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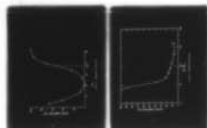
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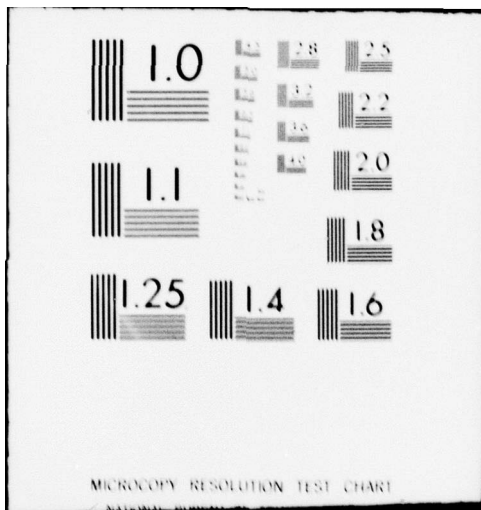
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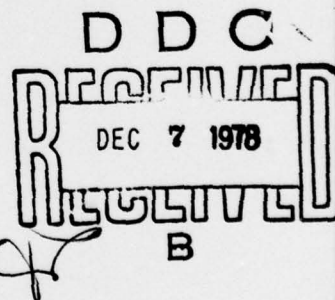
### A WALL-FLOW-DIRECTION PROBE FOR USE IN SEPARATING AND REATTACHING FLOWS

BY

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Technical Report SU-3-PU

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10 John K./Eaton, Albert H./Jeans,  
Jalal/Ashjaee and James P./Johnston  
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A WALL-FLOW-DIRECTION PROBE FOR USE IN  
SEPARATING AND REATTACHING FLOWS

by

John K. Eaton\*, Albert H. Jeans\*, Jalal Ashjaee\*  
and James P. Johnston\*\*

ABSTRACT

The measurement of the exceedingly unsteady behavior of nominally two-dimensional, turbulent flows in regions of separation and reattachment is facilitated by the development of a new instrument; the wall-flow-direction probe which determines the instantaneous flow direction (upstream or downstream) in a thin layer of fluid very close to the wall. The probe was tested in low-speed, unsteady, separating and reattaching air flows. It appears to offer considerably more accuracy than other methods for the determination of time mean separation and reattachment points. In addition, the probe and its control circuits are relatively inexpensive and easy to construct.

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## 1. INTRODUCTION

As part of a continuing program of research on internal flows we are currently studying nominally two-dimensional separating and reattaching turbulent flows which contain regions where instantaneous flow reversal frequently occurs. The most notable example of such behavior occurs in the transitory stall regime of two-dimensional diffuser flows [1]. In cases with unsteady flow reversals, the use of most conventional instrumentation is precluded. A notable exception is the laser doppler velocimeter with frequency shifting, an expensive and difficult technique.

To facilitate our research, a simple and inexpensive wall-flow-direction probe has been developed which may be used to determine the instantaneous flow direction (upstream or downstream) in a thin layer of fluid very near a wall. Although the basic idea for this probe is not new, we feel that other investigators of unsteady, reversing flows may find the probe's design very useful especially in light of its low cost, its simplicity and its relative ease of application in low-speed air flow experiments.

## 2. BASIC DESIGN

The probe (Figure 1) consists of three parallel wires mounted on short prongs which penetrate the wall and are perpendicular to the flow. The larger, center wire is heated with a D.C. current of about 1.5 amperes to create a heated wake in the layer of air close to the wall. The two sensor wires, operated as resistance thermometers, detect the wake, and through a simple electronic circuit give the instantaneous sign of the fluid velocity in the layer of air which is within 1 mm of the wall.

### 3. DESIGN DETAILS

The three wires are mounted on six copper plated sewing needles (.3 mm diameter), which are rigidly mounted in a plexiglas cylinder. The cylinder fits inside of the outer shell which itself fits into the wind tunnel instrument ports. Once installed, the surface of the probe appears to be an integral part of the test surface to  $\pm 0.03$  mm. The needles protrude through clearance holes in the face of the outer shell. With this arrangement, the needles may be extended about 5 mm from the probe surface to facilitate wire mounting. After the wires are mounted the needles are retracted so that the wires are about 1 mm above the surface. An earlier version of this probe used a center wire mounted flush to the surface. Data sets using both probes show that the two configurations give identical results to within the experimental uncertainty of either type of probe.

The sensor wires are 5 micron platinum plated tungsten and are soldered to the ends of the needles. The heater wire is 125 micron monel, and it is soldered to the side of the central pair of needles just below their tips. The solder joints on the heater wire are coated with epoxy to prevent oxidation and to provide mechanical strength. The wires are connected through the needles to a five pin connector mounted in the outer shell. Only five pins are needed since the sensor wires share a common ground.

A block diagram of the electronic circuitry is shown in Figure 2. The two sensor wires are operated in a bridge which is balanced when both wires are at the same temperature. If the temperature of sensor wire 1 is increased, its resistance will increase and a positive voltage

will appear at amplifier A1. This voltage is amplified and then applied to a comparator (C) which controls switch S. The switch gives an output of 5 volts or zero volts depending on the flow direction. The final amplifier (A2) is used to accurately adjust the output zero.

The circuit diagram is shown in Figure 3. Power supplies are needed to supply  $\pm 15$  volts and  $V_{ref}$  which may be any voltage from 0 to 12 volts. We chose 5 volts in order to facilitate computer interfacing. An additional power supply is needed to supply current to the center wire. Excluding the power supplies, the total cost of components for this control circuitry did not exceed \$40.00.

Before using the system, the probe should be placed in the flow and the input offset adjusted with the heater turned off. If the offset is adjusted correctly, the output will dither between 0 volts and  $V_{ref}$ . This adjustment is quite stable but should be checked every hour or so in the course of a run.

#### 4. APPLICATIONS

The wall-flow-direction probe can be used for several different purposes. The fraction of the time that the local flow near the wall is forward or backward can be measured by time-averaging the probe's output using an integrating voltmeter. When the fraction of time that the flow is in the downstream direction (henceforth called percent downstream flow) is measured for a number of streamwise locations in a nominally two-dimensional separating or reattaching flow, the location of the mean detachment or reattachment point\* can be determined. In addition to this

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\* We have defined the mean detachment or reattachment point to be the point where the flow very close to the wall is reversed 50 percent of the time. This point does not necessarily coincide with the point of zero mean shear stress, although the two points are probably quite close together.



measurement, spatial and temporal correlations of the wall flow direction can be made using two or more probes at the same time. Finally, the wall-flow-direction probe can be used in conjunction with hot-wire anemometers and other instruments for the purpose of conditional sampling of the anemometer output.

The probe has been tested in both a separating and a reattaching flow. In both of these flows, the measured value of percent downstream flow was a weak function of the heater current for currents of less than 1.5 amperes. Higher currents lead to shorter heater wire lifetimes so a current of 1.5 amperes was used for both cases presented here.

The probe was first used in a reattaching flow behind a backward facing step 5.08 cm high with free stream air speeds of from 5 to 20 m/sec. A typical curve of percent downstream flow plotted against streamwise location (Figure 4) shows the same general features previously observed using flow visualization, (e.g., Kim et al. [2]). These features include (i) an unsteady reattachment region approximately 3-4 step heights long, (ii) a region of fairly steady backflow located close to  $x = 4$  step heights, and (iii) a reseparation point located about 1 step height downstream of the step.

The uncertainty in each value of percent downstream flow is estimated to be  $\pm 1\%$  at 20:1 odds. The uncertainty in the location of the mean reattachment point is then less than  $\pm 1$  step height (Kline and Mc Clintock [3]) which is an order of magnitude better than can be obtained with most known methods of flow visualization\*.

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\*The only exception is the method of Rothe [4] which requires tedious frame-by-frame examination of motion picture film.

The probe has also been used in a straight-walled diffuser operating in the transitory stall regime. The throat width of the diffuser was 7.62 cm and the total included angle between the diverging walls was 12 degrees. In this case, the inlet air speed was 50 m/sec.

The percent downstream flow is plotted against streamwise location in Figure 5. Here the probe showed a small amount of asymmetry. The measured percent downstream flow was slightly different when the probe was rotated 180 degrees thus reversing the positions of the sensor wires. The average of the two measurements was used to determine the mean detachment point.

## 5. CONCLUSION

The wall-flow-direction probe is proving to be a useful and easily applied tool for studying unsteady reversing flows. It enables one to accurately measure the location of two-dimensional detachment and reattachment points in a consistent manner. Adoption of the method by future researchers could enhance our ability to compare results of different studies. For example, current uncertainties on distance to reattachment for separated flow behind steps and fences are roughly plus or minus one step height ( $H$ ). Use of the wall-flow-direction probe can reduce this uncertainty to plus or minus  $0.1 H$ .

## 6. ACKNOWLEDGEMENT

We thank Mr. Michael Eaton who contributed his time to design the electronic circuitry and Mr. Robin Birch who's fine craftsmanship lent much to the success of this project. Also, we gratefully acknowledge

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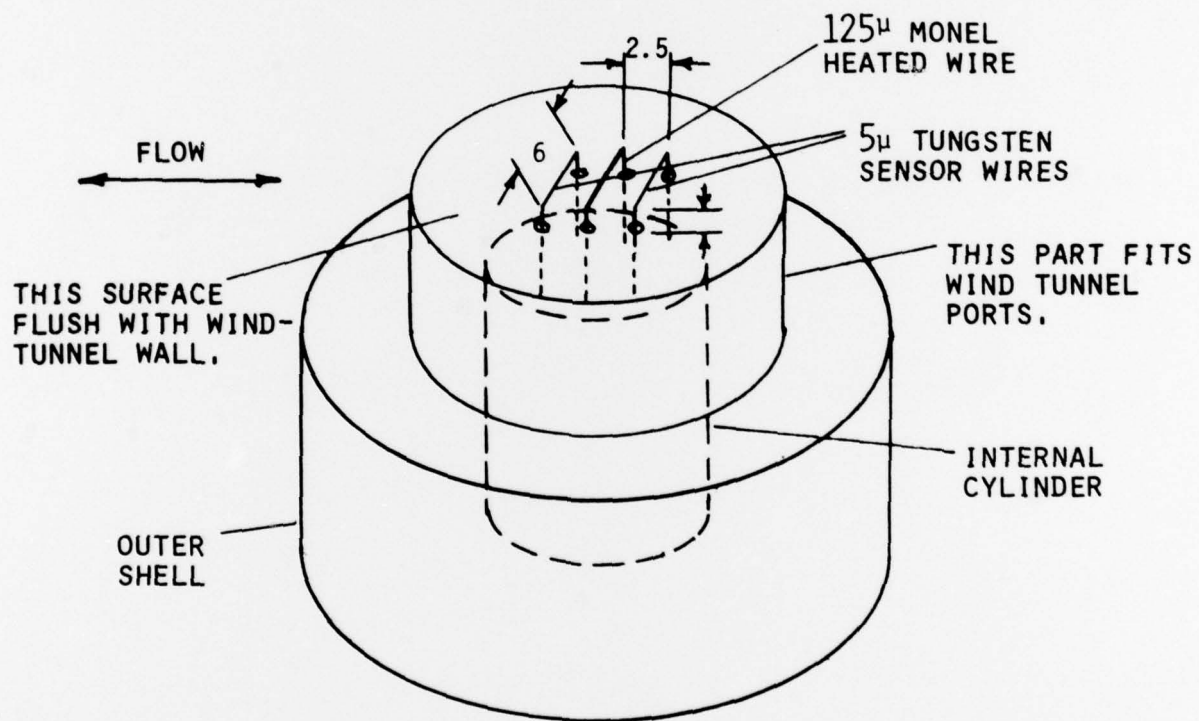


Figure 1. Wall-Flow-Direction Probe  
(dimensions in mm)



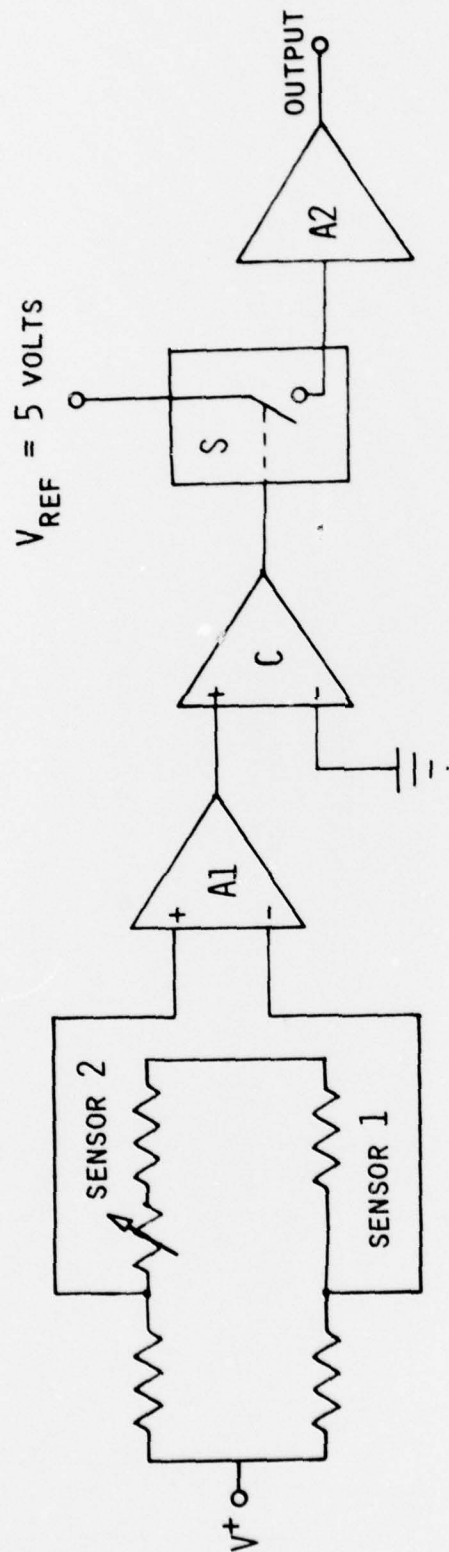


Figure 2. Electronic Circuitry Block Diagram



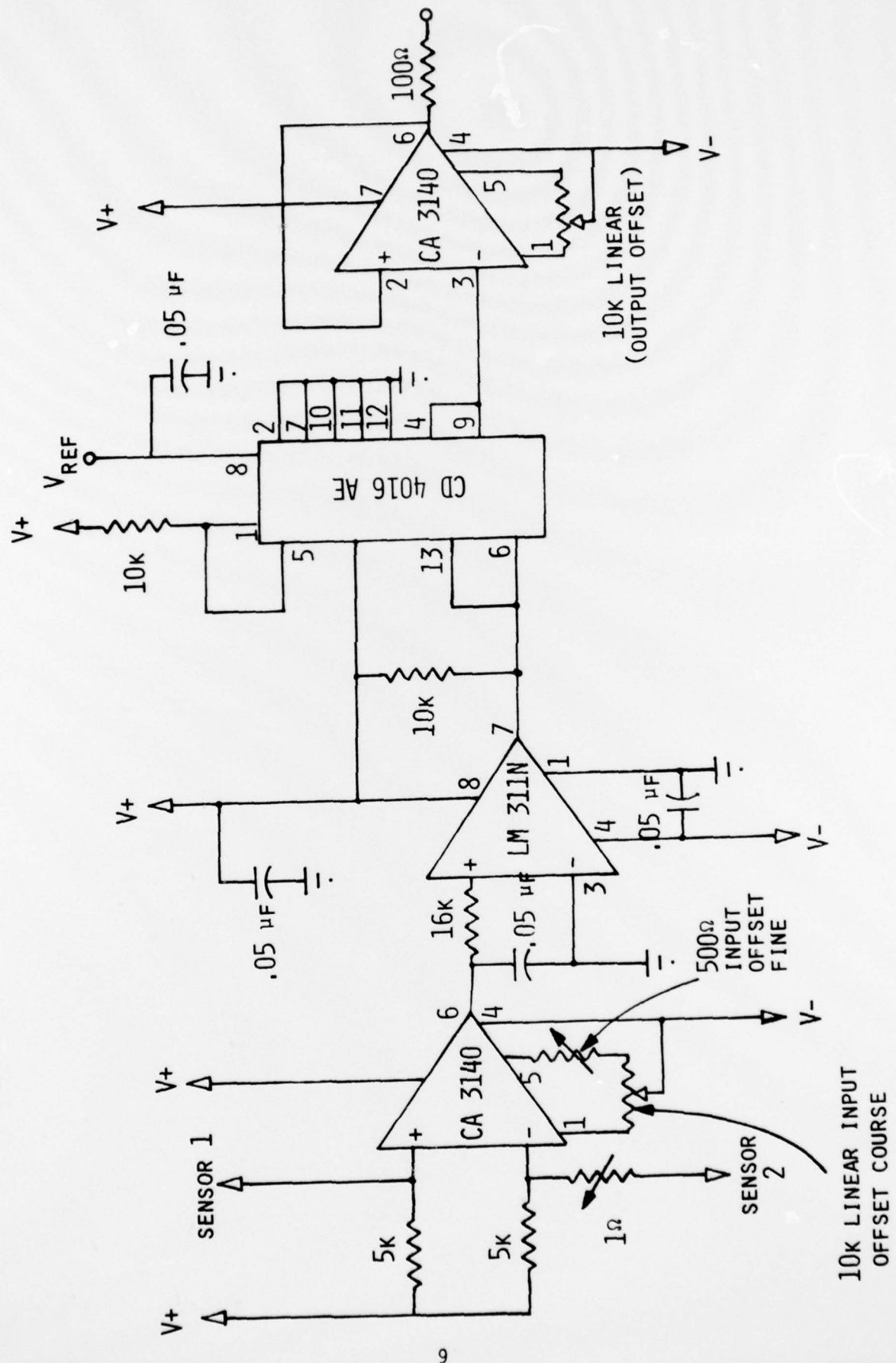


Figure 3. Circuit Schematic

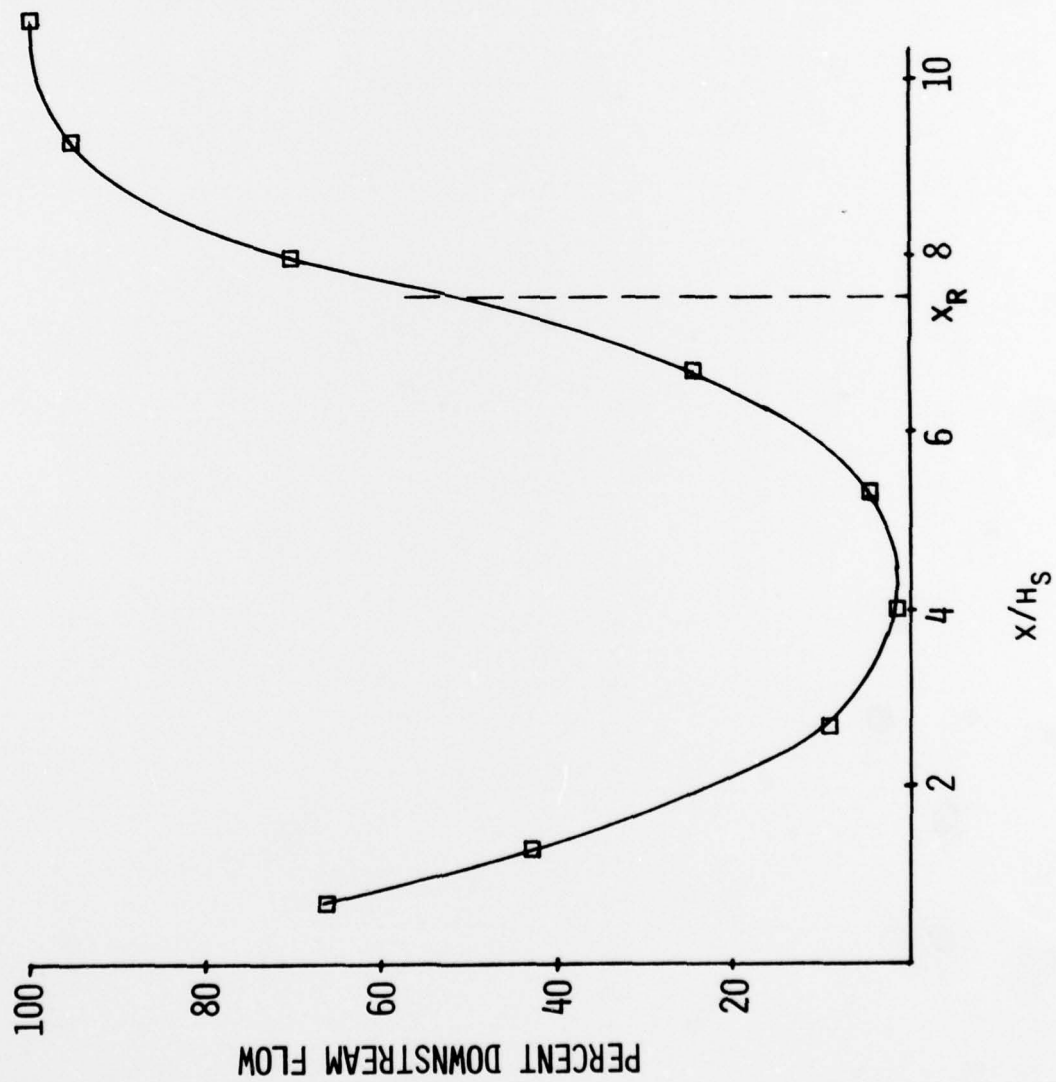


Figure 4. Reattaching Flow Data

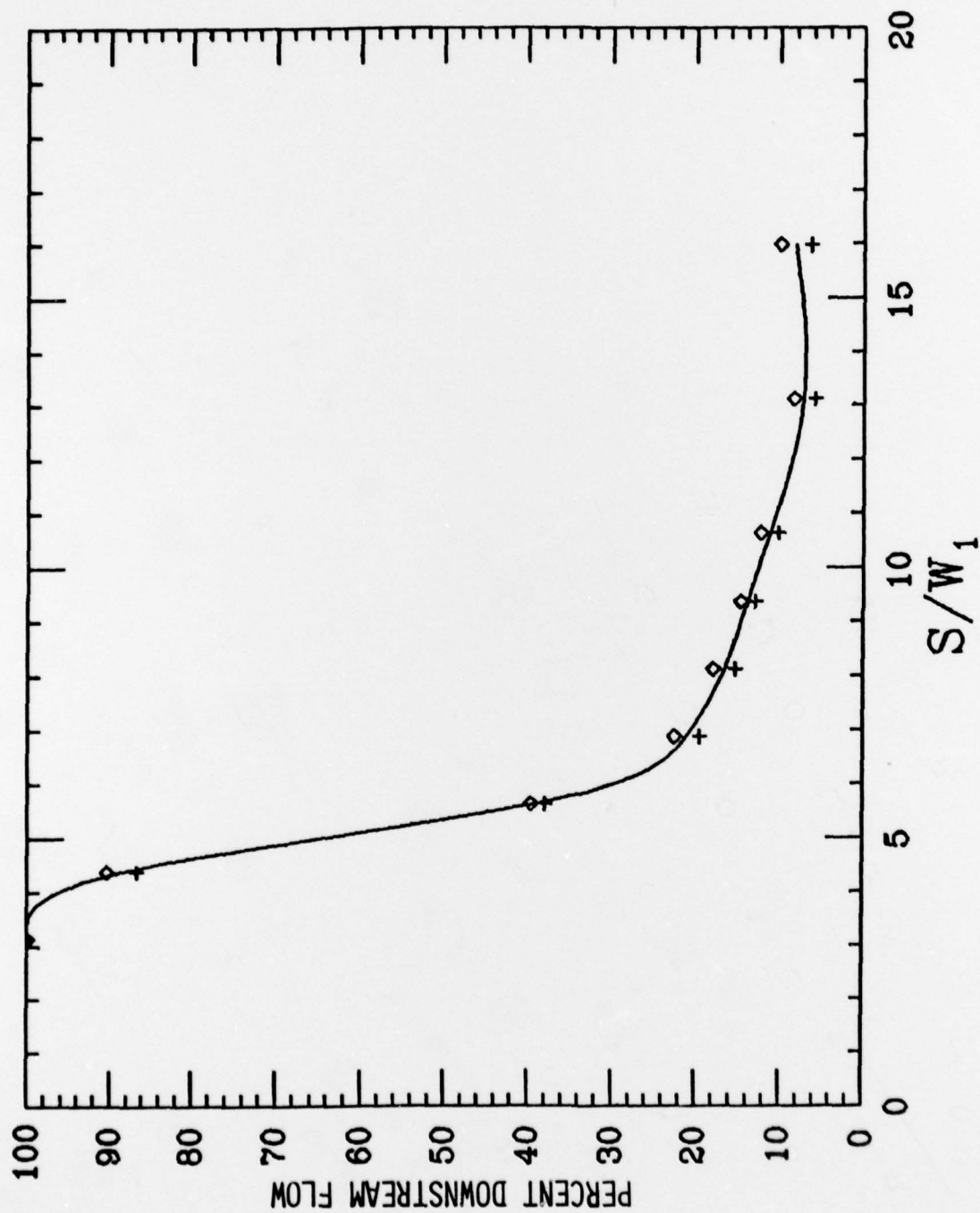


Figure 5. Separating Flow Data

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4 control circuits are relatively inexpensive and easy to construct.

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