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FLOW RATE/PRESSURE DROP DATA GATHERED FROM TESTING A SAMPLE
OF THE SPACE SHUTTLE STRAIN ISOLATION PAD (SIP): EFFECTS
OF AMBIENT PRESSURE COMBINED WITH TENSION AND COMPRESSION
CONDITIONS

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INTRODUCTION

The amount of air that will flow through the Strain Isolation Pad (SIP) for a given pressure differential is a critical parameter in the Shuttle Orbiter Thermal Protection System (TPS) design. On ascent, the flow characteristics of the SIP determines the venting rate of the SIP which, in turn, partially determines the forces on the tile. This problem is of particular interest during the transonic portion of the ascent when the normal shock can rapidly pass over a tile, thus exposing it to the pressure drop across the shock and imposing maximum dependence on the venting capabilities of the TPS. If the SIP could not vent quickly enough, there would be sufficient pressure difference to tear the tile from the SIP. During the descent, some areas of the Orbiter will experience local pressure gradients over the TPS, due either to surface contour or a local excrescence, that are constant for significant periods of time. The flow characteristics of the SIP is one of the factors that determine the amount of hot air that will circulate under the TPS due to a pressure gradient. Filler bar charring has occurred on each of the first five Shuttle flights and is believed to be directly related to this circulation. References 1 and 2 present this problem in detail.

In order to study the damage potential of situations as described in references 1 and 2 , it is necessary to perform engineering calculations of the TPS flow. The parameter of interest is the resistance of the particular medium to the flow. Review of the literature reveals engineering practice and data largely based on packed beds of sand and similar geometries, references. 3, 4, and 5. The TPS components are either narrow empty channels (the tile gaps) which are amenable to study using lubrication theory, or fibrous materials such as the filler bars, interior of the tile, and the SIP. Even for the relatively simple sand bed type of porous media, the literature usually recommends experimental determination of

the resistance coefficient. Overall, the engineering applications to materials involving porous flows is not well understood and, in critical situations, the designs must rely heavily on experimental data.

There has been an ongoing program at the Langley Research Center (LRC) to provide reliable experimental data on representative portions of the TPS and to incorporate these results in a computerized mathematical model in order to be able to predict the flow within the thousands of internal configurations found in the Shuttle Orbiter TPS. Experimental results are documented in reference 6 for the tile interior and a SIP sample, in reference 7 for a wind tunnel simulation and references 7, 8, and 9 for the analysis of the wind tunnel experiment. In the analysis of the data, it became evident that the data on SIP flow in reference 6 did not provide sufficient input for all situations, particularly changes in ambient pressure and changes in SIP geometry due to tile movement. The present paper presents additional experimental data incorporating large changes in ambient pressure and vertical translations of the tile which tend to stretch or compress the SIP. Also, the SIP sample chosen is the 0.170 inch thick type rather than the 0.090 thickness used in reference 6 .

SYMBOLS

A	cross-sectional area of SIP, ft^2
FM1	flow meter measuring flow entering the SIP Flow Simulator
$\dot{m}$	mass flow rate, lb/sec
P_0	standard atmospheric pressure, 14.694 lb/in^2
P_1	static pressure measured at SIP entrance area, lb/in^2
P24	differential pressure measured across the SIP material, lb/in^2
Q	volume flow rate, ft^3/sec
q	dynamic pressure, lb/in^2
V	calculated velocity, Q/A ft/sec
ρ	calculated density, $\rho_0 \dfrac{P_1}{P_0}$
ρ_0	standard density, .0764744 lb/ft^3

DESCRIPTION OF EXPERIMENT

A typical Shuttle Orbiter tile geometry detailing the SIP location is shown in figure 1. The SIP Flow Simulator, shown in figure 2, is intended to provide a flow environment similar to that which exists in flight beneath a Shuttle Orbiter tile and to do so in such a manner that meaningful measurements of the flow rate/pressure drop characteristics can be obtained. The interior design of the SIP Flow Simulator provides a suitable place for the location of the SIP material being tested as well as entrance and exit sections leading to and from the SIP. It is recognized that these sections do not provide the same entrance and exit characteristics as the actual tile - SIP geometry. However, it can be argued that once airflow has reached the area of the SIP in the simulator, similar flow characteristics between the simulator and the actual SIP design can be assumed. Pressure differences across the SIP were generated by the use of a vacuum sphere.

Elongated holes where the four main pieces of the SIP Flow Simulator are joined together provide variable height thickness capabilities for the SIP material. By changing the height of the SIP, the flow rate can be varied by the change in the available flow area. The original SIP height under no load was .170 inches for the sample tested. Other SIP heights tested were .108, .128, and .200 inches. A final run at a SIP height of .170 inches was made and the data was compared with the original 0.170 height data to verify that there were no changes in the interior geometry of the SIP created by the expansion or compression of the material which accompanied the changes in height.

Pressure ports were drilled into the SIP Flow Simulator so that static pressures could be measured. P_1, located at the entrance section, measures the static pressure just ahead of the SIP. It should be noted from figure 3, that air

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is passed into the entrance section of the SIP Flow Simulator on both sides to get more evenly distributed flow and to reduce the pressure drop from the flow meter (FM 1) to the entrance section. A differential pressure measurement was made from port 2 to port 4, figure 2, across 5.125 inches of the SIP material in the direction of the weave (flow parallel to the bulk of the fibers).

Instrumentation used to record the static pressure measurements include: A Bell and Howell 0-15 psia pressure transducer to measure P_1; a Datametrics Barocel Pressure Sensor and Signal Conditioner to measure the pressure differential between port 2 and 4; a Hastings Flowmeter to measure the flow rate entering the SIP Flow Simulator, and three Fluke Digital Volt Meters were used to read the values. (Table 1)

PROCEDURES

In operating this pressure measuring system, all instruments are zeroed daily. Once the instruments have been zeroed, valve V2, figure 3, is closed isolating the system from a 60 ft. vacuum sphere, used to generate flow rate, and then valve V1 is closed preventing any flow through the system. This leaves the SIP Flow Simulator at atmospheric pressure and no flow so that a zero point may be taken for the flowmeter. Test points are taken using V1 and V2 to adjust delta-P24 while maintaining a constant static pressure P_1 at the desired level. Opening valve V1 will increase both static pressure P_1 and delta-P24 while opening valve V2 will increase delta-P24, but decrease static pressure P_1. Iteration between these two valves allows P_1 to be held constant while changing delta-P24. Data are obtained for a pre-selected series of values of delta-P24's ranging from 0 to approximately 2 psi during each run (i.e., constant P_1) so that consistency can be

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maintained from run to run. Once a delta-P24 and static pressure P_1 have been reached, based on the read-outs of the digital volt meters, values are recorded for each static pressure and pressure differential along with the flow rate measured at FM1. At each of the four SIP heights, a range of delta-P24's were measured at nine different P_1 pressures (an exception being the SIP height of .128 inches for which measurements were made at only eight values of P_1). The values of static pressure static pressure P_1 ranged from 2 psi to 14.7 psia (1 atmosphere).

RESULTS

Data acquired from this test are presented in graphical form using both simple data plots and standard engineering plots. The data plots show the pressure drop across the SIP as a function of the volume flow rate and the engineering plots show the log of the pressure drop to dynamic pressure ratio as a function of the mass flow rate. Some of the plots have been arranged to show the effect of varying the SIP height from the original .170 inch thickness, or of varying the static pressure at the entrance to the SIP. The SIP sample was aligned to allow flow parallel to the weave direction, and, thus the majority of the fibers. Flow in fiberous media both normal and parallel to fibers is discussed in reference 10 with supporting data in reference 11. Also, data for flow normal to fibers is given in reference 12. According to reference 11, for a given pressure drop, the highest flow rate is expected for flow parallel to the fibers.

In evaluating the plots, figure 4 presents a base plot of the differential pressure P24 (Delta-P) as a function of the flow rate (Q) at atmospheric pressure (14.7 psi). As the flow rate is increased, the differential pressure increases as would be expected, indicating that an increase in differential pressure is required to increase the flow rate. In figures 5a through 5i, each plot presents data at a constant static pressure level (P_1), beginning with atmospheric pressure (14.7 psi) and then decreasing to as low as 2 psi. The curves on each plot represent the four SIP heights tested with .170 inch representing the base, no load height and .108 inch, .128 inch are the two values with the SIP in compression and .200 inch is the value with the SIP in tension. Each plot of a different static pressure shows that as the SIP height is increased, for a constant volume flow rate, the differential pressure decreases. In figures 6a through 6d, the same data as in figures 5a through 5i are plotted with each plot representing a constant SIP height and each curve representing a constant entrance or static pressure (P_1). From this set of plots, it can be seen that as the static pressure (P_1) is decreased for a constant flow rate, the differential pressure increases.

The plots shown in figures 7a through 7i present data in the standard engineering form for pressure drop in piping and ducts; pressure drop ratioed to dynamic pressure as a function of mass flow rate. To accommodate the range of data, the data are plotted as the log of the ratio of the differential pressure

over the dynamic pressure (q). The dynamic pressure was calculated using the equation:

$$q = \frac{1}{2} \rho V^2 \tag{1}$$

where
$$\rho = \rho_0 \frac{P_1}{P_0} \tag{2}$$

and
$$V = \frac{Q}{A} \tag{3}$$

ρ_0 and P_0 are the standard density and atmospheric pressure, respectively, for air, and "A" is the area of flow through the SIP. The mass flow rate was calculated using the equation:

$$\dot{m} = Q\rho \tag{4}$$

In these figures, each plot represents a constant static pressure level and each curve on a plot defines a different SIP height tested. When plotted in this manner, the four curves for each SIP height all collapse to one curve. For example, the four curves of figure 6a become one curve on figure 7a.

In figures 8a through 8d, each plot is for a different SIP height and the range of static pressures. Once again, these plots tend to collapse the data although the effect of reducing the static pressure shows more spread in the log of the ratio of the differential pressure over the dynamic pressure for values of the mass flow rate less than 1×10^{-6} lbs/sec. than for the higher values.

CONCLUDING REMARKS

A 5.5 inch square by .170 inch thick sample of the Shuttle Orbiter Thermal
Protection System, Strain Isolation Pad (SIP) has been tested to determine the air
flow rate in the fiber direction for a given differential pressure across the
SIP. The data presented in this report make a significant contribution
to the existing data on flow through fibrous media. In particular, the present
data is the only existing data defining the pressure drop characteristics as a
function of flow rate for a .170 inch sample of the Space Shuttle SIP at various
height values representing tension and compression. In addition, the data have
been repeated over the range of pressures typical of the Orbiter trajectory.

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Duane: Flow Through the Tile Gaps in the Space Shuttle Thermal
Protection System. Presented at the AIAA 20th Aerospace Sciences
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Media. Journal of Applied Mechanics . December 1970.

Hardware & Instrumentation

Figure 3 Locaion	Item	Purpose
FM1	Hastings Flowmeter, type H-3	Monitors flow rate into the SIP.
V1	Jamesbury 1/2 in. ball valve	Adjusts P_{24} while maintaining a constant P_1.
V2	Tescom 10000 psi Needle Valve, type 30-1301-108E	Adjusts P_{24} while maintaining a constant P_1.
P_1	Bell & Howell 0-15 psia pressure transducer, type 4-312-0002	Measures pressure at entrance to SIP.
P_{24}	Datametrics Barocel Pressure Sensor, type 570D-100T-1J2-V1BT	Measures the pressure drop across the SIP.
	Datametrics Signal Conditioner, type 1015	Used in conjunction with the Barocel Pressure Sensor.
	Hewlett Packard Precision Power Supply, 0-20 Volts, type 6114A	Used in conjunction with the Datametrics Signal Conditioner.
Read-outs	Fluke Digital Volt Meter, type 8300A	Used to provide digital read-out in millivolts with the above instrumentation.

Table 1.-   Hardware and Instrumentation.
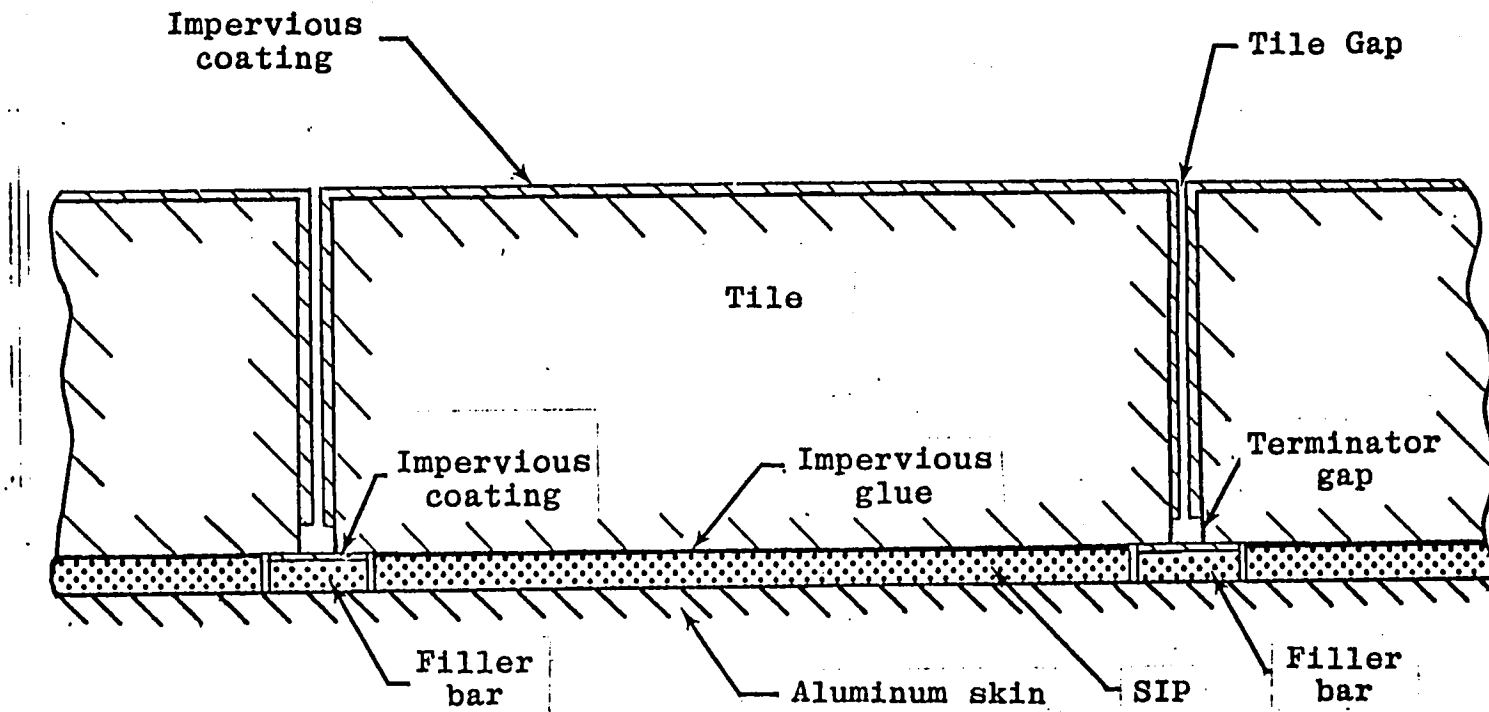
Figure 1.- Cut away view showing relative SIP location in the thermal
protection system.

SIP Flow Simulator
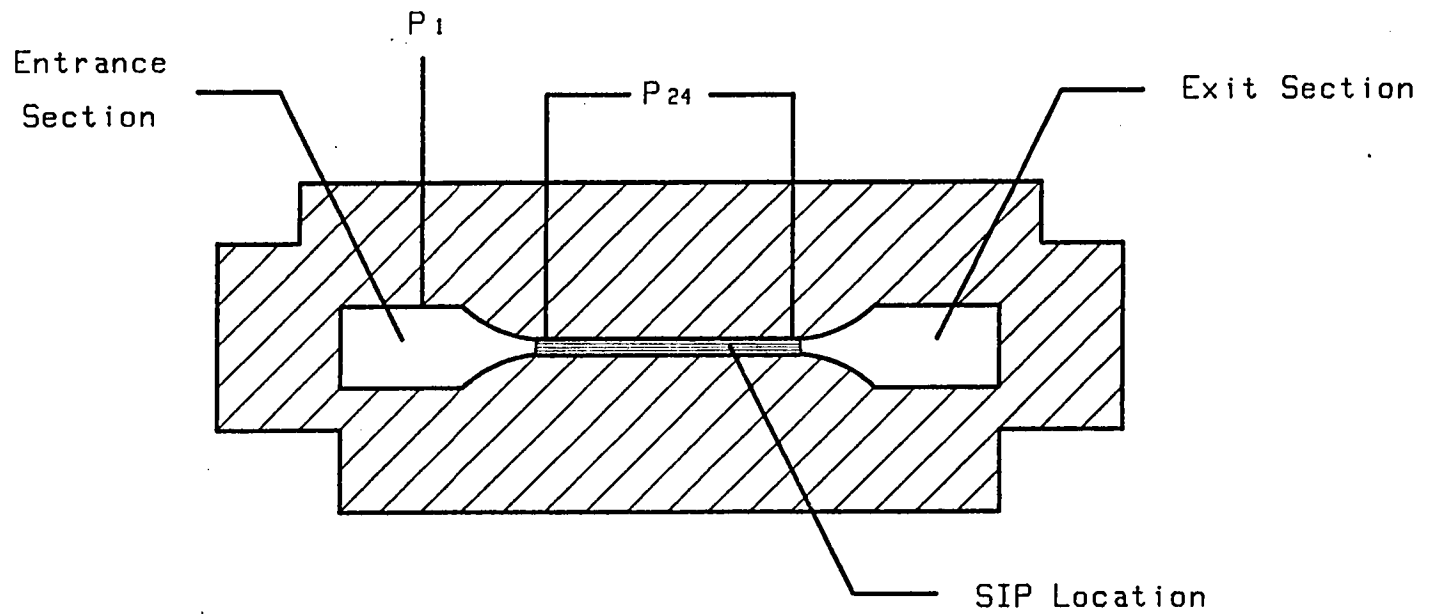
Figure 2.- Sketch of the SIP Flow Simulator.

Atmosphere

FLOW

FM 1

Vacuum

V2

V1

P 1

P 24

2   4
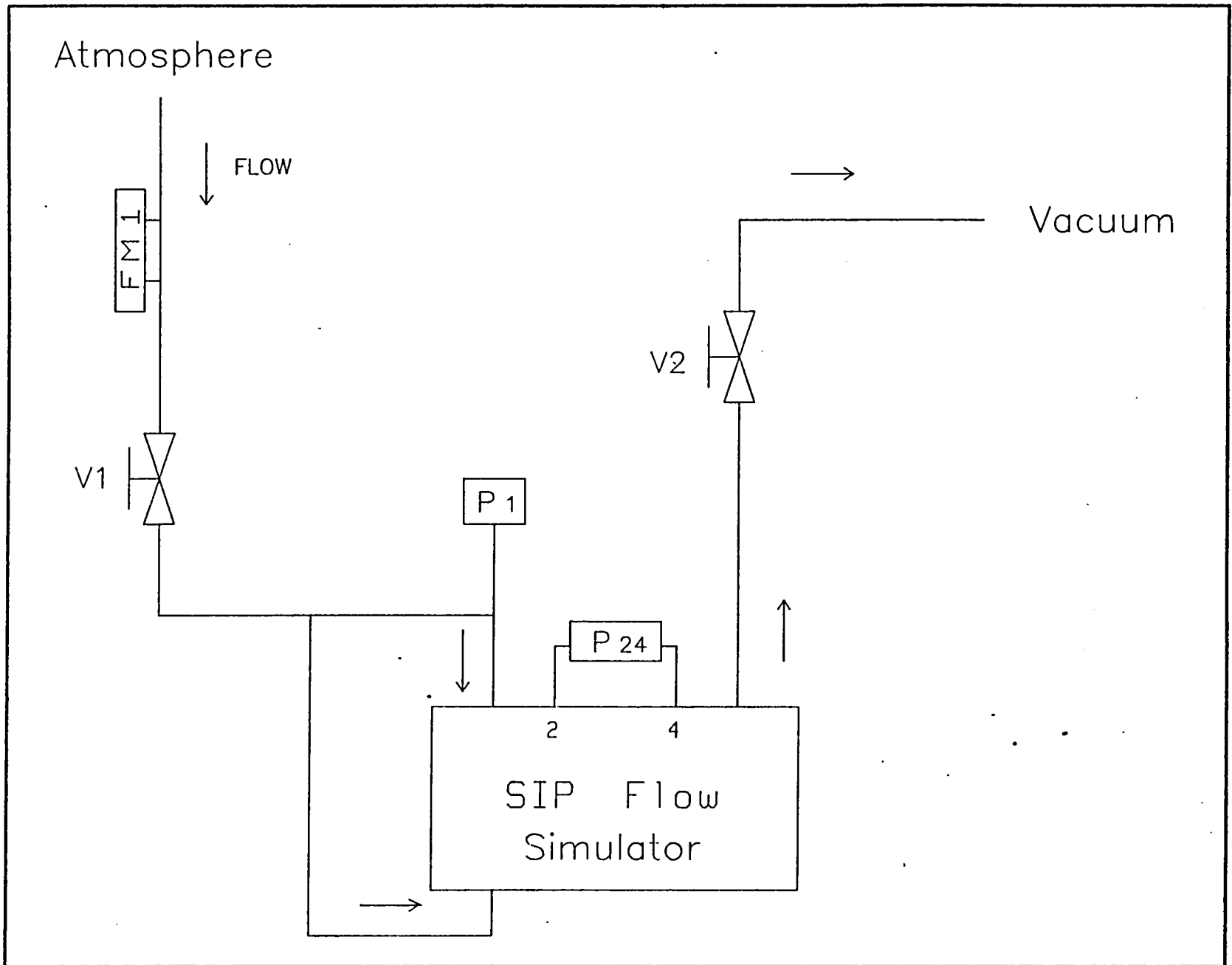
SIP Flow
Simulator

Figure 3.- Schematic of SIP Flow Simulator, associated controls, and instrumentation.
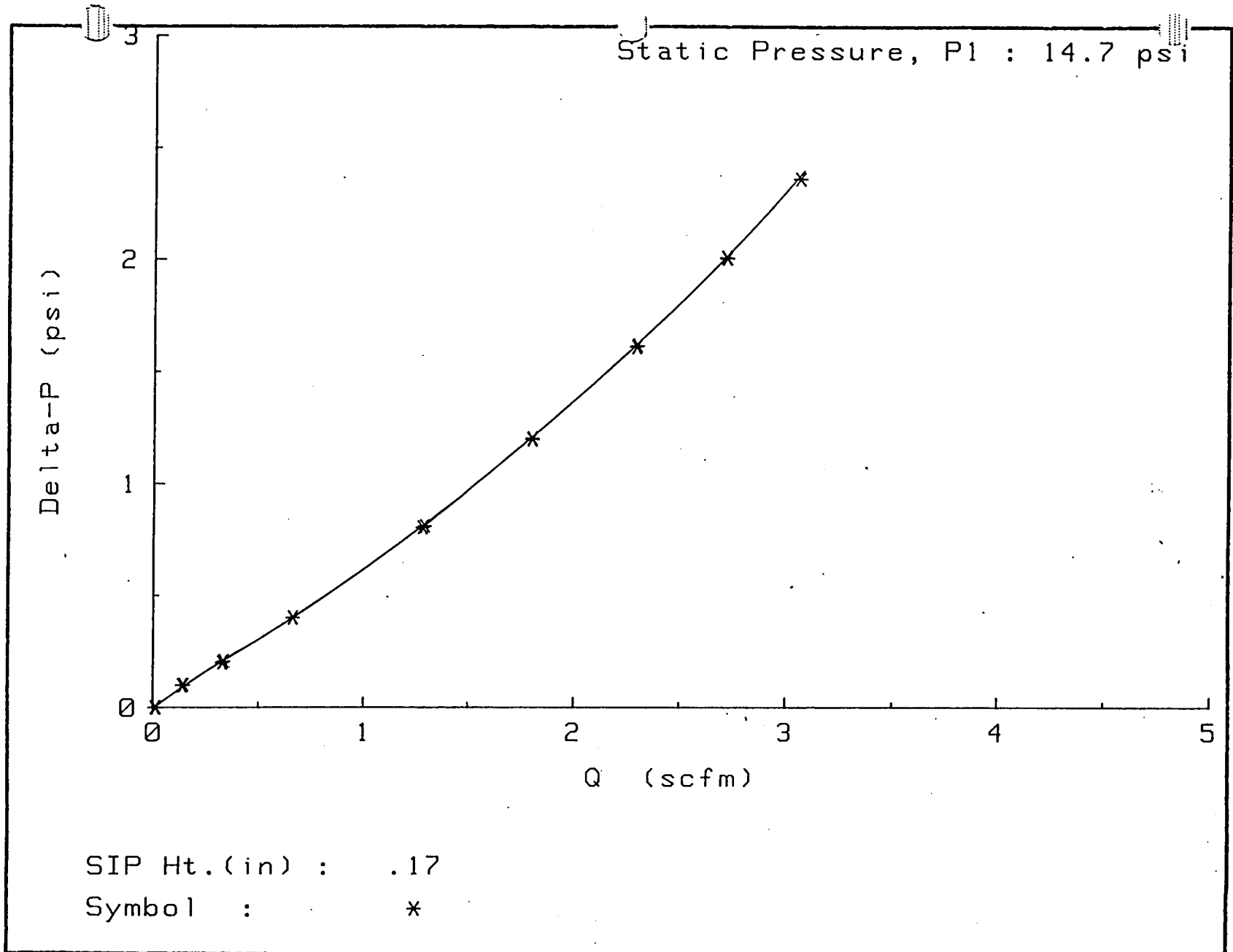
Figure 4.- Pressure drop as a function of the flow rate at near atmospheric
inlet pressure.
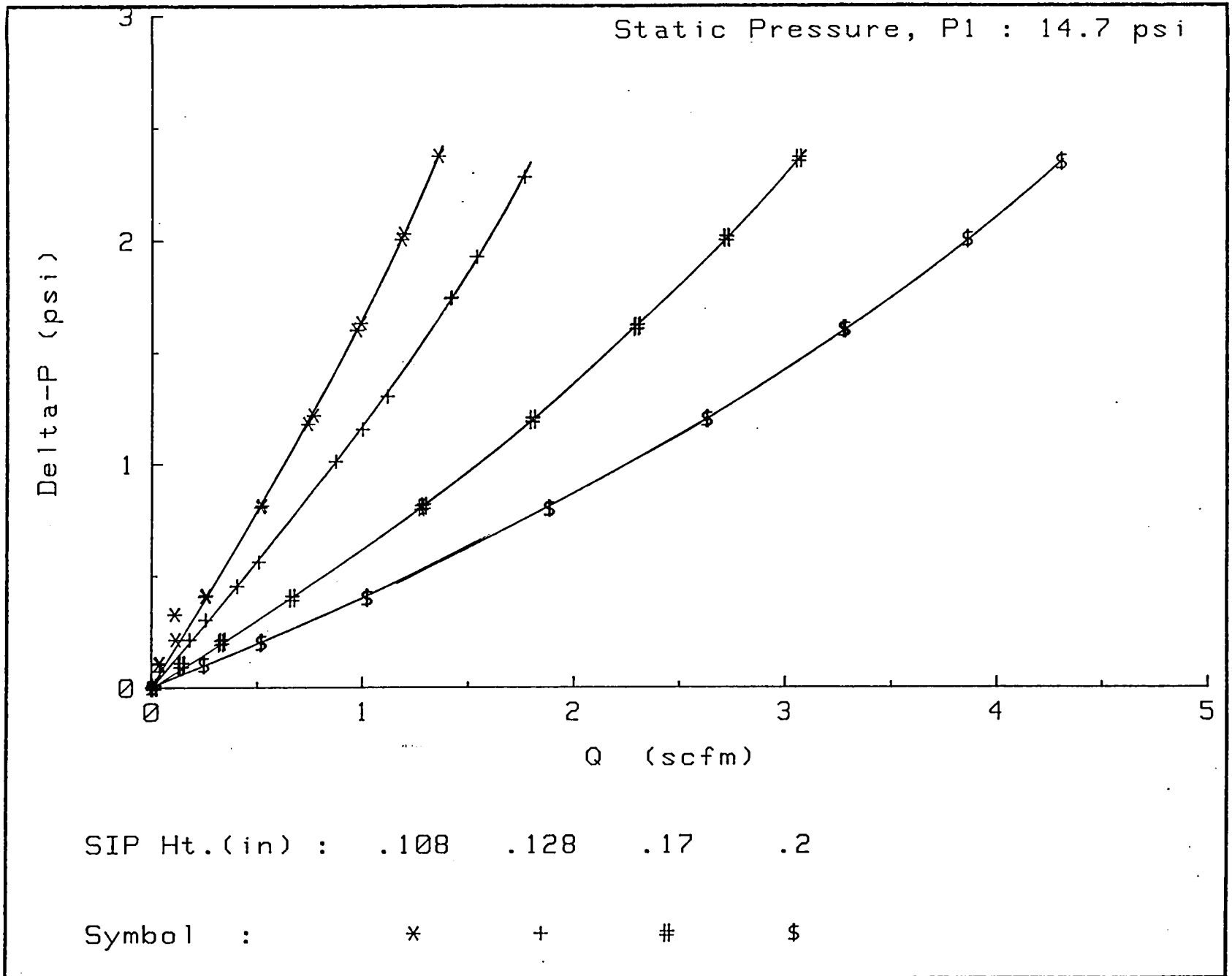
Figure 5a.- Differential pressure as a function of the flow rate for four
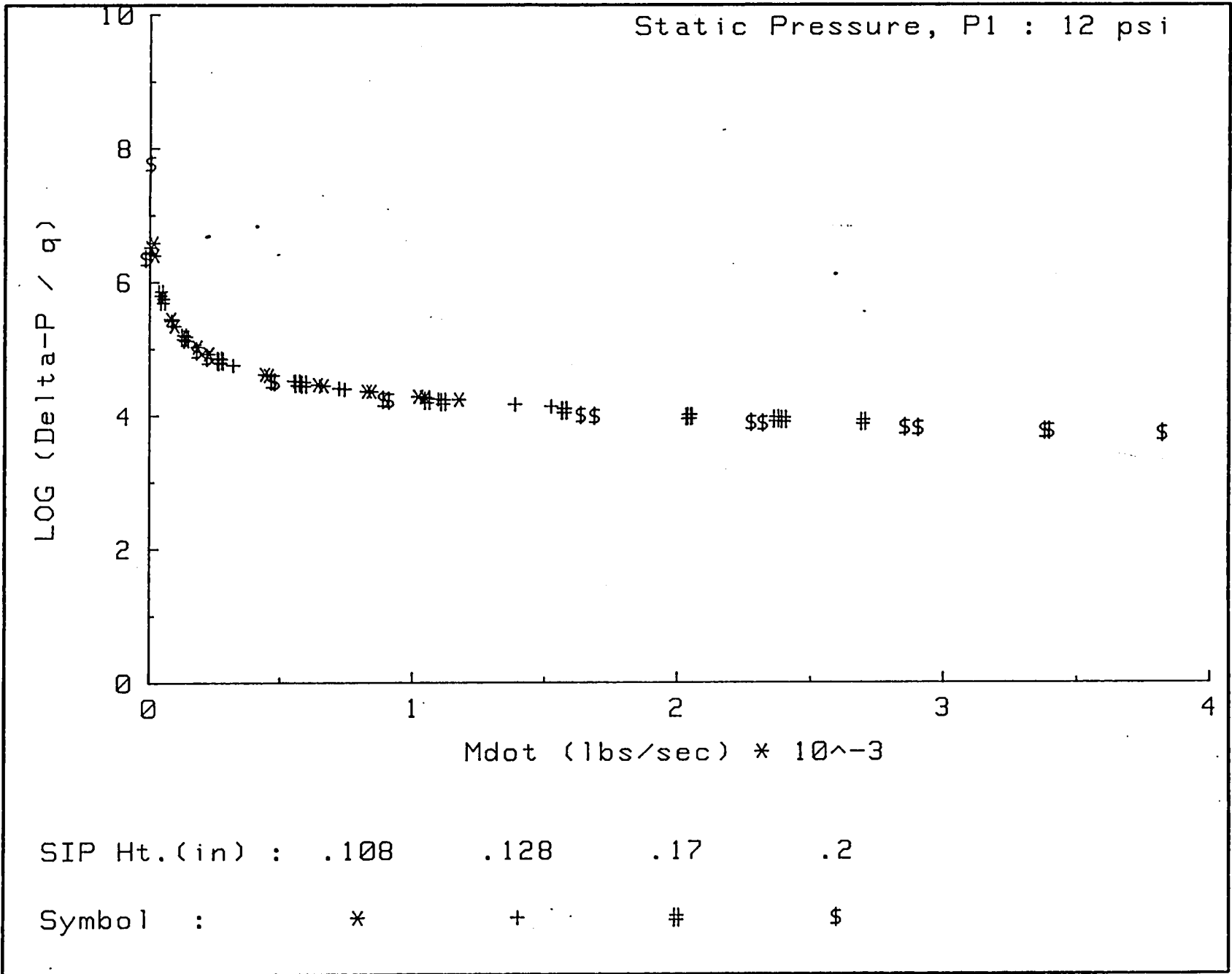different SIP heights for a static pressure of 14.7 psi.
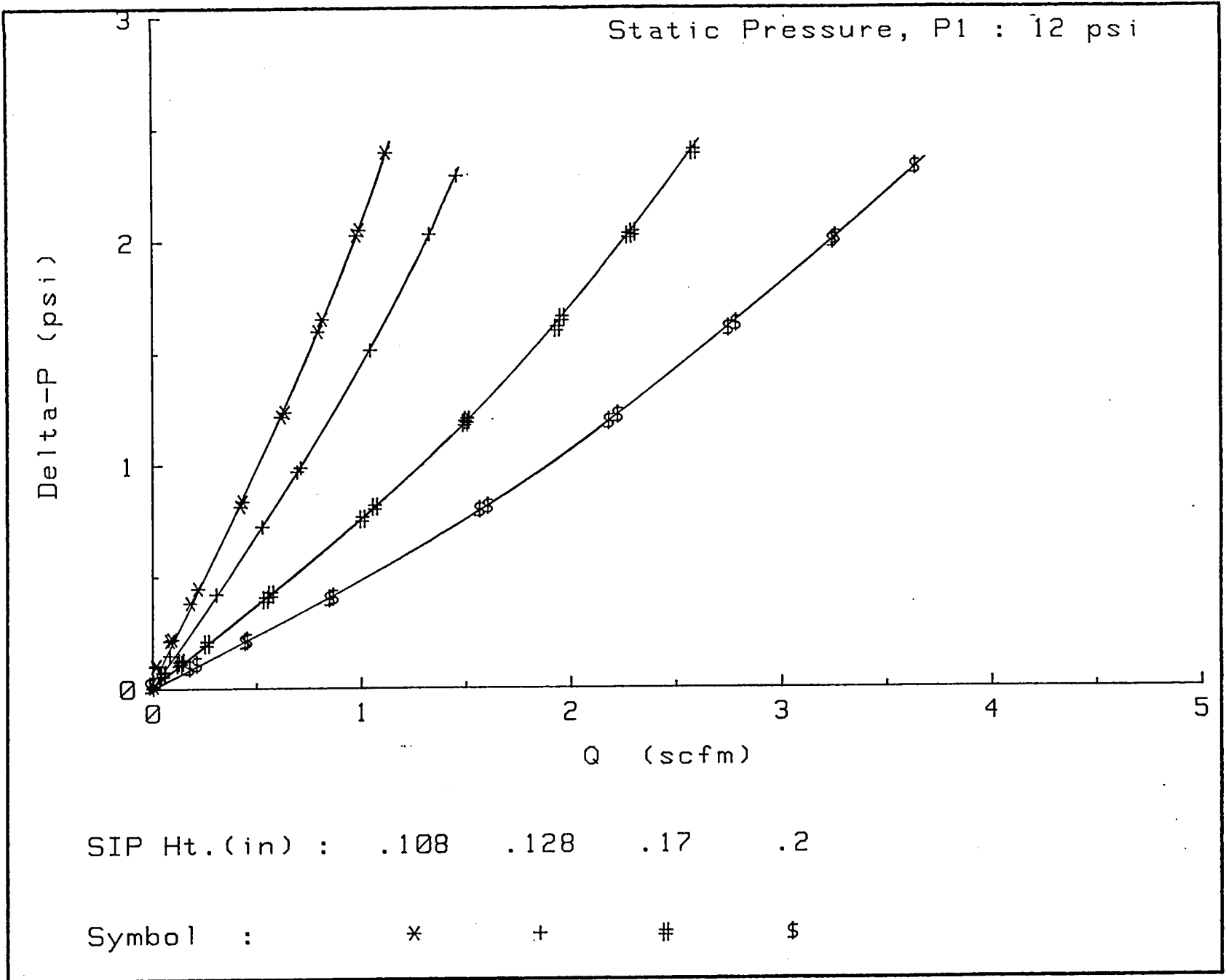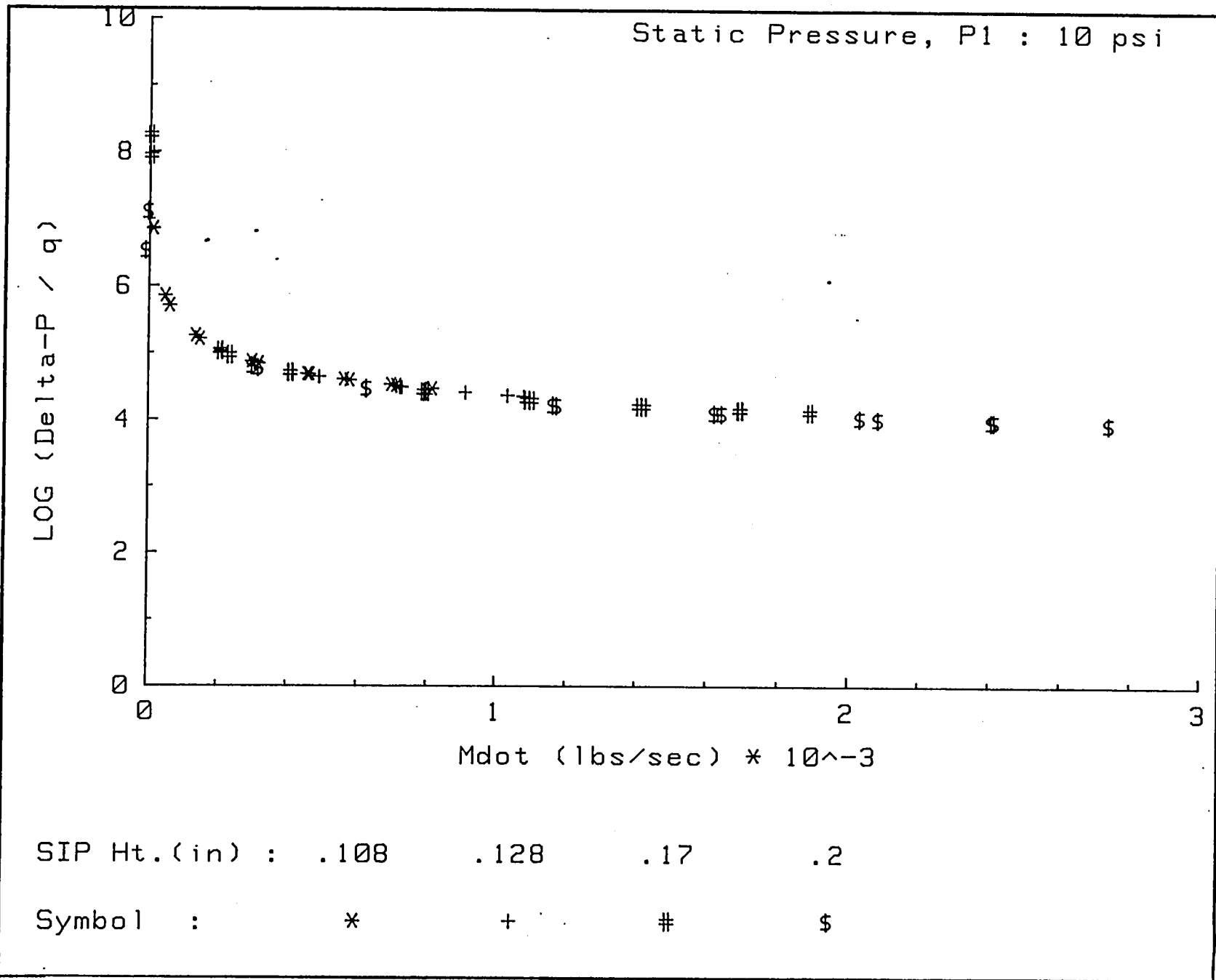
Figure 5b.- Static pressure equals 12 psi.
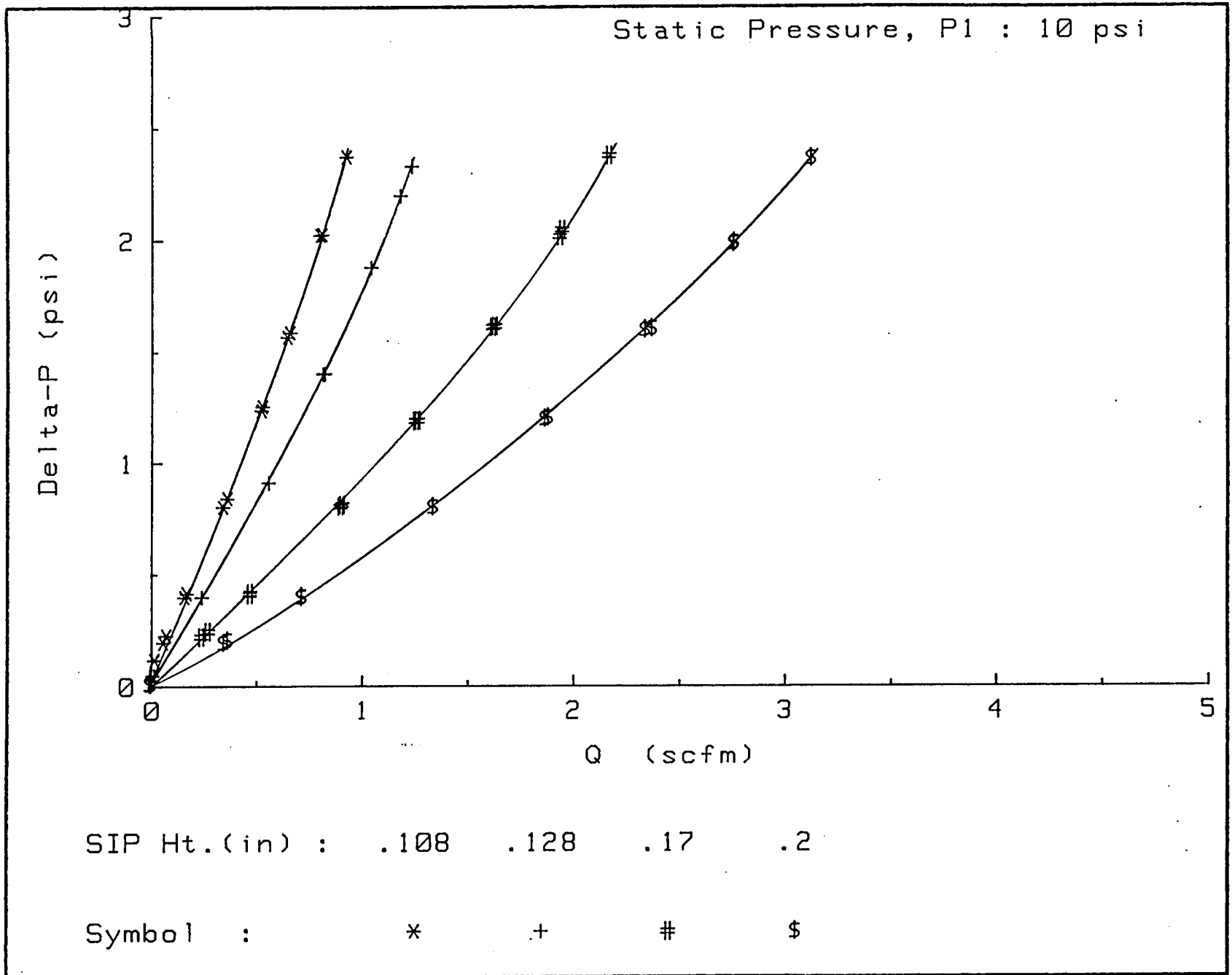
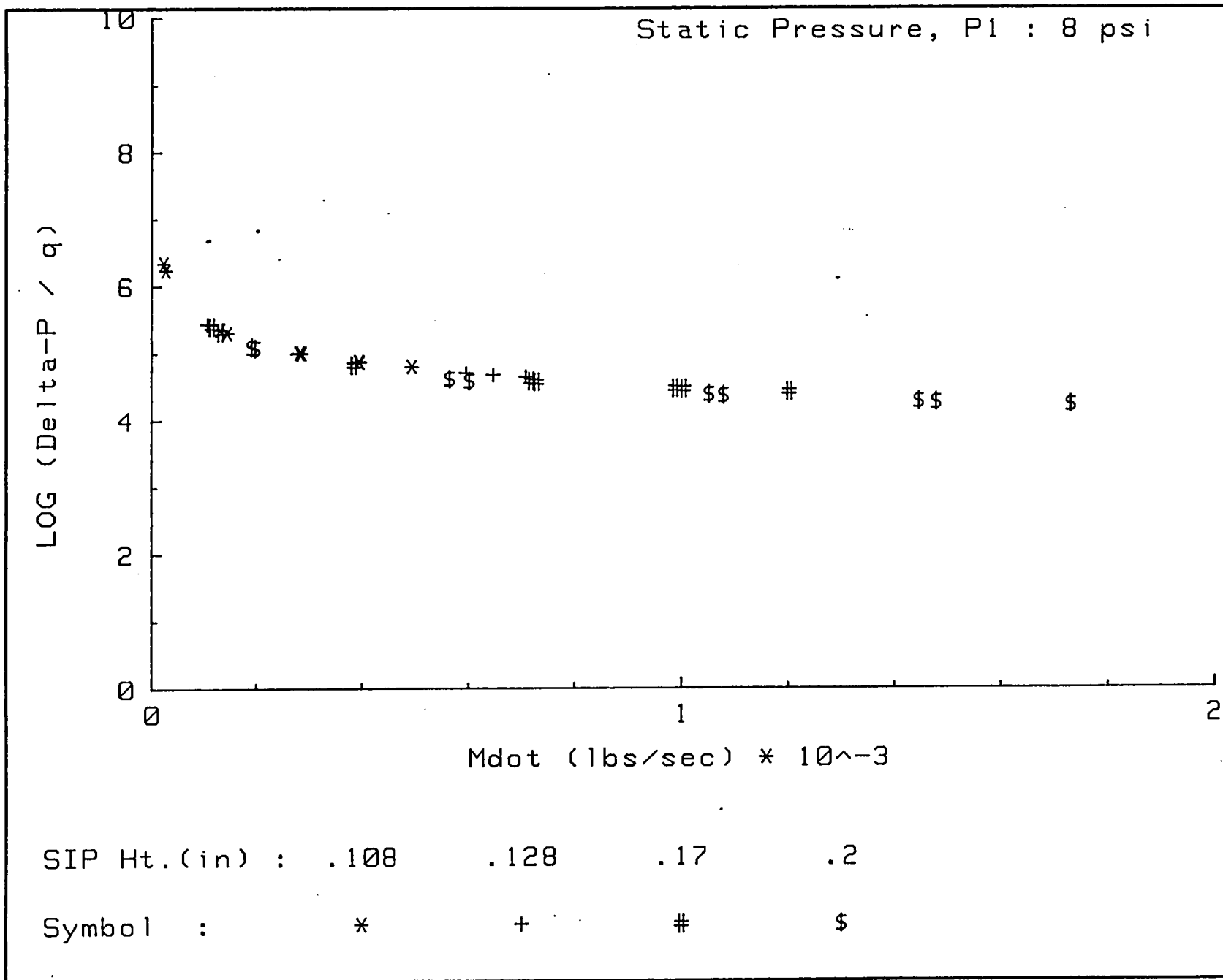Figure 5c.- Static pressure equals 10 psi.
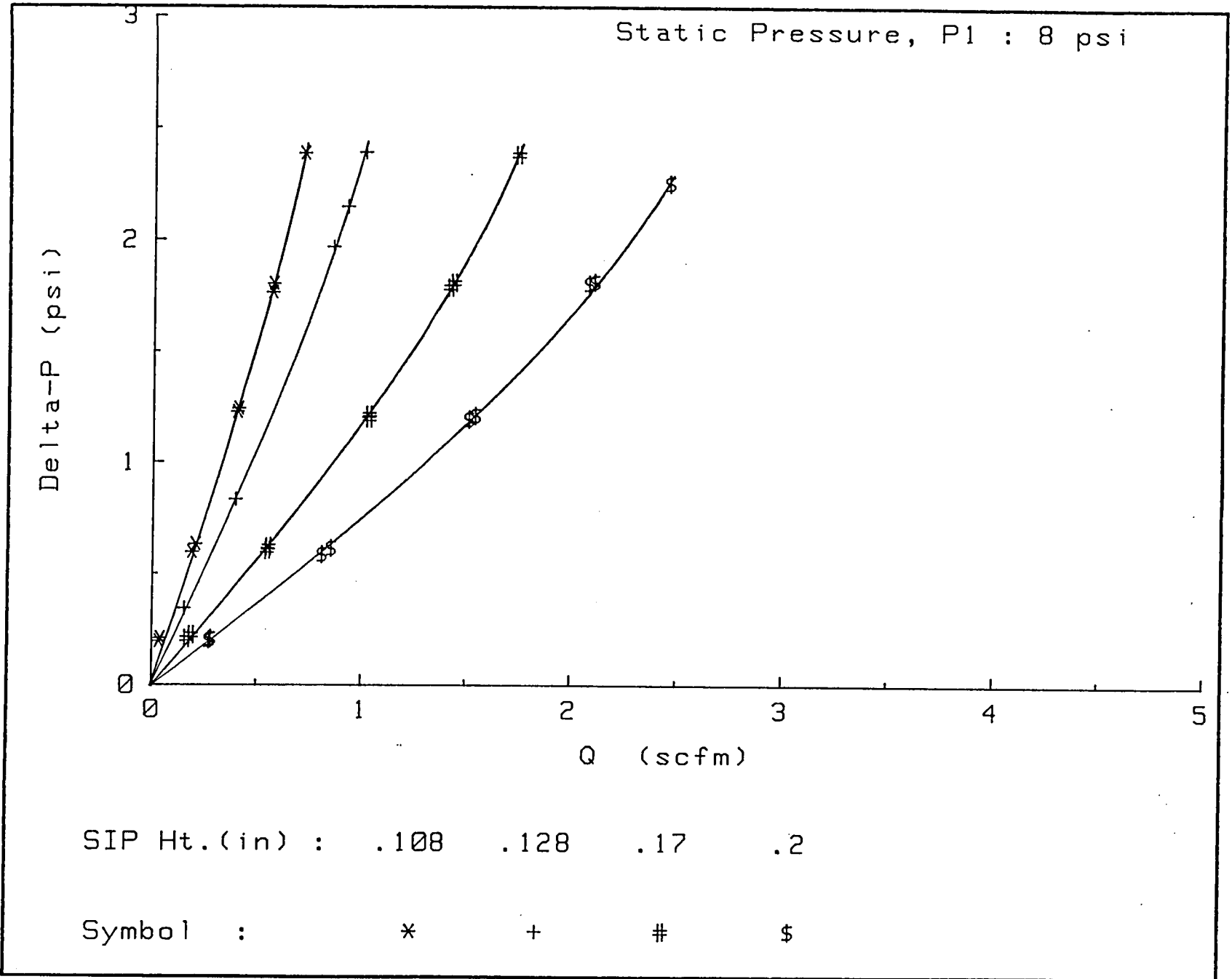
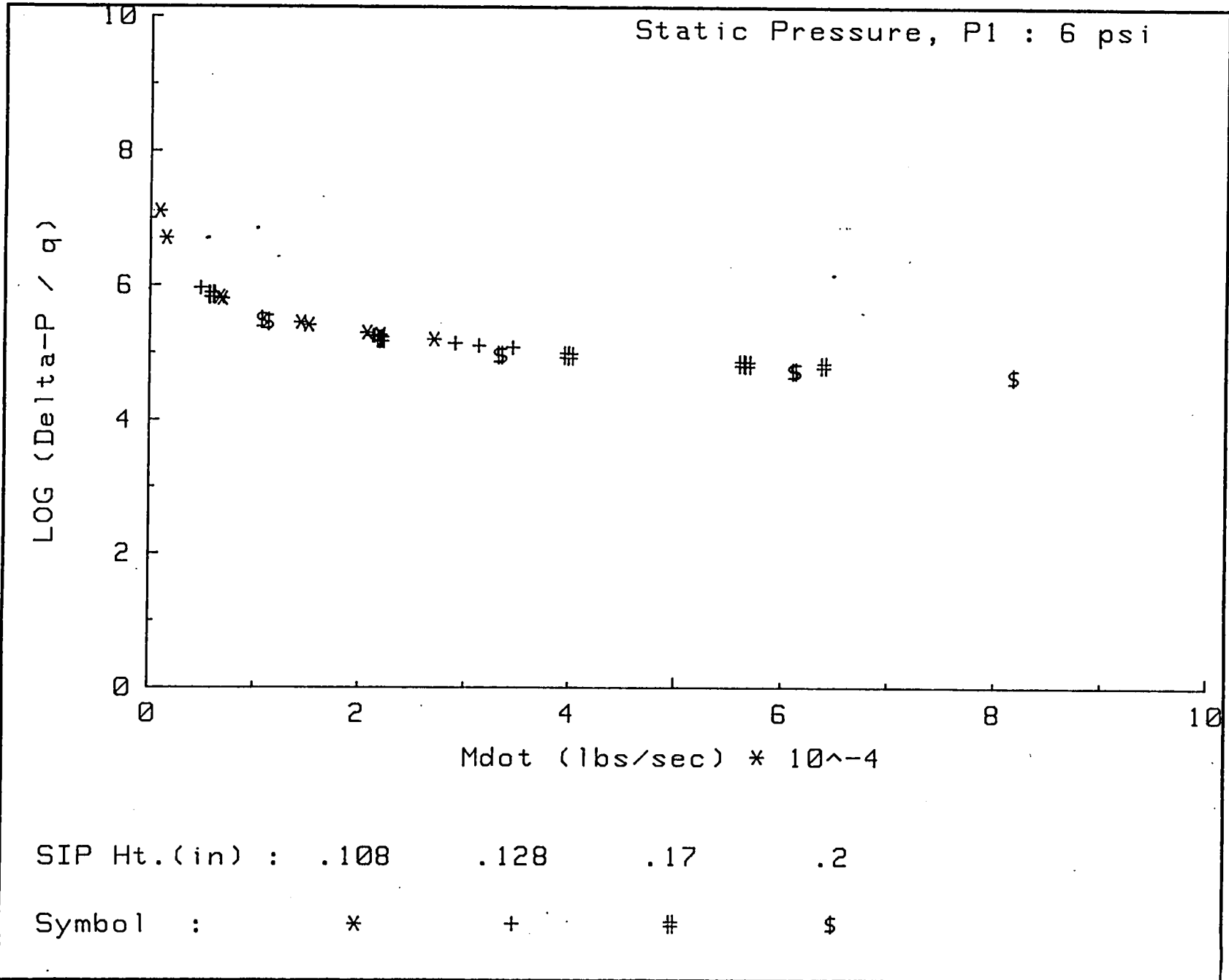Figure 5d.- Static pressure equals 8 psi.
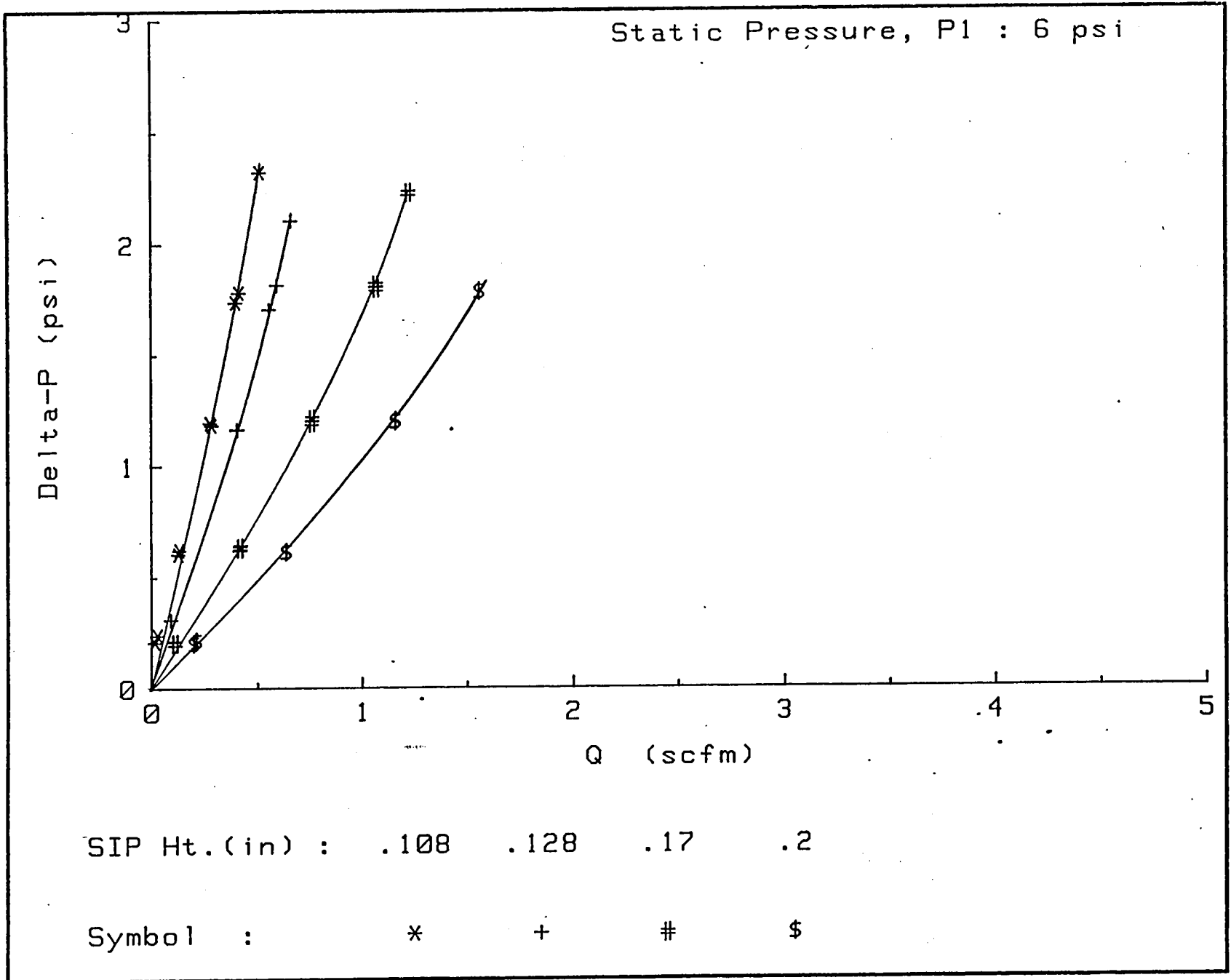
Figure 5e.- Static pressure equals 6 psi.
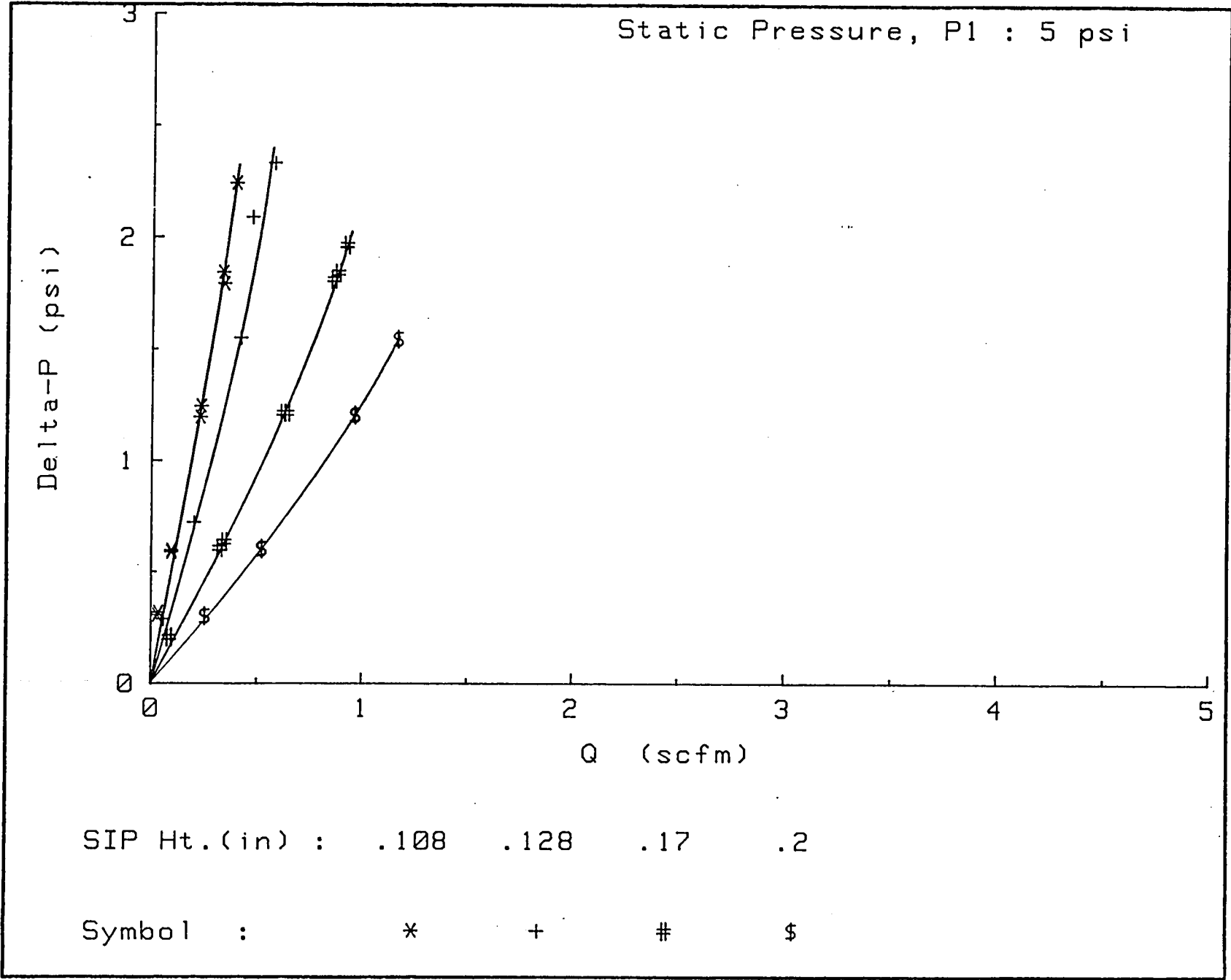
Figure 5f.- Static pressure equals 5 psi.
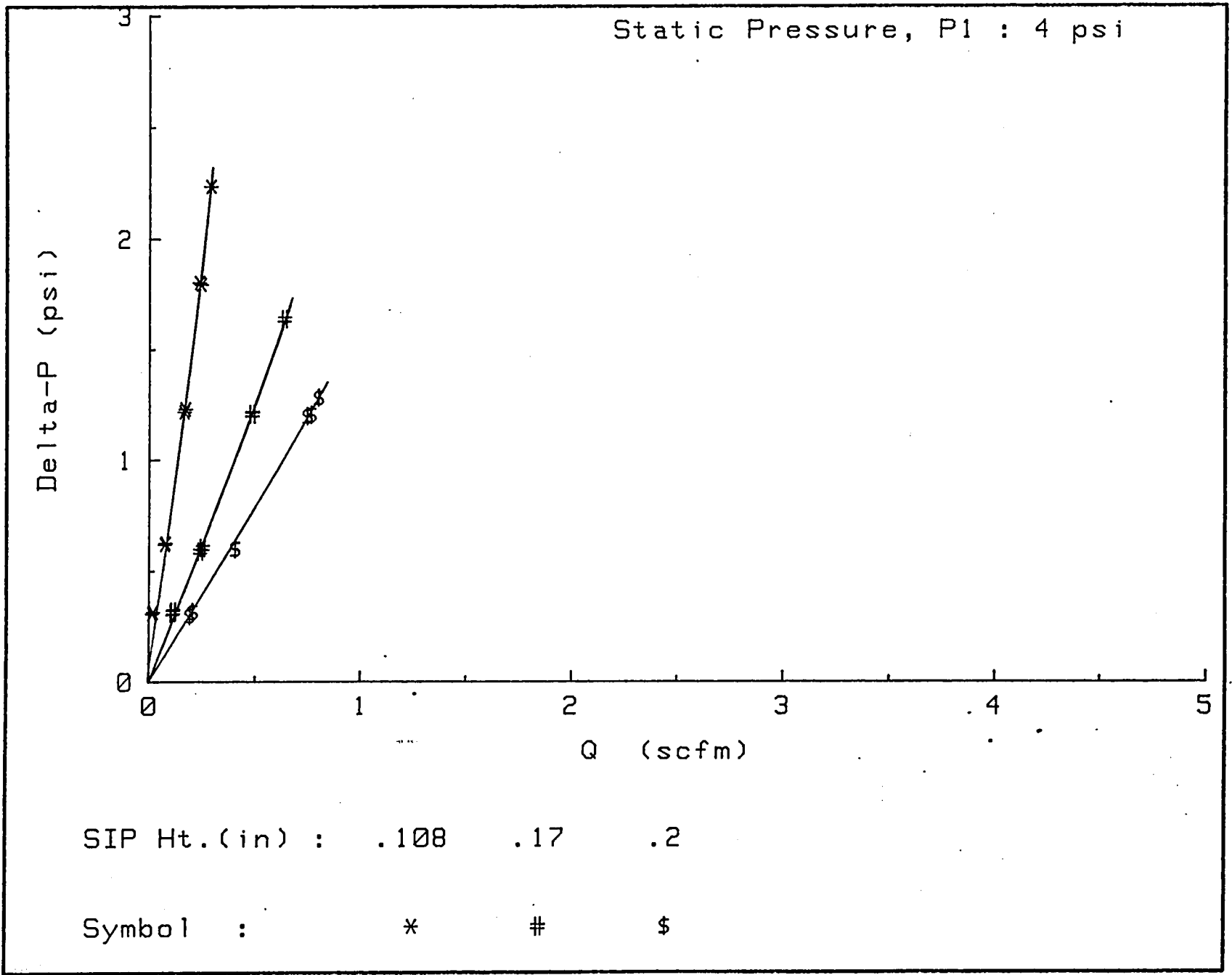
Figure 5g.- Static pressure equals 4 psi.

Static Pressure, P1 : 3 psi

Delta-P (psi)

3

2

1

0

0   1   2   3   .4   5

Q   (scfm)

SIP Ht.(in) :   .108   .17   .2
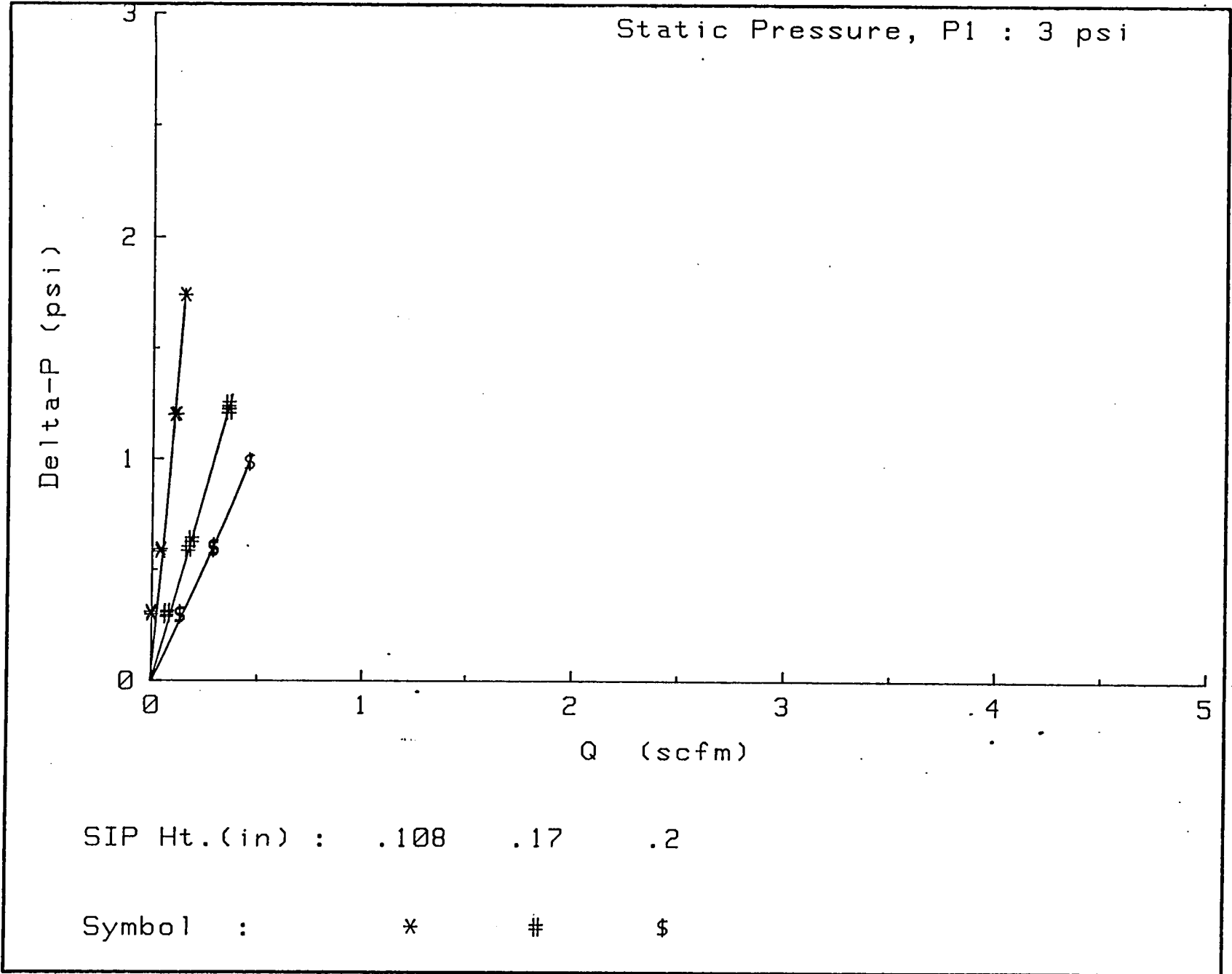
Symbol   :   *   # $

Figure 5h.- Static pressure equals 3 psi.
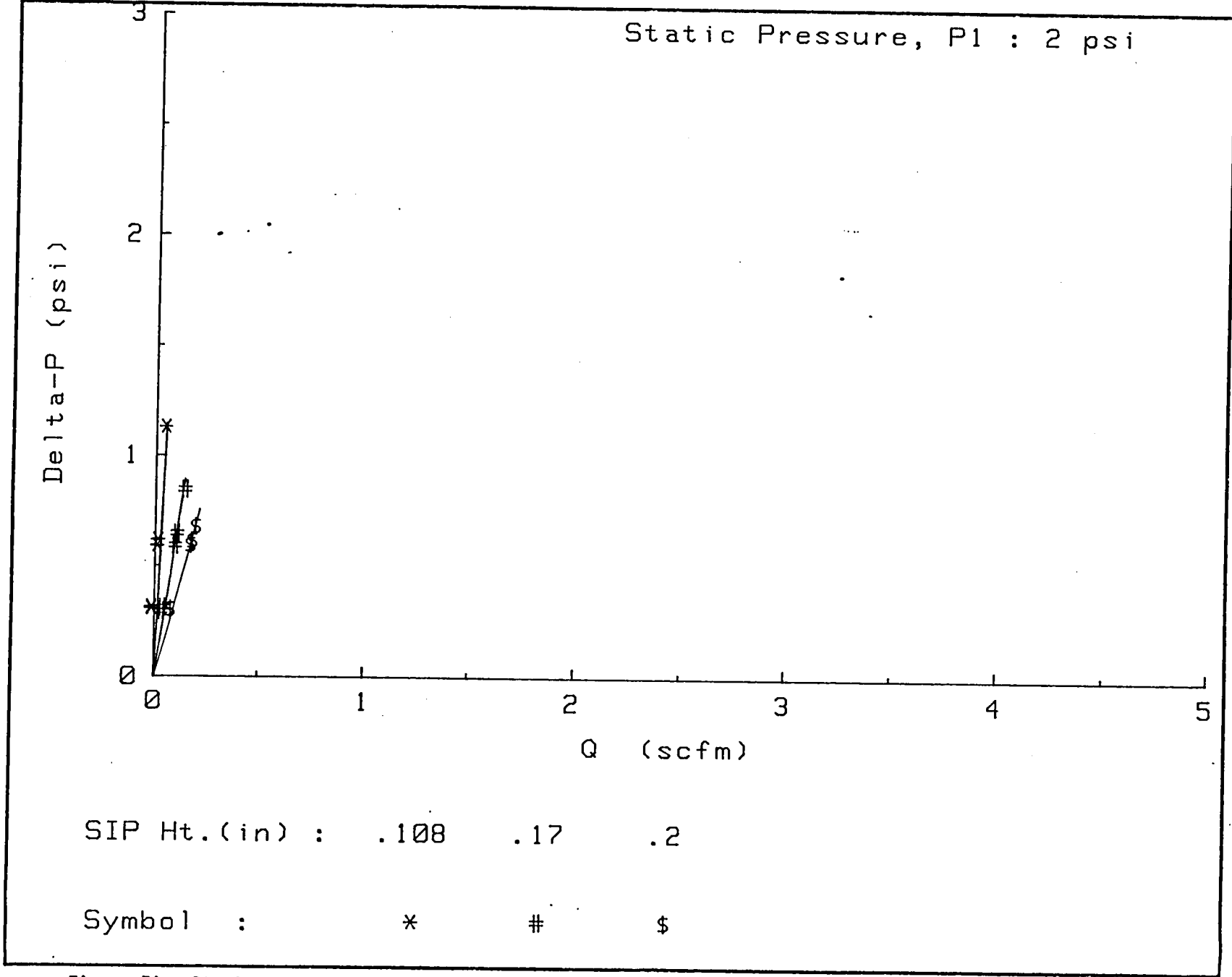
Figure 5i.- Static pressure equals 2 psi (concluded).
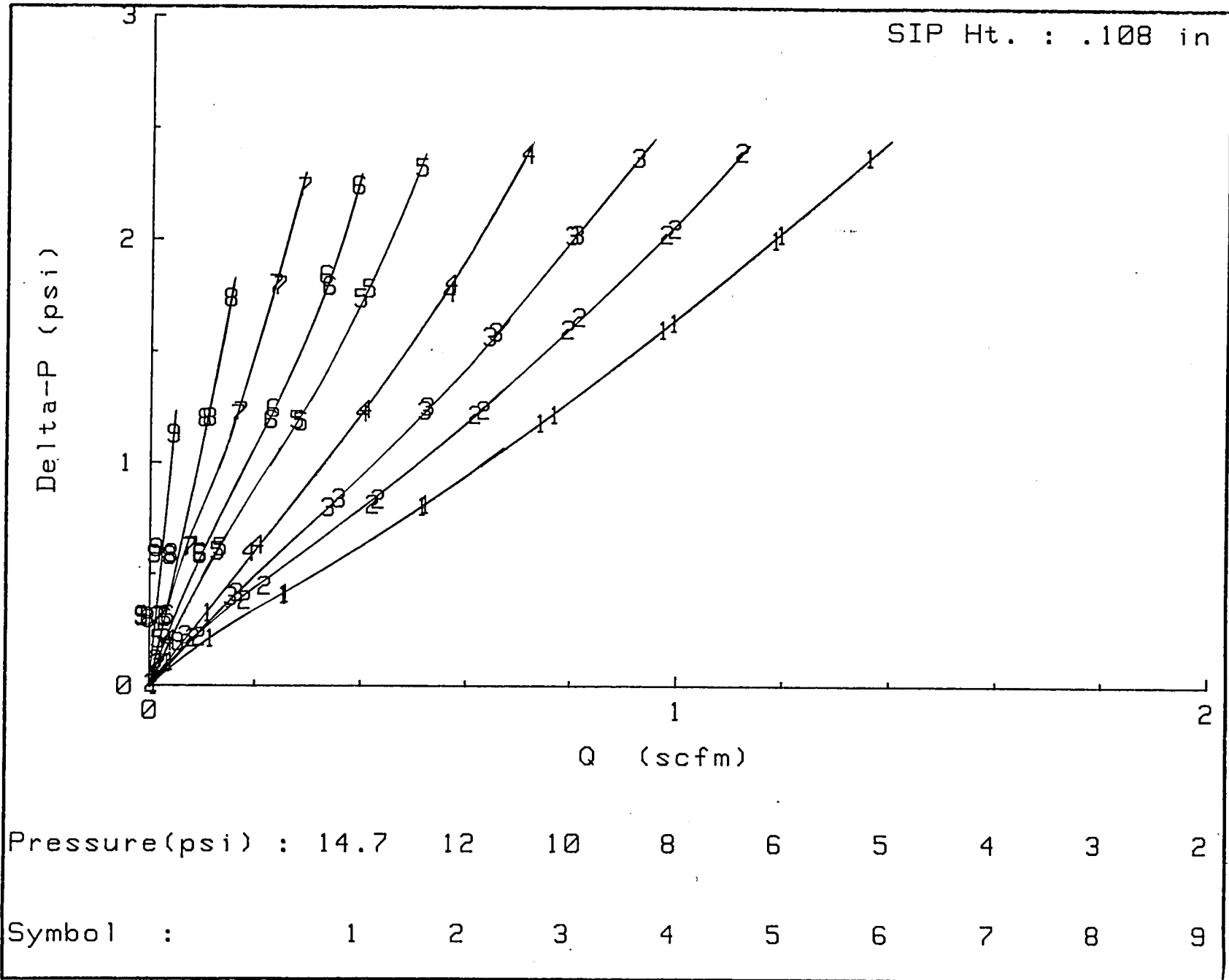
Figure 6a.- Pressure drop as a function of flow rate for different
static pressures at a constant SIP height of .108 in..
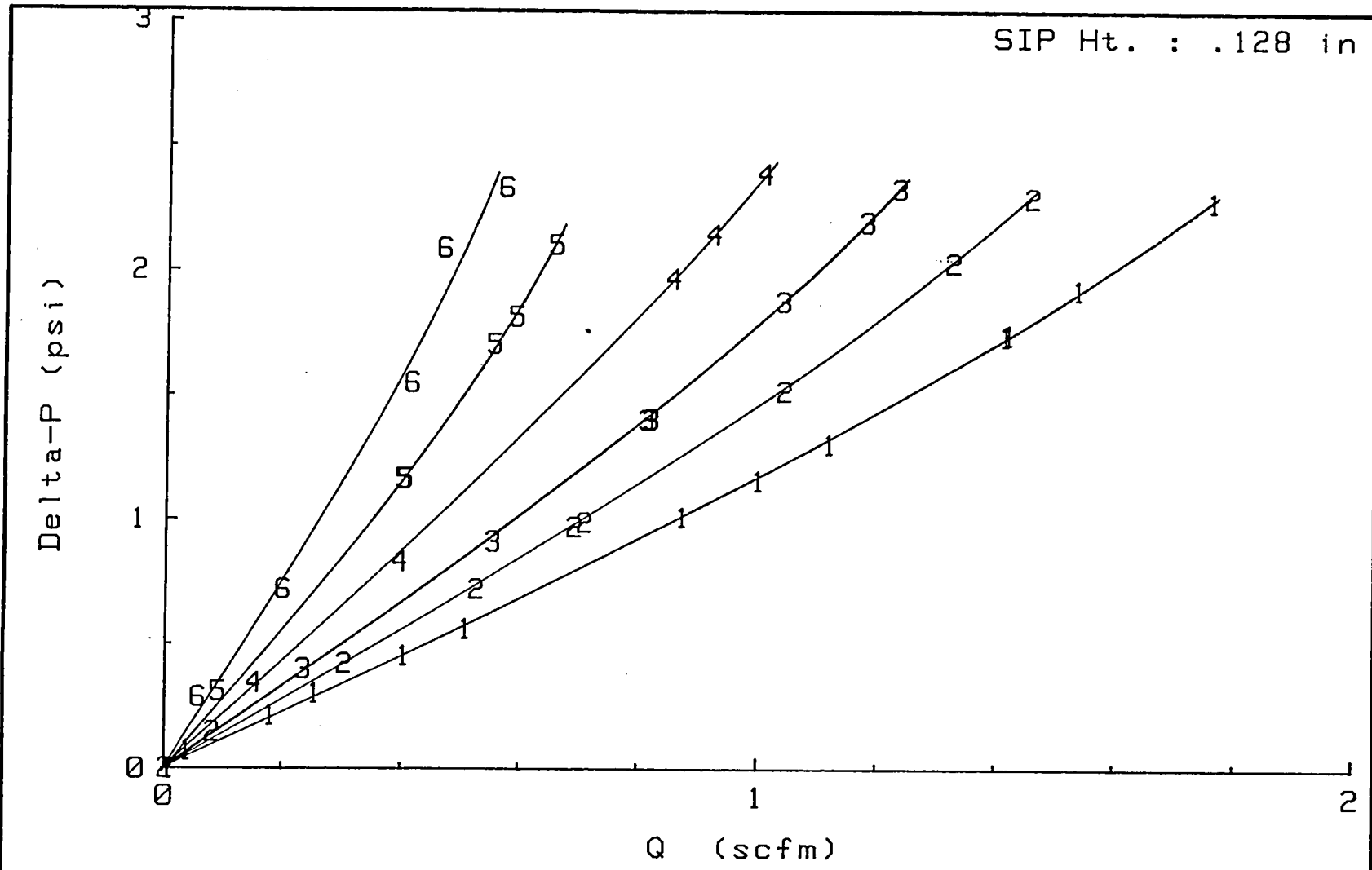
Figure 6b.- SIP height equals .128 in..
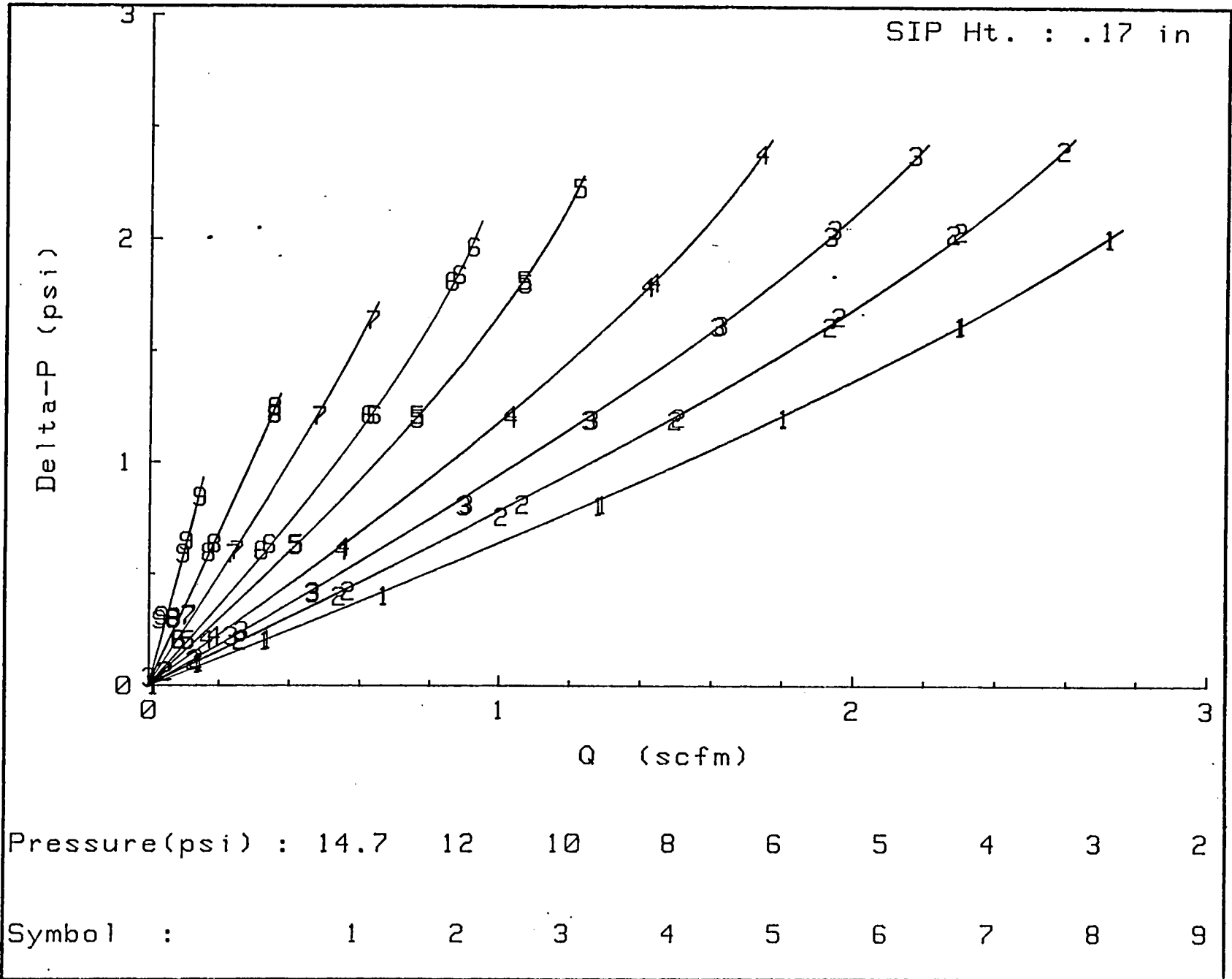
Figure 6c.- SIP height equals .170 in.
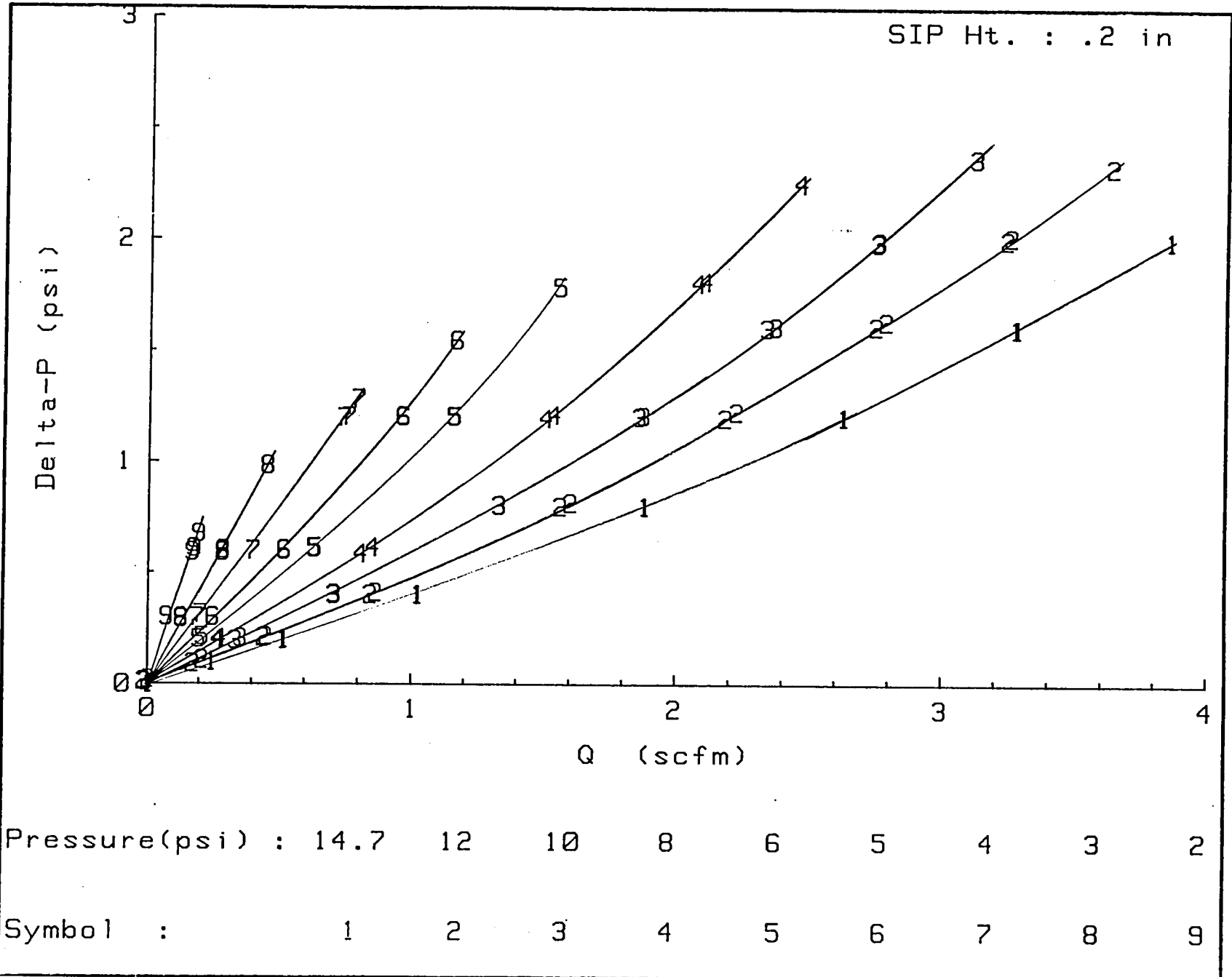
Figure 6d.- SIP height equals .200 in. (concluded)
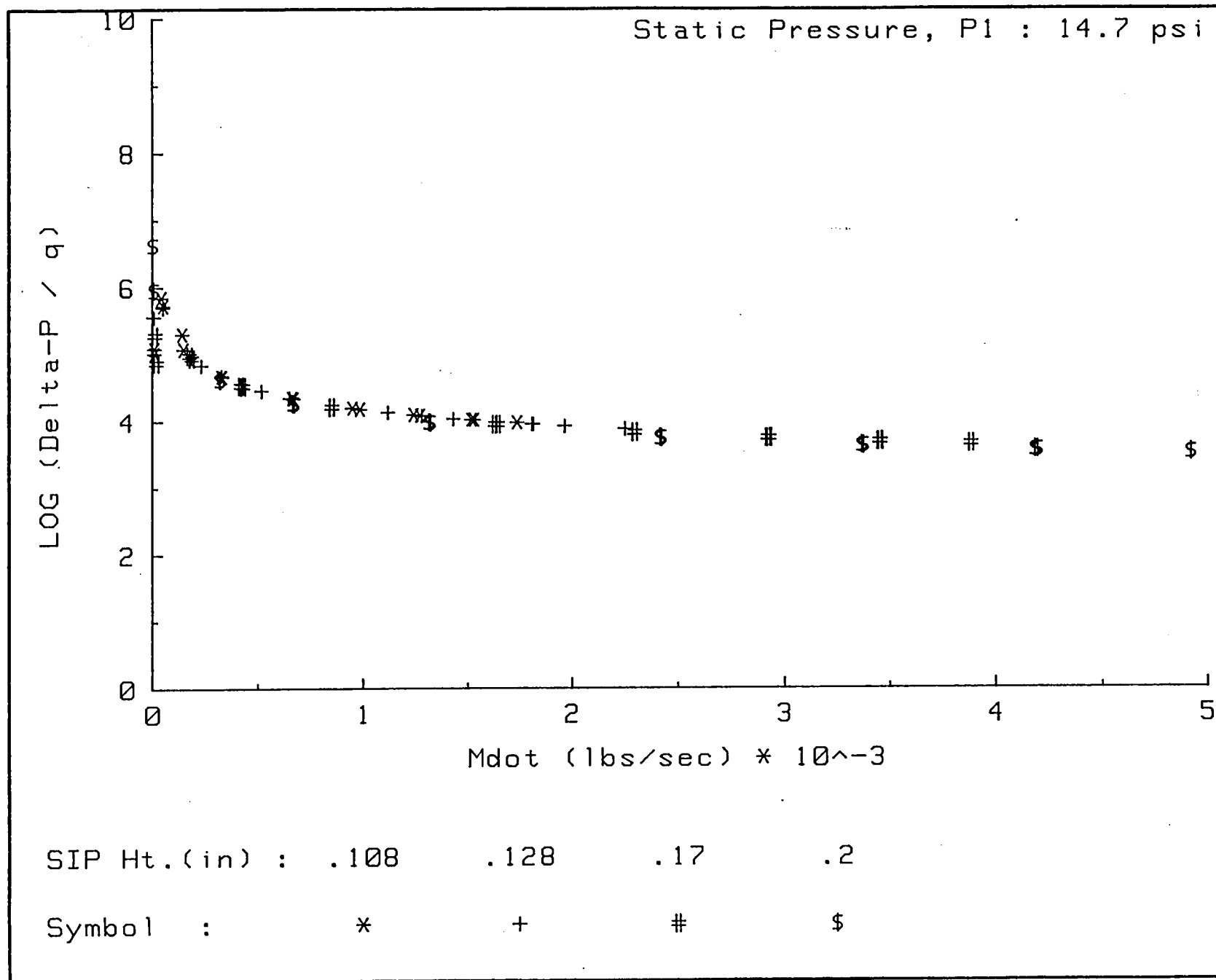
Figure 7a.- Log of the differential to dynamic pressure ratio as a function of the mass flow rate for four different SIP heights at a static pressure of 14.7 psi.
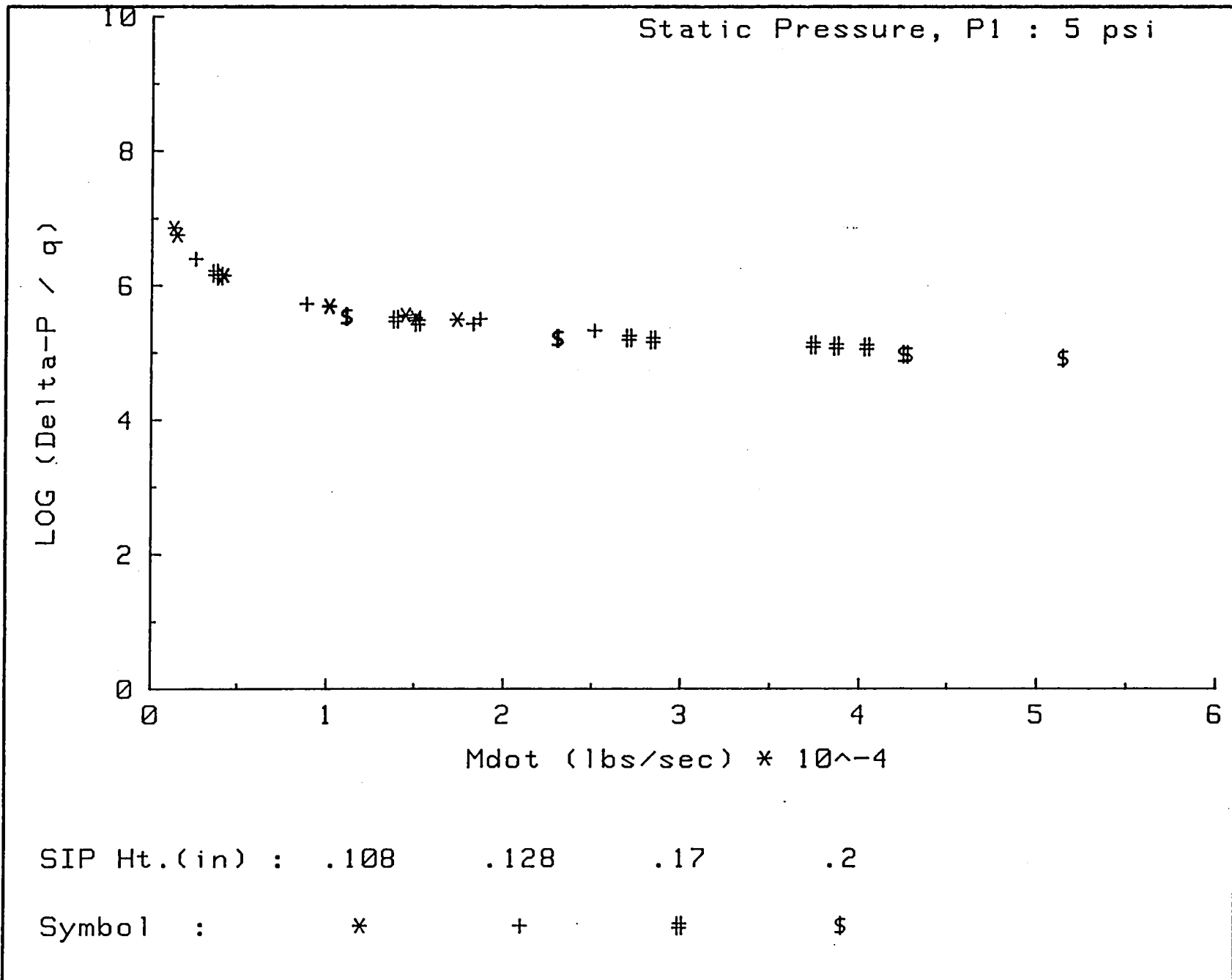
Figure 7b.- Static pressure equals 12 psi.

Figure 7c.- Static pressure equals 10 psi.

Figure 7d.- Static pressure equals 8 psi.

Figure 7e.- Static pressure equals 6 psi.
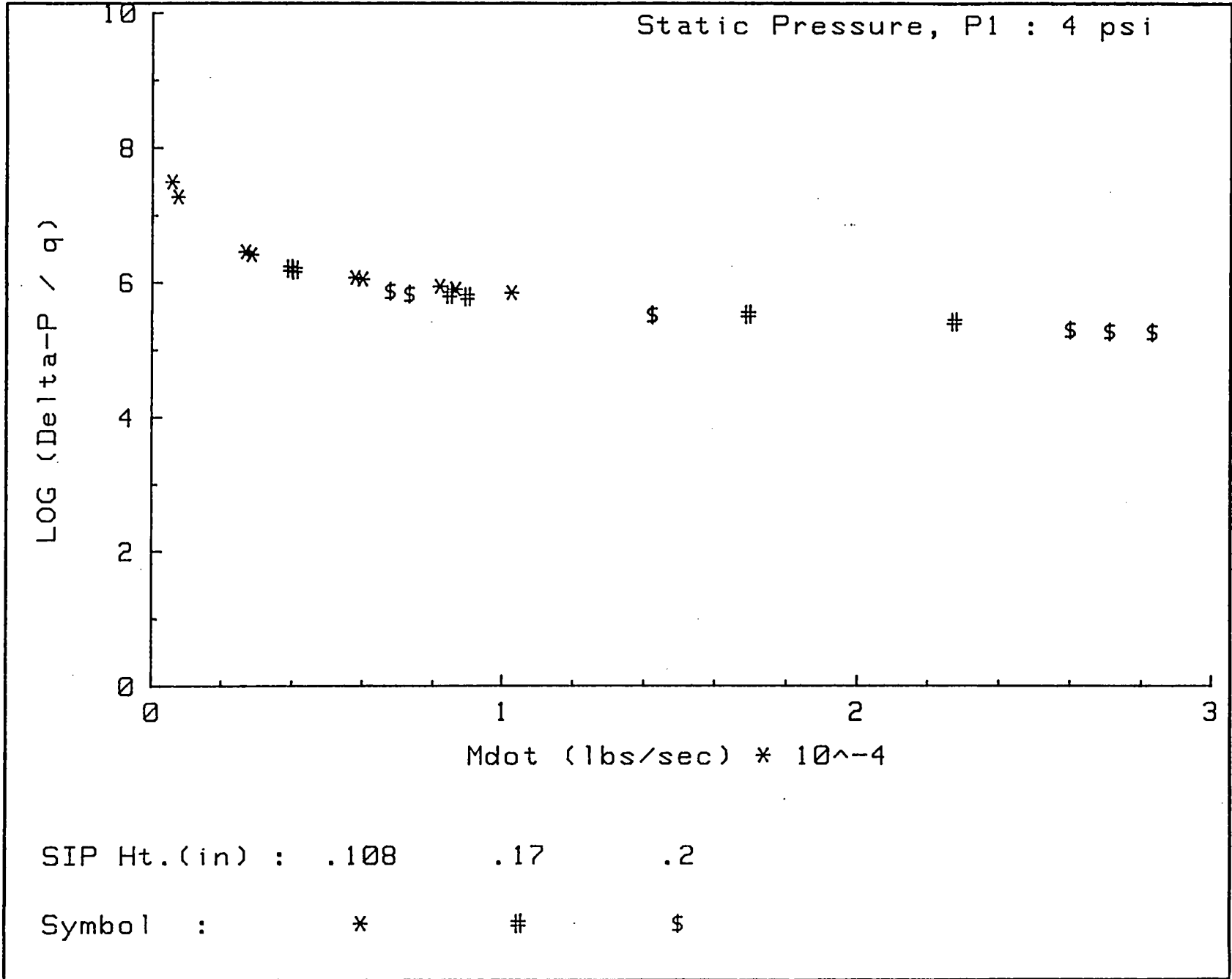
Figure 7f.- Static pressure equals 5 psi.

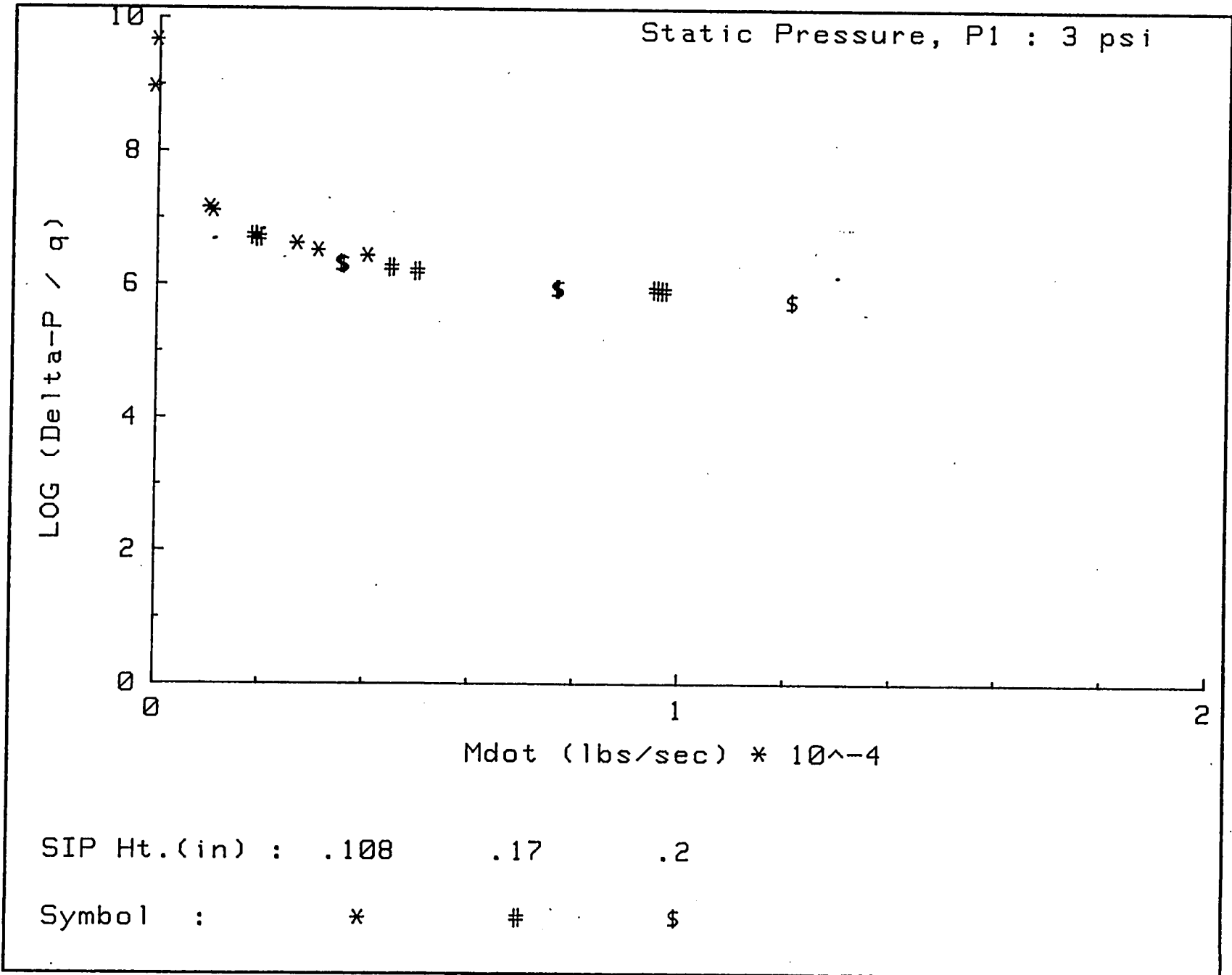Figure 7g.- Static pressure equals 4 psi.
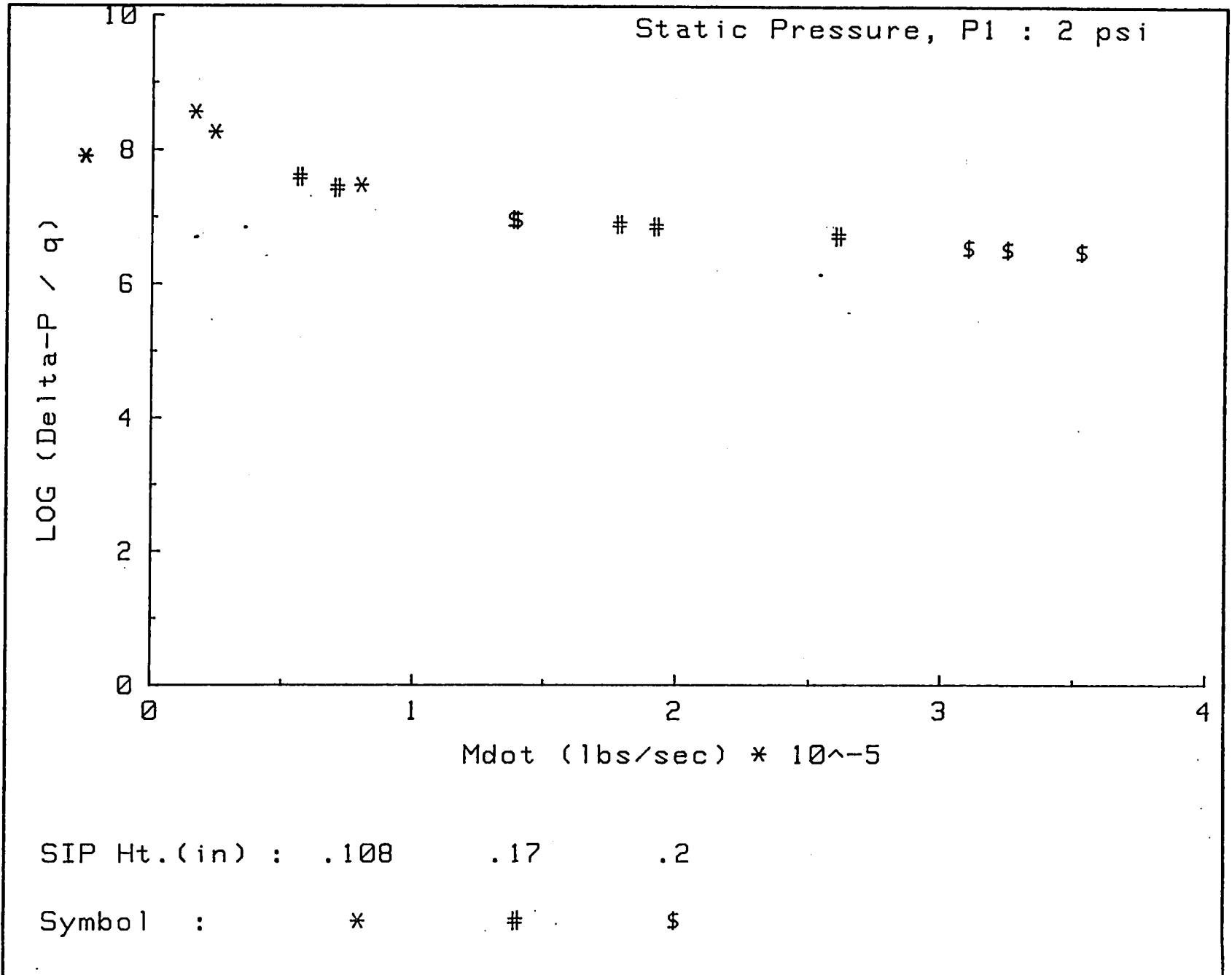
Figure 7h.- Static pressure equals 3 psi.

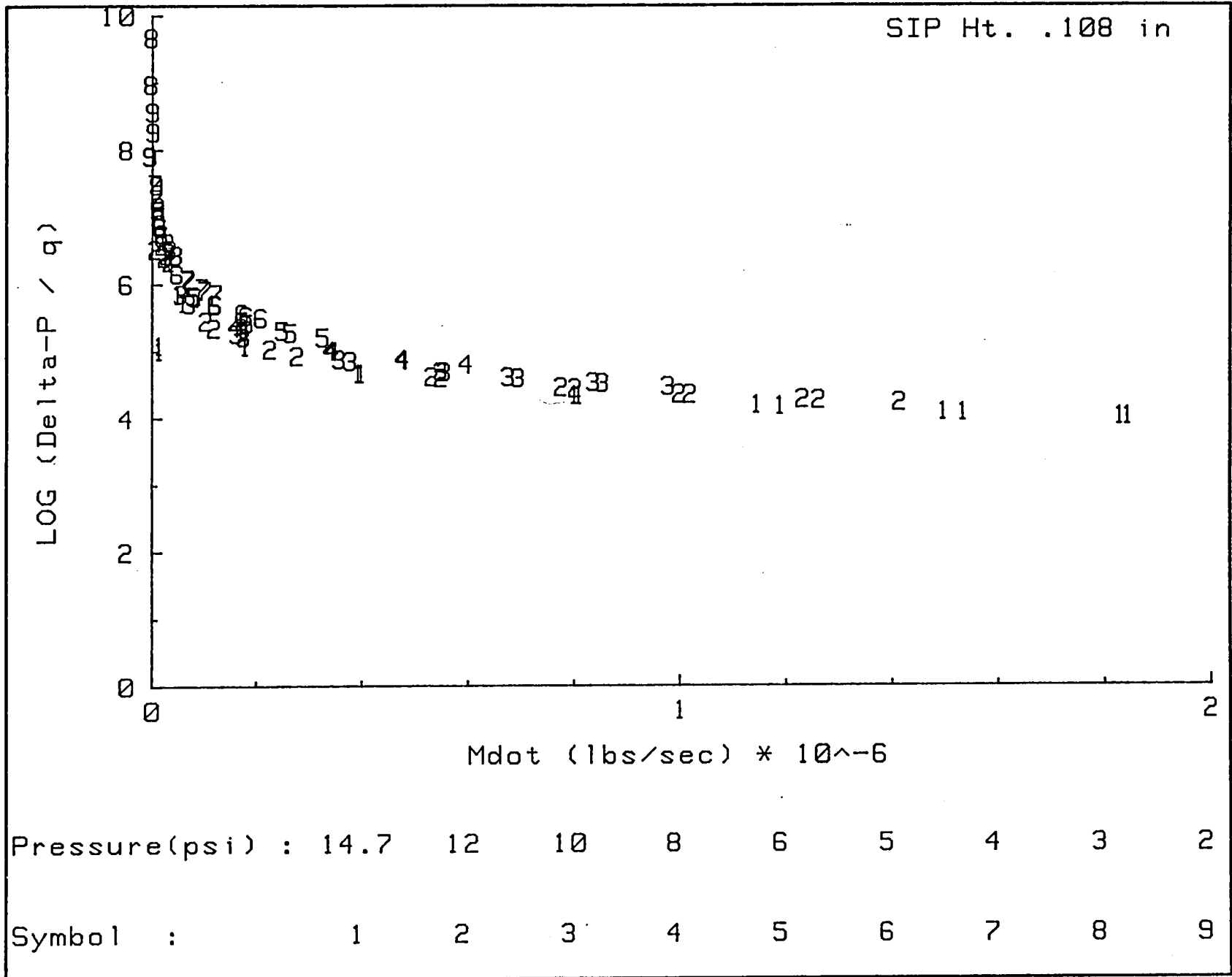Figure 7i.- Static pressure equals 2 psi. (concluded)

Figure 8a.- Log of differential to dynamic pressure ratio as a function of the mass flow rate for different static pressures at a SIP height of .108 in..
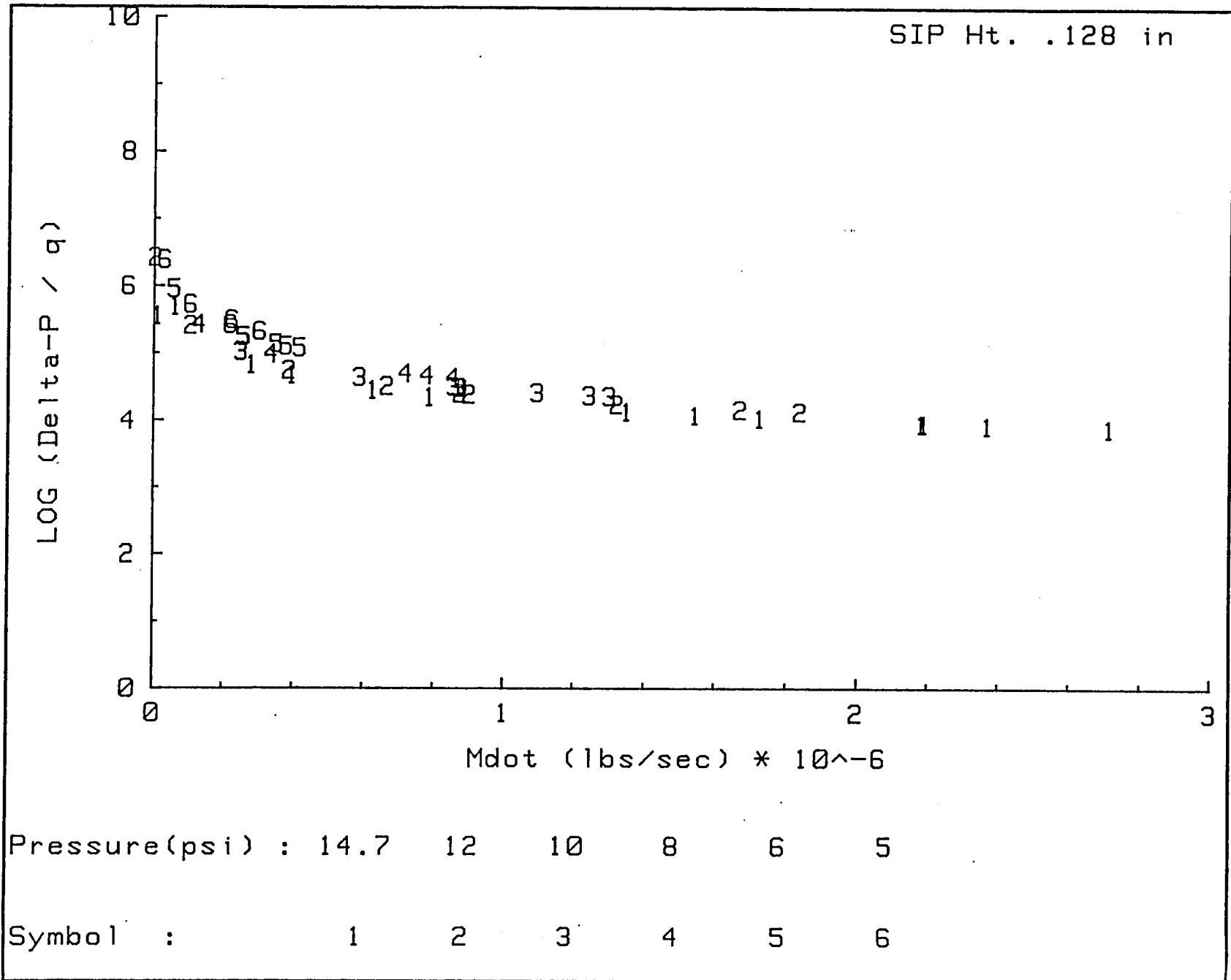
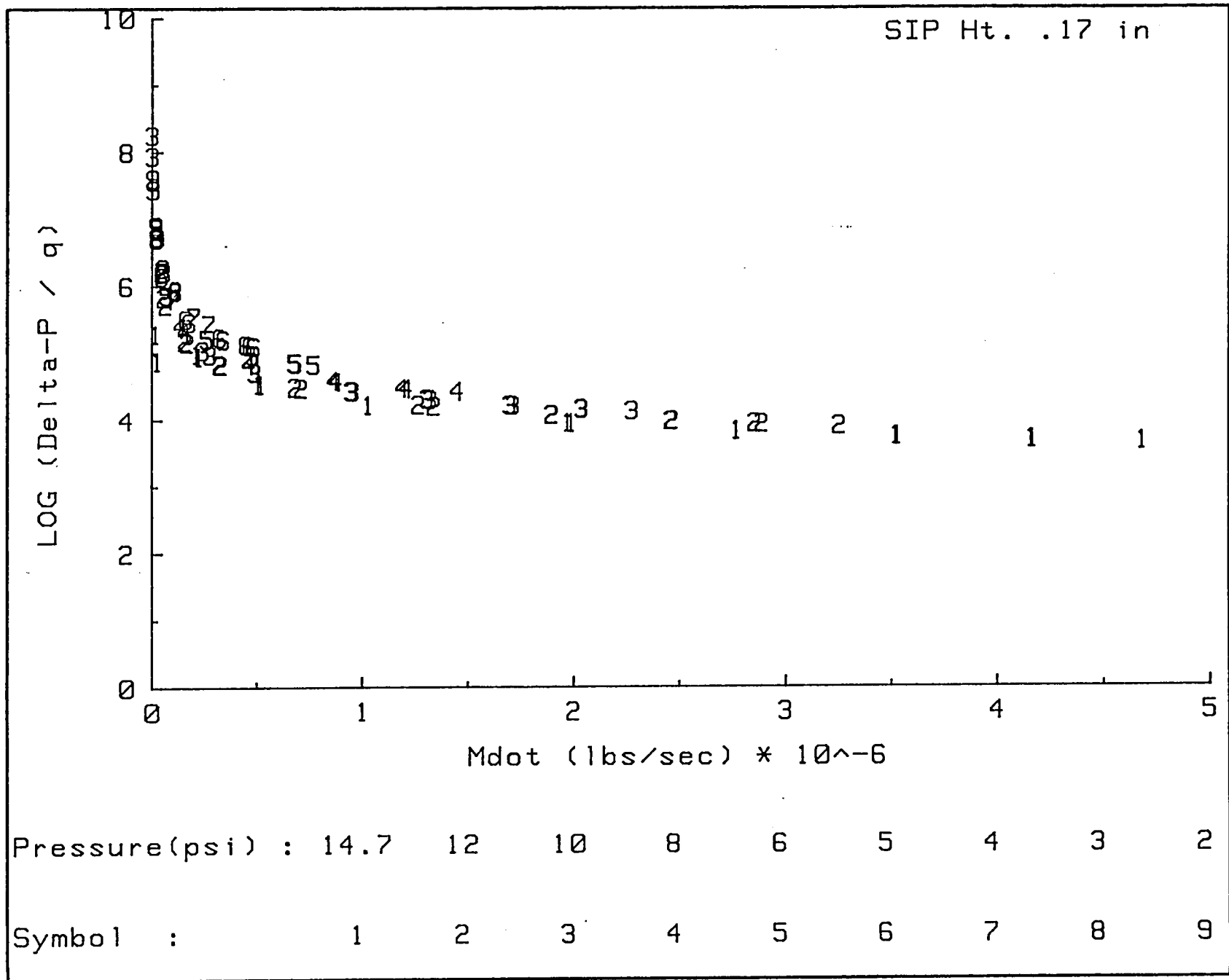Figure 8b.- SIP height equals .128 in..
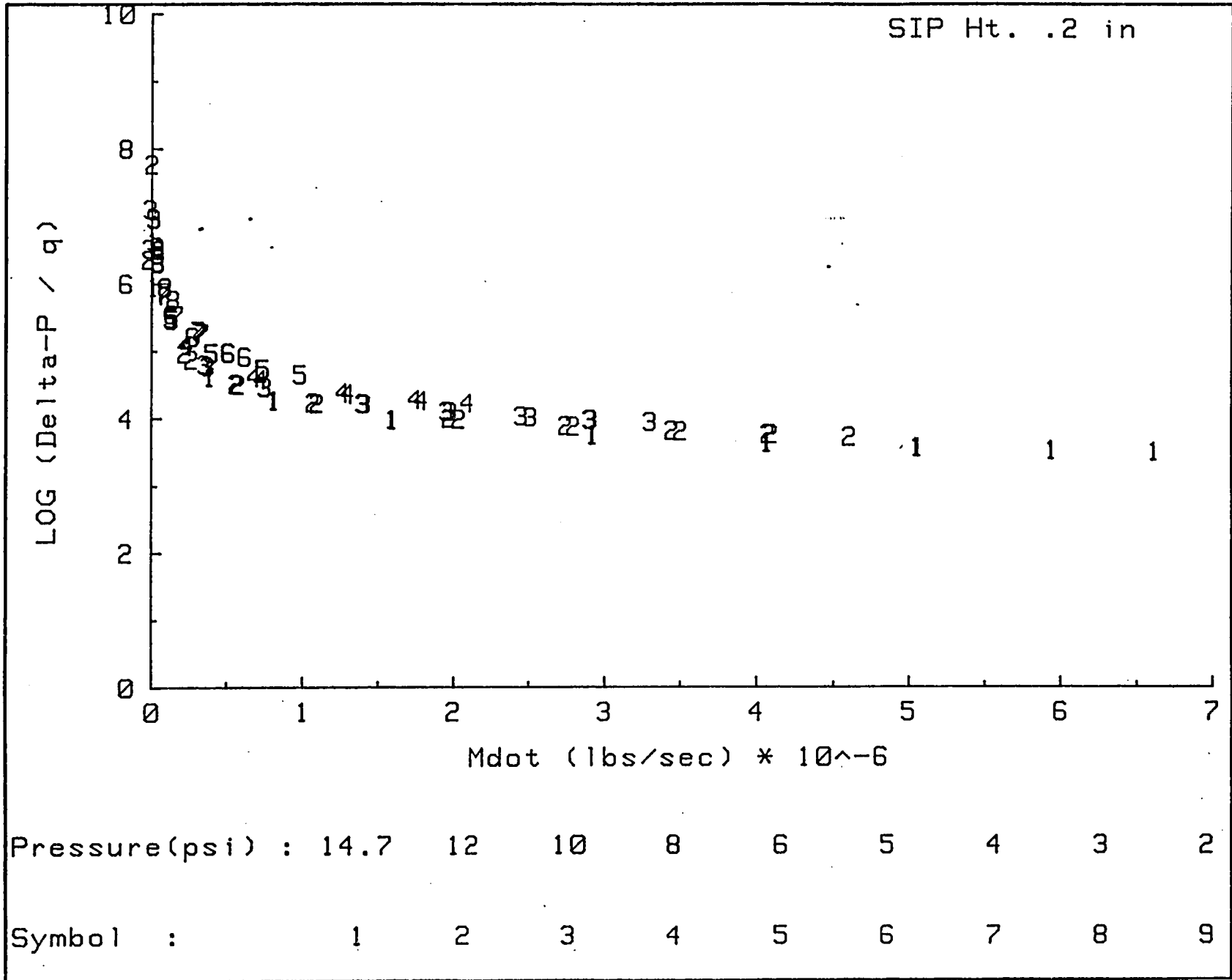
Figure 8c.- SIP height equals .170 in..

Figure 8d.- SIP height equals .200 in.. (concluded)

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7. Author(s) R. Dean Springfield and Pierce L. Lawing		8. Performing Organization Report No.
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15. Supplementary Notes

16. Abstract

Tests were conducted on a sample of Strain Isolation Pad (SIP) typical of that used in the Shuttle Orbiter Thermal Protection System to determine the characteristics of SIP internal flow. Data obtained were pressure drop as a function of flow rate for a range of ambient pressures representing various points along the Shuttle trajectory and for streched and compressed conditions of the SIP. Flow was in the direction of the weave parallel to most of the fibers. The data are plotted in several standard engineering formats in order to be of maximum utility to the user. In addition to providing support to the Space Shuttle Program, these data are a source of experimental information on flow through fiberous (rather than the more usual sand bed type) porous media.

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