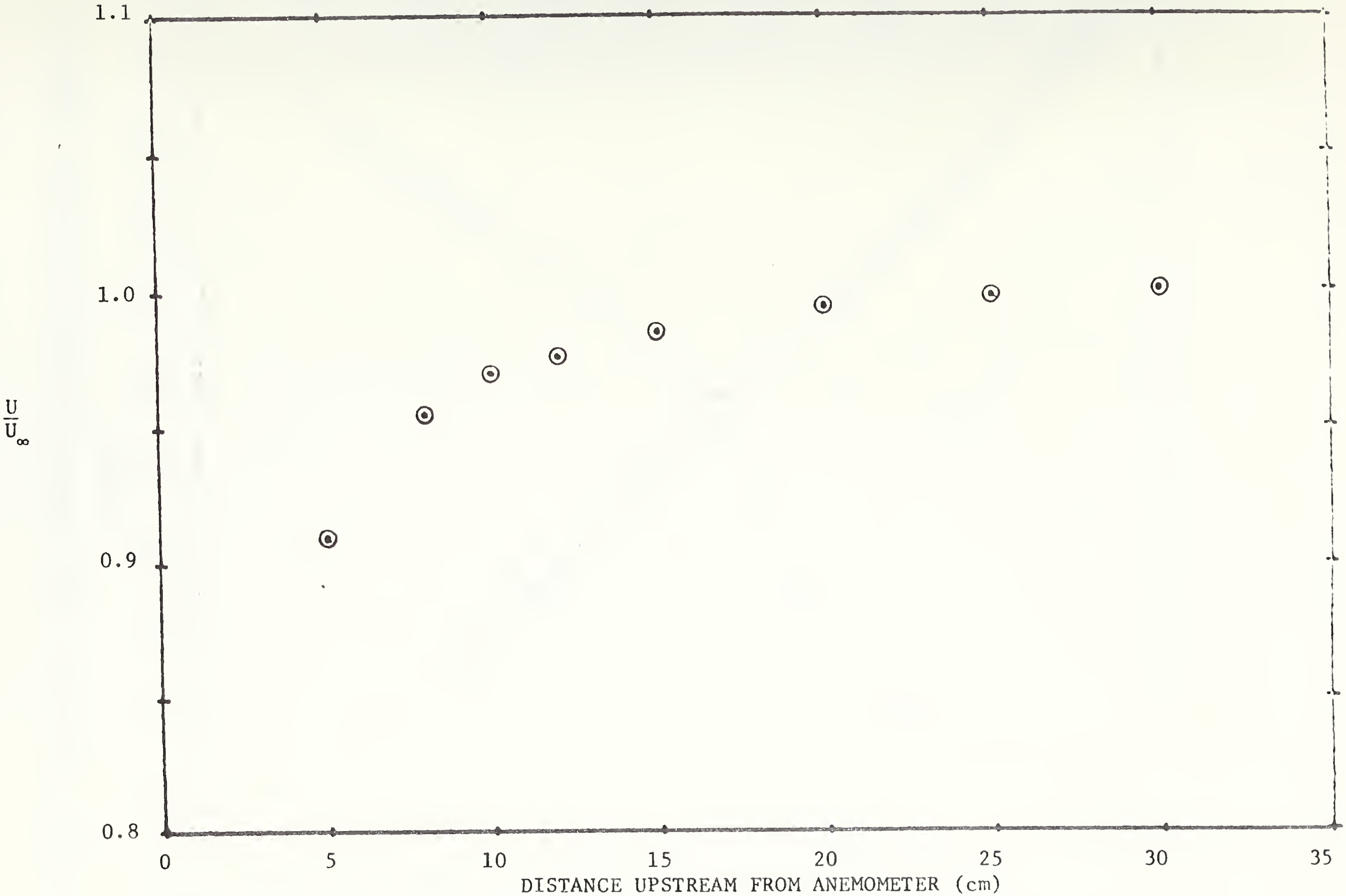

FIGURE 2. VARIATION IN VELOCITY WITH DISTANCE UPSTREAM OF ANEMOMETER. U_∞ = 205 fpm.

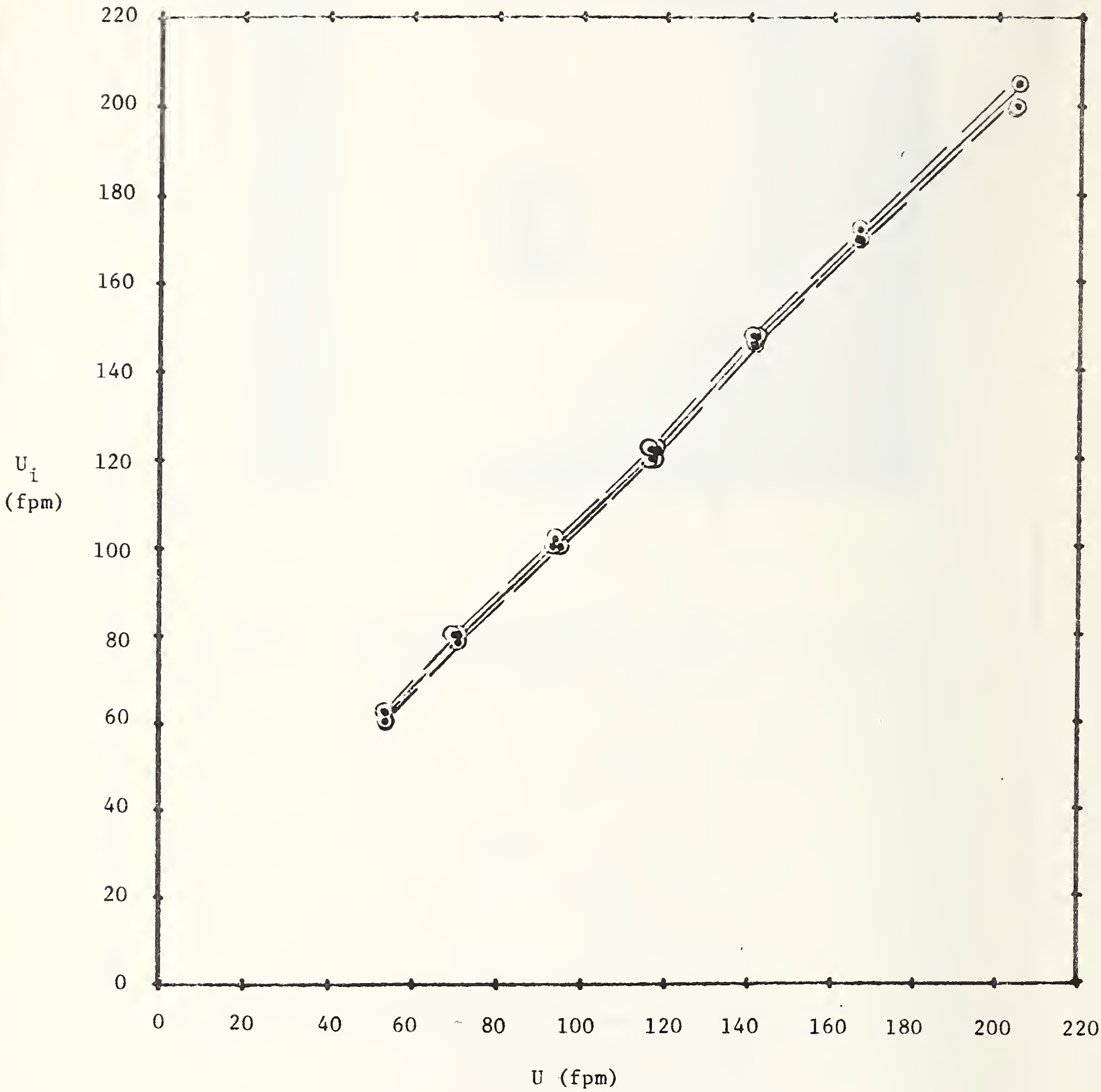

FIGURE 3. INDICATED VERSUS TRUE VELOCITY WITH ± 2 σ CURVES, LOW RANGE.

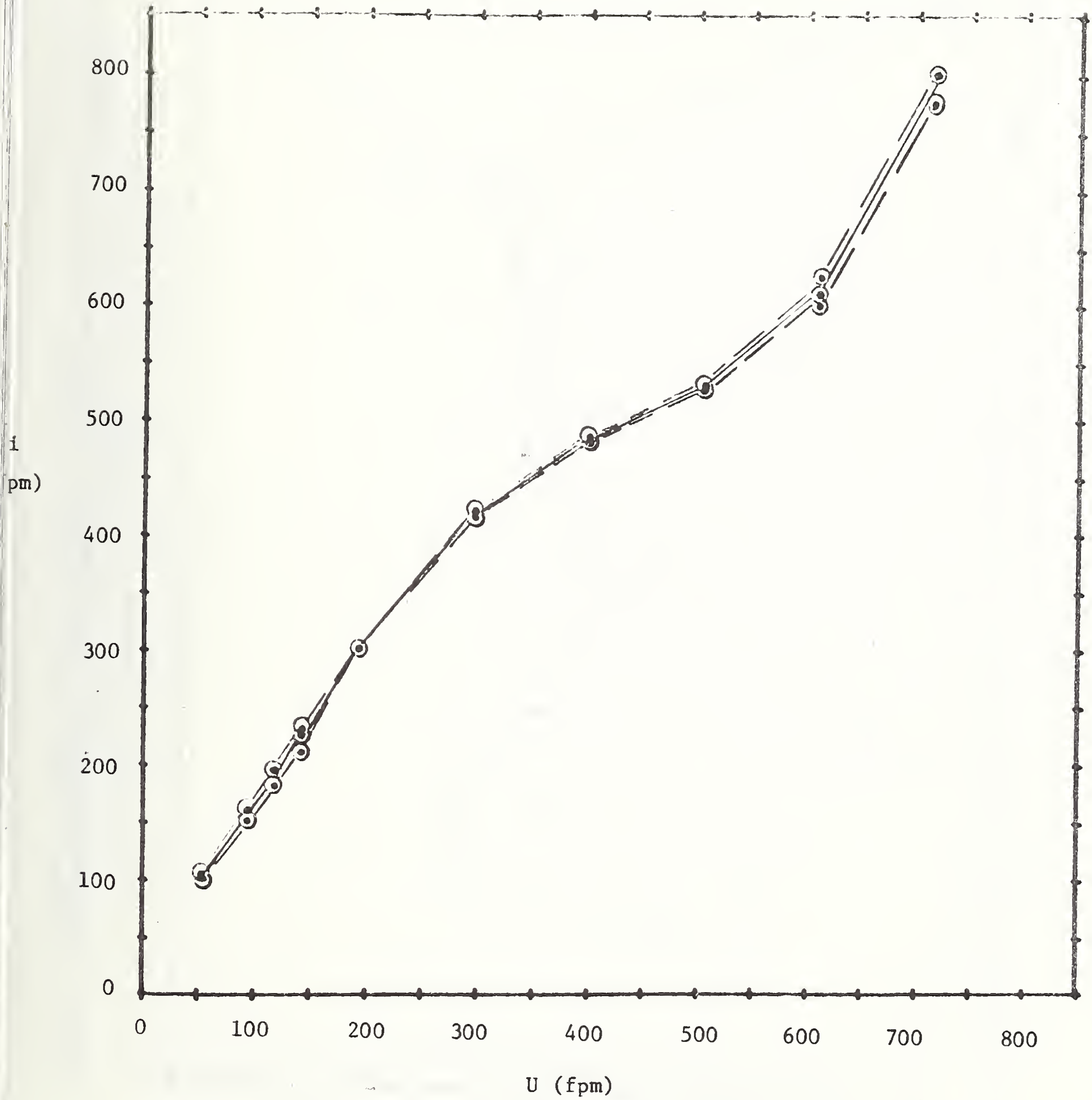

FIGURE 4. INDICATED VERSUS TRUE VELOCITY WITH ± 2 σ CURVES, HIGH RANGE.

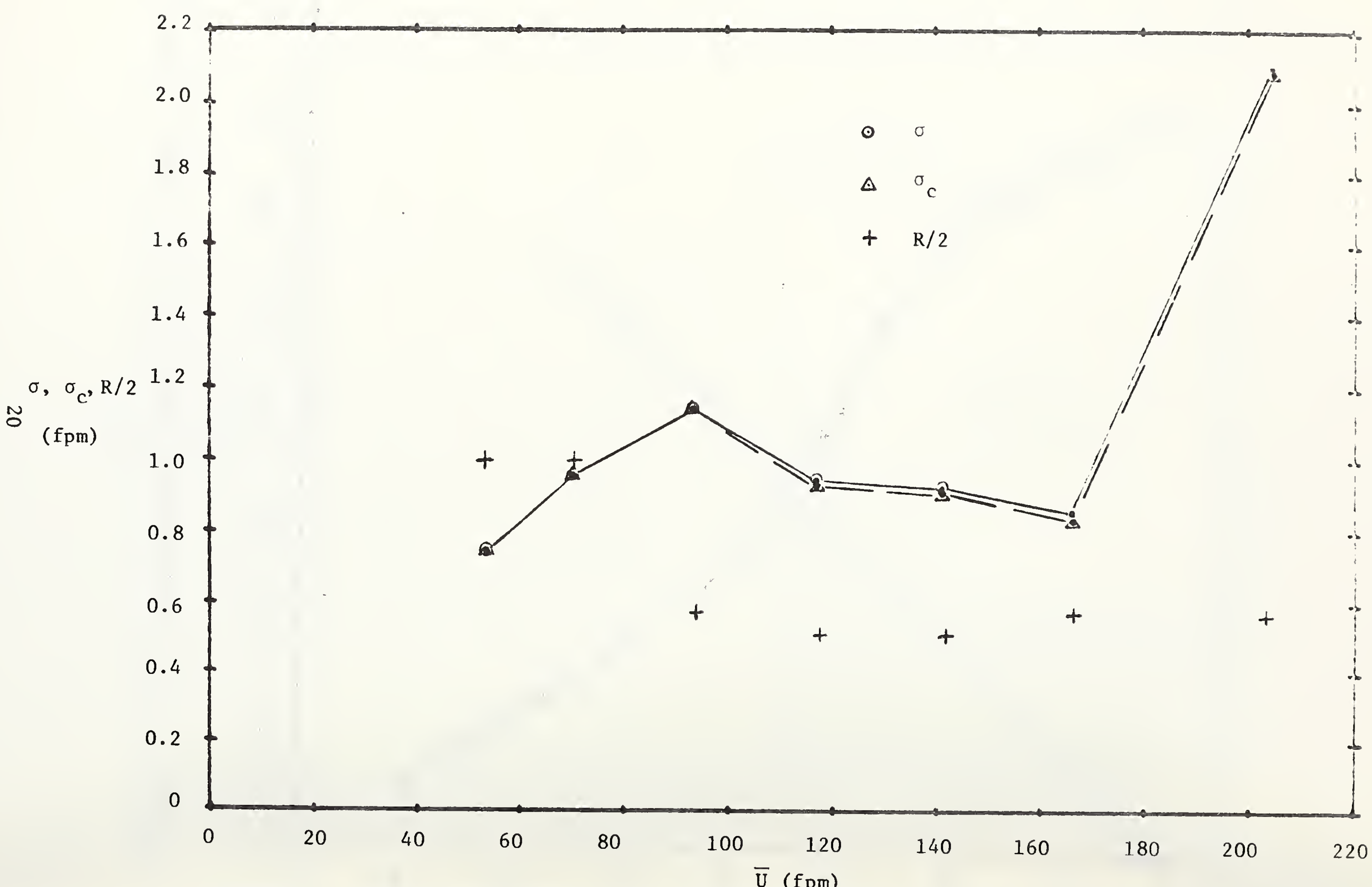

FIGURE 5. STANDARD DEVIATION, σ, AND CORRECTED STANDARD DEVIATION, σ_c, OF INDICATED VELOCITY IN TERMS OF TRUE VELOCITY, LOW RANGE. R/2 NOTED.

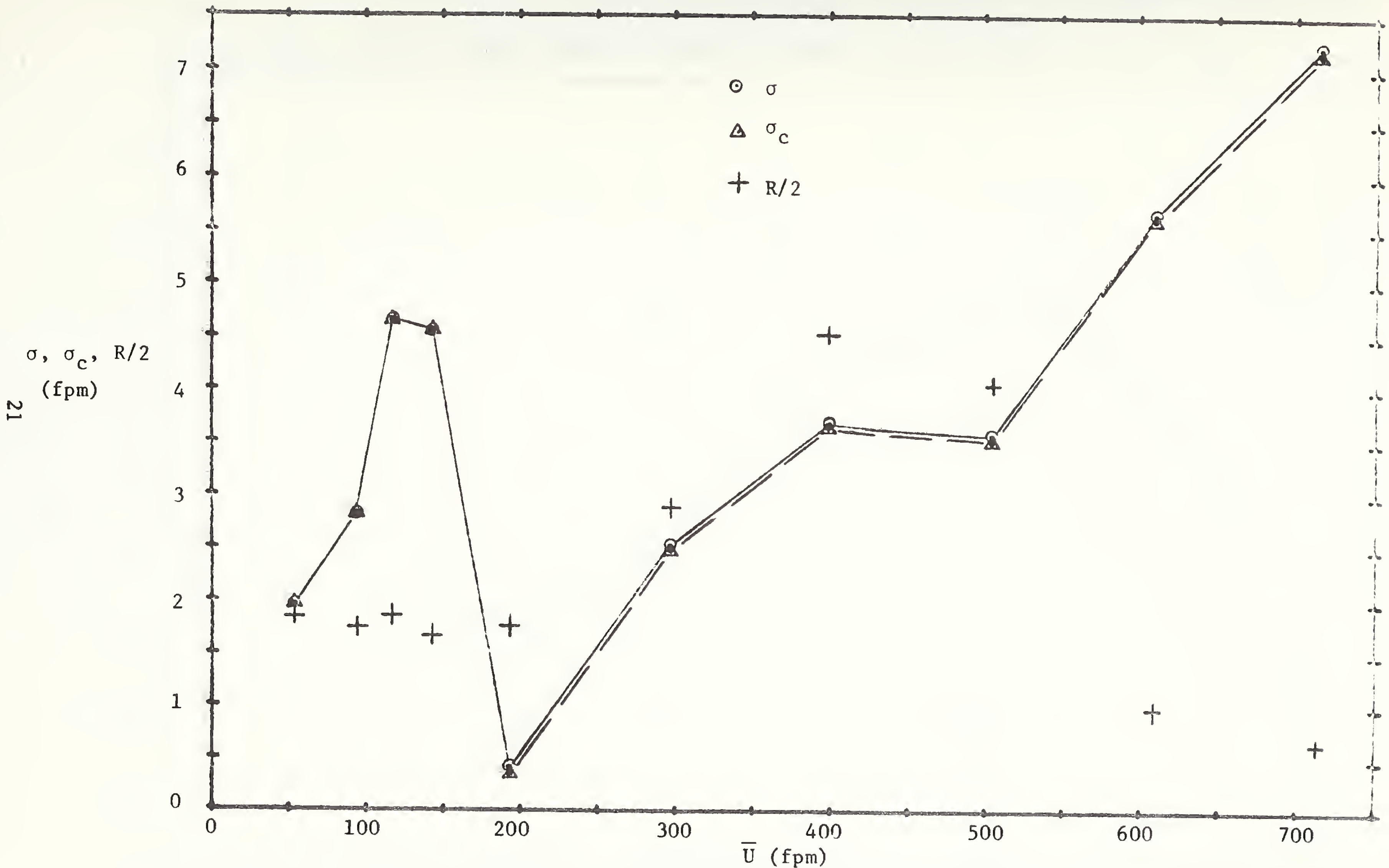

FIGURE 6. STANDARD DEVIATION, σ, AND CORRECTED STANDARD DEVIATION, σ_c, OF INDICATED VELOCITY IN TERMS OF TRUE VELOCITY, HIGH RANGE. R/2 NOTED.

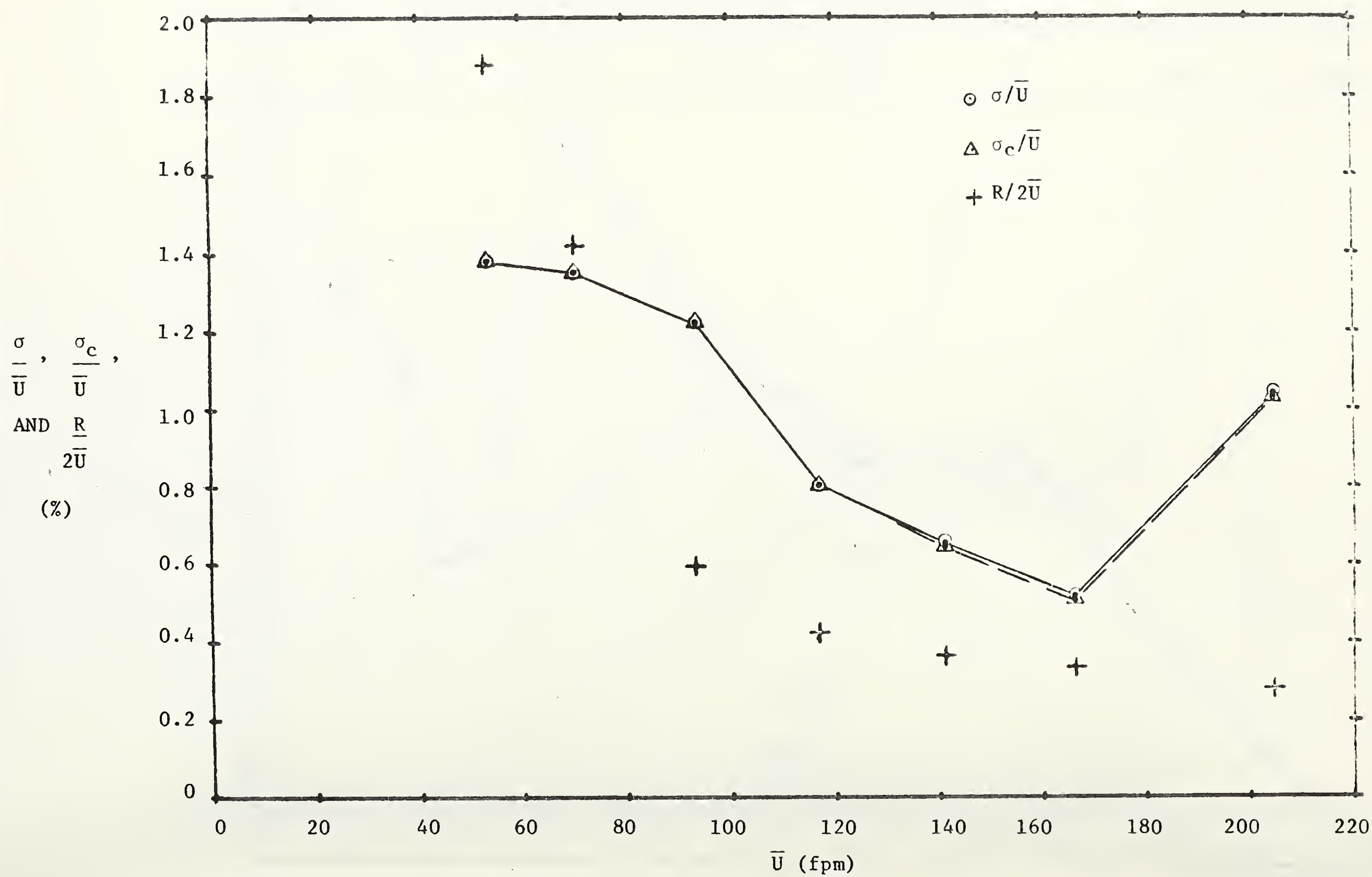

FIGURE 7. STANDARD DEVIATION, σ, AND CORRECTED STANDARD DEVIATION, σ_c, AS PERCENT OF GROUP MEAN VELOCITY, FOR LOW RANGE. R/2 $\overline{U}$ NOTED.

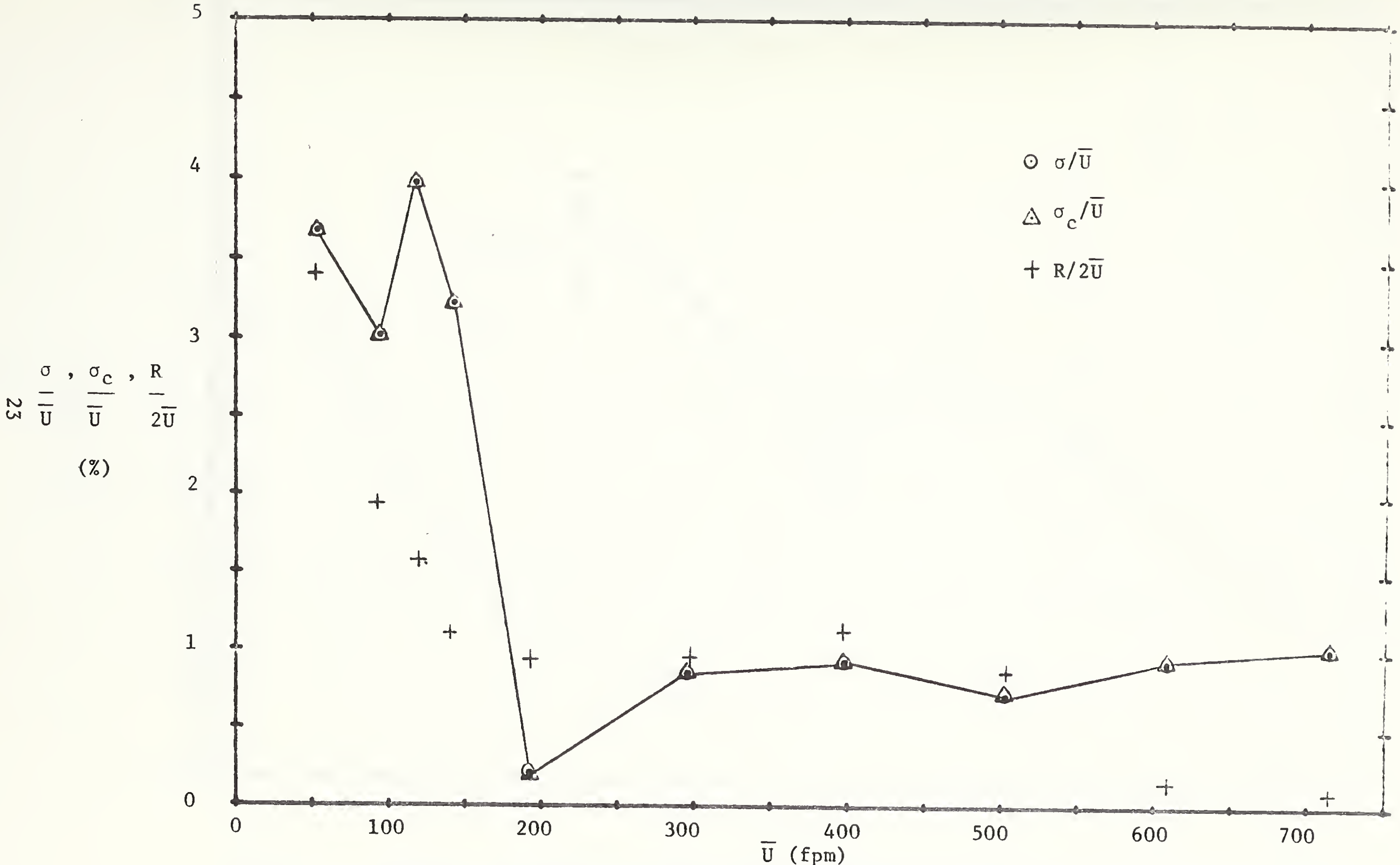

FIGURE 8. STANDARD DEVIATION, σ, AND CORRECTED STANDARD DEVIATION, σ_c, AS PERCENT OF GROUP MEAN VELOCITY, $\overline{U}$, FOR HIGH RANGE. R/2U NOTED.

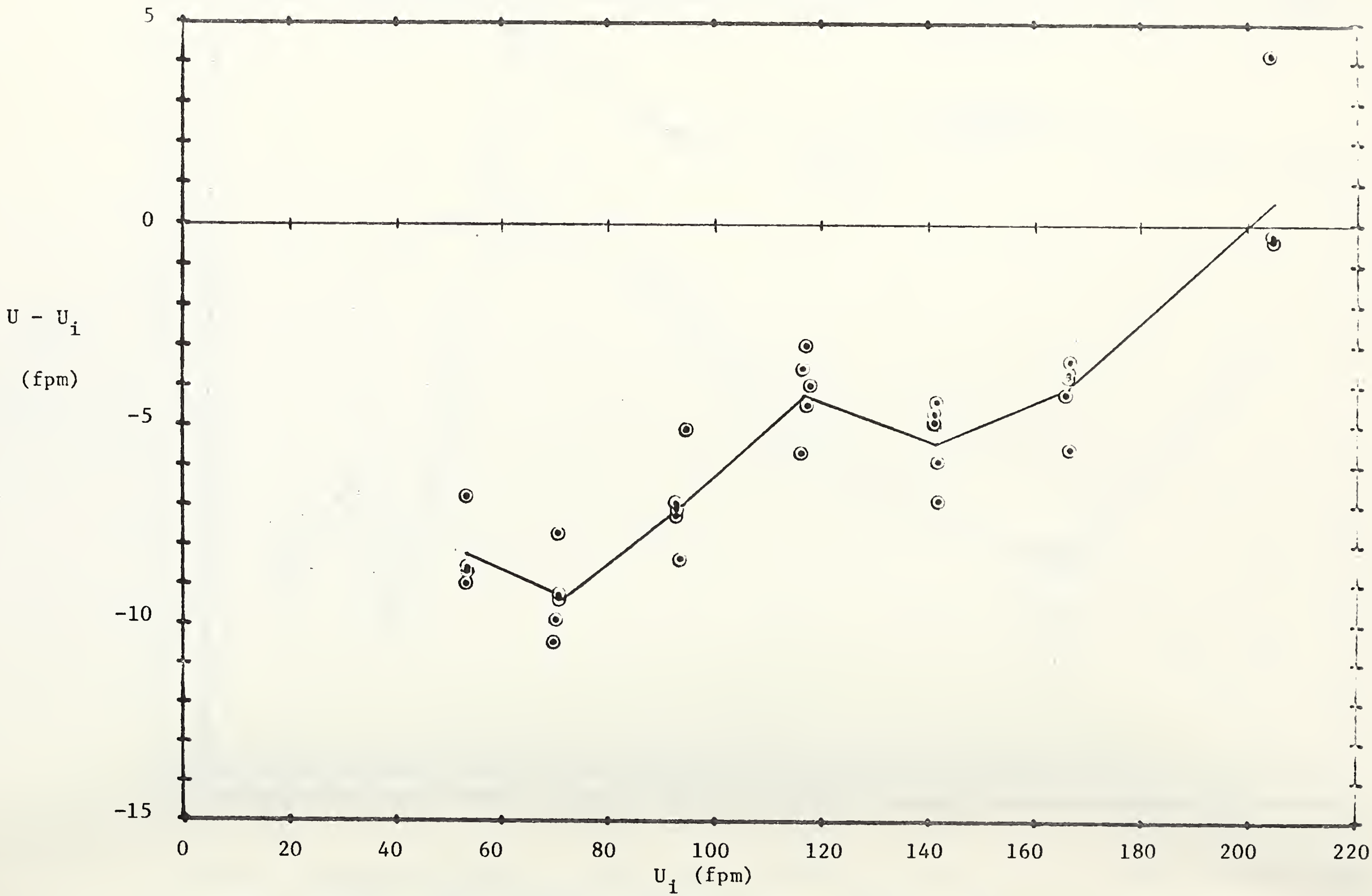

FIGURE 9. DEVIATION OF INDICATED VELOCITY FROM TRUE VELOCITY, LOW RANGE.

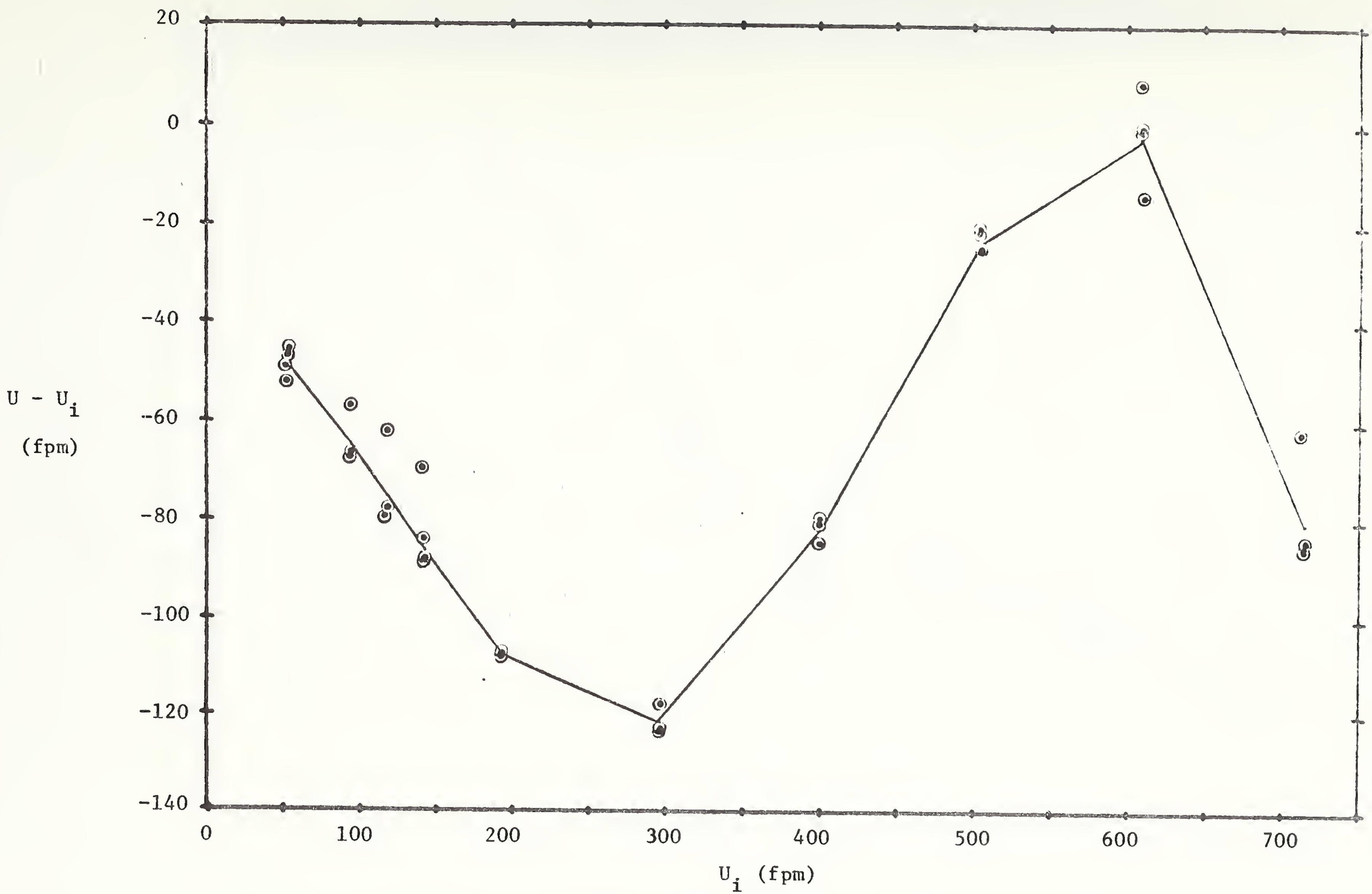

FIGURE 10. DEVIATION OF INDICATED VELOCITY FROM TRUE VELOCITY, HIGH RANGE.

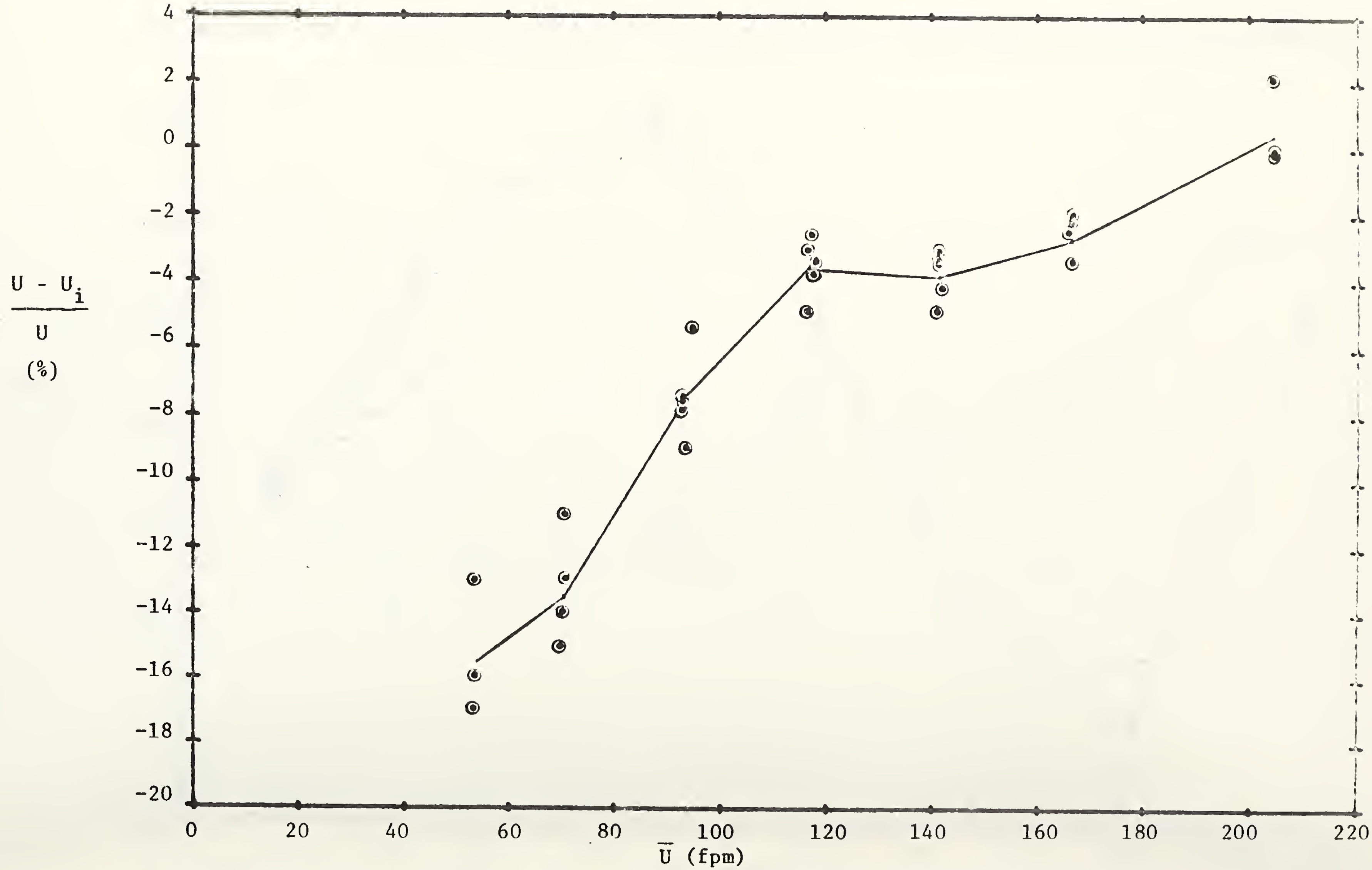

FIGURE 11. PERCENT DEVIATION OF INDICATED VELOCITY FROM TRUE VELOCITY, LOW RANGE.

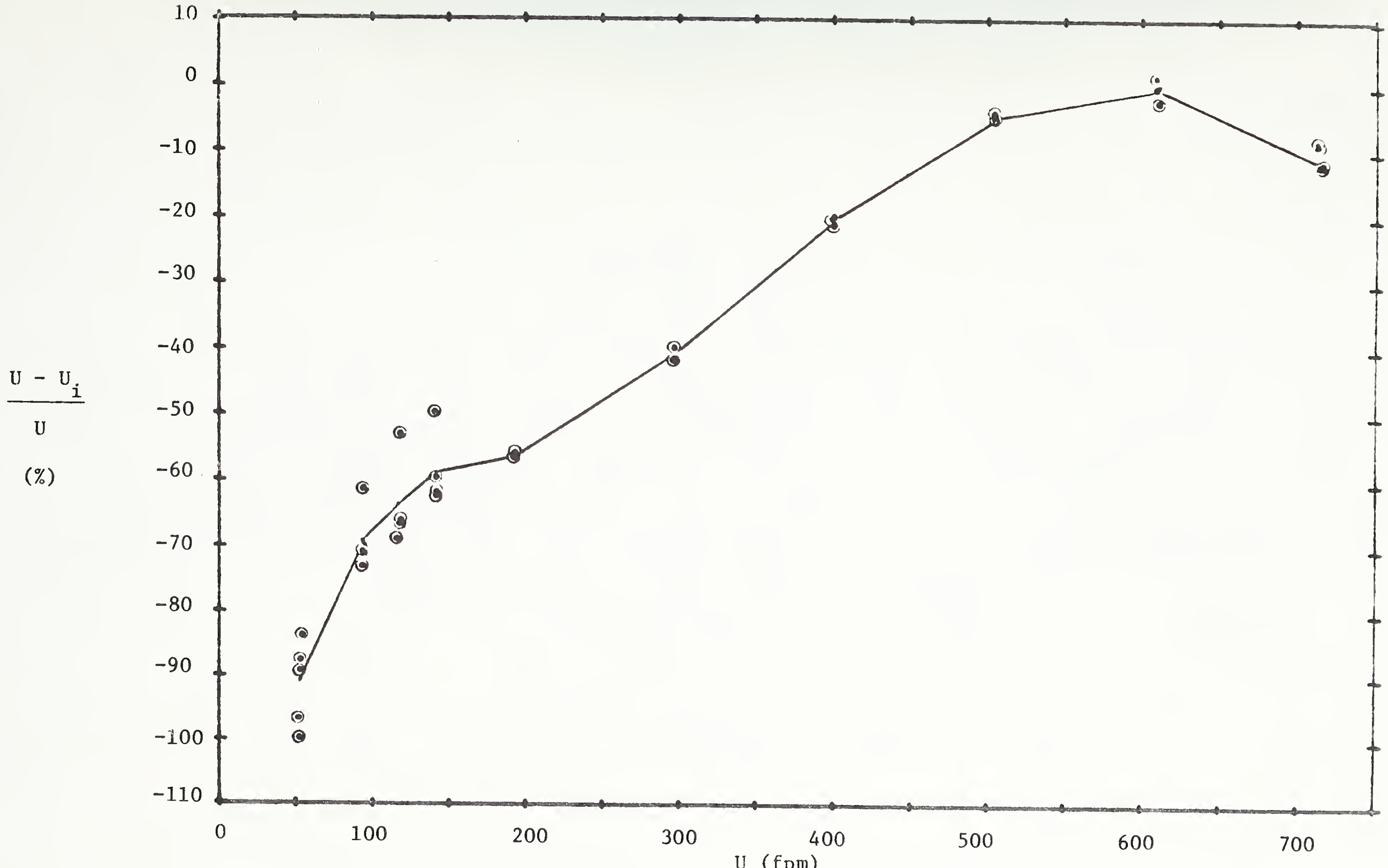

FIGURE 12. PERCENT DEVIATION OF INDICATED VELOCITY FROM TRUE VELOCITY, HIGH RANGE.