# BREATH MEASUREMENT INSTRUMENTATION AS ALCOHOL SAFETY INTERLOCK SYSTEMS

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16. Abstract

This report describes the results of field tests of in-car instruments which measure alcohol on the driver's breath and prevent him from operating his vehicle if intoxicated. Two types of breath alcohol sensors were used for these tests; a fuel-cell type developed by TSC, and a semicouductor type from the Borg-Warner Corporation. Eight vehicles were equipped with the breath measurement and instrumentation and given to volunters subjects. Subjects returned to TSC weekly to allow calibration checks of the instrumentation, determination of their reaction to the devices and discussion of any attempts to circumvent the breath test interlock. The results of the field test indicate that breath measurement interlocks are basically feasible, but that more engineering effort needs to be expended to advance the alcohol sensor technology required for the production of sensors with uniform and predictable characteristics. The utility of currently available sensors is limited by erratic calibration drift. The field test also indicates circumvention to be a major problem and solutions to the problem do not appear to be cost effective.

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# PREFACE

The work described in this report was performed in support of a program at the Transportation Systems Center (TSC) to develop and evaluate Alcohol Safety Interlock Systems (ASIS). The program is sponsored by the Department of Transportation through the National Highway Traffic Safety Administration's Research Institute.

This report describes the results of engineering field tests of instrumentation which will detect alcohol on an intoxicated driver's breath and prevent him from operating his vehicle. Two types of breath-alcohol sensors were used: a fuel-cell type developed by TSC, and a semiconductor type from the Borg-Warner Corporation.

The authors would like to acknowledge contributions made by A. Iannini in test vehicle preparation, ASIS installation, and testing. Subjects were selected and interviewed by H. Jacobs of Dunlap and Associates, Inc.

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# EXECUTIVE SUMMARY

This report describes the results of tests conducted to evaluate the feasibility of using breath alcohol measurement devices in an Alcohol Safety Interlock System (ASIS). The purpose of an ASIS is to prevent the drunk driver from operating his car by requiring the driver to take and pass a test capable of determining if the driver is intoxicated. The test must be taken each time the car is to be driven, and if failed, the interlock prevents the car from being operated normally for a preselected period of time.

The practicality of any ASIS depends basically on four factors:

(1) The alcohol sensitivity of the device,

(2) the accuracy, and reliability of the alcohol measurement,

(3) the circumventability (cheatability) of the system,

(4) and the acceptability of the system to the user.

The results of field tests indicate that alcohol sensors of sufficient stability <u>can</u> be manufactured such that measurements of the breath alcohol concentration (BAC) can be made with an accuracy of $\pm 20\%$ for a period of approximately two months before requiring recalibration. However, variations in the rate of change of alcohol sensitivity with time for both types of sensors tested indicate the need for more developmental work before breath testing can be established as a practical foundation for an ASIS.

Circumvention of the breath ASIS is also a problem and represents a major impediment to achieving a practical and effective ASIS. Circumvention can be effected by tampering with the system components or by using artificial breath samples (any air sample that is not the driver's deep lung air). Circumvention by tampering cannot be prevented, but it can be detected, and therefore tampering may be minimized by using legal sanctions. Circumvention using artificial samples such as air-filled ballons and sober-passenger breath samples present a more difficult problem since it will not always be detectable in a cost-effective manner. A relatively simple device to measure the temperature of the air sample can effectively discriminate between a valid breath sample and an ambient air-filled balloon in most cases, but will not prevent the determined driver from cheating by using a temperature controlled artificial sample.

Photographing the driver while he provides the breath sample would provide a more foolproof technique for preventing circumvention by the use of false breath samples but this would be very complex, costly, and violates the concept of a simple and cost-effective in-car ASIS.

The acceptability of the ASIS to the subjects participating in the field test was primarily influenced by the inconvenience of the device. The Alcohol Screening Device (ASD) ASIS received a more favorable rating than the Borg-Warner (B-W) ASIS because the ASD test time was six seconds, compared to approximately 40-60 seconds for the B-W unit. Users also reacted strongly to the requirement for a new breath test each time a car door was opened. (This requirement was imposed as a circumvention countermeasure to prevent a sober person from exiting the car after providing a breath sample for an intoxicated driver). The primary importance of having an operationally convenient ASIS lies in the fact that a user who is antagonized by inconvenience will be more motivated to attempt circumvention than might otherwise be the case.

The results of this study indicate the eventual technical feasibility of a breath measurement ASIS. The ultimate effectiveness of such devices in the field, however, is questionable because circumvention by false breath samples cannot be completely prevented or even readily detected. Therefore, it is recommended that further alcohol sensor testing be postponed until a practical and economical means of detecting breath sample substitutions is devised, thus increasing the feasibility of the breath test ASIS to a more acceptable level.

# 1.0 INTRODUCTION

## 1.1 BACKGROUND

As part of its program to develop methods of reducing the number of alcohol-related traffic accidents, the U.S. Department of Transportation (DOT) is investigating the efficacy of Alcohol Safety Interlock Systems (ASIS). As currently envisioned, these systems are intended to (a) determine if the individual about to drive a car is intoxicated, and (b), if so, to prevent the car from being operated.

Two basic classes of devices are being evaluated by the Transportation Systems Center for use as an ASIS; those based upon the measure of psychomotor performance and those based upon measurement of the concentration of alcohol in alveolar air. Laboratory tests of the former have identified tasks which are very sensitive to alcohol. However, the high alcohol sensitivity is reduced when pass/fail thresholds are set low enough to prevent unacceptably high (3%) percentages of false positives. Work continues on these devices. TSC has also investigated the feasibility of a breath test-ignition interlock system. Since breath measurement has been shown to be a more accurate means of determining blood alcohol concentrations (BAC) than performance testing, breath testing, in theory, would seem to provide the most reliable means of keeping the intoxicated person from driving. Furthermore, since BAC is the parameter currently used in the legal definition of intoxication, a breath ASIS may have the added advantage of greater acceptability to civilian legal authorities.

## 1.2 PURPOSE

Laboratory tests that were conducted as part of an earlier alcohol sensor development program indicated that recently developed alcohol sensors were capable of accurately indicating blood alcohol concentration (BAC). This evaluation is addressed to two of these, the Alcohol Screening Device (ASD) fuel cell sensor developed by TSC and a semiconductor sensor from Borg-Warner Corp. The simplicity, size, and responsiveness of these sensors represent major advancements in breath measurement technology since standard techniques are time consuming, require a trained operator and bulky, expensive equipment.

Although the initial intended application for these sensors was for roadside breath measurements of suspected drunk drivers, it was felt that their relative inexpensiveness and speed of measurement made them prime candidates for deployment in ASIS devices. However, the criteria for sensor performance are more rigorous than for a roadside device used by police, particulary with regard to calibration and test supervision. As a practical matter, an ASIS device must remain in reasonable calibration for at least a month, whereas more frequent calibration of an ASD by police would not be impractical. More importantly, the fact that roadside screening tests would be conducted by a police officer prevents attempts by the subject to circumvent the test by cheating or equipment tampering.

The basic purpose of the breath ASIS field test was to examine the importance of these differences under relaistic conditions.

## 1.3 SCOPE

The primary objectives of the field test were: (1) to determine the reliability and calibration stability of the alcohol sensors in the automobile environment, (2) to test the susceptibility of this type ASIS to circumvention attempts, and (3) to determine the acceptability of such devices to the user.

## 2. FIELD TESTING METHOD

In order to determine ~~assess~~ the viability of breath testing as the basis for an interlock system it was necessary to fabricate breath-ASIS devices, install them in automobiles and actually test them with a population of heavy drinkers: This approach provided the means for:

(a) Identifying engineering and implementation problems associated with installation, calibration, and maintenance of the devices:

(b) Collecting data on user acceptability and device related inconveniences

(c) Identifying circumvention procedures likely to be employed.

The field test included a "shakedown" phase and the "evaluation" phase; the first was conducted to identify unanticipated operational problems. During this phase psychology and engineering professionals from the local community drove the cars as their own for approximately four weeks. This resulted in some equipment design changes that made the devices more reliable, e.g. some components were replaced to make the devices less susceptible to malfunctions at the high temperatures (140°F) which occur in closed automobiles during the summer.

During the second phase the cars were given to volunteers representing members of a potential target population, (i.e. heavy drinkers) for a more complete and valid evaluation of the devices.

## 2.1 INSTRUMENTATION

Four Alcohol Screening Device (ASD) fuel cell sensors developed by TSC and four semiconductors sensors from Borg-Warner Corp. were incorporated in separate prototype ASIS instruments and coupled with a data recording package for installation into a fleet of eight 1973 American sedans (Chevelle Malibu).

### 2.1.1 Instrumentation Package

The ASIS instrumentation package shown in Figure 1, has three functional elements:

1. The breath tester, consisting of the sensor and its associated electronics.
2. The test-sequence logic-control electronics, which includes the anticircumvention circuitry, ~~functions~~.
3. The data-recording electronics.

The block diagram in Figure 2 shows the functional organization and the vehicle-interface requirements of the ASIS.

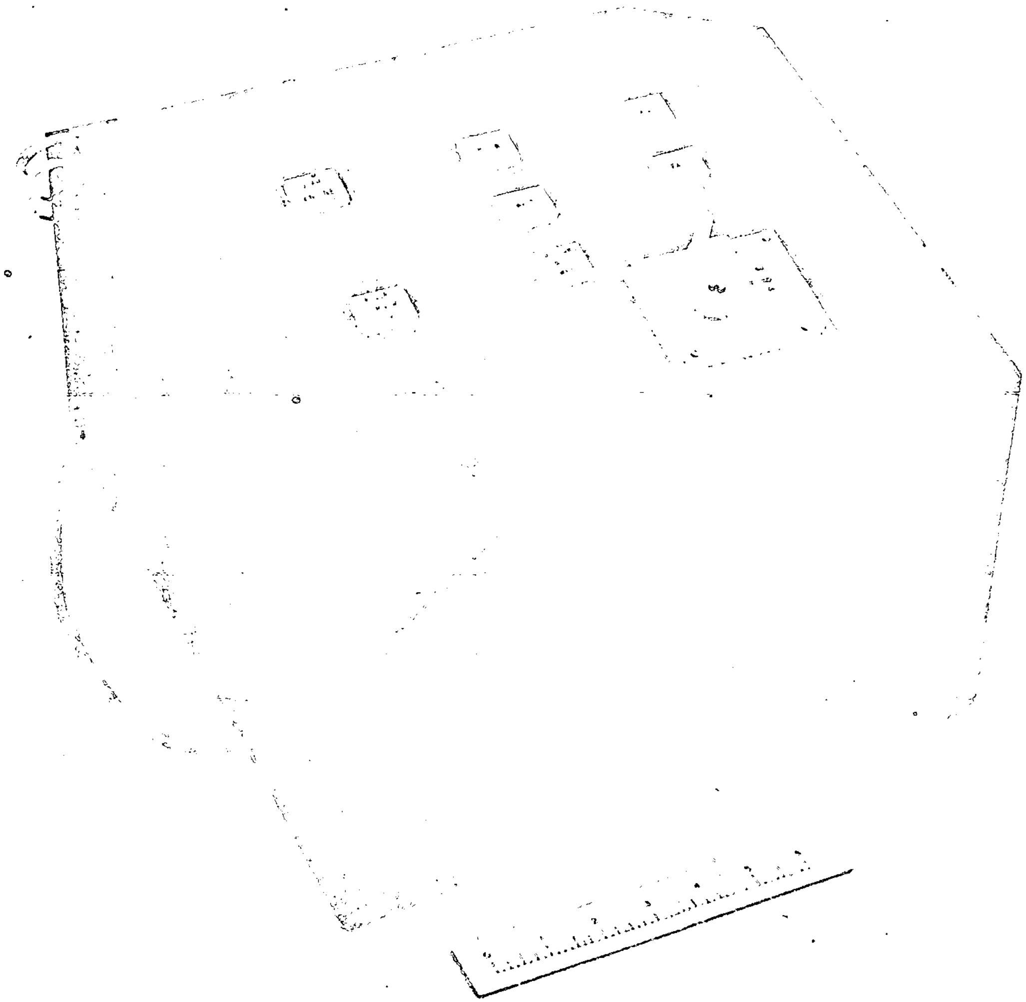

Figure 1. Photograph of ASIS

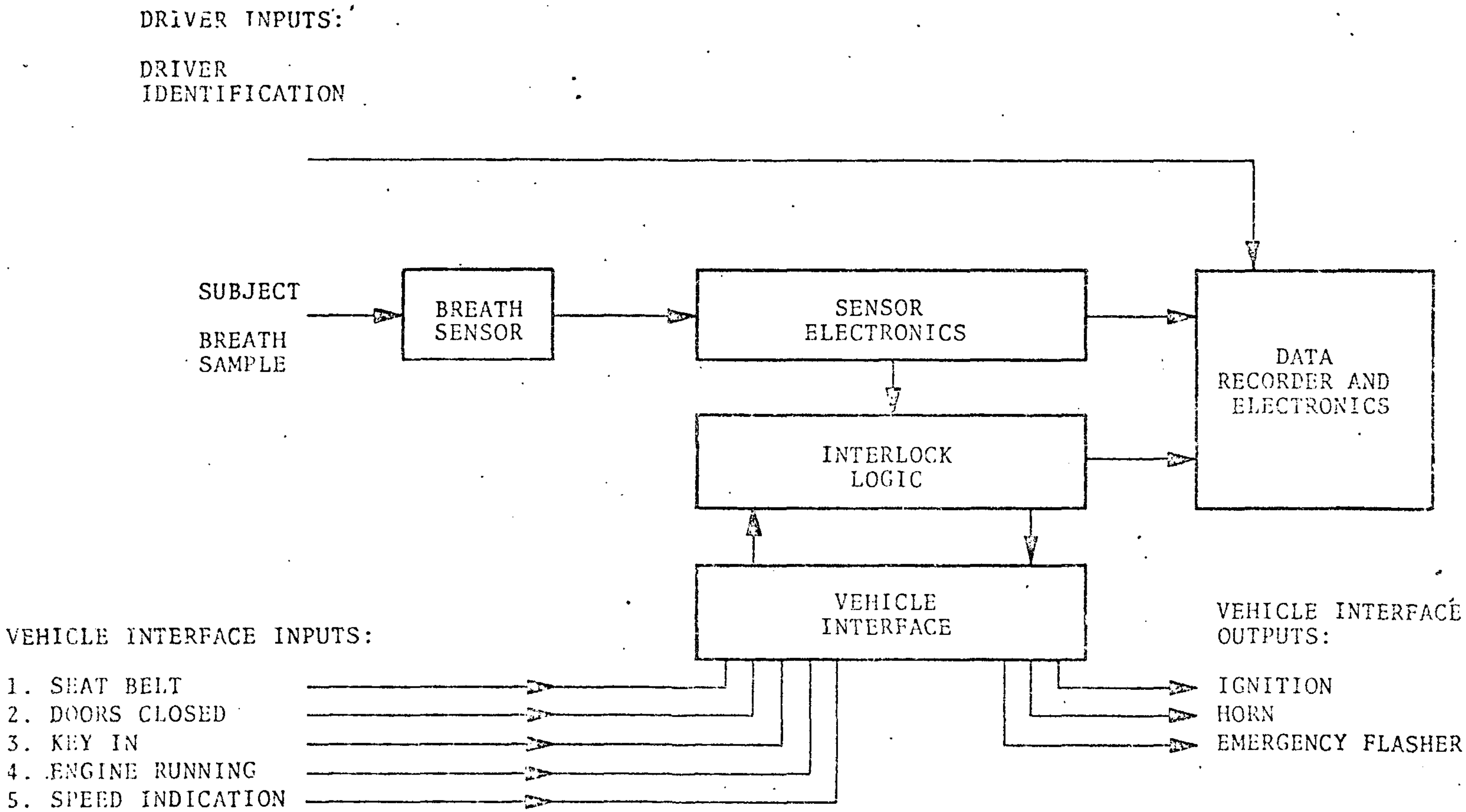


Figure 2. ASIS System Block Diagram

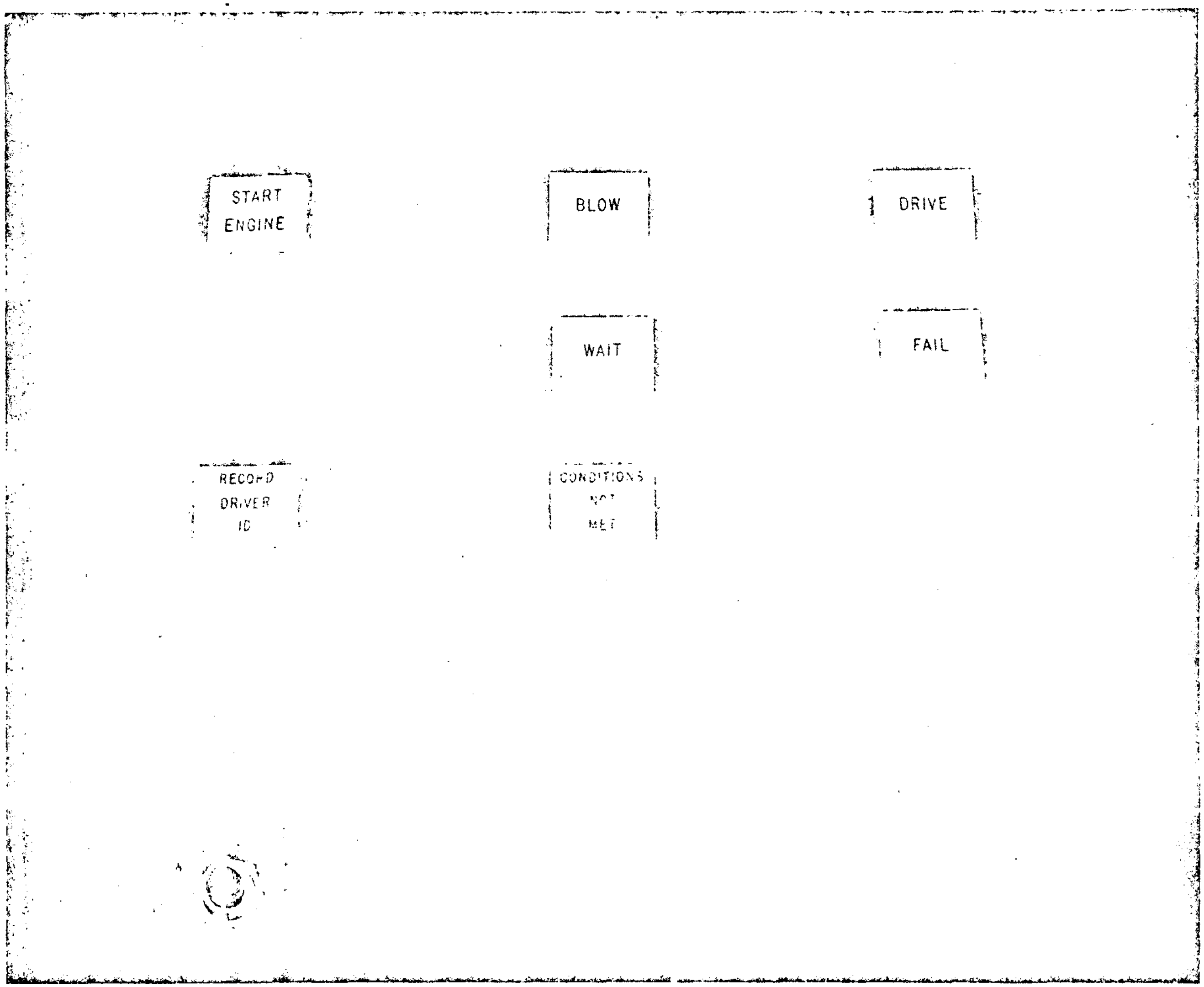


Figure 3. ASIS Console

(The digital data tape recorder and electronics portion of the system would not be included in a production design; it is used here for constant monitoring of the system performance during the field test).

### 2.1.2 Alcohol Sensors

The ASD sensor developed at TSC is an electrochemical fuel cell. It uses the alcohol in the breath as a fuel, oxidizing it to generate an electric signal proportional to the amount of alcohol in the breath. It is a semi-dry sensor, requiring several drops of phosphoric-acid electrolyte for electrical conduction.

The Borg-Warner sensor is a solid-state semiconductor whose surface resistance changes as a function of the amount of alcohol that is absorbed onto the surface. The electronics associated with each sensor are functionally similar in that they (1) verify that the breath-sample volume requirements are met and (2) evaluate the sensor output after a valid sample has been obtained and give a pass-or-fail indication.

### 2.1.2 Test-Sequence Logic

Figure 3 is a photograph of the ASIS console. A normal start is initiated by inserting the key, upon which the "START ENGINE" and "CONDITIONS NOT MET" lights come on. Starting the engine extinguishes the first light. The "CONDITIONS NOT MET" light is extinguished when:

(a) All doors are closed;

(b) The front-seat occupants have buckled their seat belts; and

(c) The engine is running.

When the first two lights are extinguished on the ASD unit, the "BLOW" light comes on, indicating that the unit is ready to accept the driver's breath sample. The Borg-Warner device requires a preliminary purge of the sensor, so the "WAIT" light will come on instead. Upon completion of the automatic purge cycle, the "BLOW" light is activated. If the subject provides a breath sample meeting the volume requirements, and if his BAC is less than the preset fail level, the "DRIVE" light activates indicating that the test is complete and the car is ready to drive. This constitutes a normal start sequence. If, however, the subject's BAC exceeds the preset fail level, the "FAIL" light will go on and the car's ignition system will be automatically disabled for 10 minutes, after which another test may be attempted.

There are two alternatives to the normal start sequence:

(a) After starting the engine, the subject may simply refuse to satisfy the initial conditions or to take the test, and drive away. However, when the speed of the car exceeds 2 MPH, the emergency lights will flash, and, when the car is driven above 15 MPH, the horn will blow continuously as well. Activation of the horn is registered on the data recorder and shows on the computer printout. This method of operating the car without taking the test permits the vehicle to be moved short distances, such as into a garage, and allows for critical situations when delays can not be tolerated, such as an emergency run to the hospital.

(b) An "OVERRIDE" pushbutton switch, located on the rear of the console, permits the car to be driven, without alarms, even though the test has been failed or not completed. This switch permits the vehicle to be returned to the test facility in the event of malfunction, and would not be part of the normal ASIS. If the subjects should depress it, the fact will be automatically recorded.

Two additional start modes exist, called the "stall start" and the "free start". A stall start is restarting the vehicle's engine after it has stalled but before the breath test has been taken. A free start is the restarting of an engine stalled after the normal start sequence has been completed and the breath test passed. A free start must be made within two minutes of a stall. Beyond that time, the complete test sequence must be repeated.

As part of the effort to prevent circumvention of the breath test, the control logic is designed to require a complete new start cycle if any initial condition is interrupted. For example, if the car door is opened after completion of the breath test, the start cycle must be repeated. (This arrangement prevents a sober person from starting the car for an intoxicated driver and then getting out.)

### 2.1.3 Data-Recording Electronics

A small digital tape recorder incorporated into the test console records all data accumulated between weekly interviews. When the tapes are reduced to a hard-copy computer printout, the following data are provided:

- Number of starts
- Date and time of each start
- Driver identification number
- Number of breath tests attempted
- Measured blood-alcohol concentration (BAC) for each test
- A pass, fail, or invalid-test indication (invalid tests occur when an insufficient breath sample is given; they require another test.)
- Type of start: Normal, Free, or Override

- Number of times that the subject tried to drive without completing a satisfactory test
- Number of times that the subject tampered with the ASIS instrumentation.

Figure 4 shows a typical printout.

### 2.1.4 Sequence Control Logic

Figure 2 shows the basic functional components of the ASIS and identifies the vehicle and driver interface inputs and outputs. The driver is responsible for two inputs: (1) identifying himself for the test record, which is done by dialing his identifying number on the console thumbwheel switches and then pressing the "DRIVER ID" button to enter it, and (2) providing the breath sample when the "BLOW" light goes on. Vehicle interface inputs 1 through 4 are used to verify that all the required initial conditions have been met. Input 5, the speed indication, triggers the horn and warning flashers if the car is moved before the breath test has been successfully completed. The vehicle interface outputs are the horn and emergency-flasher connections in case of an incomplete or improper test sequence, and the ignition connection to disable the car if a test is failed.

Figure 5 is a flow chart of the ASIS control logic. It graphically shows the sequence of the logic queries and actions during a test start.

RAW ASIS TEST DATA. VEHICLE NO. 3

| ENTRY | DATE TIME | DRIVER | BREATH TEST: TEST # | BREATH TEST: [illegible] | BREATH TEST: P/F/I | TYPE OF START | ALARM/ TAMPER/ TEST |
|---|---|---|---|---|---|---|---|
| 0 | 8/ 3/73.1230 | 0 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1320 | 0 | | | | | 0 0 0 |
| 0 | 8/ 3/73.1410 | 0 | | | | | 0 0 0 |
| 0 | 8/ 3/73.1230 | 0 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 0 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 0 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 0 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 0 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 0 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 0 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 1 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 2 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 3 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 4 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 5 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 6 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 7 | | | | | 0 0 1 |
| 0 | 9/ 3/73.1230 | 0 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 10 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 20 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 30 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 40 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 50 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 60 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 70 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 77 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 77 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 77 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 77 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 77 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 77 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 77 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 77 | | | | | 0 0 1 |
| 0 | 9/ 3/73.1230 | 77 | | | | | 0 0 1 |
| 0 | 8/ 3/73.1230 | 77 | | | | | 0 0 1 |
| 1 | 8/ 3/73.1300 | 23 | | | | NORM | 0 0 0 |
| 1 | 8/ 3/73.1310 | 3 | | | INV | | 0 0 0 |
| 1 | 8/ 3/73.1310 | 3 | 1 | 0.01 | PASS | | 0 0 0 |
| 2 | 8/ 3/73.1310 | 3 | | | | NORM | 0 0 0 |
| 2 | 8/ 3/73.1310 | 3 | 2 | 0.00 | PASS | | 0 0 0 |
| 2 | 8/ 3/73.1310 | 3 | | | | | 1 0 0 |
| 2 | 8/ 3/73.1320 | 3 | | | | | 0 1 0 |
| 2 | 8/ 3/73.1320 | 3 | | | | | 0 1 0 |
| 3 | 8/ 3/73.1320 | 3 | | | | NORM | 0 0 0 |
| 3 | 8/ 3/73.1320 | 3 | 3 | 0.01 | PASS | | 0 0 0 |
| 3 | 8/ 3/73.1320 | 3 | | | | OVER | 0 0 0 |
| 4 | 8/ 3/73.1320 | 3 | | | | NORM | 0 0 0 |
| 4 | 8/ 3/73.1320 | 3 | | | INV | | 0 0 0 |
| 4 | 8/ 3/73.1320 | 3 | | | INV | | 0 0 0 |
| 4 | 8/ 3/73.1330 | 3 | 4 | 0.01 | PASS | | 0 0 0 |
| 5 | 8/ 3/73.1330 | 3 | | | | NORM | 0 0 0 |
| 5 | [illegible] | 3 | [illegible] | 0.0[illegible] | [illegible] | | 0 0 0 |
| 6 | 8/ 3/73.1330 | 3 | | | | NORM | 0 0 0 |
| 6 | 8/ 3/73.1330 | 3 | 6 | 0.14 | FAIL | | 0 0 0 |

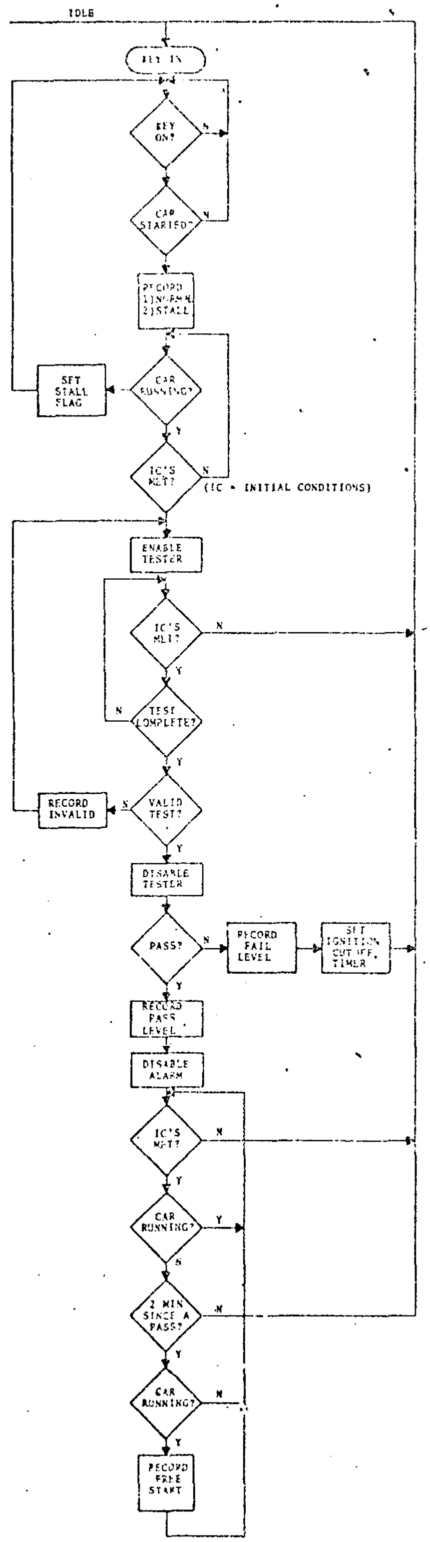


Figure 5 ASIS Control-Logic Flowchart

IDLE describes the condition of the logic which exists before the ignition key has been inserted. A continuing logic check is made to determine whether the key has been inserted. Once it has been inserted, a check is made to determine whether the car has been started. If the engine is not running, the state of the key is continuously monitored until the car has been started. When the car is started the tape recorder records a normal start. If the car stalls, a flag is set and the logic returns to check that the key is on. When the car has been restarted, a stall start will be recorded. When the engine is running, the initial conditions (seat belts fastened, doors closed, driver identification recorded) are continuously monitored. When they have been satisfied the breath tester will be enabled. Any subsequent check revealing that the initial condition have been violated will cause the test sequence to be aborted; the system will return to "IDLE", and a complete new start cycle will be required. (This is an anticircumvention feature which prevents the breath sample from being given by a sober person not intending to ride with the intoxicated driver). With the breath tester enabled and initial conditions maintained, and following collection of the breath sample, the sample is examined for compliance with the volume requirement. If the requirements are not satisfied, the breath tester is re-enabled for a repeat of the test. If it is satisfied, the tester will be disabled and the breath sample analyzed and the result recorded. If the BAC is above the pass/fail threshold, the ignition will be interrupted for 10 minutes (and the logic will return to IDLE). If the BAC value is below threshold, the horn and light alarms will be disabled and the driver will be informed by illumination of the "DRIVE" light. Thereafter, the initial conditions and "engine running" status will be continually checked. Shutting off the engine or violating the initial conditions will cause the logic to recycle to IDLE. If, however, the engine should stall within two minutes of successful completion of a test, the car may simple be re-started. This is recorded as a free start. This option is provided to allow for the stalls that often occur when a car is cold.

Figure 6 is a flow chart of the OVERRIDE sequence. It is shown as a separate chart, since pressing the "OVERRIDE" button can occur at any point in the test sequence and requires only that the key be in the ignition. If the "OVERRIDE" button is pushed and the key is in the ignition, the action is recorded and the alarms and ignition cutoff are disabled. Turning off the engine will reset the logic to IDLE.

## 2.3 SUBJECTS

Eighteen male subjects satisfying the following criteria were selected as drivers:

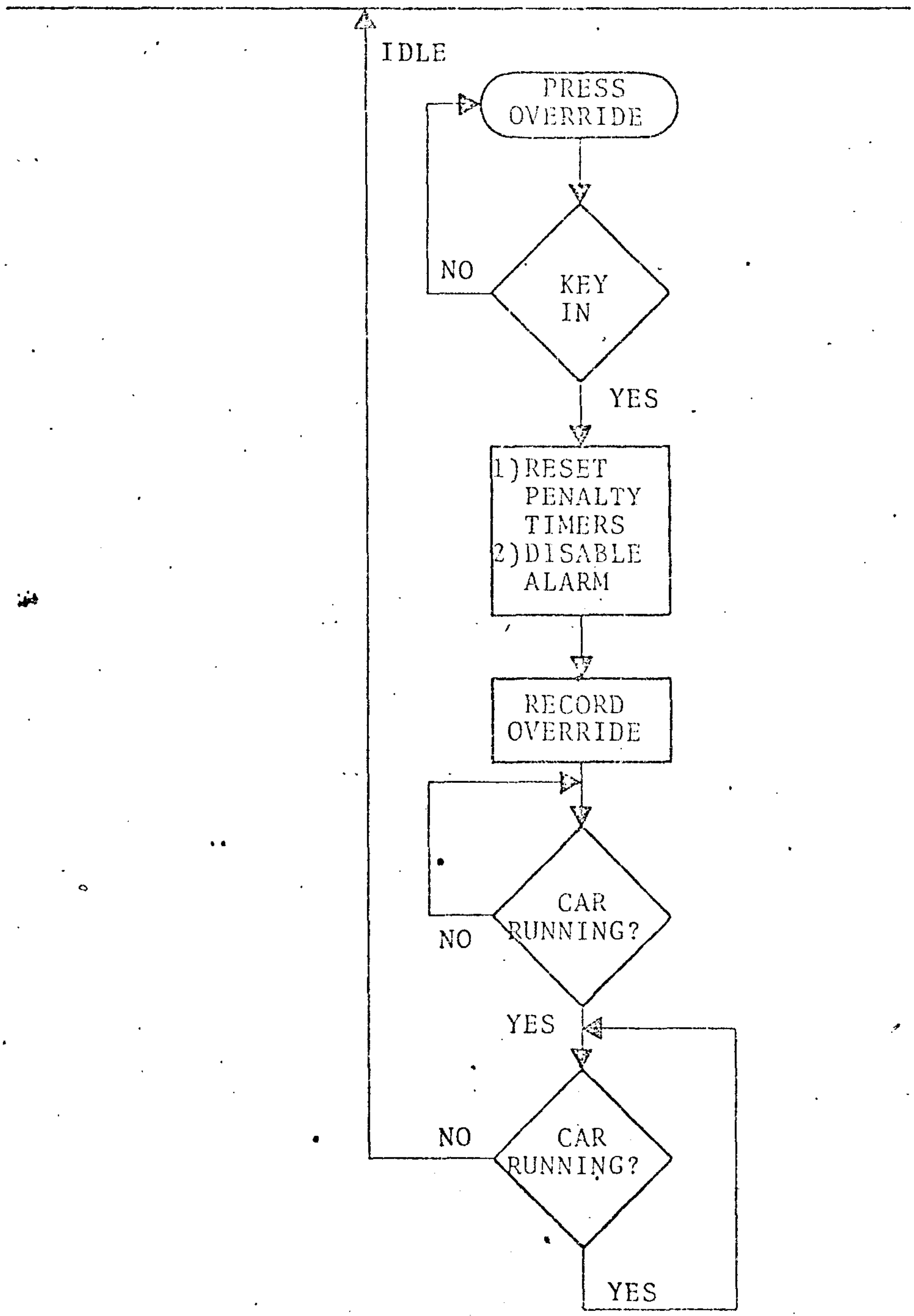


Figure 6 ASIS Control-Logic Flow Chart - Override Sequence

- Over 21 years of age (mean age 28)
- No convictions for driving while intoxicated.
- Ownership or daily operation of an automobile
- Relatively high number (more than 4) of automobile starts per day.
- No more than a combined total of four violations and accidents in the last three years.
- Ability to report for interviews during normal working hours.
- Not an assigned risk for automobile insurance.
- Heavy alcohol consumption (frequency/quantity index) as determined using a questionnaire responses.

Each subject was interviewed to establish his acceptability, and to obtain detailed information on his general background, drinking habits, and initial attitude toward the ASIS concept. Surveys were administered during the four-week cycle to monitor any changes in attitude associated with exposure to the ASIS vehicles.

Subjects selected for participation in the field test were trained in the operation of the ASIS and then given free use (including gasoline) of a test vehicle for four weeks. Those completing the four-week cycle were given a bonus of $25.00.

## 2.4 DATA COLLECTION

Information on the operation of the system, the experiences of the users, and user opinions were collected weekly. These data were obtained through calibration tests of the breath alcohol sensors, analysis of the tape recorded performance data and through interviews with the driver.

### 2.4.1 Calibration

The accuracy of each ASIS was tested weekly by blowing several samples of air containing a known quantity of alcohol into the device. Standard Stephenson "breath simulators" were used to generate the calibrated breath samples. The calibrated breath samples were measured by the ASIS and the readings recorded. In those cases where the checks showed that the calibration had changed by 20%, recalibration was effected and the percentage calibration change recorded. Recording the percentage calibration change allowed proper modification of subsequent data so that calibration stability of the devices over the duration of the entire test could be presented.

### 2.4.2 Taped Performance Data

The tape cassettes were removed from the recording package, played out on a Honeywell 516, and the data produced as a computer printout. The printouts were examined for entries requiring clarification or elaboration and the drivers were interviewed regarding these entries.

### 2.4.3 Interview

Using the printout as reference material, the drivers were interviewed regarding each test-fail occasion in order to determine the reason for failure and the amount of alcohol consumed prior to test failure. In addition, other selected data entries were discussed to obtain information on the limitations of the ASIS system and the drivers attitudes and opinions regarding system deployment.

ASIS FIELD TEST
ASD
CAR #0
.10 SOLUTION

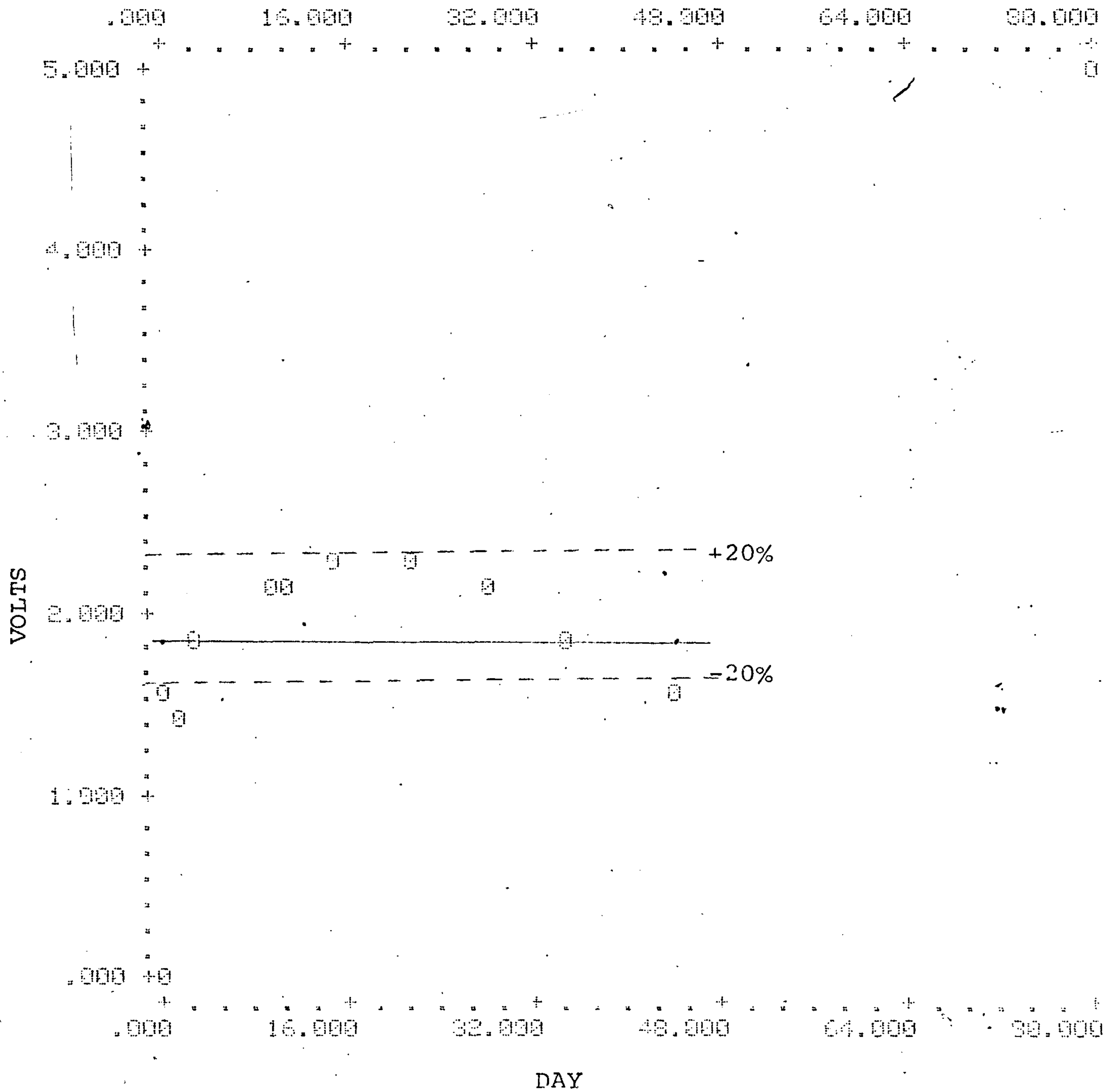


FIG 7

ASIS FIELD TEST
ASD
CAR #1
.10 SOLUTION

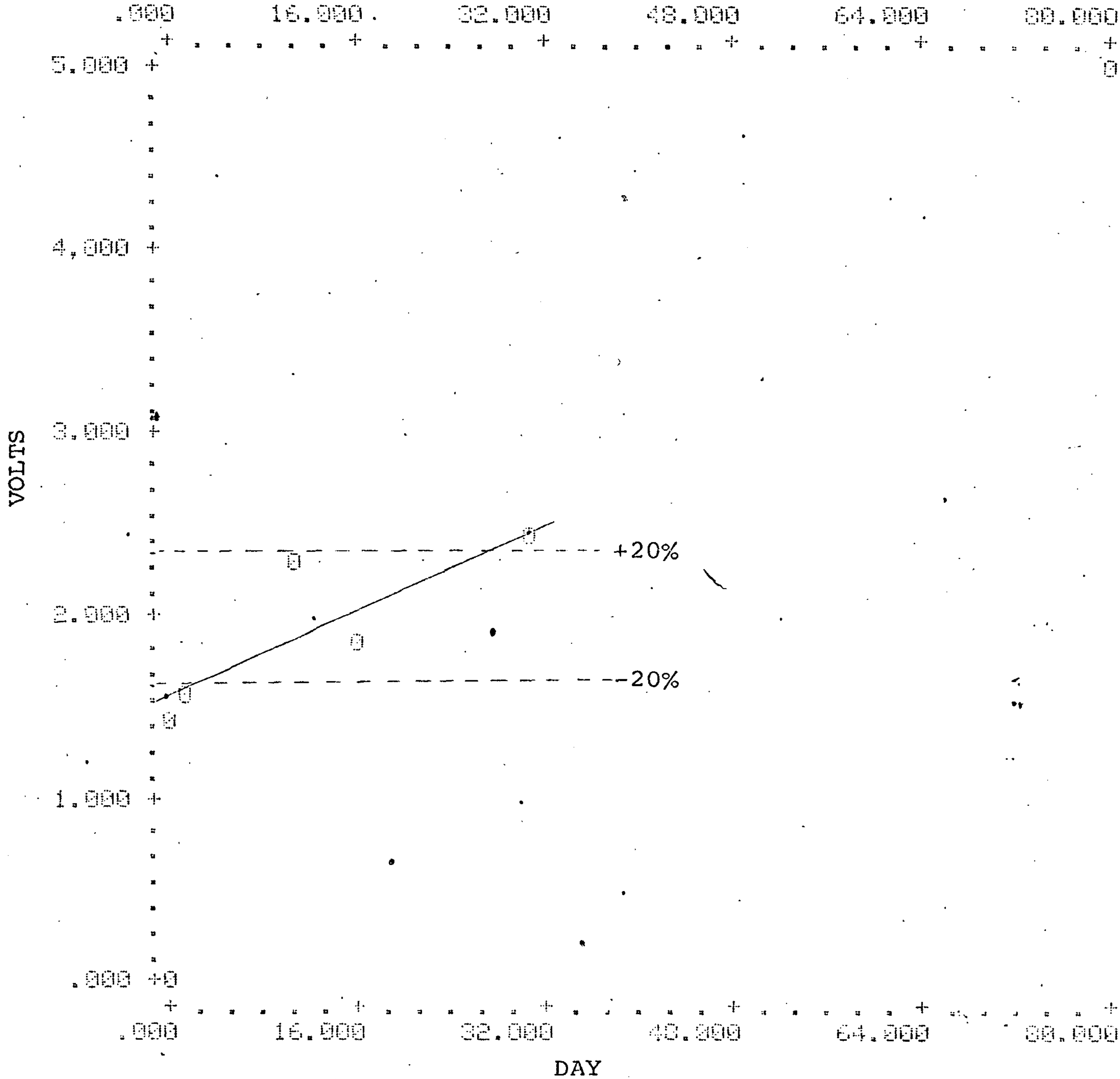


FIG. 8

ASIS FIELD TEST
ASD
CAR #2
.10 SOLUTION

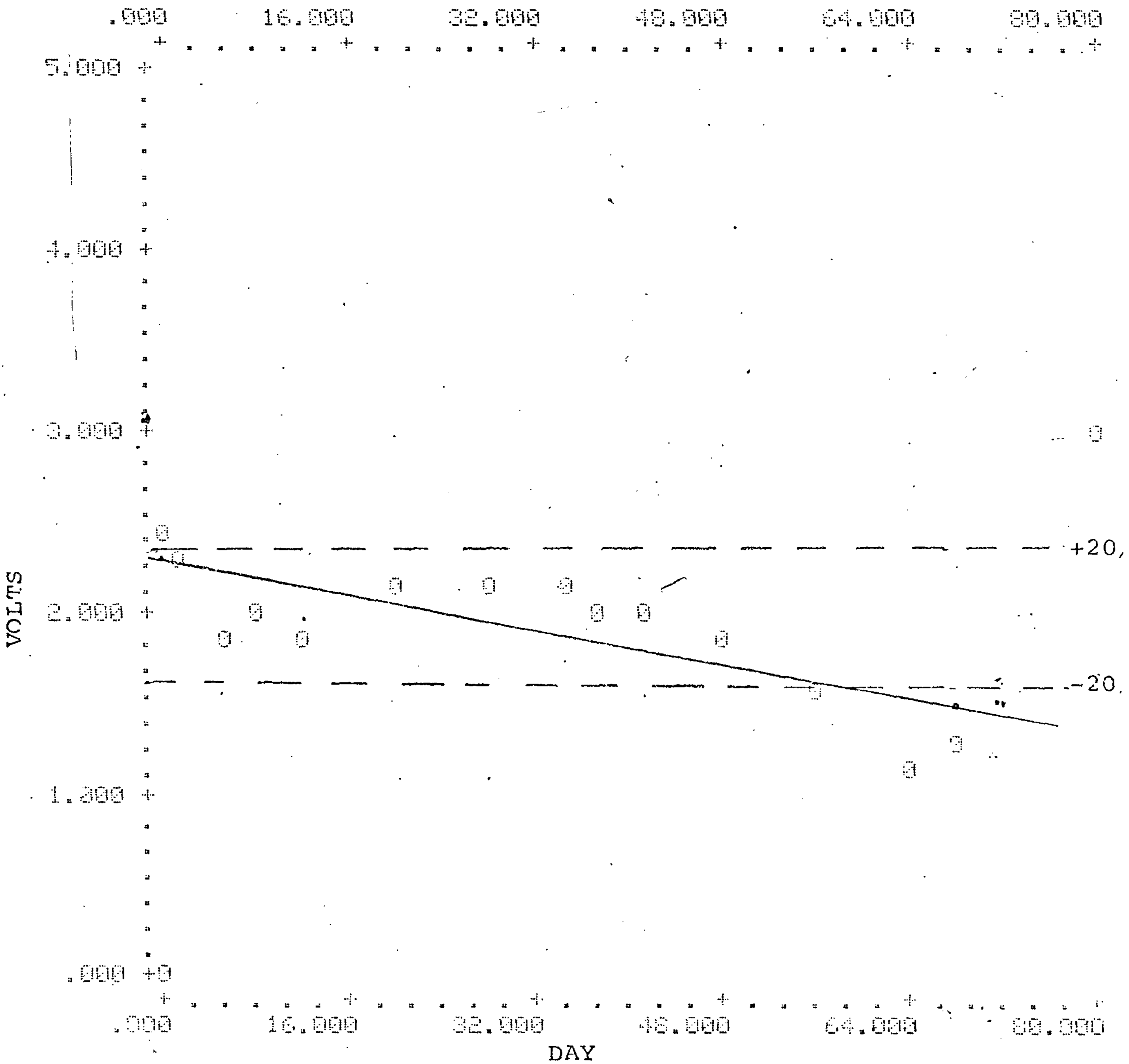


FIG. 9

ASIS FIELD TEST
ASD
CAR #3
.10 SOLUTION

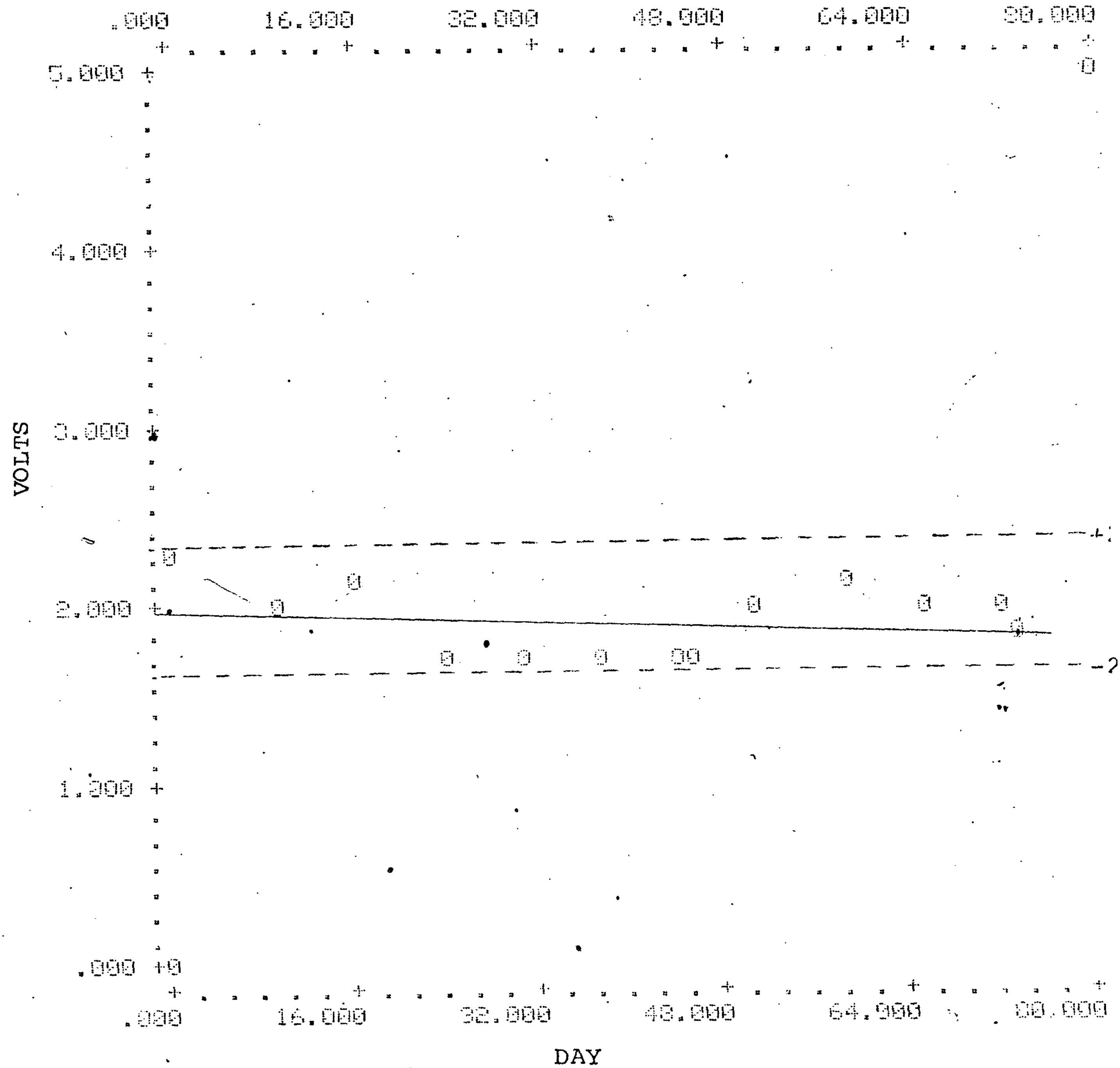


FIG 10

ASIS FIELD TEST
BW
CAR #4
.10 SOLUTION

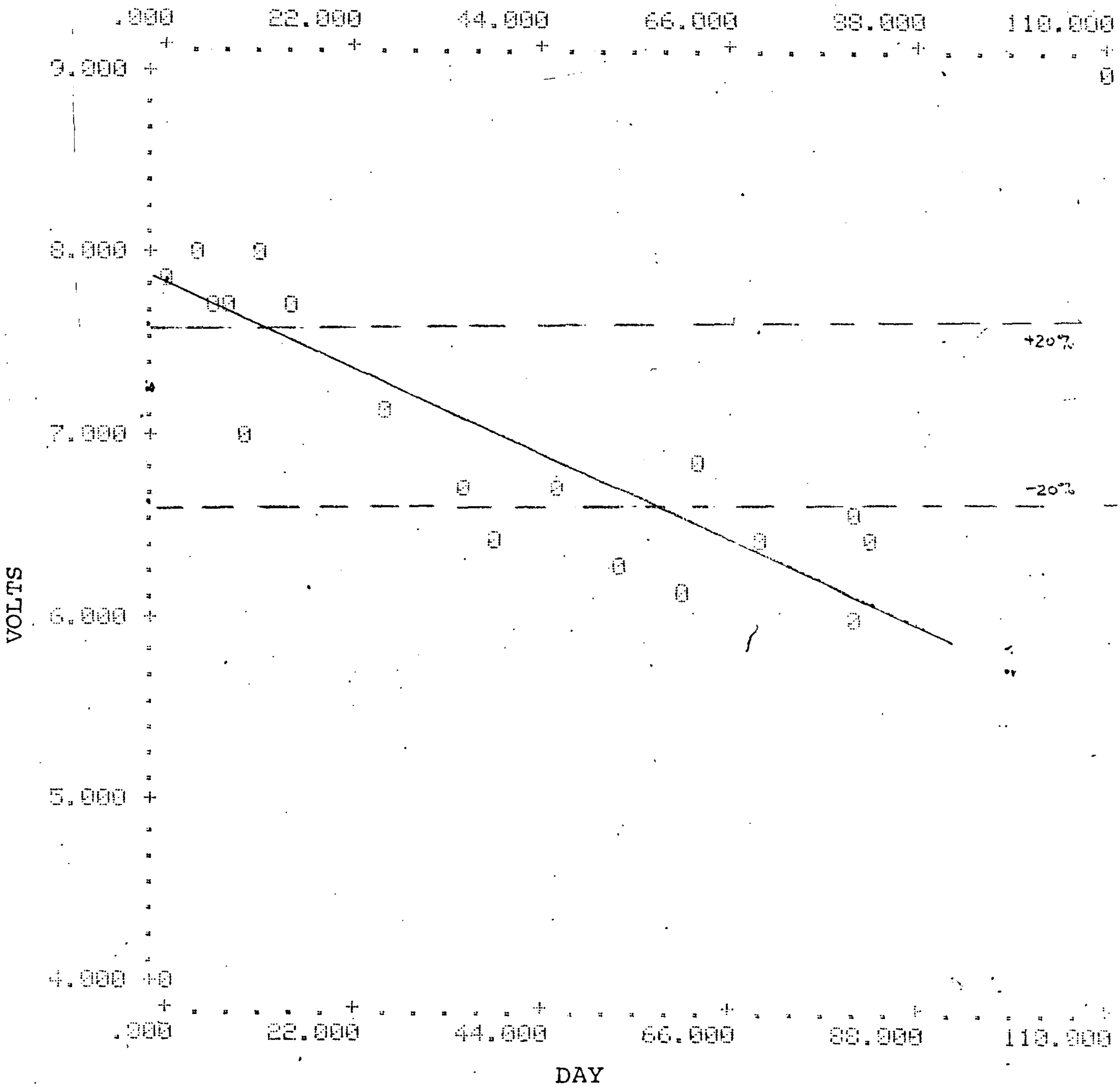


FIG. 11

ASIS FIELD TEST
BW
CAR #5
.10 SOLUTION

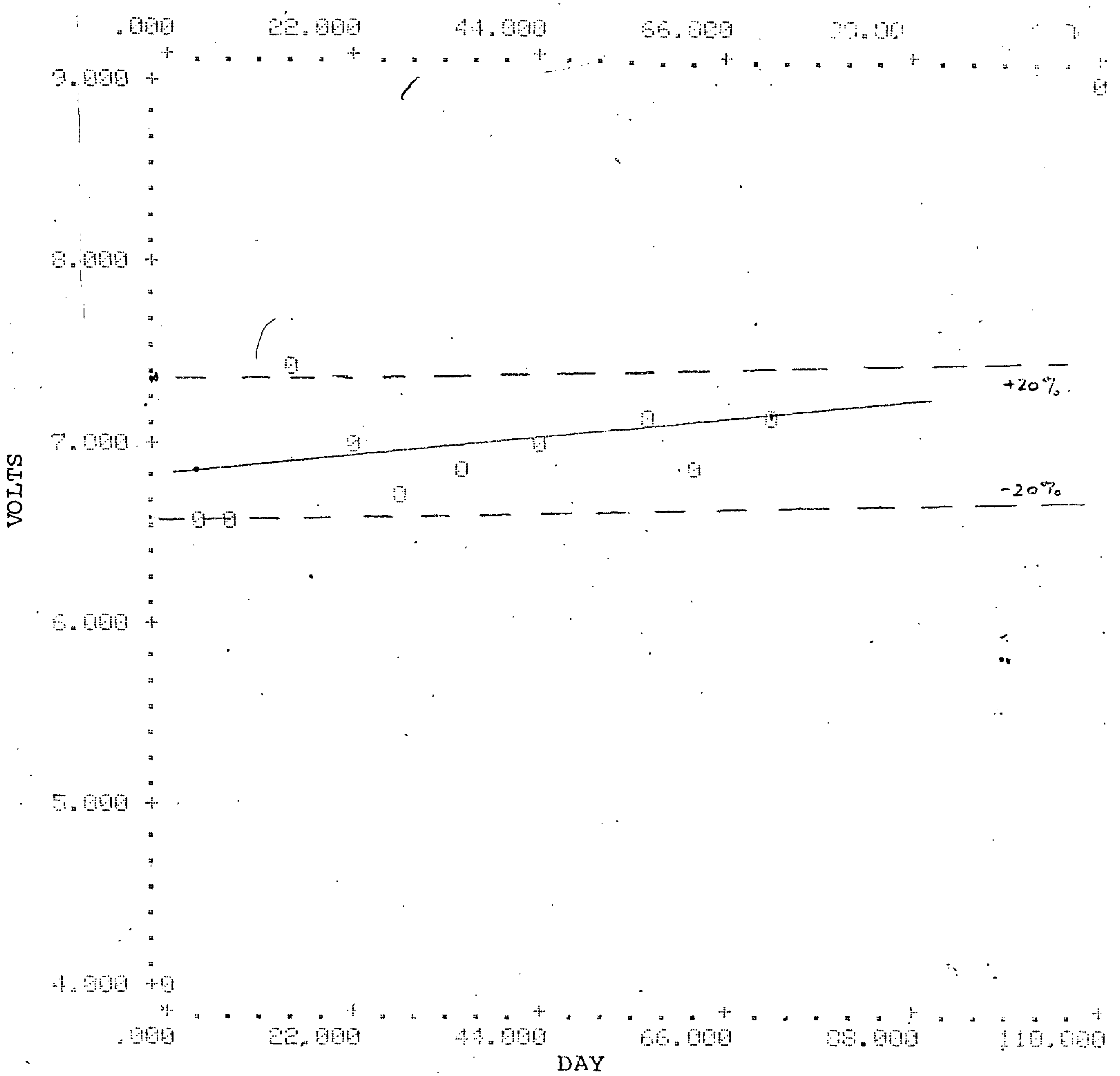


FIG 12

ASIS FIELD TEST
BW
CAR #6
.10 SOLUTION

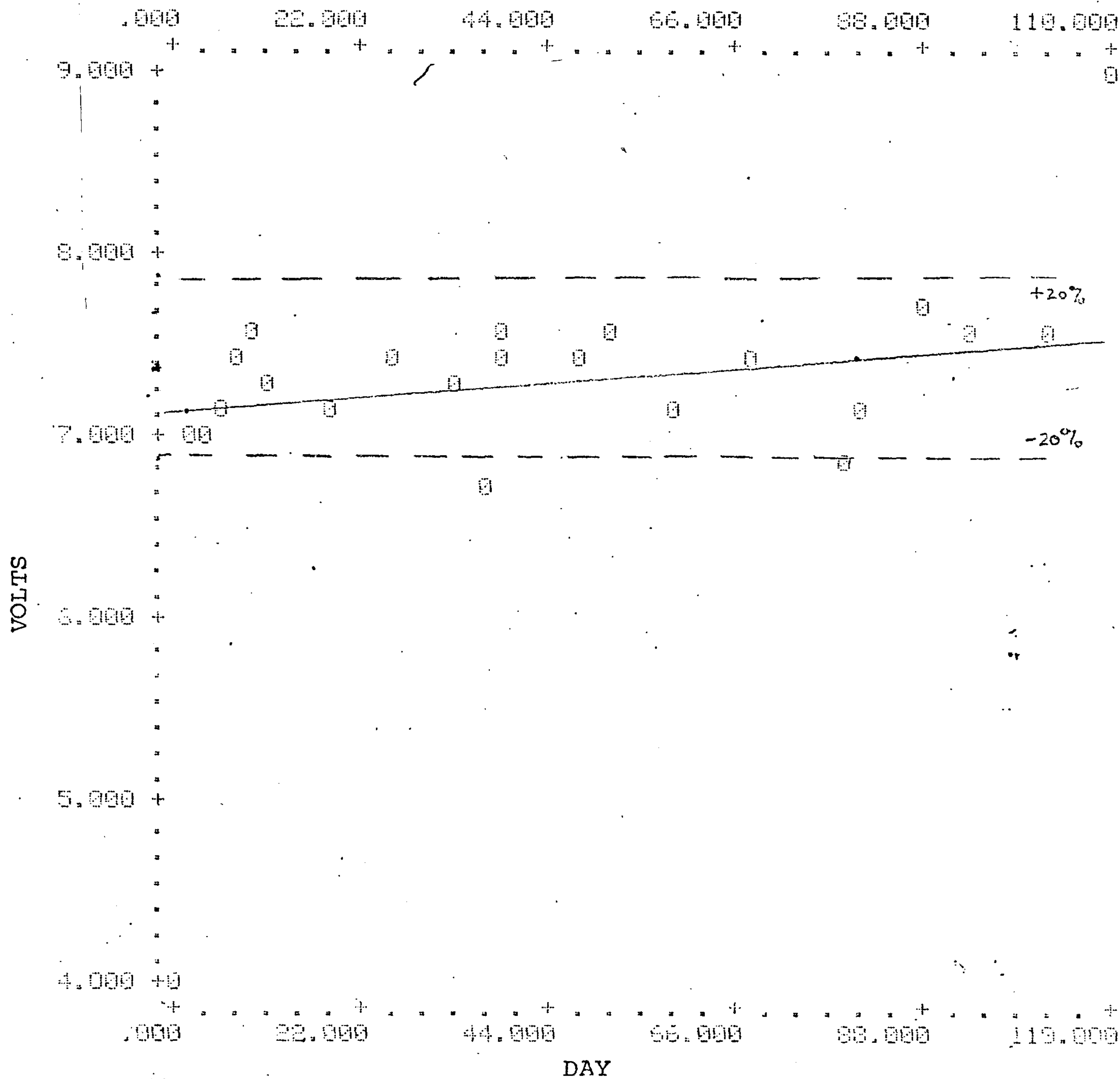


FIG. 13

ASIS FIELD TEST
BW
CAR #7
.06 SOLUTION

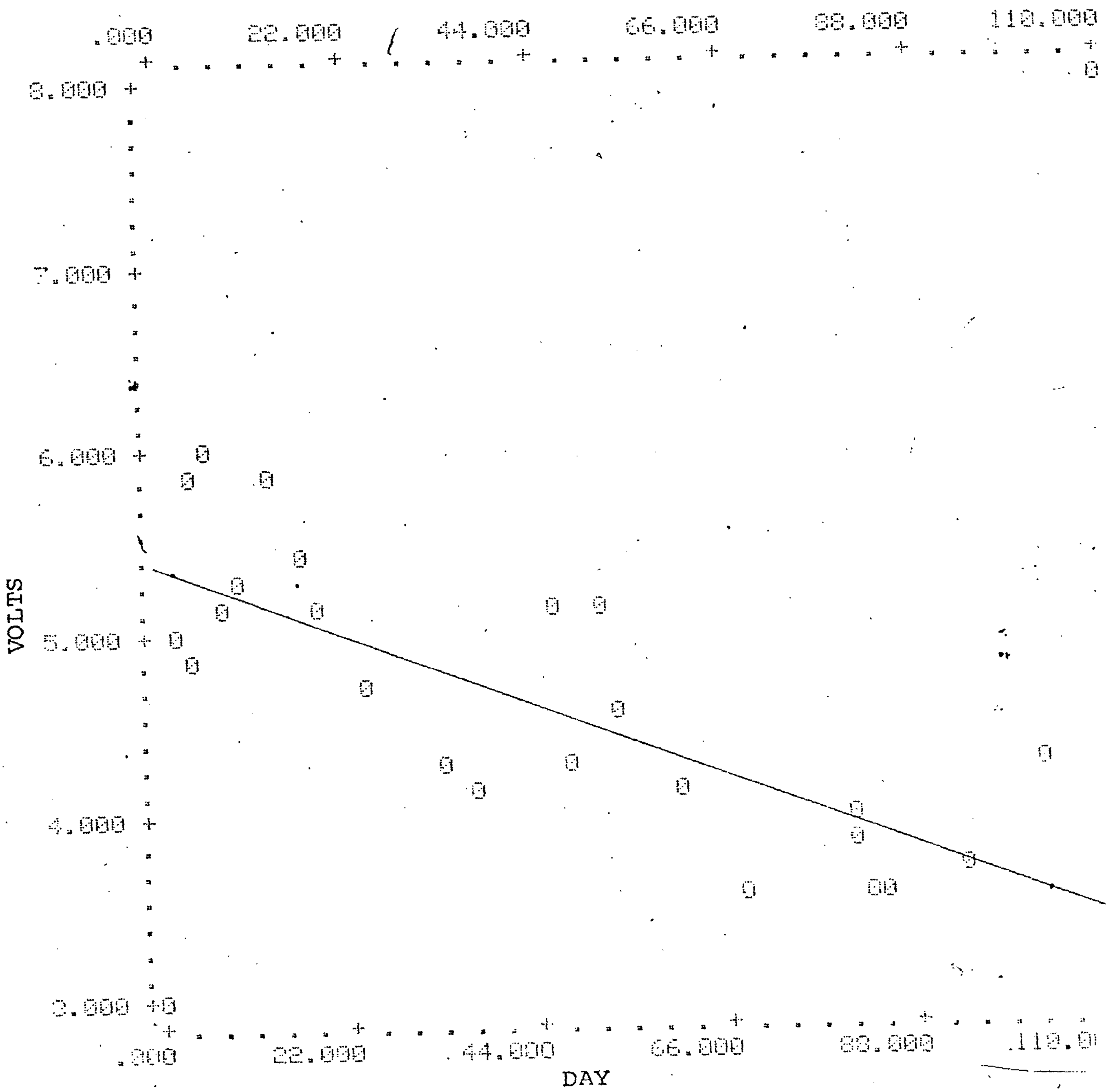


FIG 14

# 3.0 RESULTS

## 3.1 SENSOR PERFORMANCE

During the course of the field test approximately 5,200 breath tests were taken. Three hundred and one "fails" (BAC greater than .06) were recorded that were the result of ingested alcohol as determined from the data recording printout and validated by interviews with the subjects. An additional 14 fails were apparently false positives, that may have resulted from such uncontrolled sources of variance as residual mouth alcohol (mouthwash) and cigarette smoke. (The B-W sensor is particularly sensitive to cigarette smoke and may indicate a "Fail" when the lungs have not been cleared by at least two deep breaths).

Of the 301 actual alcohol "fails", 117 were recorded on the ASD and 184 on the B-W. The median fail BAC for each type sensor was .073 and .090 respectively.

In order to estimate how accurate the alcohol measurements were, the devices were tested and calibrated during each weekly interview. The magnitude of any changes in the voltage gain necessary to recalibrate were recorded and used as an indication of sensor calibration drift. The results of the calibration measurements are shown in Figures 7 through 14 as a function of the time elapsed (in days) since the system was installed in the cars. These graphs show the alcohol sensor output in volts when measuring a calibrated .10 BAC breath simulator sample. For the ASD sensors, the voltage output was linear and corresponds to 0.2 volts/.01 BAC. For the B-W sensors the voltage - BAC relationship was nonlinear and varied between units. The ±20% lines indicate the voltages delineating the .08-.120 BAC range for each sensor, and the solid line functions are best-fit straight lines derived using the least squares process. The duration of the test period varies but represents the longest period of continuous operation for each sensor. The durations of observation were longer for the B-W sensors because of considerably fewer sensor reliability problems. Sensor failures are discussed in the next section.

The data indicate that only one device produced measurements completely within the ±20% boundaries. The other sensors produced at least one reading outside of this range and all devices had highly variable performance as shown in Figures 7 through 14. Unfortunately the reasons for this variability are not clear. Not only are the slopes of the straight-line functions different for each unit, the direction of slope of these lines are not consistent, even within sensor type. There appears to be no characteristic pattern of variation which can be used to describe the sensors or to differentiate between types, with the possible exception that the data appear to fall into patterns having strong curvilinear components indicating a periodic, i.e. systematic, influence of some sort. In an effort to determine if ambient temperature variations were the source of the cyclic variations, laboratory tests at room temperature were conducted on a B-W sensor. Figure 15 shows the results of that test which was conducted over a 3 week period. While all the data points fell within ±20% and the performance was superior to any of the B-W devices field tested, there still appears to be a strong curvilinear component, indicating that temperature variations are not the primary cause of the periodic variations of sensor output.

Statistics representing the range and distribution of readings obtained with each sensor using the standard .10 BAC air sample are shown in Table 1. The range of standard deviations of measurement obtained with this population of sensors exemplifies the lack of performance similarity within each sensor type and indicates the need for further engineering and sensor development work so that more consistent and predictable sensors can be readily manufactured.

## 3.2 SENSOR FAILURES

A total of 13 sensors were replaced during the field test, four B-W and nine ASD's. All four B-W failures resulted

3.9.0

10A RUN: VOLT WITH 0

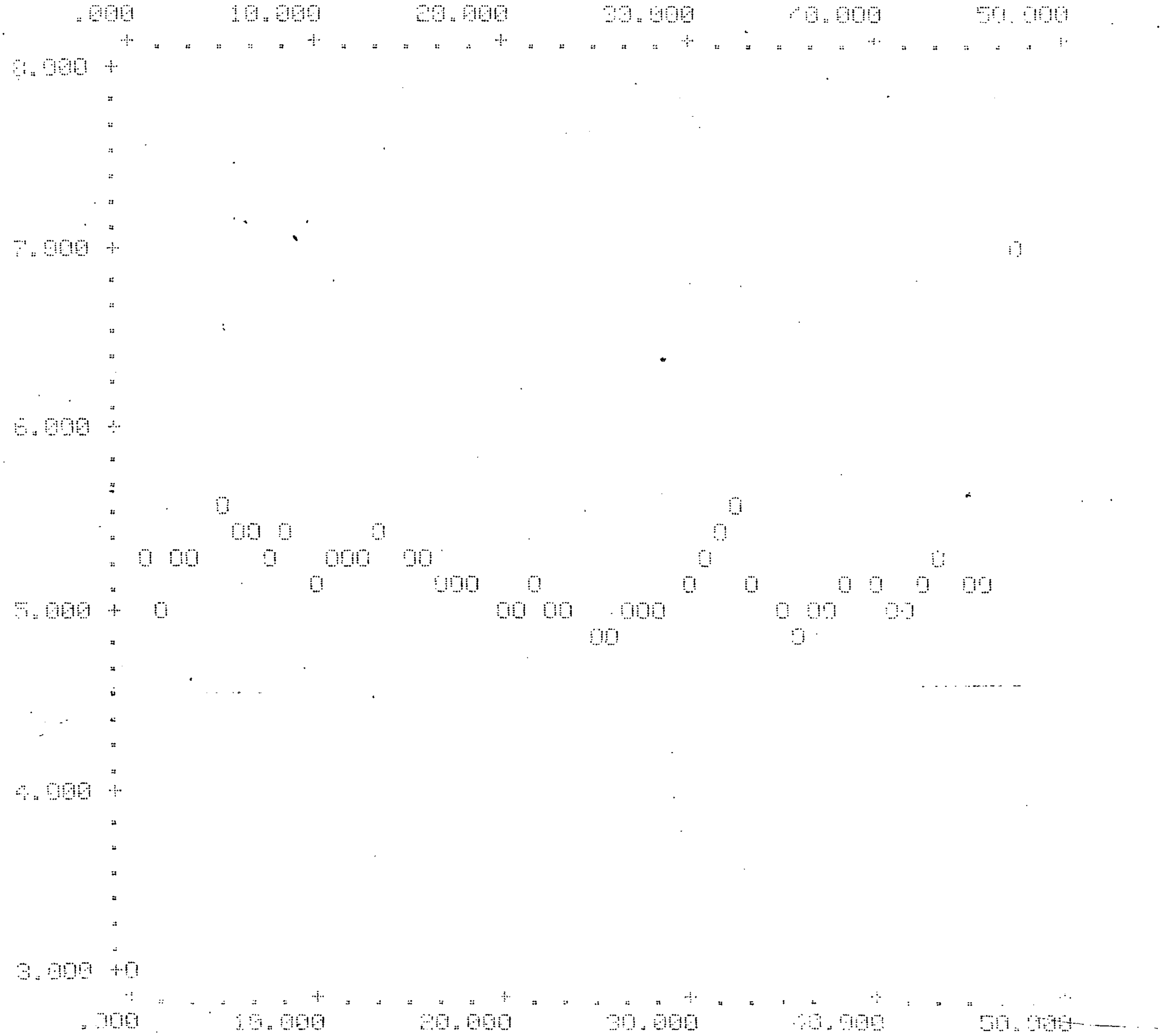


FIG. 15

TABLE 1 SUMMARY OF FUEL CELL (ASD) AND SEMICONDUCTOR (BW) SENSOR CALIBRATION READINGS OVER TEST PERIOD

| Car No. | Alcohol Sensor Type | Simulator BAC | BAC Measurement Min-Max | BAC Measurement 10-90 Percentile Min-Max | Std. Dev. of BAC Measure | % Accuracy of Measure At ±2S | % Accuracy of Measure at 10-90 Percentile |
|---|---|---|---|---|---|---|---|
| 0 | ASD | .100% | .073-.110% | .078-.115% | .017% | ±34% | +15%<br>-22% |
| 1 | ASD | .100% | .076-.128% | .078-.125% | .023% | ±46% | +25%<br>-22% |
| 2 | ASD | .100% | .064-.125% | .070-.115% | .018% | ±36% | +15%<br>-30% |
| 3 | ASD | .100% | .087-.121% | .089-.109% | .010% | ±20% | + 9%<br>-11% |
| 4 | BW | .100% | .053-.141% | .067-.138% | .030% | ±60% | +38%<br>-33% |
| 5 | BW | .100% | .081-.124% | .084-.113% | .013% | ±26% | +13%<br>-16% |
| 6 | BW | .100% | .079-.115% | .087-.113% | .010% | ±20% | +13%<br>-13% |
| 7 | BW | .100 | .028-.170% | .048-.145% | .040% | ±80% | +45%<br>-50% |

from contamination of the sensor surface by a residue from the outgassing of the epoxy potting compound used to secure the sensor, purge pump, and motor in place. Following replacement of the sensors and removal of the potting compound, no further B-W sensor failures were encountered. All calibration data which have been reported were obtained with the replacement sensors.

The ASD sensors were susceptible to a variety of problems. Of the nine failures, two were caused by electrolyte leakage from the sensor interior, five were associated with the failure of peripheral electrical equipment, one was caused by the presence of an unidentified liquid on the sensor surface, and another failed for an undetermined reason.

One characteristic of the ASD sensor which makes it susceptible to damage is the necessity of continuously maintaining a control voltage of the sensor. If the control voltage is lost and the sensor connections are not open-circuited, damage may result. Four of the five sensor failures associated with electronics problems resulted from the loss of the sensor control voltage. There were three other instances when the sensor voltage was lost but the sensor was not destroyed. However, the loss of control voltage did result in a change of sensor output characteristics. Although these occurrences were not classed as sensor failures, the change in sensor characteristics did destroy the continuity of the data being collected. Another weakness of the ASD sensor is the sensitivity of the sensor electrode surfaces to moisture. Under normal use, condensation of breath moisture is prevented by heating the sensor to a temperature above that of the human body. However, liquids which do reach the electrode surfaces may destroy the cell.

The high number of ASC sensor failures and disruptions in data continuity account for the relatively shorter elapsed test time of ASD cars compared to B-W.

## 3.4 CIRCUMVENTION

The effectiveness of an ASIS in keeping the drunk driver off the road is influenced by the ease with which the device can be circumvented. If the device is easily circumvented and the driver avails himself of this weakness, the ASIS is totally ineffective. Anticircumvention measures are therefore an important part of ASIS evaluations.

There are basically three techniques that can be used to circumvent an ASIS:

1. System tampering, which includes any attempts to eliminate or bypass the ASIS, or to modify the test result by physically altering the system;

2. Second party assistance, wherein someone takes the test instead of the impaired driver; and

3. False breath samples, which includes any technique designed to satisfy the breath sample requirements of the ASIS without using the driver's deep lung breath as the sample.

System tampering and second party assistance are techniques which can be used to circumvent both performance and breath measurement type devices. False breath samples are obviously useful only against breath measurement interlocks.

### 3.4.1 Field Test Circumvention

During the weekly interviews drivers were encouraged to develop ideas for circumventing the ASIS. Some drivers actually attempted circumvention while others only suggested the possible methods. Those most commonly suggested are shown in Table 2. It can be seen that, by far, the most popular technique was the use of substitute breath samples. All the listed techniques that were actually used, with the exception of hyperventilation, were successful at least some of the time. In addition to the circumvention methods listed, two drivers avoided taking the test by simply driving the car at a speed below the alarm trip level (15 MPH), a technique which is effective but of limited usefulness. Two other drivers avoided retaking the test by

TABLE 2 ASIS CIRCUMVENTION BY FIELD TEST SUBJECTS

| | | | No. Subjects Who Used Technique | No. Subjects Suggesting Technique |
|---|---|---|---|---|
| TAMPERING | 1. | Disconnect Alarms | 4 | 3 |
| | 2. | Ignition modification (e.g., additional coil to bypass present system) | 0 | 4 |
| SECOND PARTY ASSISTANCE | 3. | Another person, either inside or outside car, taking test | 14 | 5 |
| FALSE SAMPLES | 4. | Air Filled Balloons | 4 | 8 |
| | 5. | Hyperventilation (unsuccessful) | 4 | 0 |
| | 6. | Pumped or compressed air | 3 | 9 |
| | 7. | Long length of tubing to blow through (to condense some alcohol) | 0 | 2 |
| | 8. | Chemical to absorb alcohol | 0 | 1 |

leaving the engine running and climbing out the window (to prevent the retest that is required when doors are opened). The occasions when this type of circumvention would be practical are few, but the fact that the two subjects did attempt to beat the ASIS in this very difficult maneuver indicates the lengths to which some users may go to bypass the system.

The devices used in the field test incorporated three features designed to discourage circumvention attempts. First, the horn was monitored electronically so that a record was made each time it was disconnected. This record was inspected weekly for this type of violation. Second, if the seat belts of occupied seats were disconnected, and/or any of the car doors were opened, a new breath test was required. Third, breath pressure sensors were used to insure that the breath sample satisfied the minimum volume requirement and was provided in the form of a single expiration. This was incorporated to increase the likelihood that alveolar air was provided for measurement.

### 3.4.2 Circumvention Countermeasures

3.4.2.1 Tampering. Since the ASIS is in the posession, and therefore the personal control of the user, there is no practical way to physically prevent tampering. Procedures may, however, be employed to detect such circumvention efforts.

Thus, the ASIS system may be packaged in one or more sealed units, and violation of the system seals would be clear evidence of tampering. The cabling between the sensor and control units could be connectorless and distinctively shielded for easy inspection, with sealed interface wiring connections. However, because of the multiplicity of required electrical connections and splice locations throughout the car, effective inspection of all these wires to detect tampering may be difficult. The need for a thorough wiring inspection could be eliminated by incrementing a simple electro-mechanical counter each time the vehicle is operated above 15 MPH and taken, with the counter sealed inside the ASIS unit, a zero count would indicate proper vehicle operation, and only the wires between the ASIS and speed sensor would need inspection.

3.4.2.2 False Breath Samples. The field tests revealed that circumvention by the use of false breath samples was a far more effective and more frequently used technique than tampering. Unfortunately, cost effective countermeasures for false samples are not completely fool proof and their effectiveness is dependent upon the capabilities and motivation of the user.

Fundamentally all that is required to make a valid breath measurement is the presentation of a continuous sample of air exceeding the minimum volume requirements. Thus, air samples provided from a balloon, bottle of compressed air or by another person could be used to circumvent the test. While there are physical characteristics, such as temperature, moisture content and gas composition, which in combination identify breath, the complexity of the techniques needed to monitor all these characteristics precludes a system providing absolute identification. For example exhaled breath contains $CO_2$. The sample given the ASIS could be examined for the presence of $CO_2$ by means of an infrared detection system. Disregarding the cost, such a system would still only be marginally successful since it could still be circumvented by using a stored breath sample, and only the use of compressed air and most other non-breath gases would be eliminated as a circumvention method.

Photographing the driver as he provided the breath sample was considered as a circumvention countermeasure but an assessment of the cost and technical problems revealed that photographic records are reasonable only as a last resort. The two major problems are the initial system cost and the environmental temperature control needed to preserve the film. One more promising approach is based on a temperature measurement of the air sample as supplied to the ASIS. The technique is not completely foolproof but can prevent breath sample substitution attempts in most cases. Furthermore, the temperature measurement feature could be incorporated into an ASIS at very little cost.

A breath sample temperature detector was fabricated and tested for use as a breath ASIS circumvention countermeasure. Environmental tests were conducted on the temperature detecting device, which required that the sample temperature fall within a narrow range of body temperature. In ambients ranging from 32°F to 125°F, the device correctly recognized valid breath samples and consistently detected balloon air and compressed air as false samples when the ambient temperature differed from body temperature by more than 15°F. The major weakness to this circumvention countermeasure lies in the fact that if the artificial sample is properly temperature regulated successful circumvention is achievable and undetectable. However, assuming that breath temperature regulators for ASIS circumvention can be prevented from being commercially marketed, the cost and difficulty of coming up with a workable device may reasonably deter all but the most aggressive users.

Further laboratory tests were conducted to determine the efficacy of using chemical filters to remove alcohol from the breath. The results are summarized in Table 3. Small dry chemical filters would conceptually be desirable as a circumvention device because of their relative convenience compared to a temperature regulator. The interesting result is that, of the chemicals tested, those that are effective in removing alcohol from the breath also change the temperature of the breath sample as a result of chemical action, and are therefore subject to detection by temperature measurement.

The effectiveness of temperature measurement as a circumvention countermeasure can be enhanced further by the use of on-the-spot "inconvenience" penalties such as automatically preventing any further breath tests for a nominal period of 5 minutes when false samples are detected.

By recording the number of attempted false samples on an electromechanical counter, the extent of circumvention activity can be inferred and used as the basis for increasing inconvenience and/or other penalties.

3.4.2.3 Second Party Assistance. Another circumvention technique frequently suggested or used by the field test subjects is that of second party assistance wherein a sober passenger or pedestrian takes the test for the presumably intoxicated driver. Although the technique was used with some success in the field test, the extent of its successful use in a real world application may be limited since in every instance where someone outside the car provided the breath sample, the purpose was to demonstrate the circumventability of the ASIS to a friend and not to circumvent the ASIS so that the car could be used by a subject incapable of passing the test. On the other hand, there were instances when passengers provided the breath sample because it was expected that the driver would fail the test, and use of the car was intended. However this technique was only occasionally successful since the passenger providing the breath sample in most cases has also been drinking and was "elected" to take the test on the basis of being "most likely" to pass.

The use and effectiveness of passenger samples can be reduced by locating the mouthpiece of the device out of reach by passengers and pedestrians. If extension tubes are used to circumvent this feature, the sample would cool before reaching the sensor and so be detected by the temperature sensor.

Performance type interlocks in general are substan tially less susceptible to this type circumvention than breath measurement devices since most performance testers require some nominal training or practice time before the test can be consistently passed by anybody. Thus, the likelihood that a willing but inexperienced second party could successfully pass a performance test is minimized.

## 3.5 User Acceptability

As part of the data collection process, subjects were interviewed weekly to obtain their opinions and discuss their experiences with the breath test interlocks. In addition, attitudinal surveys were administered at selected intervals in order to obtain a qualitative measure. The results of these surveys are contained in a contractor report, DOT-TSC-251-7, prepared by Dunlap and Associates, Inc.

In brief, the results indicate that the acceptability of a breath test interlock is primarily influenced by the convenience of the device. The most frequent complaint was the requirement that new test be taken any time a seat belt or door was opened. While both ASD and BW users complained of this requirement, the BW users were more negatively affected, primarily because of the lengthy purge cycle requirement.

In addition to being an important factor in user acceptability, device convenience is important to the overall effectiveness of a breath interlock since inconveniences will motivate a user to circumvent the test.

## 4.0 Conclusions

The results of the field test indicate that it is possible to make breath alcohol sensors of sufficient accuracy and stability to form the basis of a practical breath test interlock. However, the variability of performance among sensors of the same type indicate the need for more engineering and sensor development so that devices of more uniform and predicatble characteristics can be readily manufactured.

The basic weakness of breath measurement approach to Alcohol safety interlocks is its susceptibility to circumvention through the use of artificial breath samples. Although circumvention can be made more difficult by judicious location of the device in the car, and through the use of sample temperature and pressure sensors, it probably cannot be completely prevented in a cost-effective manner. The effectiveness of a breath measurement