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Low Velocity Performance of a Magnetic Pick-Up Vane Anemometer

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

December 1978

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

Issued January 1979

Prepared for
United States Department of the Interior
Bureau of Mines

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and Process Technology
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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 magnetic pick-up vane anemometer is evaluated over the speed range of 54.9 to 717 feet per minute including starting and stopping speed. 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; laser velocimeter; low velocity; mine ventilation; vane anemometers; 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 January 1, 1978 to April 30, 1978. This report was submitted by the author December 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
$\overline{U}$	group mean true velocity
$\overline{U}_i$	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 MAGNETIC PICK-UP VANE 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 (Abbirko Instruments, Ltd., Flowmaster, S/N 6184)[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's vane housing is approximately 2.75 inches in diameter (see Figure 1) with an attached block for the magnetic pick-up, and a handle projecting down from the block. The magnetic pick-up detects the passage of the metal vanes, and the resulting electrical signal is converted to a deflection of a meter connected to the probe by a cable. The meter was located outside the tunnel during the tests and was oriented horizontally. Three ranges of operation are selectable, low - 0 to 300 fpm, medium - 0 to 1000 fpm, and high - 0 to 3000 fpm. The anemometer requires a 9 volt battery for operation.

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

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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.

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 streamwise velocity upstream of anemometers previously tested - anemometers which offered greater blockage than the present one, e.g., [2], was measured on the centerline of the test section 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 measurements. It was found that a distance of less than 30 cm upstream of the anemometers was sufficient. Thus 30 cm was also chosen for the anemometer reported on here. With no anemometer in the tunnel, variation in velocity along the centerline is imperceptible over this 30 cm distance.

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 ten different velocities for the low range, nine for the medium range, and seven for the high range. The data are presented in chronological order in Tables 1A to 1E, 2A to 2E, and 3A to 3E for the low, medium and high ranges, respectively.

To determine the starting speeds of the instrument, the velocity in the tunnel was increased from below the starting speed at a smooth acceleration of approximately 30 fpm/min until movement of the vanes could be detected by eye. At that moment the air velocity would be fixed and the laser velocimeter measurements initiated. If the anemometer continued rotating for at least thirty seconds and did not decelerate, the measurement of velocity by the laser velocimeter was recorded as the starting speed. Five such measurements are presented in Table 4 and have an average of 59.6 fpm and a standard deviation of 0.6 fpm.

Because of the anemometer's angular momentum, stopping speed is more difficult to determine than starting speed. Some preliminary runs indicated that a two minute interval between reductions in air velocity of approximately 2 fpm was sufficient for the anemometer to come to rest if the stopping speed had been reached. Five such measurements are presented in Table 5 with an average of 39.5 fpm and a standard deviation of 0.6 fpm.

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 fitted 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)	Medium Range (fpm)	High Range (fpm)
$U < 60.0$	$U < 70.0$	$U < 150$
$60.0 < U < 70.0$	$70.0 < U < 90.0$	$150 < U < 250$
$70.0 < U < 80.0$	$90.0 < U < 150$	$250 < U < 350$
$80.0 < U < 90.0$	$150 < U < 250$	$350 < U < 450$
$90.0 < U < 100$	$250 < U < 350$	$450 < U < 550$
$100 < U < 130$	$350 < U < 450$	$550 < U < 650$
$130 < U < 180$	$450 < U < 550$	$650 < U$
$180 < U < 220$	$550 < U < 650$	
$220 < U < 280$	$650 < U$	
$280 < U$		

Since the groups of data are compact (small range of U within a group; see Figures 2, 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 group ($\bar{U} > 280$ and 650 fpm) there is only one adjacent group, and thus the line segment for the lowest groups ($U < 60$, 70, and 150 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 $\sigma_i(\bar{U})$ 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 and σ_c are presented in Figures 5, 6, and 7 as velocity and in Figures 8, 9, and 10 as percentage of $\bar{U}$. 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 2, 3, and 4 as dashed lines.

The actual differences between the true and indicated velocities, $U - U_i$, are presented in Figures 11, 12, and 13 and as a percentage of U in Figures 14, 15 and 16. 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 <u>large</u> (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:

<u>Low Range</u>

$U_i < 300$ fpm, $R_i = 1/10$ division or 2 fpm

<u>Medium Range</u>

$U_i < 1000$ fpm, $R_i = 1/10$ division or 5 fpm

<u>High Range</u>

$U_i < 3000$ fpm, $R_i = 1/5$ division or 20 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, 6, and 7 in units of velocity and in Figures 8, 9, and 10 as percentage of $\bar{U}$. As may be seen in Figures 5, 6, and 7, 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. 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 a battery 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 magnetic pick-up vane anemometer has been evaluated at air speeds up to 717 fpm. Evaluation of the repeatability was found to involve considering 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. Starting and stopping speed measurements are presented and give an average starting speed of 59.6 fpm and an average stopping speed of 39.5 fpm.

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
Abbirko Flowmaster
S/N 6184
Low Range

Indicated Air Speed, fpm	True Air Speed, fpm
50	59.9
52	64.1
64	74.5
74	86.1
86	97.2
96	108.4
144	157
184	200
228	248
272	300

T = 20.8°C
B = 758.4 mm Hg

Table 1B
Abbirko Flowmaster
S/N 6184
Low Range

Indicated Air Speed, fpm	True Air Speed, fpm
50	59.6
54	64.0
64	74.0
76	86.4
86	97.1
98	108.8
144	157
186	200
228	250
274	299

T = 20.8°C
B = 758.4 mm Hg

Table 1C
Abbirko Flowmaster
S/N 6184
Low Range

Indicated Air Speed, fpm	True Air Speed, fpm
52	59.8
54	64.1
64	74.3
76	86.2
86	96.7
98	107.8
144	157
184	199
230	249
274	298

T = 20.9°C
B = 758.4 mm Hg

Table 1D
Abbirko Flowmaster
S/N 6184
Low Range

Indicated Air Speed, fpm	True Air Speed, fpm
48	54.9
50	60.0
60	72.1
74	82.8
84	94.4
98	106.8
142	155
184	198
228	248
272	299

T = 22.2°C
B = 750.3 mm Hg

Table 1E
Abbirko Flowmaster
S/N 6184
Low Range

Indicated Air Speed, fpm	True Air Speed, fpm
50	56.6
52	60.7
60	72.1
76	84.2
84	95.3
98	106.4
142	155
182	199
228	249
272	298

T = 22.3°C
B = 751.1 mm Hg

Table 2A
Abbirko Flowmaster
S/N 6184
Medium Range

Indicated Air Speed, fpm	True Air Speed, fpm
30	63.4
55	86.1
75	108.1
170	199
265	299
370	402
475	507
585	611
685	716

T = 20.8°C
B = 758.4 mm Hg

Table 2B
Abbirko Flowmaster
S/N 6184
Medium Range

Indicated Air Speed, fpm	True Air Speed, fpm
25	64.4
55	86.1
80	108.2
170	200
270	298
375	401
480	507
585	612
685	716

T = 20.9°C
B = 758.4 mm Hg

Table 2C
Abbirko Flowmaster
S/N 6184
Medium Range

Indicated Air Speed, fpm	True Air Speed, fpm
25	59.9
50	82.8
75	106.2
165	199
265	298
370	402
475	506
580	611
685	714

T = 22.2°C
B = 750.0 mm Hg

Table 2D
Abbirko Flowmaster
S/N 6184
Medium Range

Indicated Air Speed, fpm	True Air Speed, fpm
25	61.1
50	83.6
80	107.5
170	199
265	299
375	402
485	506
585	611
690	716

T = 22.3°C
B = 750.8 mm Hg

Table 2E
Abbirko Flowmaster
S/N 6184
Medium Range

Indicated Air Speed, fpm	True Air Speed, fpm
25	61.2
50	83.0
75	106.8
170	199
265	299
375	402
480	506
585	611
685	717

T = 22.4°C
B = 751.2 mm Hg

Table 3A
Abbirko Flowmaster
S/N 6184
High Range

Indicated Air Speed, fpm	True Air Speed, fpm
80	107.4
170	199
270	298
370	401
480	506
580	612
690	711

T = 20.6°C
B = 758.4 mm Hg

Table 3B
Abbirko Flowmaster
S/N 6184
High Range

Indicated Air Speed, fpm	True Air Speed, fpm
90	108.6
170	199
270	299
380	403
480	507
590	613
690	716

T = 20.9°C
B = 758.4 mm Hg

Table 3C
Abbirko Flowmaster
S/N 6184
High Range

Indicated Air Speed, fpm	True Air Speed, fpm
90	106.3
180	198
280	299
380	401
490	505
590	612
695	712

T = 22.1°C
B = 750.0 mm Hg

Table 3D
Abbirko Flowmaster
S/N 6184
High Range

Indicated Air Speed, fpm	True Air Speed, fpm
90	106.7
180	199
280	299
380	403
490	507
590	611
695	715

T = 22.3°C
B = 751.1 mm Hg

Table 3E
Abbirko Flowmaster
S/N 6184
High Range

Indicated Air Speed, fpm	True Air Speed, fpm
80	107.9
180	200
280	299
390	403
490	506
590	612
695	715

T = 22.4°C
B = 751.2 mm Hg

Table 4
Abbirko Flowmaster
S/N 6184

Starting Speed, fpm

59.8	Average: 59.6 fpm
59.2	
58.9	
59.7	Standard
60.5	Deviation: 0.6 fpm

Table 5
Abbirko Flowmaster
S/N 6184

Stopping Speed, fpm

39.0	Average: 39.5 fpm
38.9	
39.5	
40.4	Standard
39.5	Deviation: 0.6 fpm

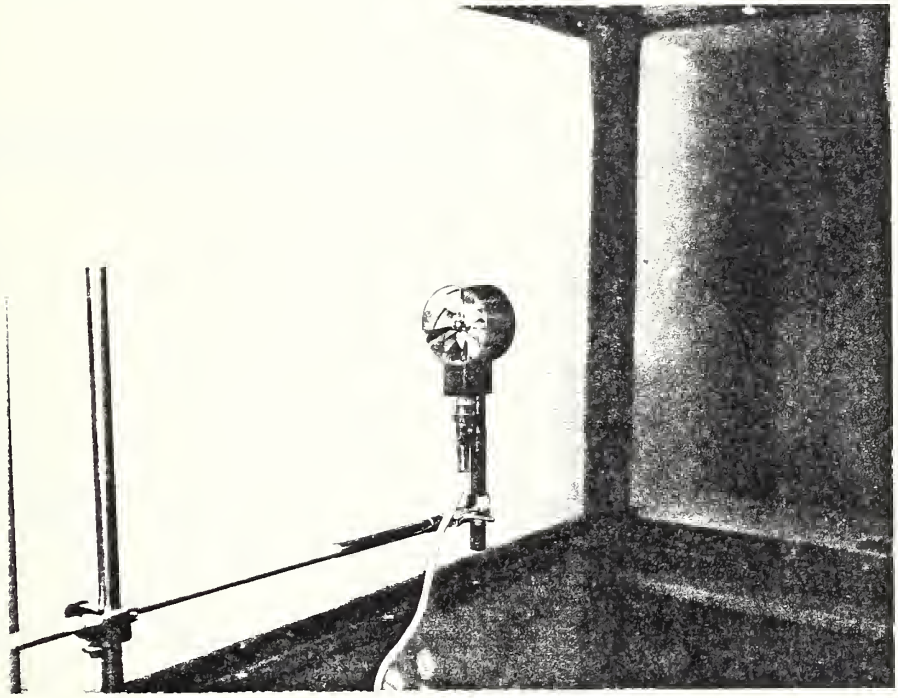

FIGURE 1. THE ANEMOMETER MOUNTED IN THE TUNNEL SHOWING METHOD OF SUPPORT.

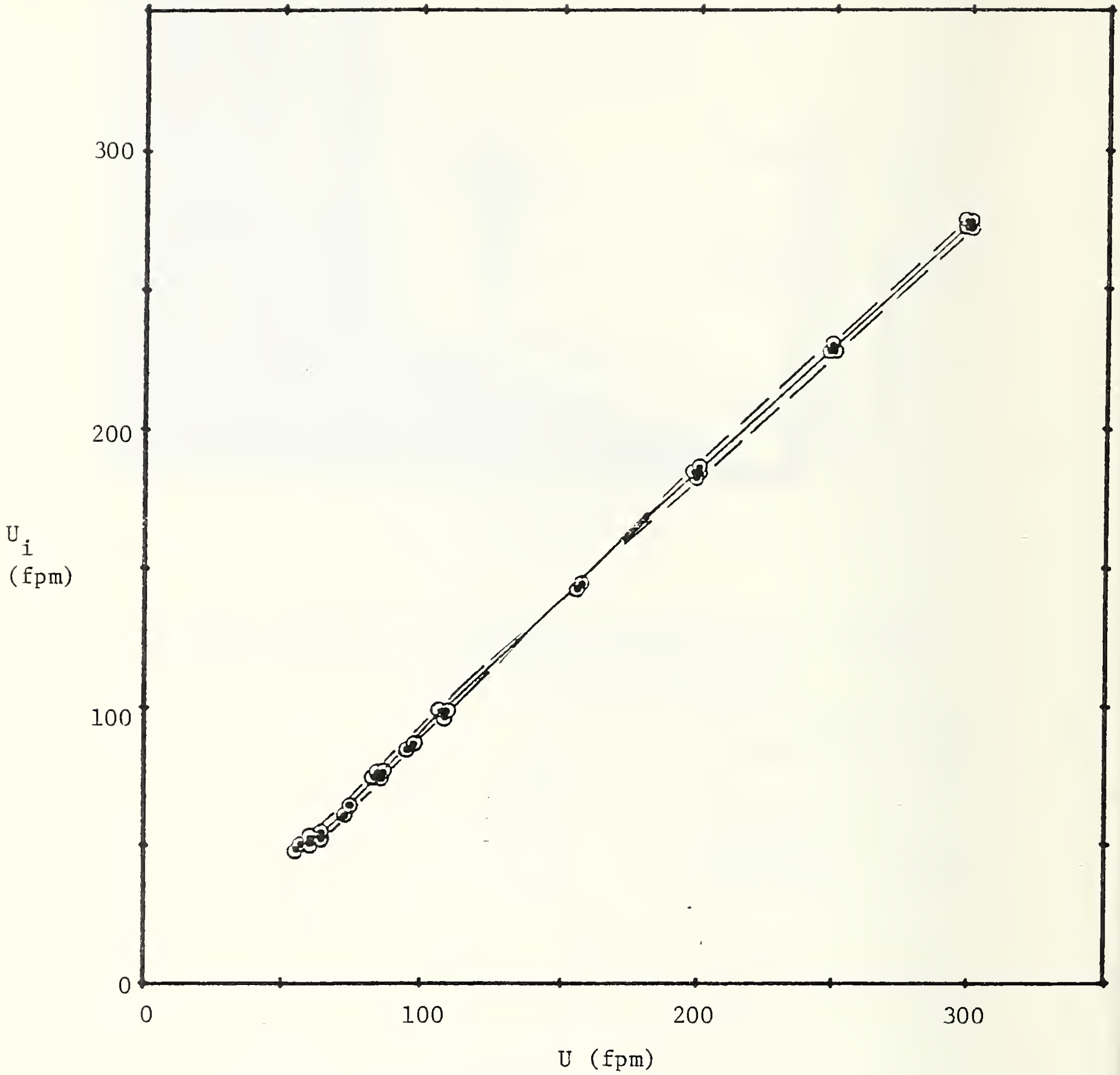

FIGURE 2. INDICATED VERSUS TRUE VELOCITY WITH ± 2σ CURVES, LOW RANGE.

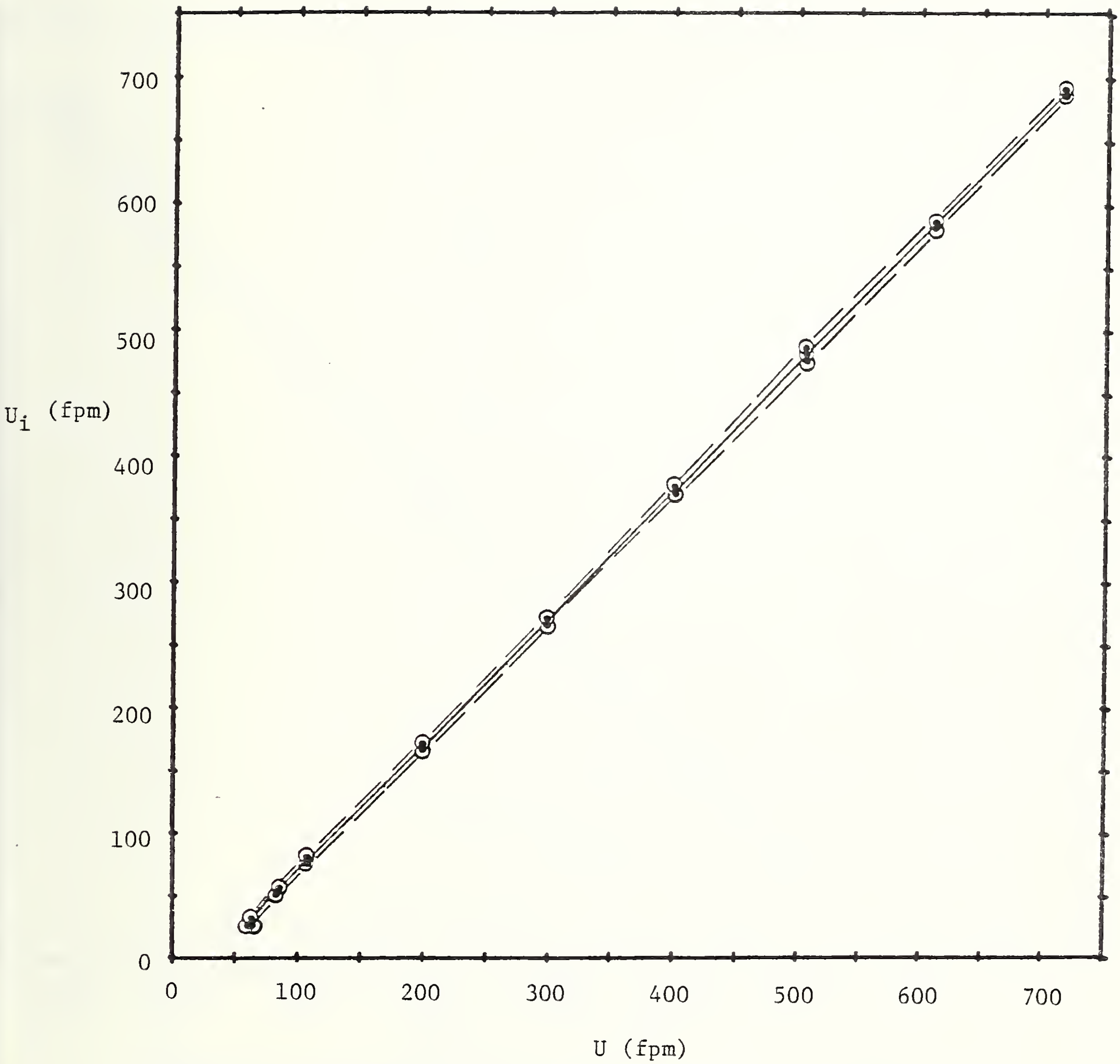

FIGURE 3. INDICATED VERSUS TRUE VELOCITY WITH ± 2σ CURVES, MEDIUM RANGE.

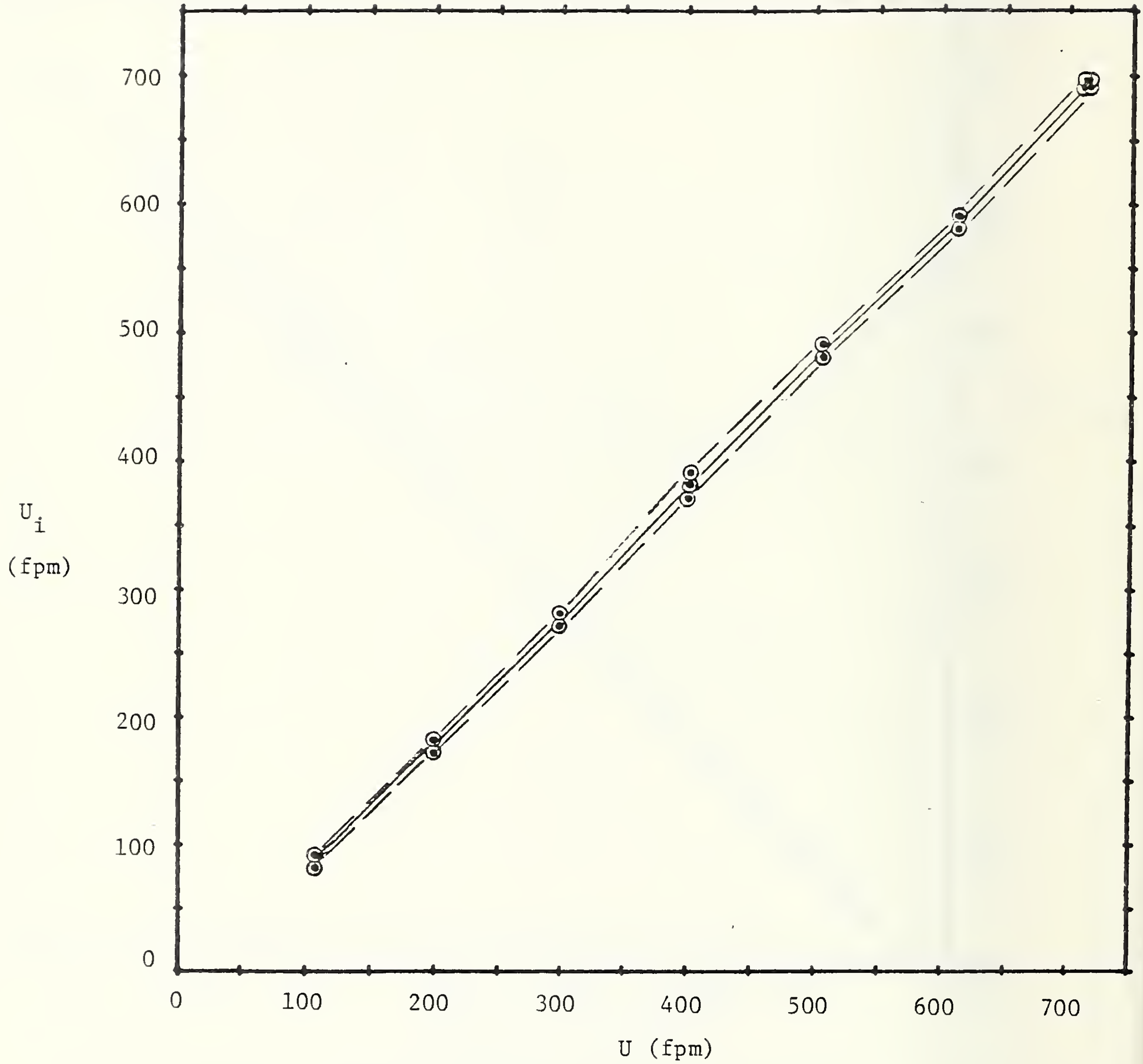

FIGURE 4. INDICATED VERSUS TRUE VELOCITY WITH $\pm 2\sigma$ CURVES, HIGH RANGE.

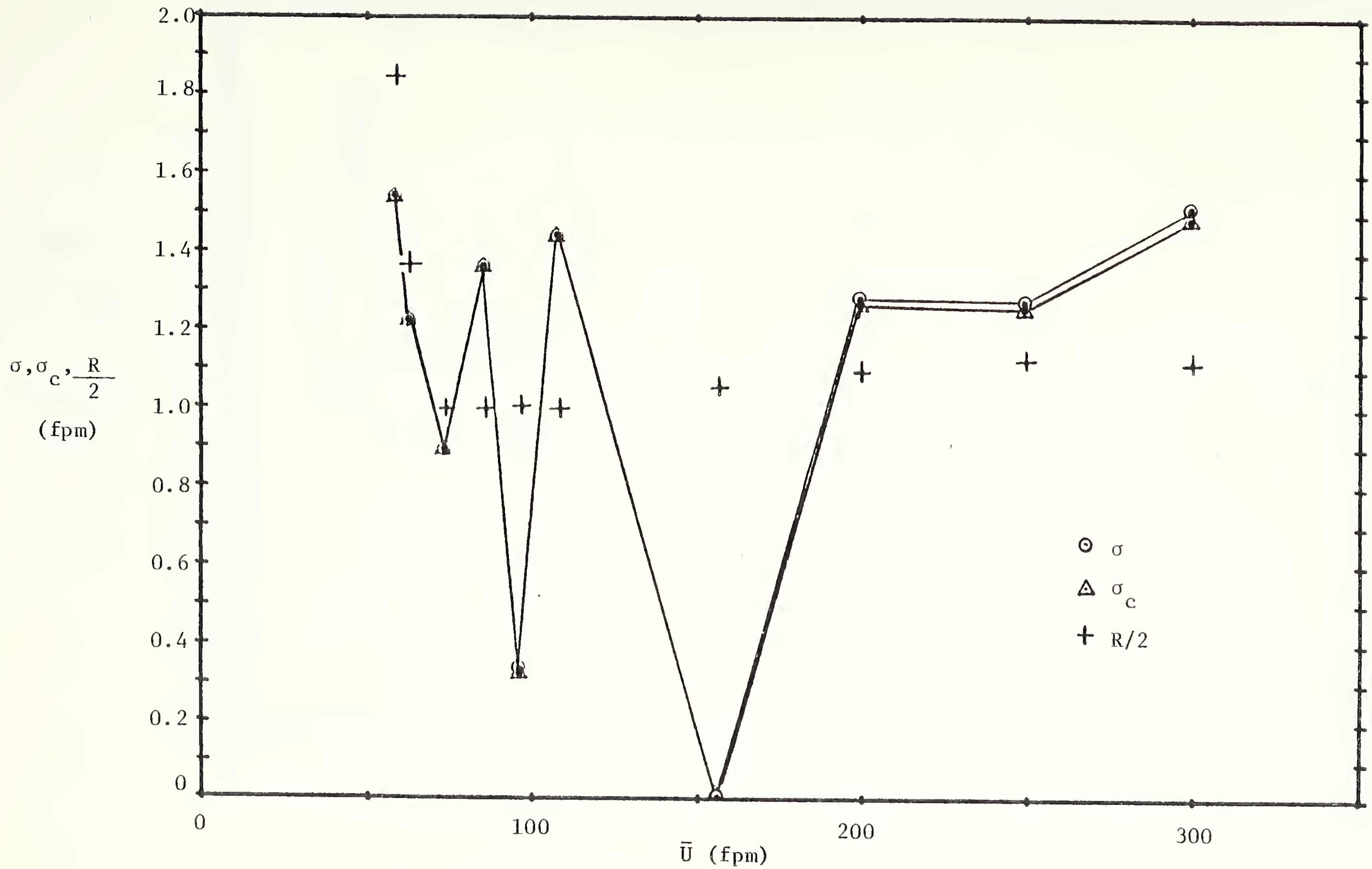

FIGURE 5. σ AND σ_c IN TERMS OF TRUE VELOCITY, LOW RANGE. R/2 NOTED.

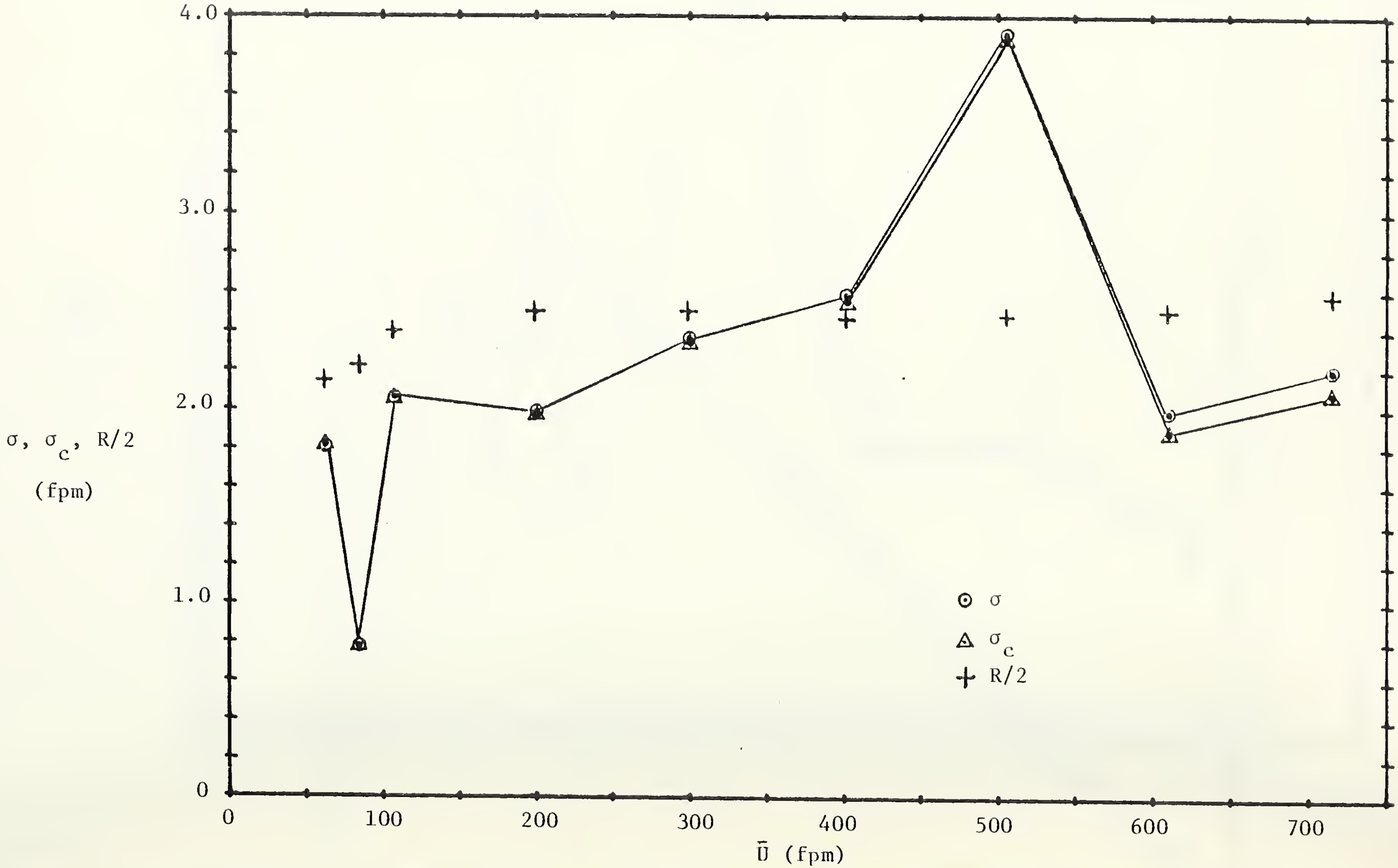

FIGURE 6. σ AND σ_c IN TERMS OF TRUE VELOCITY, MEDIUM RANGE. R/2 NOTED.

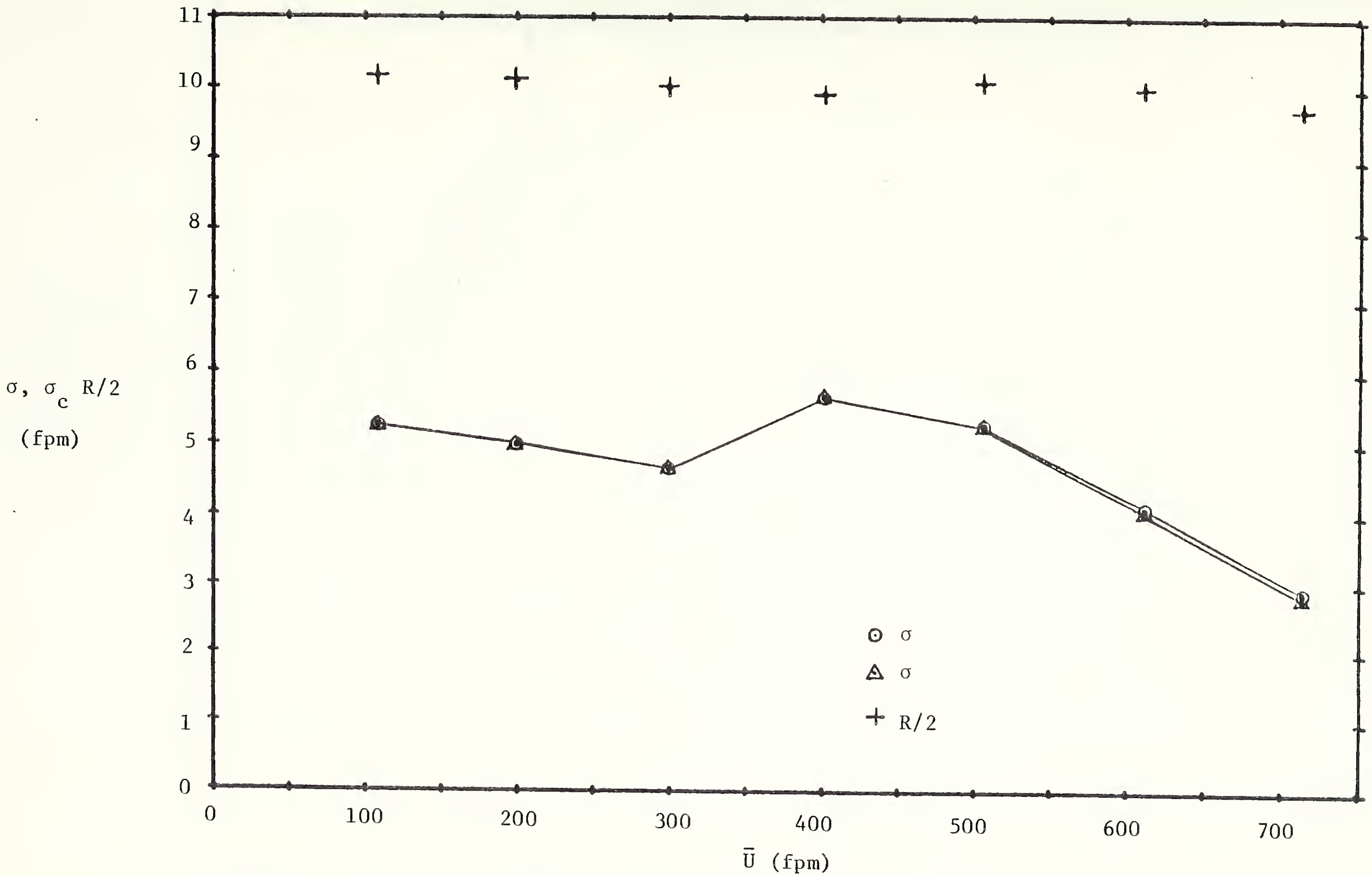

FIGURE 7. σ AND σ_c IN TERMS OF TRUE VELOCITY, HIGH RANGE. R/2 NOTED.

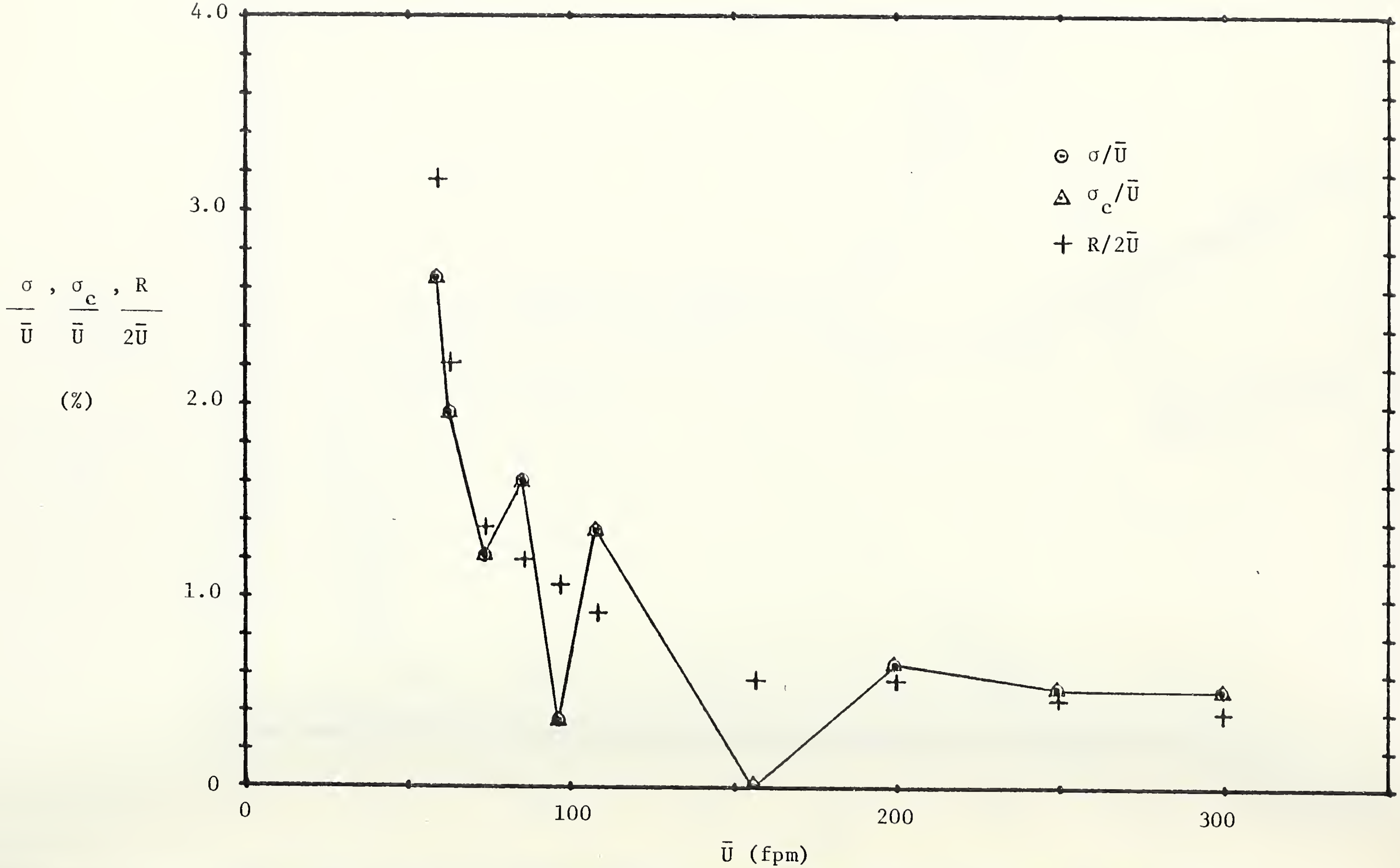

FIGURE 8. σ AND σ_c AS PERCENT OF GROUP MEAN VELOCITY, LOW RANGE. $R/2\bar{U}$ NOTED.

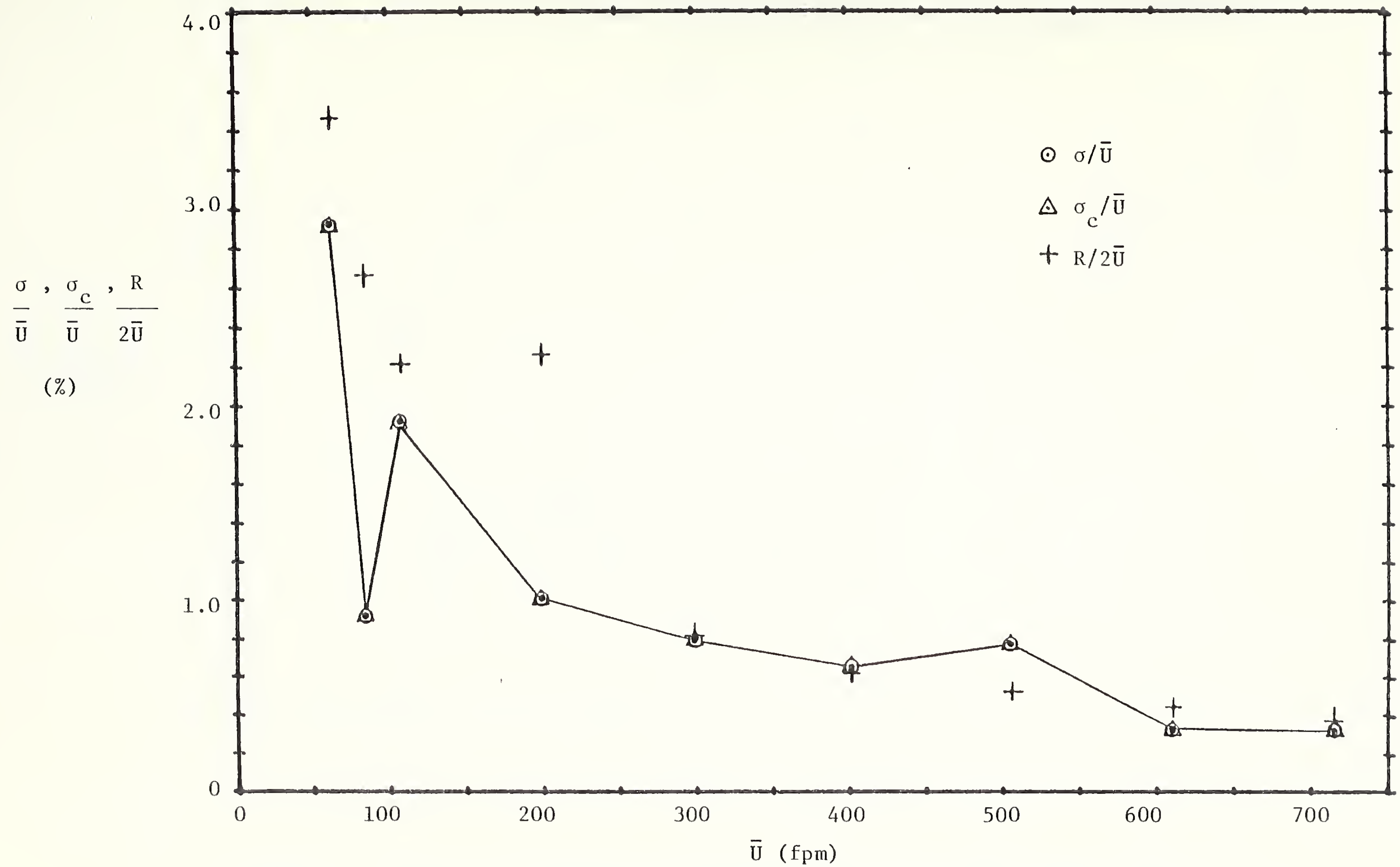

FIGURE 9. σ AND σ_c AS PERCENT OF GROUP MEAN VELOCITY, MEDIUM RANGE. $R/2\bar{U}$ NOTED.

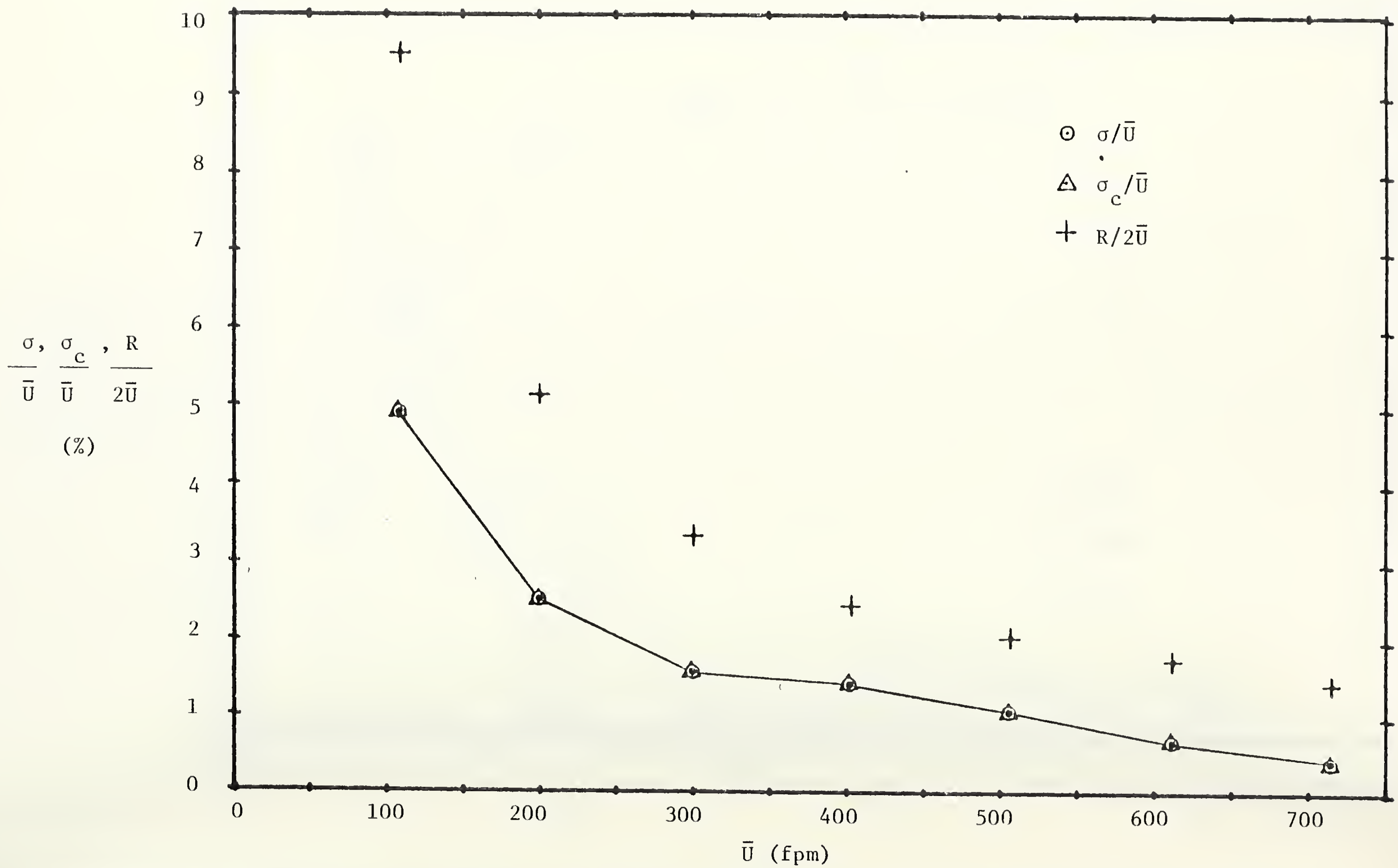

FIGURE 10. σ AND σ_c AS PERCENT OF GROUP MEAN VELOCITY, HIGH RANGE. $R/2\bar{U}$ NOTED.

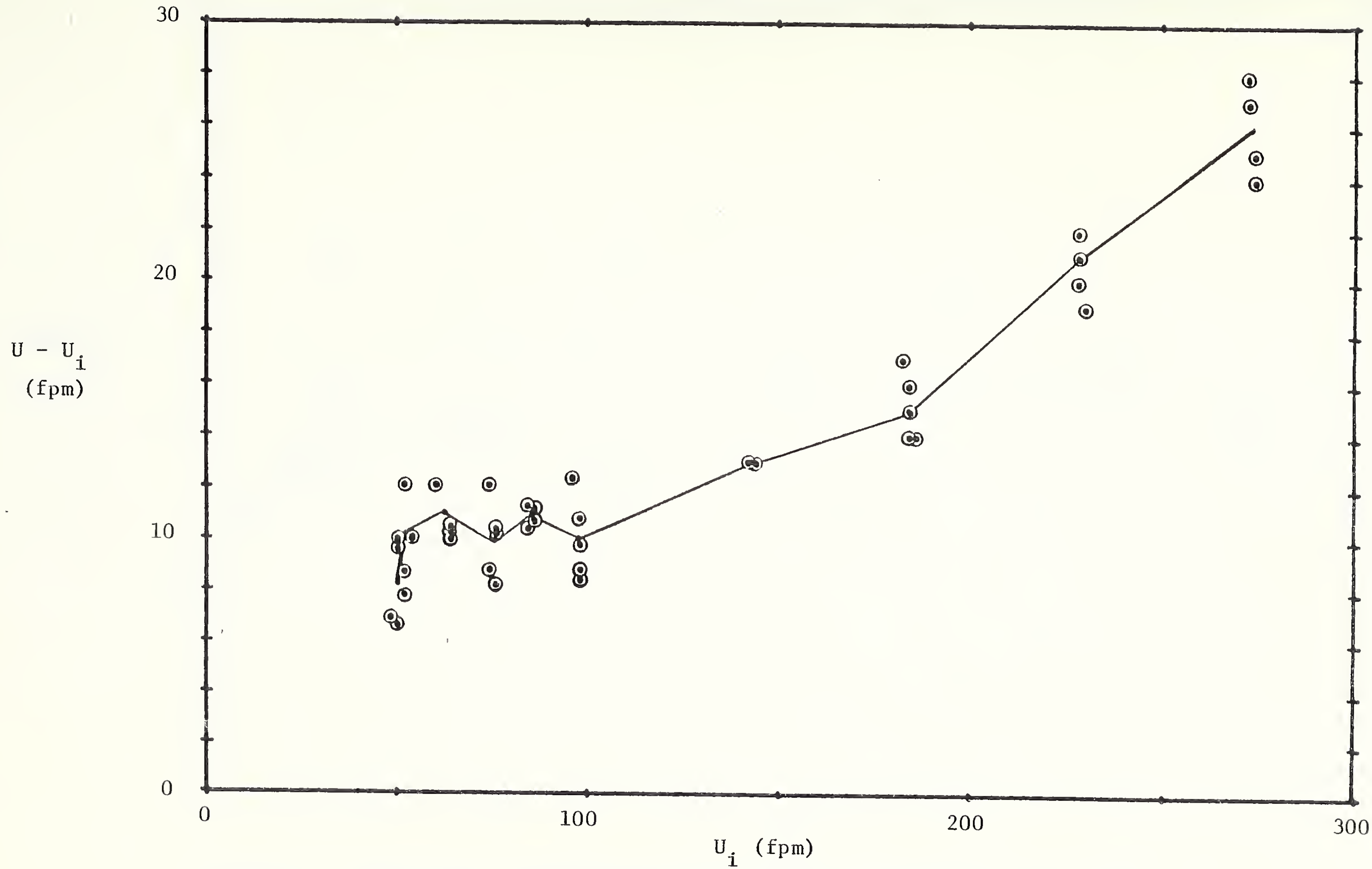

FIGURE 11. DEVIATION OF INDICATED VELOCITY FROM TRUE VELOCITY, LOW RANGE.

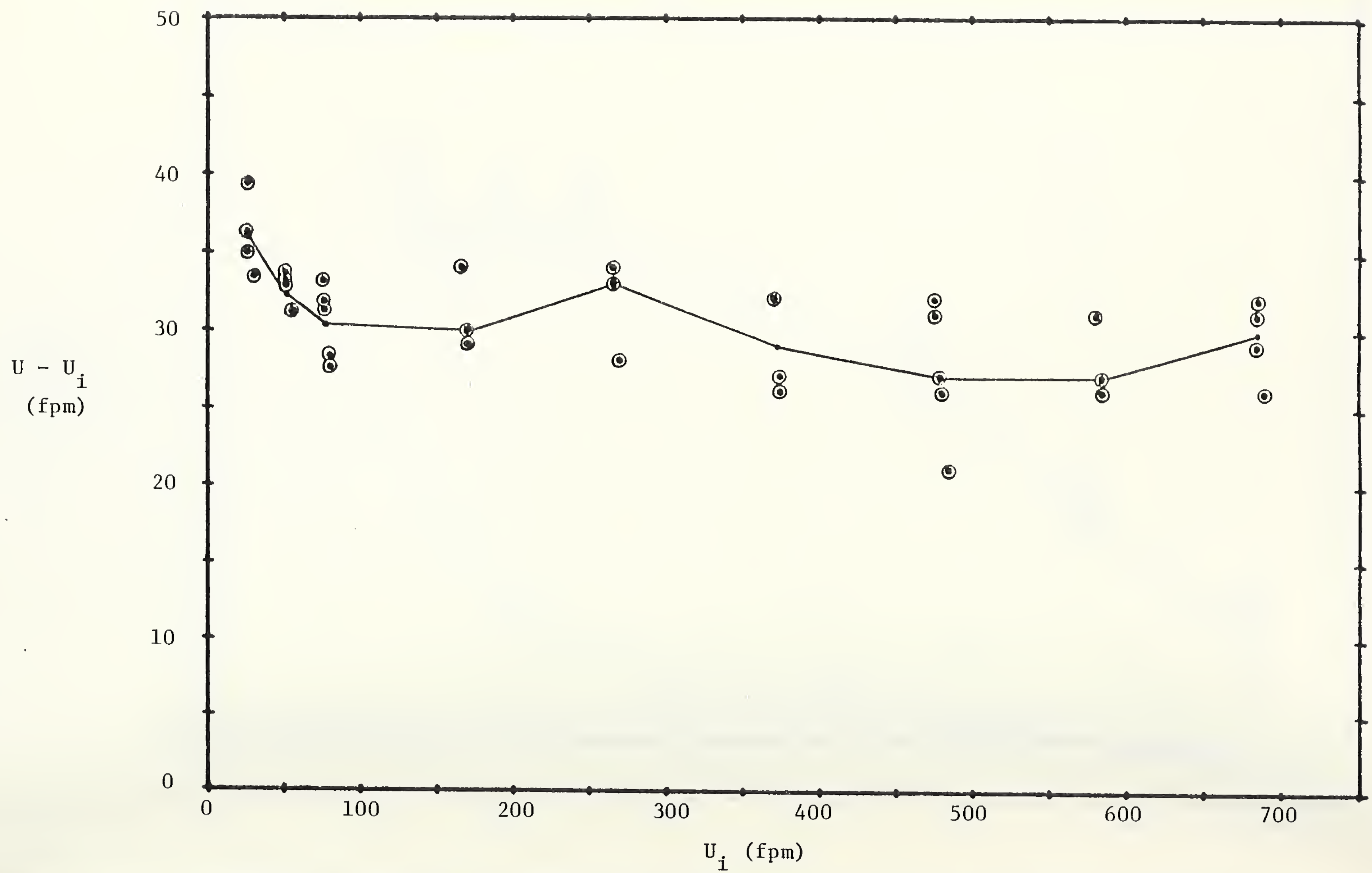

FIGURE 12. DEVIATION OF INDICATED VELOCITY FROM TRUE VELOCITY, MEDIUM RANGE.

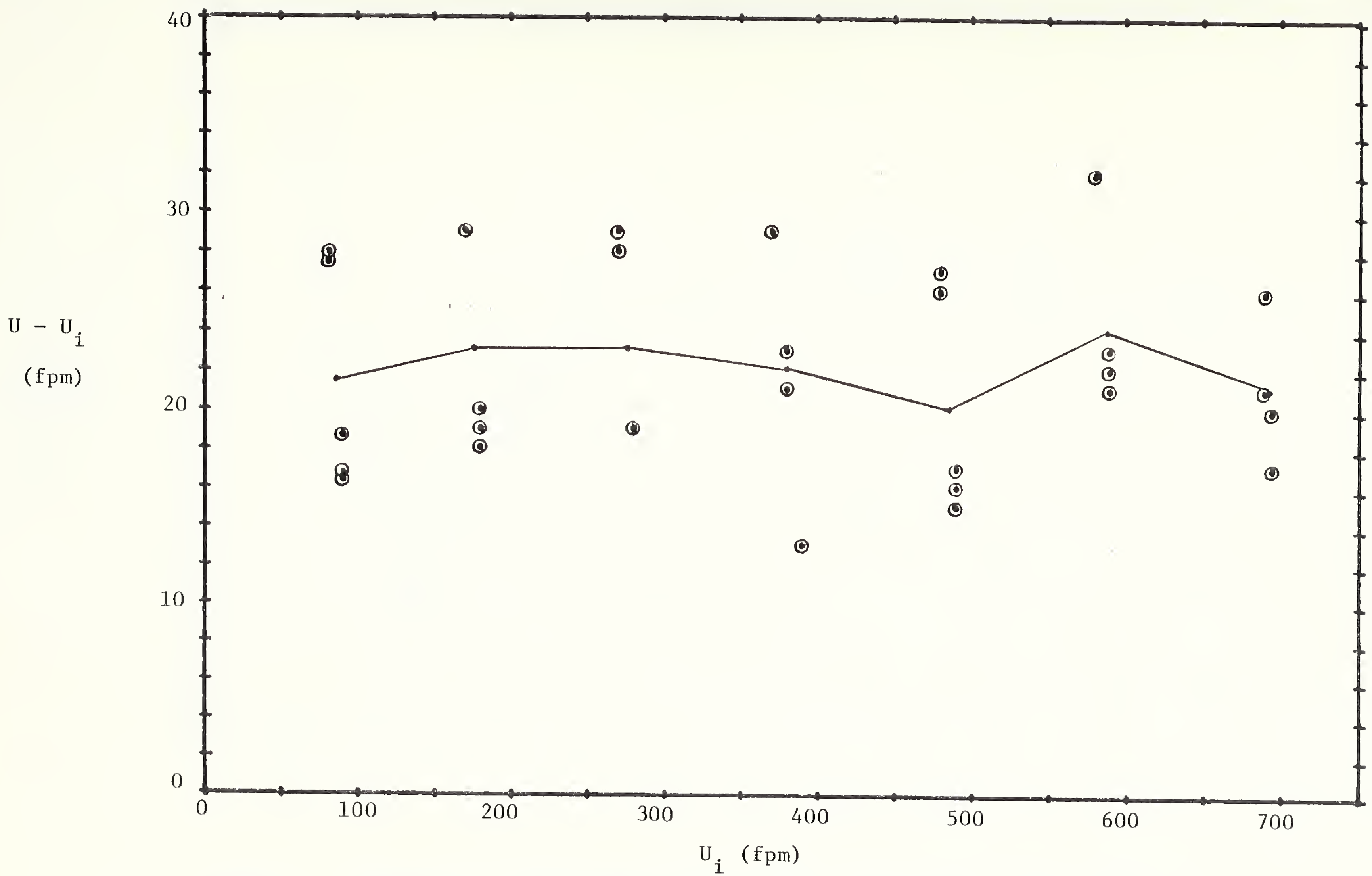

FIGURE 13. DEVIATION OF INDICATED VELOCITY FROM TRUE VELOCITY, HIGH RANGE.

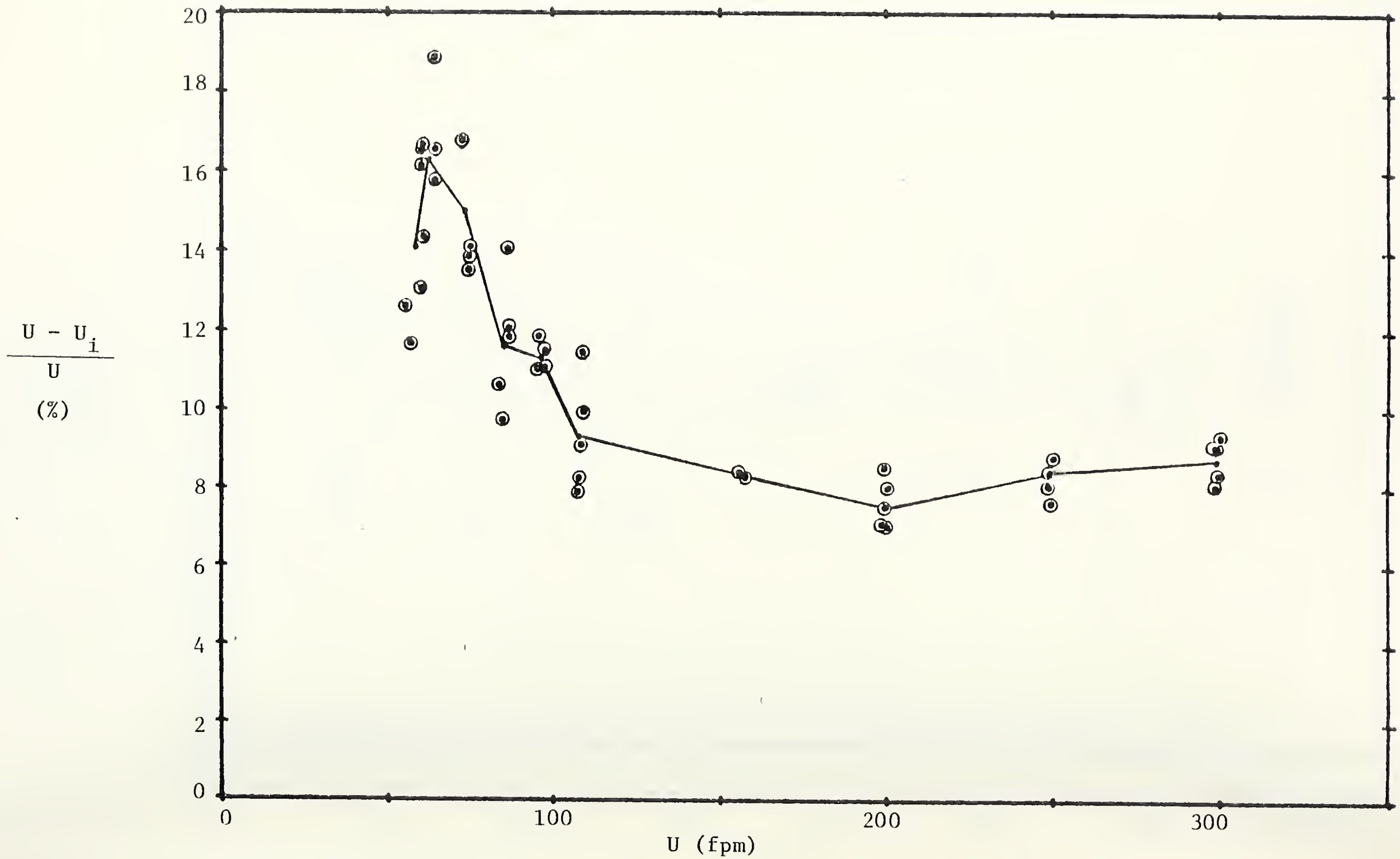

FIGURE 14. PERCENT DEVIATION OF INDICATED FROM TRUE VELOCITY, LOW RANGE.

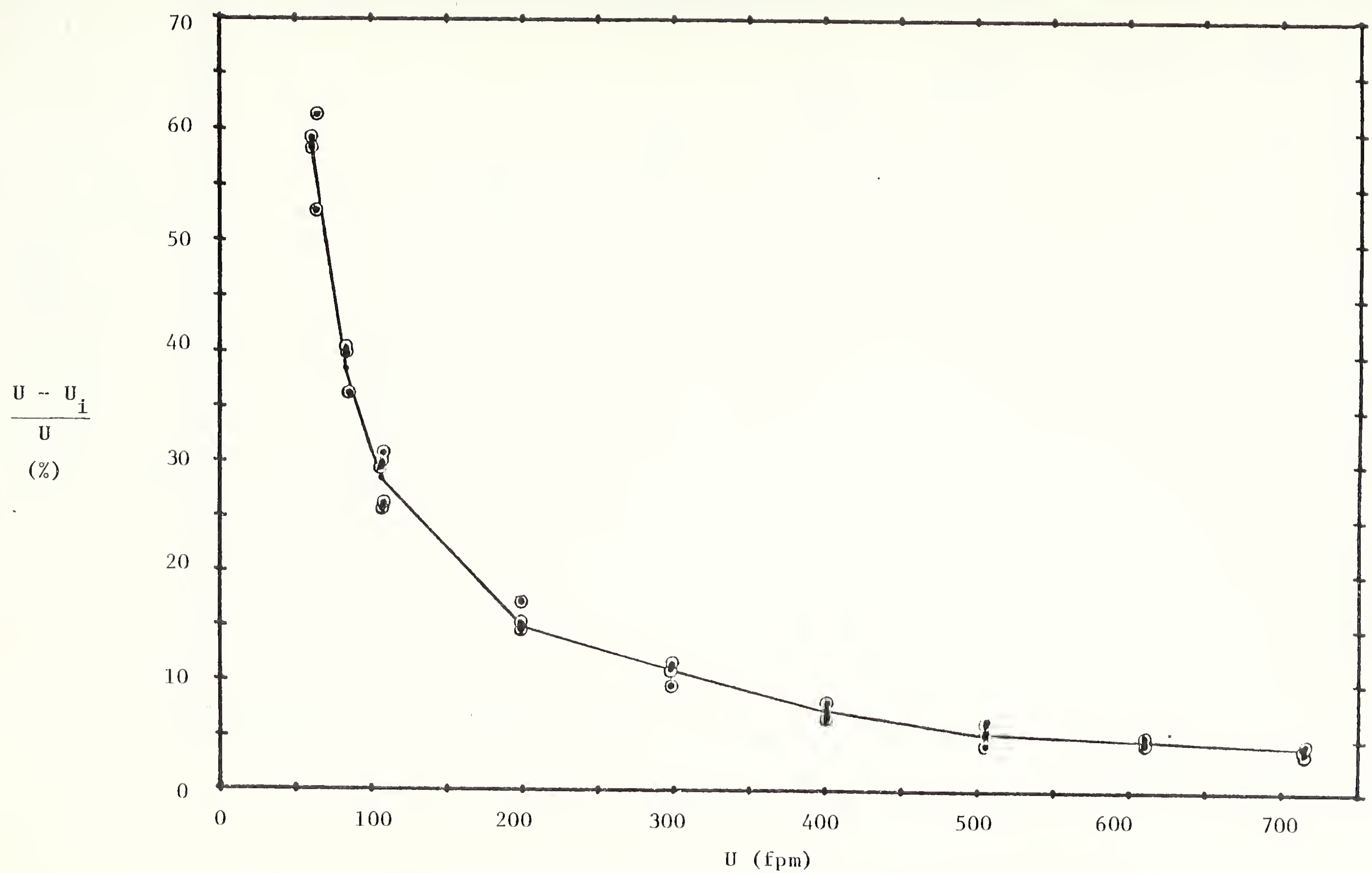

FIGURE 15. PERCENT DEVIATION OF INDICATED FROM TRUE VELOCITY, MEDIUM RANGE.

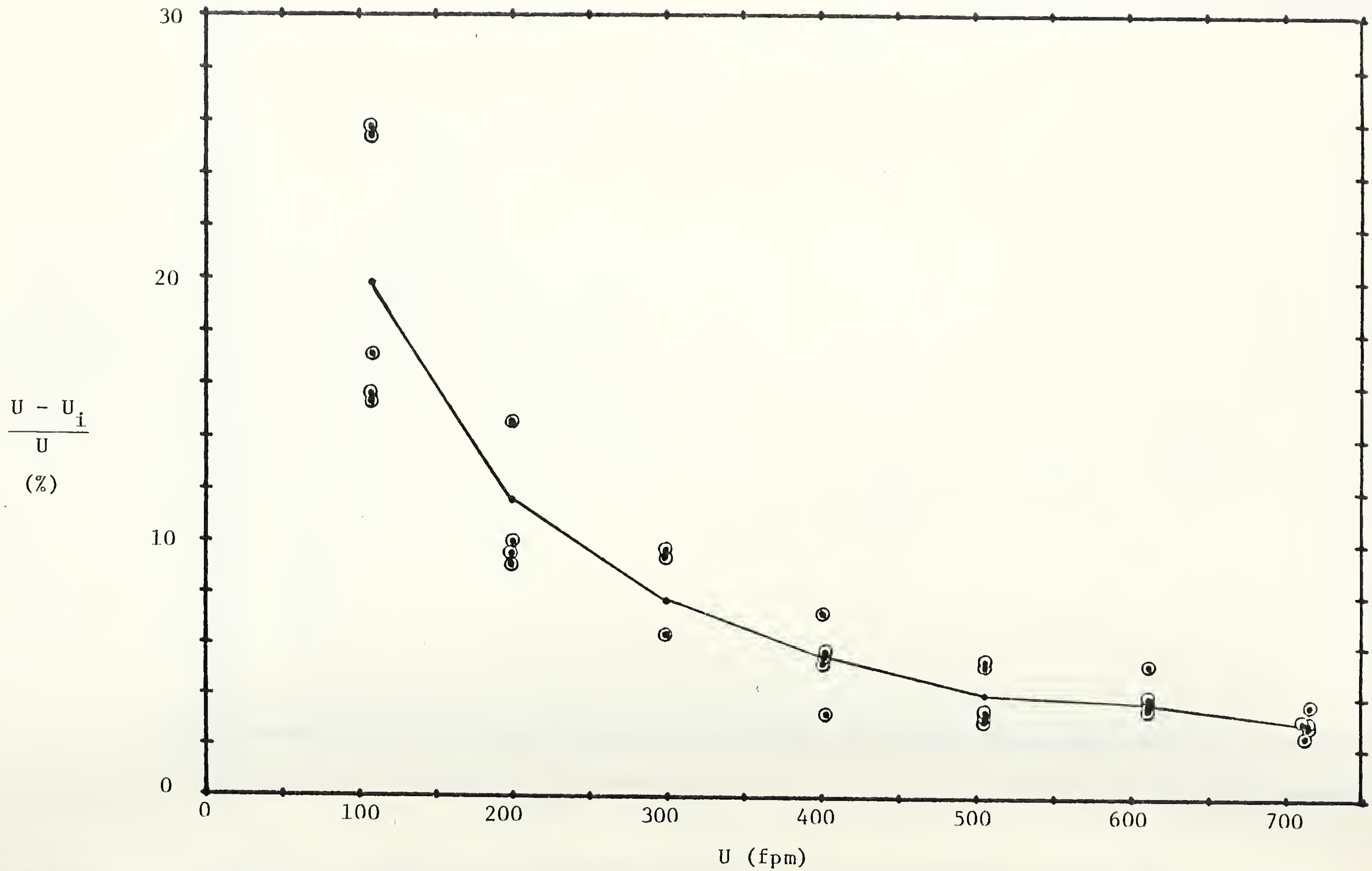

FIGURE 16. PERCENT DEVIATION OF INDICATED FROM TRUE VELOCITY, HIGH RANGE.