UNPUBLISHED REPORT

CURRENT METER COMPARISON STUDY

ES-517

B.F. WHITE
ENGINEERING SERVICES SECTION
SCIENTIFIC SUPPORT DIVISION
NATIONAL WATER RESEARCH INSTITUTE
CANADA CENTRE FOR INLAND WATERS

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APPENDICES

1.0 INTRODUCTION

1.1 Objectives

The objectives for the second year of the Current Meter Comparison Study were twofold. Firstly the study team was to assist and participate in the selection of a means of replacing the depleted inventory of operational hydro-mechanical current meters. A second objective was to establish understanding and confidence in water current measurement technology, with particular emphasis on solid state sensors. The following report partially meets these objectives.

Section 2.0 describes the state-of-the-art as we reviewed it at CCIW. Historically, the CCIW has measured water current in lakes by using self-recording current meters moored in situ. The inventory of meters has suffered from attrition due to loss, damage and failures which could not be repaired economically. This subject is discussed further in Section 3.0

Section 4.0 outlines a history of experience with a specific brand of a solid-state current meter.

1.2 Chronology

The Current Meter Comparison Study started mid fiscal year 1976. The first activity was to implement a current measurement systems comparison experiment at the WAVES platform in February and March of 1977. The follow on work, to reduce and evaulate the data collected is summarized in Section 5.0

Section 6.0 gives a compressed data base for future design reference. This data base outlines the present and future scientific needs in current meter technology.

Recommendations for continuing studies are given in Section 7.0

1.3 Executive Summary

This report describes an accumulation of experience with a variety of current measurement systems over the period 1973 to 1979. It forms a record of our piecemeal understanding of the general and specific problems of measuring water current. Consequently, the scope and volume of information included make the report unwieldy. To ease the burden on the reader this summary has been added to the introduction. Comments in the summary should be reviewed in the context of the original section if they should seem to be severe or vague.

The review of current measurement technology included in Section 2 surveys briefly the state of the art as it applies to water current measurement in inland water studies. The requirements for measurements in more dynamic zones and for reduced sensitivity to fouling have led to both new hydromechanical sensor and solid state sensor developments. No sensor type can offer uniform directional response, good linearity and low threshold in the optimum mix to make it the ideal low cost, low power, universally applicable instrument. Hydromechanical sensors are intrinsically nonlinear, suffer from fouling and stiction, and may be sensitive to inertial coupling. Electromagnetic sensors are vulnerable to system integration errors, may suffer from external electromagnetic interference, and suffer from the uncertainties of measuring flow in their own boundary layer. Electroacoustic sensors are vulnerable to fouling and to the influence of subresonant bubbles on the speed of sound.

The tradition of Eulerian water current measurements has been to use hydro-mechanical sensors. NWRI has a large inventory of Plessey and Geodyne current meters. Section 3 reviews the rationale for the re-building of a portion of the Plessey inventory. The difficulties encountered in that program are not reported here. Efforts to improve the performance of the Plessey meters have continued.

NWRI experience with electromagnetic current sensors has included more than twelve measurement trials, each with more than one sensor deployed.

The data return from these trials has been disappointing. These missions and the results of a number of laboratory trials are summarized in Section 4. Consultation with the manufacturer and laboratory testing demonstrated that most of the measurement difficulties with electromagnetic current sensors at NWRI arose from incorrect system grounding arrangements and subtle system power supply impedance problems. The provision of utility power line independent, capacitively decoupled battery supplies, and the use of synchronized sensors for multiple sensor systems have improved the systematic performance of the sensors. An attempted application at the NWRI Littoral Drift experiment was unsuccessful. It is presumed that interference from the EHV power corridor was responsible, however, the testing to confirm the nature of the problem has not been undertaken. Test data indicate that the sensors may be used in water with conductivity greater than 100 μS. Application of these sensors has been hampered by the problem of interference of the tow carriage electrical system on the operation of the sensors at speeds less than 20 $cm.s^{-1}$.

The Current Meter Comparison Study of 1977 undertook to compare a number of CCIW instruments in a field experiment in the period of February to March 1977. The subsequent investigations of the data collected by the CATS systems in this study played a large role in the improvement of our understanding of the performance of the CATS systems specifically, and the characteristics of the electromagnetic current sensors in particular. The experiment was based on the WAVES Platform, an NWRI facility located in Southwestern Lake Ontario in 12 metre water depth. Eleven systems or meters were installed at three depths for most of the period with two brief installations of the KVAPS system. Plessey and Aanderaa instruments were deployed at 5 m along with WAVES electromagnetic current sensor, a CATS (2) sensor and K VAPS. Two Plessey meters were deployed at 3 m. The two CATS systems were on the lake bed.

The data return from the experiment was disappointing. The Plessey meters suffered battery failures. The Aanderaa meters were improperly prepared and lost their rotors. Access to the site and intensive diver operations necessary proved difficult under winter conditions.

The details of the experiment, and the resulting data set are discussed in Section 5. Time series comparisons and statistical summaries are provided for four flow cases. The data show evidence of rotor overspeeding in the presence of wave motion for the shallowest Plessey MO-21 meters and the Aanderaa meters relative to the other instruments. The Plessey 9021 showed lower speeds than the adjacent MO-21 meters -- which may be consistent with better hydrodynamic design. The 9021 showed poor compass performance due to limited gimbal range.

More recent work in support of CATS system developments has shown that the Plessey MO-21 current meters are not reliable with mean speeds less than 7 or 8 $cm.s^{-1}$ in estimating the mean speed relative to the CATS system, but that the directional performance was good in low mean speeds in the absence of orbital motion.

The comparison experiments have shown the difficulty in planning and mounting a field comparison experiment that produces results bearing on the scientific measurement requirements. This work, along with a paper by J. McCullough (WHOI) inspired a polling of the CCIW scientists with regard to their perception of the scientific requirements for water current measurements in terms that would be useful to instrumentation engineers. The results of the poll were cast into a form which emphasizes the influence of wave orbital motion on the mean current estimate. This form is also applied in Section 6 to describe the performance of specific current measurement systems. It is apparent from these displays that near surface and near shore current measurement requirements demand instrument performance characteristics for which there is very little supporting analysis or test data available. Several of the most common instruments are represented with performance characteristics based largely on conjecture.

Resolving this scarcity of analysis and data for specific instruments is only the first step in improving our understanding of current measurement systems. Existing data sets may be scrutinized for evidence of non-ideal measurement performance. The analysis of measurement systems with a view to their sensitivity to specific characteristics which may not be well defined, or easily determined is important to this work. Special system measurements may require improvements to existing facilities, or new facilities. These recommendations are collected in Section 7.

Five appendices are attached to the report to provide more information regarding solid state current sensors, and to elaborate on the system view of water current measurement.

2.0 REVIEW OF CURRENT MEASUREMENT TECHNOLOGY

As stated in Appendix III the performance of the current measurement system is crucial to final estimate of the currents measured. Reviews of the relevant measurement technology exist which explore the state-of-the-art, or the claimed performance for the sensors/current measurement subsystems. The corresponding system level reviews do not exist apart from reports of field comparison experiments due to the diversity of methods, instruments and natural conditions to be studied. The discussion which follows in this section will highlight briefly the principles of the technology and discuss its limitations and assets as a measurement method.

2.1 Hydromechanical Sensors

The term hydromechanical sensor is intended to describe the class of water current sensors/subsystems which rely on the hydrodynamical interaction of the flow field with some mechanical object to effect sensing. Examples are impellor devices (e.g. Plessey), rotor devices (e.g. Aanderaa), drag devices (e.g. General Oceanics), vortex shedding (e.g. J-Tec). As a class, all such sensors suffer (more or less) from nonlinear dynamic speed and direction sensing characteristics whose temporal responses may or may not be well matched.

In a dynamic flow field (i.e., oscillating or reversing current at arbitrary angle to mean current) such a sensor, depending on other system characteristics may overspeed in the presence of waves and indicate anomalous mean current directions. To apply such sensors it is necessary to avoid flow regimes where these errors are unacceptable and to constrain the system design to minimize the influence of non-local effects on the measurement. An example of the latter is wave coupling via a surface float to the mooring line.

Hydromechanical sensors are particularly vulnerable to fouling and subsequent loss of calibration or failure. However, they offer simplicity, relatively low cost per instrument, low power consumption, and relatively rugged construction. They exhibit threshold behaviour which limits the dynamic range and sensing linearity - but the simple information that the mean flows are below some threshold at certain times is in itself useful data for many studies.

2.2 Electromagnetic Sensors

Electromagnetic current sensors function by sensing the potential induced when the conductive fluid moves relative to a magnetic field. Devices exist which use the vertical component of the earth's magnetic field as well as others which generate their own field. Of the latter, it is most common to sense the potentials from a housing containing a solenoid coil. This offers the advantages of a rugged compact sensing probe with the penalty that the measurement is made in the hydrodynamic boundary layer of the device. Consequently the speed response characteristic is nonlinear as the boundary layer characteristics change with the onset of turbulence. As an example the Marsh McBirney M552 (spherical) class of sensors would be typically +1 $cm.s^{-1}$ at full scale (250 $cm.s^{-1}$) -3 $cm.s^{-1}$ at 30 - 35 $cm.s^{-1}$ yet overall within their specification of 2% of reading or ±2 $cm.s^{-1}$.* The alternative to the "probe type" sensor is the Helmholtz coil configuration. The physical complexity of such sensors is presumably the reason for the lack of examples of field instruments.

Apart from their hydrodynamic limitations, the electromagnetic current sensors are limited in their performance by the nature of the sensing principle. The high impedance front end circuits sense the induced potentials via electrodes. Electrode electrochemistry is apparently a sufficiently difficult subject that further improvement in sensing performance may require additional expertise in this field. Such sensors suffer from zero offset instability with resulting large uncertainties implied in low speed measurements. They also are sensitive to grounding techniques and external electromagnetic influence. They offer fast temporal response, convenient hydrodynamic design and reasonable cost. They typically require one watt of power and are consequently expensive to deploy for long periods with a self-contained power supply.

2.3 Electroacoustic Sensors

The propogation of sound in fluids is applied to accomplish diverse measurement objectives. At low Mach numbers it offers several effective

* Personal communication from J. Darby

alternatives to sense fluid flow. This may be done locally - i.e., between electroacoustic transducers or remotely. The former may be done using the differential propogation delay (phase or time) between upstream and downstream paths. The remote sensing technique utilizes acoustic backscatter from inhomogeneities in the medium and senses the doppler shift associated with the natural tracer velocity relative to the instrument.

Phase or time delay instruments require complex electronics to measure the very small differential delays associated with low flow speeds corresponding to extremely small Mach numbers. Instruments exist which succesfully sense these differences down to a few parts per million corresponding to speed resolutions of $mm.s^{-1}$. The speed of sound determines the sensitivity of most sensor designs and hence the flow signal must be compensated for sound speed variability. These instruments are sensitive to fouling as well as to bubbles in the medium. They are of limited utility in the wave zone or where fouling or aeration are probable.

The sensitivity and speed of response of these instruments are sufficient that the hydrodynamic limitations of the measurement subsystem configuration may be readily observed in calibration data. Flow interference and vortex shedding from members produce errors of the order of 10% in the speed estimate derived from the components.

Acoustic backscatter doppler sensors have not been successful as high sensitivity geophysical flow sensors. The devices used as ship's speed logs are presently being developed to sense currents remotely at speeds greater than 15 $cm.s^{-1}$. The development of a miniature doppler sensor has not yet met with success. The best effort to date was the NOAA/NDBO/Westinghouse/Edo Western development (1973). Unfortunately, the development fell short of the objectives and no practicable commercial sensor exists.

The doppler sensor has the advantage of remote sensing - and is therefore less vulnerable to hydrodynamic interference. It requires suspended material to function and is well suited to the wave zone/surf zone applications. Tested versions have a threshold an order of magnitude greater than the differential delay devices. The sensitivity is dependent on the speed of sound. A separate estimate of the speed of sound may be necessary - expecially in wave/surf zones where the medium is contaminated - to achieve a target accuracy. (Such a measurement in the surf zone may require a second instrument development to support the doppler sensor development!) Electroacoustic differential delay sensors require typically >1W. The prototype doppler device requires 840 mW pk, 20 mW standby. Long baseline (1-100m) acoustic devices exist for use in rivers, channels or other high flow sites where they may be installed.

2.4 Other Sensors

There exists a wide variety of other sensor types which have been developed. Most current measurements are made with devices described in preceding sections. Donelan (15) *has a complete summary of other current sensor types. Two worthy of special discussion are truly non-conventional "electromagnetic current sensors" - but are separated from that discussion because of the difference in principles.

In the way of Eulerian Sensors, optical methods offer the laser doppler technique. It seems highly unlikely that this technology will be developed into an in situ multicomponent current sensing system other than for specialized studies. The existing laboratory and industrial instruments offer dynamic range and speed of response far in excess of the requirements for environmental current sensing. Other optical methods are being considered for development, but none are immediately available.

A novel system has been developed at the NOAA/ERL/Wave Propogation Laboratory which senses surface currents by measuring the doppler shifts of radar bursts backscattered from surface waves (CODAR). The sensing relies on Bragg scattering properties to define the effective wavelength of the contributing surface waves. The measured doppler shift(s) are compared

* CCIW Unpublished Report: "Measurement Technology of Physical Parameters in Environmental Fluids".

to the phase velocity predicted for such waves by the dispersion relation to deduce the advection of the waves by the surface currents. Each sensing station resolves the radial current component in 3 x 3 km cells to a maximum range of 70 km (over the salt water). The resulting data from two such stations can be vectorially added for the area of common coverage. In this manner synoptic estimates of the surface currents can be produced in less than 20 minutes for very large areas compared to other methods. The accuracy - as divined from drifter measurement comparison studies is better than ±25 $cm.s^{-1}$. Resolution is claimed to be 5 $cm.s^{-1}$. Much of the art in using such systems is in effectively reducing the wealth of data produced.

3.0 CCIW HYDROMECHANICAL CURRENT METER UPGRADING

The CCIW has had a continuing requirement for moored current measurement systems. Starting in 1967 Plessey current meters have been used - originally M021's and recently 9021's. A total of 62 have been acquired and 14 lost, leaving a present inventory of 48. In 1969 Geodyne Model 920 current meters were introduced to CCIW applications. A total of 44 were acquired, 11 lost, leaving 33. The Plessey meters have a more linear response characteristic than the Geodynes. Historically, they have been applied in the more dynamic near surface and shallow water applications where wave action on the mooring and orbital velocity lead to substantial differences in performance.

The Plessey M021 current meters have rather antiquated electronic circuitry and use electromechanical multiplexors and analog to digital convertors. Intensive maintenance has been required to support data quantity and quality. Replacement components are becoming increasingly scarce and costly. Systematic failures have reduced the efficacy of cannibalizing. By comparison, the Geodyne 920 meters have modular solid state electronics and have had a better maintenance history.

It is in this context that an action plan was formed. The objective is to replace the loss of existing current measurement capability with the best effective technology available. Hydromechanical sensors are preferred due to their lower cost and acceptable performance characteristics for a range of experiments. Solid state current sensors require expensive batteries, are higher cost, and have not yet demonstrated accepted performance characteristics which are an effective improvement over the hydromechanical technology for the same range of experiments. Impellor type sensors (Plessey-Roberts) are preferred over Savonius rotor type sensors (Geodyne 920, VACM). Indeed, a modern version of the M021 would be desireable, however, they do not exist. The new Plessey 9021 is similar to the M021, but sufficiently different that more evaluation of the 9021 is planned to estimate the dynamic performance difference vis a vis the M021.

Competitive bids were solicited including new current meters and a rebuild

CCIW PLESSEY MO-21 CURRENT METER

REFURBISHMENT - TARGET PERFORMANCE SPECIFICATION

Data Acquisition Characteristics:		
Number of channels	:	7 - Reference Number, Temperature, Time, Speed, Direction, Depth, Synch
Number of bits per word	:	10 (expandable to 12)
Medium	:	1/4 - inch magnetic tape
Format	:	Plessey 9021 (and Aanderaa) compatible
Data Capacity	:	1 M bit (100 days at 5 channels x 5 minute rate)
Sample Rate	:	Switch selectable
Environmental Sensing Characteristics:		
Temperature	:	-2 to +22°C, ±0.5°C
Speed	:	2.5 to 150 $cm.s^{-1}$, ±2% FS (true rotor rotation)
Direction	:	1.4° resolution digital compass gimballed to ±5° roll, ±20° pitch
Depth	:	0-100 m, ±10%

Hydrodynamic Characteristics:

Similar to MO-21 as only internal modifications are to be made. (Mass and moment of inertia may be slightly different.)

Testing	:	Manufacturer to perform functional tests including environmental temperature cycling -10 to 30°C and final assembly gas leak test.

Notes:

Direction will be sampled once (or twice - if depth deleted) per scan. Present MO-21 samples direction 3 times at 8 second interval.

Number being rebuilt : 15

Table 3.1

of the existing MO-21's in the worst condition. The rebuild was to feature a new compass, a rotor counting scheme (better than that offered in the Plessey 9021), a magnetic tape data recording format compatible with the existing Plessey translator, and a real time clock. Table 3.1 summarizes the target specification for the rebuilt work.

Plans for application of the rebuilt current meters call for the following:

- tow test and calibration of each unit
- application in FY78 only in redundant moorings where conventional MO-21 data will be available for comparison

4.0 REVIEW OF CCIW EXPERIENCE WITH MARSH McBIRNEY ELECTROMAGNETIC CURRENT SENSORS

4.1 CCIW Applications

CCIW experience with these sensors dates from 1973. There have been three sensor types used: the M501 (Cylindrical), M552B (Spherical), M522 (Miniature Spherical). Each is a two axis current sensor using an alternating DC magnetic field excitation. The M501 sensors used 8 sensing electrodes to achieve an acceptable cosine response. These represent the manufacturer's first attempt at a self-contained current sensor derived from their ship's speed log designs. Within a given body type there may be more than one circuit improvement.

These first sensors were specified by CCIW to have a 6 pin connector and to operate off a 24 volt supply. The resulting sensor operates off ±24 V DC (i.e., 48V centre tapped). A consequence of this constraint has only recently been appreciated. Marsh McBirney's post M501 designs have been 12 volt devices or DC/DC convertor types with the result that our M552B devices are special in certain respects - principly the magnet and its excitation circuitry. As reported in Section 4.2, Marsh McBirney found that CCIW applications of these sensors were adversely affected by failure to adhere to the manufacturer's recommended grounding practices.

The specific applications are summarized in the following Table 4.1, and system descriptors. Special mention has been made of the grounding practices used and any other unusual electrical parameters for the systems.

4.1.1 Self Recording Assembly: The first field application of the M501 sensors was in these systems. The coarse sampling resulted in confused signals in wave events. Subsequent experience suggests that some zero offset error is probable with possible variability in some sensors due to grounding practice and power supply configuration. See Fig. 4.1.1 and Table 4.1.1.

4.1.2 CATS: Current and Temperature Studies: The history and specifics of the CATS systems are described at length in a companion study year end report for AR7-007. A number of specific points are worthy of mention:

CCIW APPLICATIONS OF MARSH McBIRNEY
ELECTROMAGNETIC CURRENT SENSORS

SYSTEM	SENSOR MODEL	APPLICATION	GROUNDING (SEE LEGEND)*	PERFORMANCE SUMMARY & COMMENTS
Self Recording Assembly	M501	Pt.Pelee 1974,75 Arctic 1975		- data recorded at low sampling rate on Rustrak - wave currents aliased - data considered useful
CATS System CATTS System	M501 1,2,3 Sensors 1,2 Sensors M552B	Pickering 1975-76 Byng Inlet 1976 CMC Study 1977 trials 1978/WAVES site	} 1,2 "correct"	- data contaminated with constant and step offsets. Subsets of CMC data show promise - data not available at this time
Photologger	M552B	Van Wagner's Beach	1,2,4	- no useful data - burst sampling
WAVES Tower	M501 M522	WAVES site 1976,77 1977	1,2,3 1	- questionable - constant offsets (?) - higher frequency components useful
Littoral Drift	M501 M552B	Van Wagner's Beach 1976	1,3,4 multiple sensors	- failed to function in all tests - including floating battery supply - sensors cabled to shore >~100 m

* 1. Incorrect grounding - manufacturer recommends tieing "magnet return" and "signal common" at supply.

2. System interconnection provided multiple water grounds for sensor "signal common"

3. Sensor power supplies are coupled to AC power line

4. Adjacent EHV multiphase AC power corridor <u>may</u> cause interference with sensor operation.

TABLE 4.1

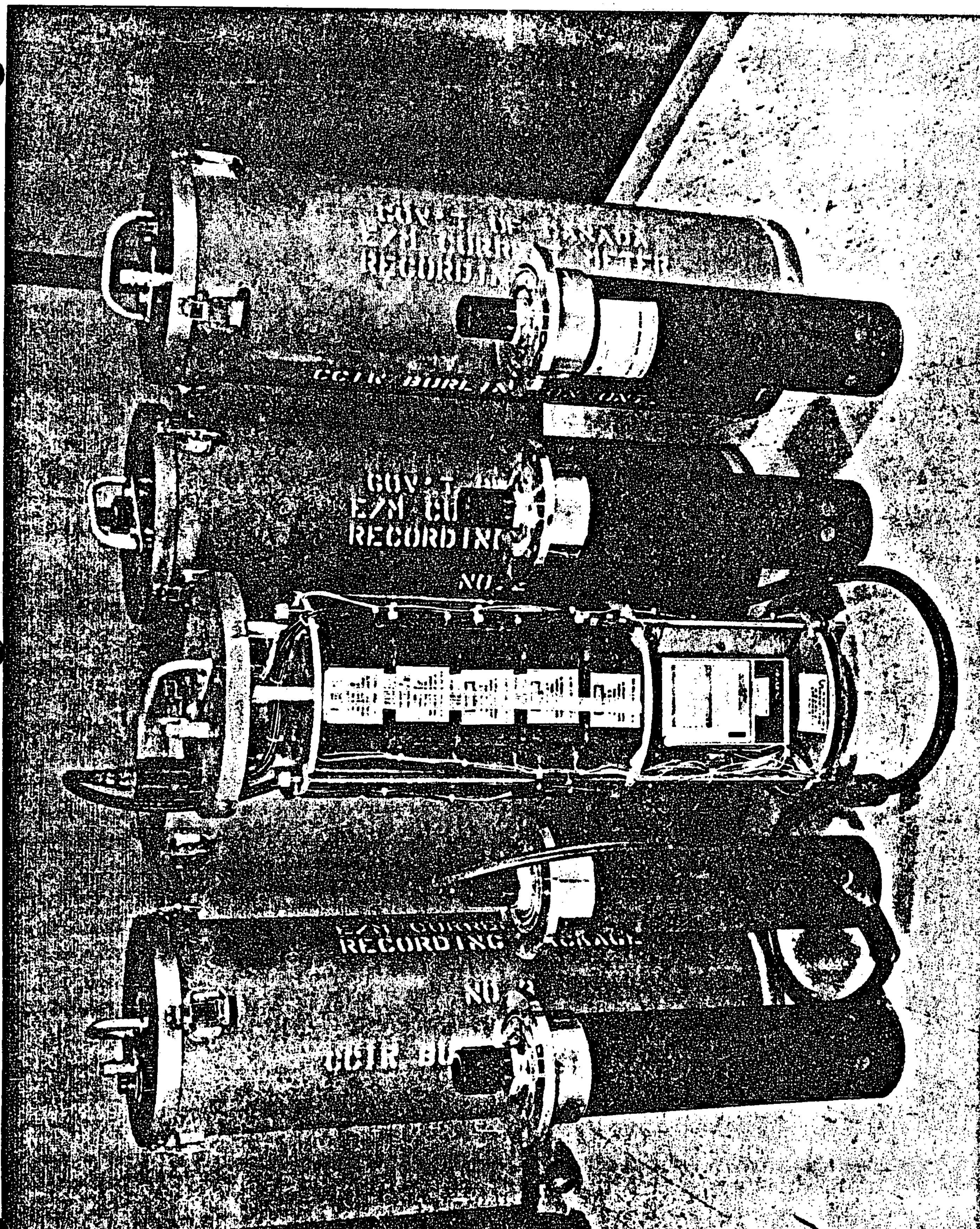

FIG. 4.1.1

SELF-RECORDING SOLID-STATE ELECTRO-MAGNETIC CURRENT SENSORS

(Quantity 4 (four) Recording Packages)

These self-recording packages were used by MSD, Shore Property Survey Group for shore erosion studies at Point Pelee.

The recording package and current sensor were attached to a stationary mounting pipe which was anchored in the lake's bottom.

Three stations were set-up, one each, on the west and east side of the point approximately 100 metres from the shore and another approximately 1.6 km off the shore.

The sensor was mounted on the stationary pipe, 1 metre from the lake's bottom in water depths of 3 - 10 metres.

Performance Specification:	
Current Sensor:	Mfd. March-McBirney Model 501
D.C. Power Excitation:	Dual Supply ± 24 volts @ 50 ma. maximum
Water Velocity Range:	0 to 2.5 metres/second on each axis
Operating Depth Range:	4900 kPa (500 metres)
Operating Conductivity Range:	Saline Water 5×10^4 μmho/cm Fresh Water 50 μmho/cm
Accuracy:	Error band < 1 cm/sec. or 2% of reading, whichever is larger each axis.
Time Constant: (63%)	0.2 seconds ± 5%
Output Signal:	"X" and "Y" components of water velocity perpendicular to flow of probe.
Output Voltage:	Output voltage corresponds to ± 5 volts = ± 2.5 metres/sec.
Output Drive:	Capable of driving loads from 10KΩ to 1MΩ shunted by 8 to 0.3 μfd.
Recording Package:	
	Weight 37 Kg. (82 lbs.)
Recorder:	- Rustrak Model F137 time share feature
	- 30 day chart
	- 12 volts (-motor 15 ma continuous (-relay 70 ma 50% duty cycle
Batteries:	- Eveready Y1711 or Mallory CSR-479
	- 3 sections, 12V., 7.9" dia., alkaline cells
	- requires 5 modules, underwater operation 1 month, shelf life 1 year.

TABLE 4.1.1

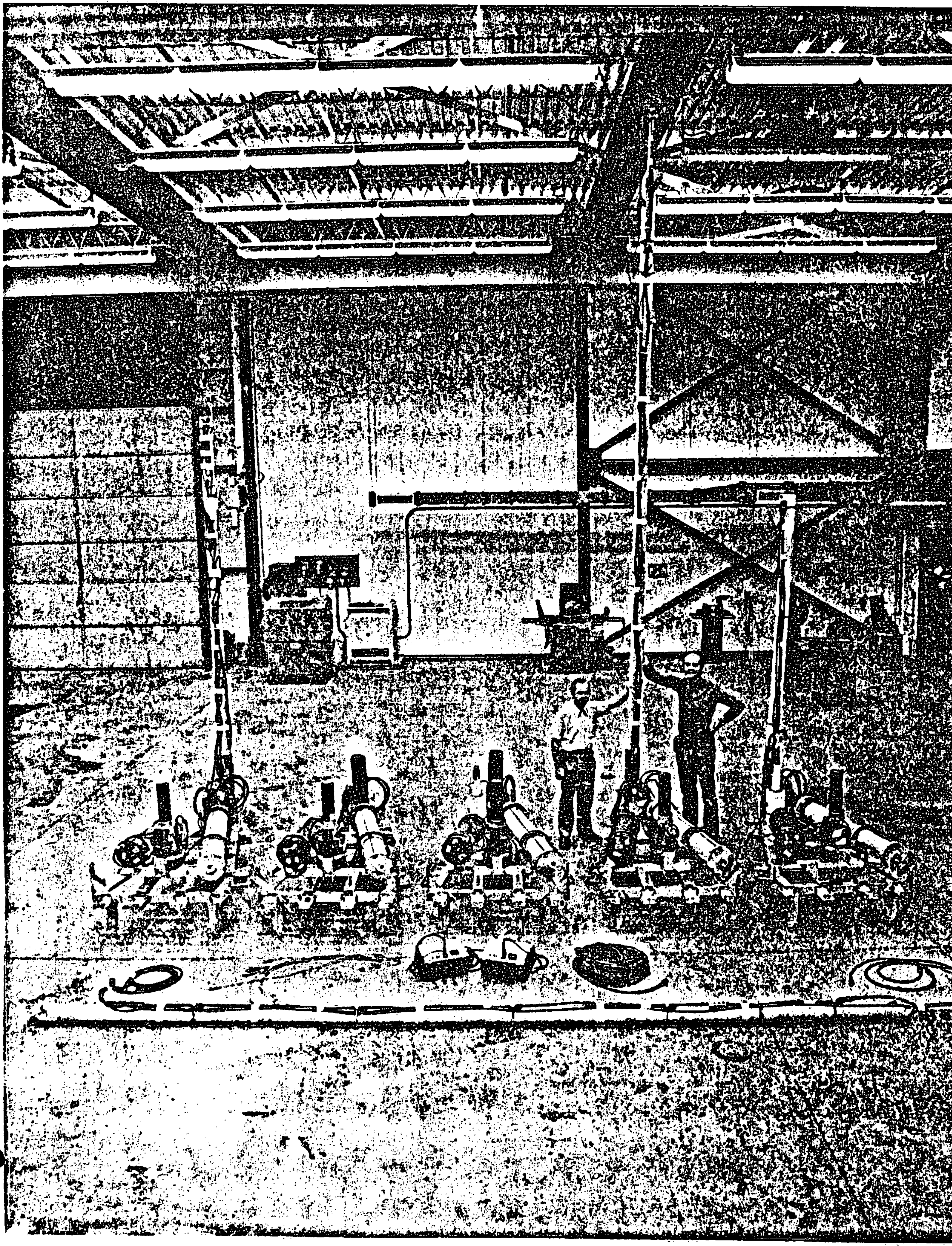

FIG. 4.1.2

SHALLOW-WATER CURRENT-AND-TEMPERATURE (CATS) SYSTEMS

(CCIW inventory: Qty. 5 Systems)

These systems were designed for nearshore application, and in particular for monitoring the presence and movement of thermal-plumes and "sinking-plumes" at power-station sites. Operability under ice cover, and insitu monitoring close to the surface, are also featured.

PERFORMANCE SPECIFICATION

1. TEMPERATURE: (UP TO 10 SENSORS)

	. RANGE	:	-2 to 40°C
	. RESOLUTION	:	15 mC°
	. ACCURACY	:	± 50 mC°
	. TIME CONSTANT	:	(WITH BOOT) 4.0 MINUTE
	. TYPE	:	THERMISTOR FENWAL K2284 4K-ISO CURVE

2. DEPTH: DETERMINED BY DIVER POSITIONING AND LOCATION.

. RESOLUTION : 1M. MAX. ON THE STAFF
ACTUAL DEPTH GIVEN BY DIVER REFERENCE PLUS CALCULATION
BASED ON THE TILT SENSOR AND THERMISTOR SPACING.

. TILT:	RANGE	:	± 45° (2-AXIS)
	RESOLUTION	:	0.45°
	ACCURACY	:	0.5°
	TIME CONSTANT	:	7 MIN. APPROX. (YIELDS ∿ 16 DB REJECTION AT A 10 MIN. SAMPLING INTERVAL).
	TYPE	:	HUMPHREY VI 13-0502-1

3. WATER VELOCITY:

SPEED	. RANGE	:	2 to 250 cm/sec.
	. RESOLUTION	:	0.5 cm/s.
	. ACCURACY	:	± 1 cm/s UP TO 50 cm/s.
	. THRESHOLD	:	2 cm/s
	. AVERAGING	:	LINEAR TO 99.5 cm/s.
DIRECTION	. RANGE	:	0 TO 360°
	. RESOLUTION	:	1.5°
	. ACCURACY	:	± 5°
	. AVERAGING	:	LINEAR OVER SAMPLING INTERVAL.
	. THRESHOLD	:	2 CM/SEC.
	. TYPE	:	MARSH-McBIRNEY E/M OR AANDERAA SAVONIUS ROTOR.

4. ENDURANCE:

	. SAMPLE	:	1 RECORD/10 MINUTES
	. CAPACITY	:	15000 - 14 WORD RECORDS 12000 - 19 WORD RECORDS
	. MOORING PERIOD	:	100 DAYS - 14 WORD RECORDS 80 DAYS - 19 WORD RECORDS 60 DAYS - 21 WORD RECORDS

5. TIME:

	. RESOLUTION	:	8 SECONDS MINIMUM
	. DRIFT	:	1 MINUTE/MONTH MAXIMUM
	. TYPE	:	DECREMENTING DIGITAL WORD

6. PHYSICAL:

	. WEIGHT	:	∿ 450 kg. IN AIR
	. DIMENSIONS	:	ANCHOR ASSEMBLY 2M x 1M x 0.5M TEMPERATURE STAFF 3M TO 10M

TABLE 4.1.2

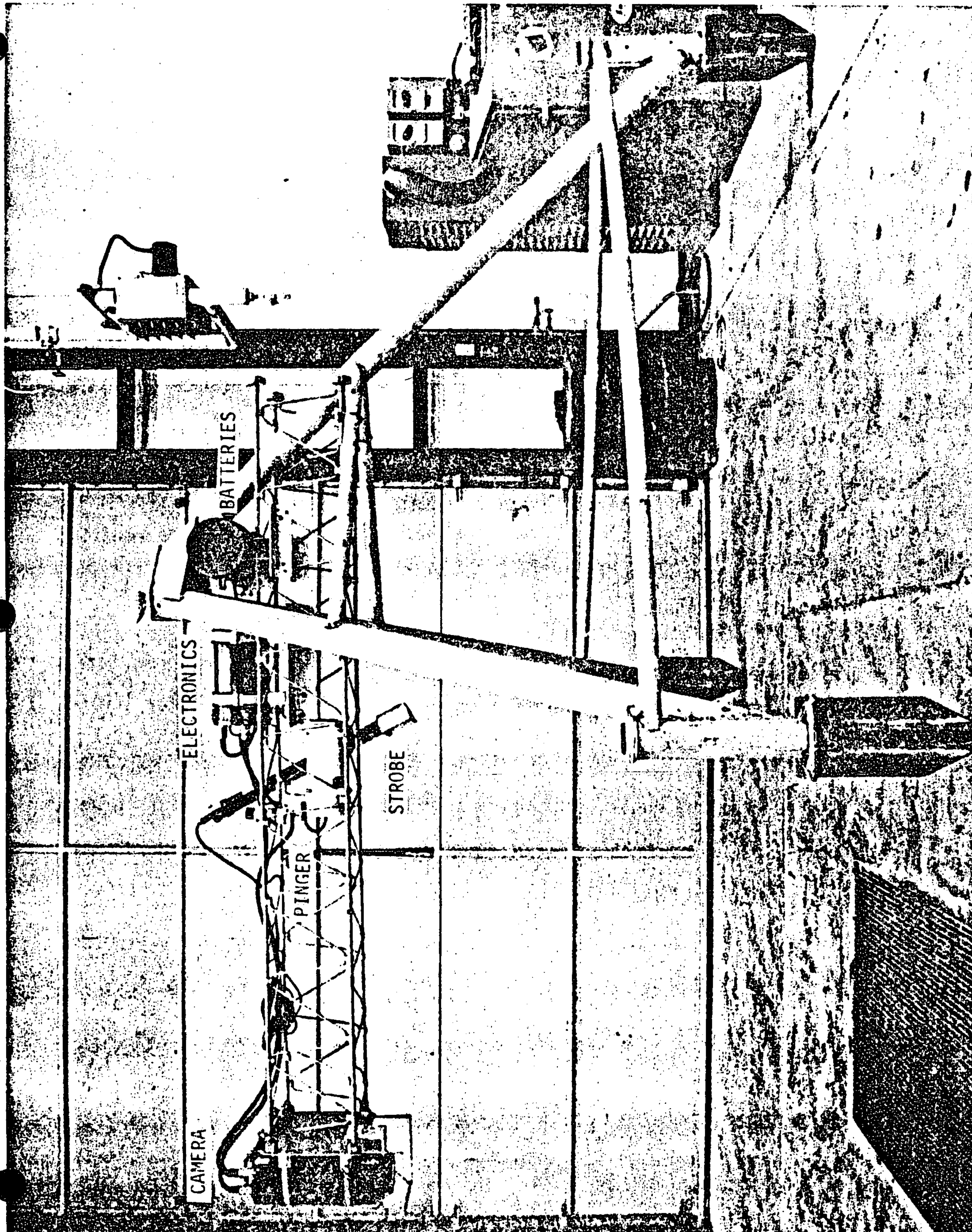

FIG. 4.1.3

UNDERWATER/ABOVEWATER TIMELAPSE PHOTOLOGGER SYSTEM

(CCIW inventory: Quantity 1 prototype)

This equipment is a functionally-flexible 16-millimetre time-lapse photo-logger system able to record extensive series of photo-images either underwater or above water, in the laboratory or in lakes. Many applications exist at C.C.I.W. for such a photo-logger. The system is modular and features sets of air-compensated and water-compensated lenses; incremental operation with wide-range timing controls (milliseconds to hours), strobe and/or photocell-inhibit; and digital recording in the image plane of data from associated environmental sensors.

TARGET SYSTEM SPECIFICATION FOR CCIW TIME-LAPSE PHOTOLOGGER SYSTEM FOR ABOVE WATER OR UNDERWATER USE

- Image Size: 16 mm film (10 x 8 mm image)
- System Exposure Capacity: 16,000 (400 ft. magazine)
- Range of Frame Rates: Assorted frame rates from 10 fps to 1 frame per 30 min. (depends on timing program). Rates to 400 fps available in cine mode.
  Accuracy: 0.1 %
- System optics: In Water
  - (1) 6.5 mm lens (water-corrected Leitz Canada lens C205).
    - Aperture range: f/2.4 to f/16
    - Field of view: 75° diagonal included angle
    - Depth of field: 20 cm to ∞ (@ 5' & f/16)

  Above Water
  - (1) 10 mm lens (Schneider Cinegon)
    - Aperture range: f/1.5 to f/16
    - Field of view: 65° diagonal included angle
    - Depth of field: 2.4 m at 3 m distance and f/8
      1.2 m at 3 m distance and f/1.8
  - (11) 150 mm lens (Schneider Tele-Xenar)
    - Aperture range: f/4 to f/16
    - Field of view: 6°
    - Depth of field: 30 cm at 3 m distance (@ f/4)
      90 cm at 3 m distance (@ f/22)
- Timing/event/I.D. recording: Digital Data on film (9 BCD characters). Includes frame count to 99,999 exposures, remaining characters available for external data.
- Test points for following functions: Battery Voltage monitor
  Strobe output monitor
  Shutter pulse monitor
- System lighting: Underwater: Xenon strobes (200 Joule) or natural lighting
  Above water: Natural lighting (other lighting optional)
- Exposure Control: Above Water: Sensor to have wide angle field of view -35°
  ASA 25 to 1600
  Aperture variation f/1.8 - f/16
  Speed 1/50 - 1/10,000 sec.
  Underwater: to be available at a later date (optional)
- Resolution: 75 lines/mm. at center. (maximum)
  35 lines/mm. at edge (maximum)
- System power: 36 VDC and ± 12 VDC (Separate submersible battery-pack)
  120 VAC optional
- Maximum operating depth: 450 m (Canada's inland waters)
- Temperature range of operation: - Underwater: -0°C to +40°C.
  In Air: -40°C to +40°C (Heaters) (with 120 VAC power)
- System packaging: three modules (a) camera module
  (b) control module
  (see sketches) (c) power supply module
- Strapable options: strobes, current meters, turbidimeters (underwater configuration)
  solarimeter, wind velocity, artifical illumination (above water configuration)

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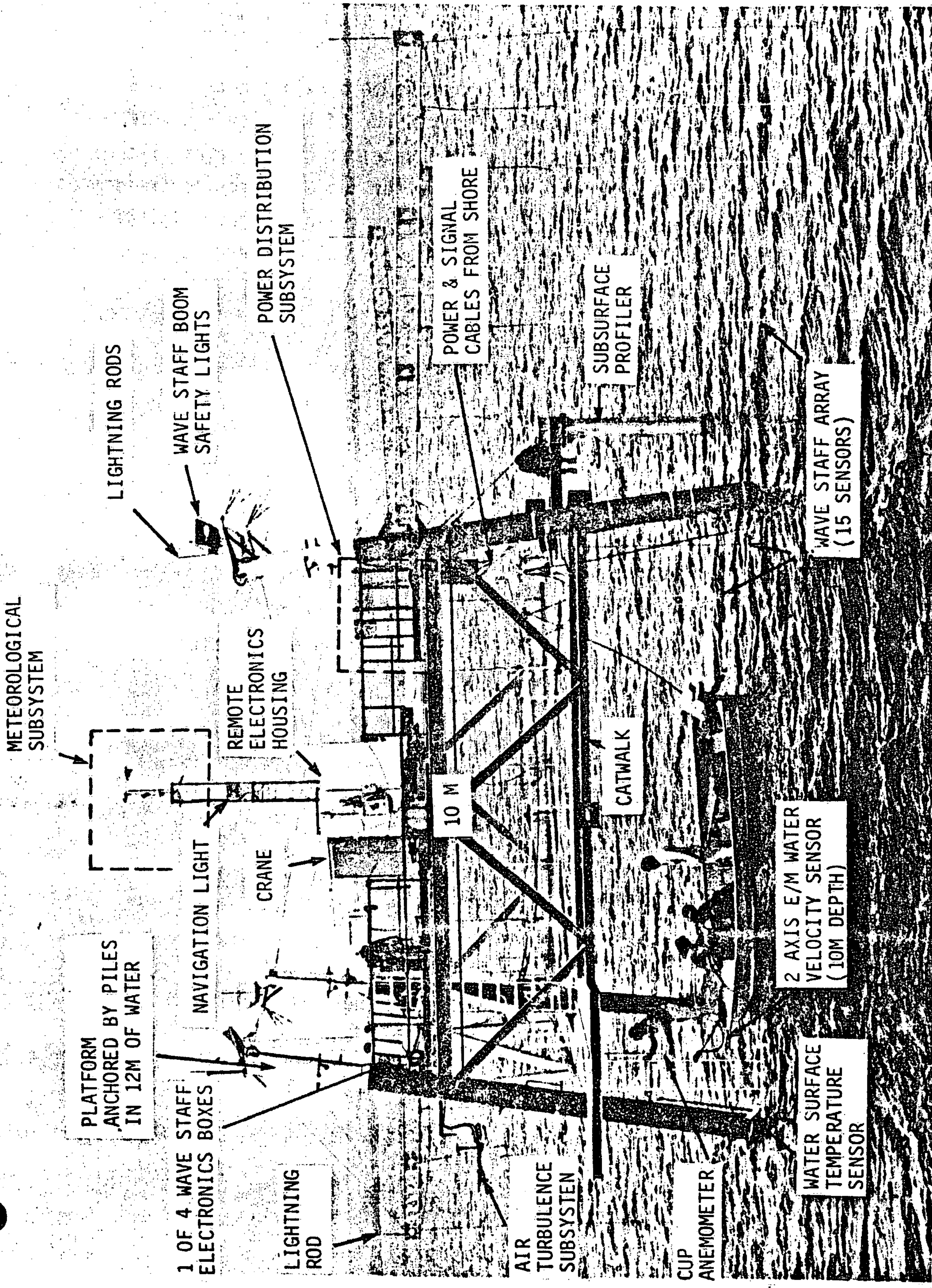
TABLE 4.1.3



WAVES-76 PLATFORM WITH INSTRUMENTATION

FIG. 4.1.4.1

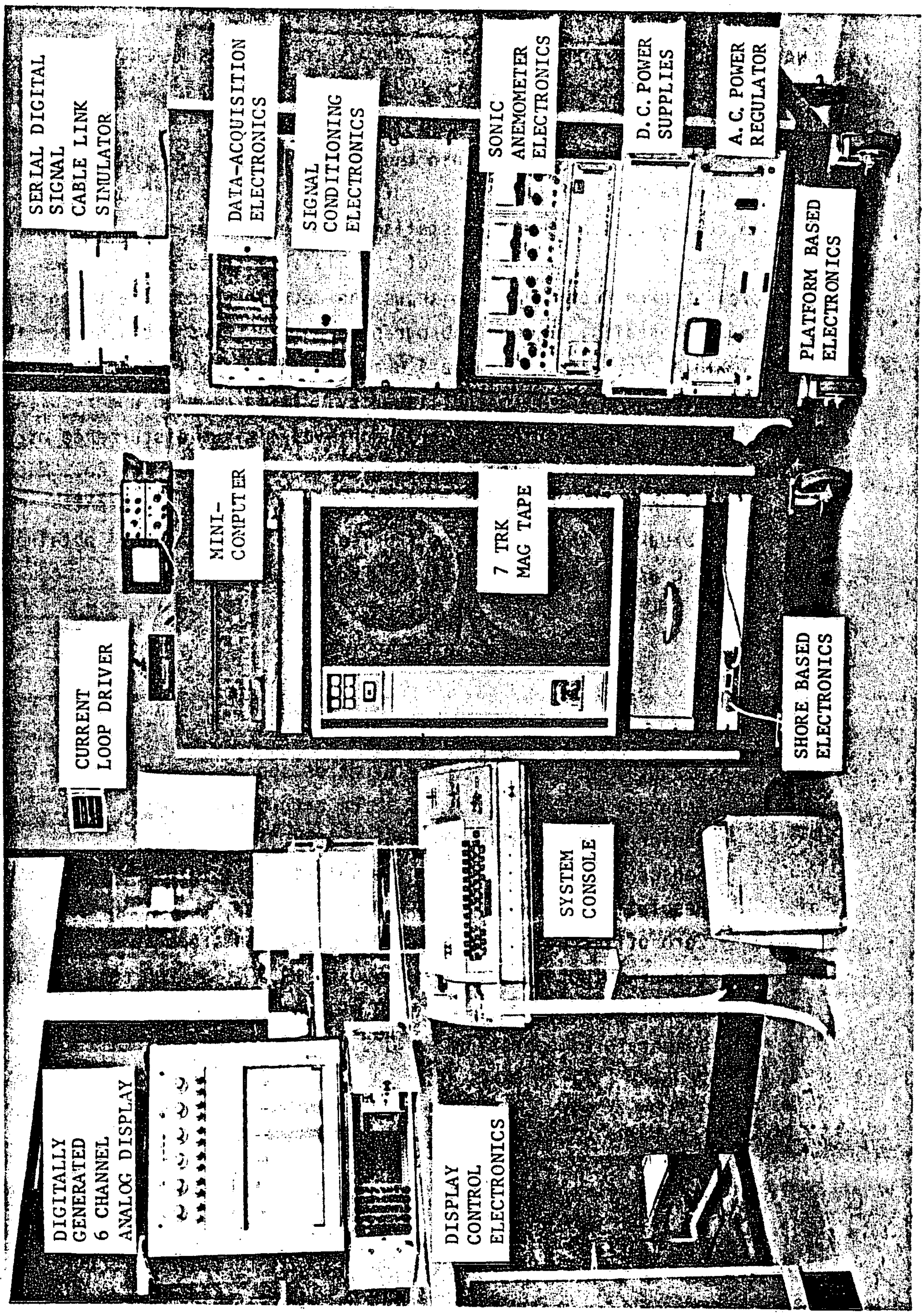


FIGURE 4 COMPUTER-BASED DATA ACQUISITION SYSTEM FOR W.A.V.E.S.-76

FIG. 4.1.4.2

W.A.V.E.S. - 76

SYSTEM SPECIFICATION

SUBSYSTEM	PARAMETER	SENSOR	RANGE	RESOLUTION	ACCURACY
Tower Subsystem (5 Hz)	Wind Speed	Cup Anem.	0.4 to 50 m/s	3 cm/s	±10 cm/s
	Wind Direction	Vane	0 to 352°	0.2°	±2°
	Wind Speed	Prop	0.2 to 30 m/s	2 cm/s	±10 cm/s
	Elevation	Vane	±50°	0.05°	±1°
	Air Temp.	Thermistor	-5 - 30°C	0.02°	±0.1°C
	Humidity	Arch	0 to 35 gm/kg	0.02	±1 gm/kgm
Turbulence Subsystem (20 Hz)	Wind Speed +60°	Sonic A	0 to 10 m/s	0.5 cm/s	±3% F.S.
	Wind Speed -60°	Sonic B	0 to 10 m/s	0.5 cm/s	±3% F.S.
	Wind Speed Z	Sonic W	±5 m/s	0.25 cm/s	±3% F.S.
	Air Temp.	Cold Wire	0 to 30°C	0.05°C	±1°C
	Humidity	Lyman-	0 to 35 gm/kg	0.02 gm/kgm	±1 gm/kgm
	Plat. Control	N/A	±180°	See below	±2°
	Position	Potentiom.	±180°	0.3°	±1°
Subsurface Profiler (20 Hz)	Water Speed X	DRAG SPHERE	±0.2 to 2 m/s	0.5 cm/s	±5 cm/s
	Water Speed Y	DRAG SPHERE	±0.2 to 2 m/s	0.5 cm/s	±5 cm/s
	Water Speed Z	DRAG SPHERE	±0.2 to 2 m/s	0.5 cm/s	±5 cm/s
	Water Temp.	Thermistor	0 to 25°	0.02°C	±0.05°C
	Vert. Control	N/A	+3 to -6 m	See below	±5 cm
	Vert. Position	Potentiom.	+3 to -6 m	0.5 cm	±2 cm
	Horiz. Control	N/A	±90°	See below	±2°
	Horiz.Position	Potentiom.	±90°	0.15°	±1°
Wave Staffs	Water Level	Capacitive	±3 m	0.3 cm	±5 cm
Average Parameters	Water Velocity	E/M	±2.5 m/s	0.5 cm/s	±5%
	Surf. Temp.	Therm.	0 - 30°C	0.02°C	±0.1°C
Signals Subsystem (940 sps max)	Analog 48 Chan.	Single Ended	0 to ±5.12V	2.5 mV	0.05% F.S.
	Digital Input 6 lines	Single Ended	C/MOS and TTL Compatible		
	Digital Output 18 lines	Single Ended	C/MOS and TTL Compatible		
Shore Subsystem	Real Time Clock			1 ms	300 ppm
	Analog Outputs (selectable)	Single Ended	0 to ±5.12	2.5 mV	

TABLE 4.1.4.1

OFFSHORE RESEARCH PLATFORM

This moderately large steel tower has been installed 43°16'.1 North Lat., 79°45'.6 West Long., approximately one kilometre off Van Wagners Beach (Hamilton, Ont.) at the west end of Lake Ontario. The tower provides a stable, fixed platform for limnological observations and experiments. High strength steel pipe-piles, driven down through the pipe legs, anchor the tower structure to the lake bottom. The structure was designed to produce minimum interference in the wave zone by eliminating cross bracing between 4.5 m above and below mean water level. The depth of water at the tower location is approximately 12 metres. The assumed maximum wave height is 6 metres trough to crest.

This structure safely accommodates large instrumentation packages and sensor arrays for both long and short term multi-discipline research. It provides a more stable, flexible and economic alternative to other towers used for wave zone studies in the past. The design life of the tower is ten years. The consultant was Byrne and Associates, the contractor was Bermingham Construction Company.

SPECIFICATIONS

PLATFORM STRUCTURE DIMENSIONS	
Structure height (from base)	23.17 metres
Base dimension	14.18 m (square)
Platform	9.15 m (square)
Structure mass, approximate	22 Mg
Design platform payload (uniformly distributed)	9 Mg
Diameter of legs	40.6 cm
PLATFORM POWER SUBSYSTEM	
Total unregulated	6 kw
Total 110 V AC	3 kw
Service outlets locations	9
PLATFORM ACCESSORIES	
Vertical profiler, travel	6 m
Vertical profiler, rotation	270°
Extension booms at 3 corners, length	10 m
Meteorological mast, height	5 m
Floodlights	4 mercury vapour 200 W each
Crane, payload	4 kN
Public address system, type	two-way
Electronics cabinet, volume	1.3 m^3

The electronic data logger, telemetering to shore and initial sensor array are described elsewhere.

TABLE 4.1.4.2

- The CATS current sensor is powered from an alkaline primary battery whose parallel circuits are summed with diodes. Early tests showed that capacitors across the supply were necessary to support satisfactory operation.
- The method of tieing of signal common and magnet power common was found to cause only small offset errors (due to the addition of the capacitors above).
- In the CATS systems the current sensor signal common was tied via the control electronics to the digitizer case which provides a variable impedance water ground. This is suspected of being the largest source of anomalous current data in the CATS system.
- The CATTS (1978) systems are free from these error sources, to the best of our knowledge.

4.1.3 Photologger: This application shares most of the errors identified for the CATS systems above. See Fig. 4.1.3 and Table 4.1.3.

4.1.4 WAVES Tower:

The M501 sensor deployment in the WAVES system has produced a variety of current-like and current-unlike responses. The signals were most current like during high current events, but are not believed to be correct in view of other data.

The M522 sensor was battery powered in the WAVES system application. Its performance generally met expectations with the exception of constant zero offsets. Further tests by C.Y. Der are reported in Section 4.4. See Fig. 4.1.4.1,2 and Table 4.1.4.1,2.

4.1.5 Littoral Drift:

The 1976 field experience showed very dynamic, large scale malfunctions by the EM current sensors under a variety of test conditions. The system grounding is now known to be incorrect. The question of Ontario Hydro EHV corridor electrical interference remains a possibility.

MEMORANDUM **NOTE DE SERVICE**

DATE 19 AUGUST 1977

FROM: C. Y. DER
ENGINEERING SERVICES SECTION

Our file Notre référence

TO: A.S. WATSON, P. ENG.
HEAD, ELECTRONICS ENGINEERING UNIT
ENGINEERING SERVICES SECTION

Your file Votre référence

SUBJECT: RE: MARSH-MCBIRNEY CONSULTING TRIP

A preliminary conclusion by L. Marsh is that there is a common "ground" problem existing in all four case histories that were discussed. In the miniature EMCM and Littoral Drift deployments, there was no connection between the power and signal commons (ie. a missing wire, the EMCM is not designed to operate in this fashion.), whereas in the CATS and W.A.V.E.S. Tower EMCM deployments, there is a significant distance from the power and signal common tie point and the battery common. The former has unpredictable results; the latter generates offsets when only one EMCM is being operated and both offsets and beat signals when two or more are operated off the same power supply. Virtually all of the anomalous data can be explained by problems associated with the ground. From L. Marsh's experience, the effects of ground problems often masks other anomalies due to other causes.

From my discussions with L. Marsh and J. Darby, I am very confident that they are correct in their assessment. By implementing a defined grounding procedure, we should be able to eliminate offset and beat signal problems. Interference from electric fields and inductive coupling requires other techniques to eliminate/minimize their effects. (We can address these problems only when the proper grounding procedure has been implemented.)

Charles Y.E. Der
Engineering Services Section

J.S.F.

Herewith Charles' immediate opinion as to the chance-of-success arising from the Marsh trip, as per your request.
We will get back into this area as soon as his OCEAN paper is complete.

ASW
19.8.77

MARSH-McBIRNEY, INC.
8595 GROVEMONT CIRCLE
GAITHERSBURG, MD. 20760
(301) 869-4700

TO: A. S. WATSON

FROM: L. B. MARSH

DATE: AUGUST 23, 1977

SUBJECT: TRIP REPORT COVERING TECHNICAL DISCUSSIONS BETWEEN MARSH-McBIRNEY PERSONNEL & CCIW PERSONNEL HELD AT CCIW ON AUGUST 16, 17, 18, 1977.

INTRODUCTION

Discussions were held between Larry Marsh and Jim Darby of Marsh-McBirney, Inc., Gaithersburg, Md. manufacturers of electromagnetic EM water current meters and Charles Der, A. S. Watson, Jim Bull, Brian White, and Mark Donelan all of CCIW. Not all of the CCIW people were present simultaneously but were called upon by CCIW coordinator, Charles Der, as necessary to supply supplementary information concerning either the test setup or the test data.

Basic discussions centered around the use of various Marsh-McBirney electromagnetic water current meters including the original prototype cylindrical units, later spherical 4" diameter sensors, and the latest 3/8" diameter spherical sensor. At CCIW these instruments have been used in various combinations with each other as well as in various electronic instrumentation hookups.

The projects in which the instrumentation can be categorized is as follows:

1. The CATS Project, Current and Temperature System.
2. The Littoral Drift Program.
3. The Waves Program.
4. Special tests utilizing the 3/8" spherical sensor.

The analyses that follows will give a description of the instrumentation hookup as we presently understand it and will describe the malfunctions that were indicated by CCIW personnel.

In addition, we present our thoughts as to how these malfunctions may have occured and how we could suggest preventing these problems in the future.

CATS Program

General Description of Installation

The CATS project utilized the five original cylindrical current meters in conjunction with the Geodyne resistor digitizer which provides this digitized information to a tape recorder for the final data recovery. It is our understanding that there is a CATS I and CATS II program with slightly different setups and spaced several years apart in implementation. The CATS units were powered from batteries and the first use of the instruments on the CATS program was to have the final outputs of the Marsh-McBirney electromagnetic current meters integrated and converted to angle and magnitude data where they were then compared with savonious rotor instruments in the same vicinity.

The Marsh-McBirney instruments were supplied with the power connection consisting of +24 volts, -24 volts, signal ground, and magnet return. (These two separate ground leads are provided to insure that the large magnet currents which flow in the magnet return lead do not contaminate the signal ground of the instrumentation. These 30 Hz current pulses which are on the magnet line can be interpreted by the instrumentation of the electromagnetic current meters to be water velocity signals and therefore, these two grounds are required to be connected only at the very lowest impedance point of the battery setup. See Figure 1.) It was determined that the setup for the CATS December 1974 and January 1975 tests had the signal ground and the magnet return tied together to the battery return but had a small amount of additional resistance between the tie point and the battery. See Figure 2.

Description of Malfunction

The data plots of the integrated velocity signals from the December 1974 and January 1975 tests indicated that the electromagnetic meters yielded data which indicated a flow direction that was approximately 120 degrees from that yielded by savonious rotor instruments. When each of the instruments were measuring steady-state flow conditions where there were no contaminations due to wave action, this angular discrepancy was shown. In observing these plots, however, it was noted that when the velocity appeared to change direction as seen on the savonious rotor instruments, the same Δ change in direction occurred on the electromagnetic meter. This would seem to be an indication that the electromagnetic meters were working but for some reason the axes may have been reversed either in the instrument or in the data handling system itself. When the electromagnetic meter was compared to the savonious rotor when contaminated with wave action the savonious rotor had a wide scattering plot of both magnitude and direction, whereas, the Marsh-McBirney meter had a grouping of data indicating that it was indeed providing the proper vector averaging in face of this wave action. Since these two differ so greatly under wave conditions it is difficult to determine any correlation between the savonious rotor and the electromagnetic in this case in light of their differing characteristics.

In the CATS II program the data was not integrated and there was some intercomparisons that indicated that the lower EM instrument on the CATS II when compared with a nearby CATS 1 EM instrument gave magnitude data which was nearly identical but the angular data appeared to be approximately 100 to 120° different. Discussions with personnel at CCIW indicated that this difference in direction could very well come about from the uncertainty of the orientation of the probe due to current compass problems which the diver had during installation. Axis reversal could account for 90° of this difference.

Additionally, the bottom EM instrument of CATS II had three twelve-hour periods in which there was wild data excursions which could come about only from a malfunctioning of the system. It certainly could not represent true velocity data. It was noted that the same instrument that had the large excursions also took much longer to settle down when the entire system was set up in the laboratory and the water current meters placed in the water. The savonious rotors which were placed nearby during the CATS II and CATS I comparison malfunctioned and thus there is no baseline data to determine whether or not either of the two electromagnetic meters placed at the lower depths were functioning according to another standard. The grounding system that was described, although incorrect, should not cause these large excursions in the data. This wiring can cause possible zero offsets which may or may not be stable. The recommended wiring is to connect each of the two grounds at the lowest impedance point of the battery.

LITTORAL DRIFT PROGRAM

General Description of Installation

The Littoral Drift installation consisted of one spherical sensor and one cylindrical sensor. Littoral Drift current meters were run along cables to the on-shore trailor within which the data system was placed. Power for the Littoral Drift current meters were batteries near the location of the current meters. They were not powered from shore.

The ground hookup for these instruments consisted of the +, −, and magnet ground being connected to the battery system in the proper manner but the fourth wire from the electromagnetic sensors was not returned to the battery but was used only as a signal ground for the X and Y outputs so as to differentially take the signal off between the signal ground and the X and Y outputs. (See Figure 3.)

Description of Malfunction

The outputs of the two electromagnetic water current meters had various amounts of unexplained offsets as well as the low frequency beating between the two instruments. There never appeared to be any useful data obtained from these instruments.

Possible Sources of Malfunction

The fact that the signal ground of the electromagnetic current meters was not directly connected to the battery common can explain the malfunctions that were seen. Figure 1 included in this report indicates the basic design technique of the Marsh-McBirney electromagnetic current meter as it pertains to grounding. The fact that the signal ground of the instrument was not connected to the battery allowed the sensing portion of the electromagnetic sensor to float relative to the magnet drive system and therefore be faced with large inputs of common mode 30 Hz.

It should be noted that the electromagnetic water current meter is a high gain device. Signals generated in the water from the interaction of the flowing water with the electromagnetic field produces voltages of approximately 10 microvolts for each meter per second of water flow. Therefore, the large input of common mode 30 Hz voltages which the instrument is forced to see due to the lack of this signal ground can easily get into the data system and cause an apparent steady state flow velocity. That is, since the instrument is sensitive to 30 Hz amplitude modulated signals in the water, any 30 Hz that is present in the instrumentation amplifiers will appear to be flow velocities. The large 30 Hz excursions that exist on the magnet return wire will inevitably get into the channel amplifier if the signal ground is not connected with this magnet return wire at the lowest point on the battery.

In this particular case, the two instruments were powered from the common battery. Since their frequencies of operation can be slightly different since they operate from separate oscillators, each instrument can cause a beat frequency on the other instrument. Thus one could expect to see with this setup not only large offsets but beat notes between the two instruments since they are utilizing a common battery and were hooked up without their signal grounds connected.

Information obtained on a test unit placed nearby and which was powered from the trailer appeared to have been wired with the ground tied together. That is, the signal ground and power ground were tied together to a power supply in the trailer. This instrument also indicated that it too had a beat note.

Since the amount of data on this test instrument is very limited it is difficult to come to any basic conclusions. It is highly possible that its connection to an AC power supply at a trailer several hundred meters from its sensor caused an AC ground loop, thus causing the beat frequency. In this case rearranging of the ground could have been attempted to determine if the ground loop could be eliminated.

Waves

General Description of Instrumentation

The Waves tower is approximately 1000 meters offshore and on the same site on which the Littoral Drift tests were made. The data that was recorded is not averaged like CATS, but is fast response data. This data is contained on magnetic tape and strip chart recorders. The digitized data is sent to shore by means of a hard wired cable.

It is understood that the grounding system had the magnet return wire and the signal grounds connected together but there was a possibility of higher resistance than desired connection between the common point and the battery. (See Figure 2.) The power supplies which run the cylindrical sensor on tower was AC powered and the commons of all the instruments were tied together by means of an extensive grounding system. The third prong of the Hewlett-Packard power supply was thought to be attached to the tower itself. The Hewlett-Packard also supplies the other instruments used on the test.

Description of the Malfunction

The various types of malfunctions on this setup were many. Malfunctions consisted of beat notes on both channels simultaneously, beat notes in individual channels without a comparable beat note on the other channel. and a high correlation of abnormal tracking between the X and Y channels which were obviously not wave induced velocities.

Possible Sources of Malfunction

Since the data was sampled prior to presentation on the strip chart recorders, it is not possible to determine if high frequencies above the sampling frequency were present on the water current meter outputs. Thus we do not know whether the frequencies which are shown on the strip chart recorder were indicative of the velocity of the electromagnetic current meter outputs or possibly new frequencies introduced due to the sampling rate.

It is highly unusual for an electromagnetic current meter to generate beat notes due to 60 cycle interference on only one channel. The experiences indicated that when 60 cycle interference mixes with the 60 cycle sampling rate and causes the beat frequency, this malfunction occurs simultaneously on both channels albeit in different magnitude. It is difficult if not impossible to have only one channel showing AC interference due to the nature of the design of the instrument.

There was a distinct tracking (see Figure 4) quite often between the channels. The magnitude of this tracking of the two signals was approximately 75 millivolts. Since the self-noise of each channel is a random noise signal of approximately 25 millivolts, it is virtually impossible for these outputs to track this close and have their front end differential amplifiers still functional. It is therefore highly likely (when the units appear to be tracking very closely) that large saturating 60 cycle voltages have made the front end inoperative. Since it is impossible to determine at this time if there was a malfunction in the commutator which selects the recorder outputs then we must assume that the commutator was operating properly and not selecting one channel twice.

The electromagnetic current meter in this particular setup appeared to go from (1) giving very good wave data that coincided with exactly what was expected from the corresponding wave staff data to (2) a tracking mode and to (3) occasional operation where there appeared to be beat frequencies involved. It is interesting to note that these types of malfunctionings appear to shift around according to which channel on the chart recorder is selected by the data system. There is not enough data to conclusively determine that there is a high degree of correlation but it was noticed that data differed when it was being presented on the different channels on the chart recorder.

In either case it appears that the instrument intermittently operated and that it would be most likely that the malfunctioning came about primarily from AC ground loops causing intermittent saturation of the instruments' front end.

3/8" Diameter Spherical Sensor

Description of Installation

The 3/8" spherical sensor is similar in design to the larger spherical sensors and utilizes electronics that is virtually identical to the later spherical probes. This 3/8" sensor was tested in laboratories at CCIW as well as having been installed in the field. The operation during laboratory tests was quite satisfactory and was performed using the power and signal cable that was not taken into the field.

The field setup consisted of a different cabling system than used in the laboratory and the grounding setup was one in which the magnet return ground was connected to the battery but the signal return ground was not. The resulting data consisted of a 1 volt offset on the output of the instrument with what appeared to be good wave data riding on top of this offset.

A second setup was attempted after telephone communication with Marsh-McBirney that culminated in the rearranging of the ground system so that the two grounds were tied together. This reduced the offset in the output to approximately 70 millivolts in one channel and 20 millivolts in the other channel. The final setup as it presently exists today has the power leads and the ground leads going through several connectors and several relay contacts and then to a battery pack.

Description of Malfunction

The offsets which exist on the output of the 3/8" spherical sensor are unequivocably coming from the grounding system which has been used. (See Figure 3.) Similar to wiring done on the Littoral Drift units, the instrument is being faced with large amounts of coherent 30 Hz signals and is unable to reject this large common mode signal. The attaching of the two ground wires together reduced the problem considerably. However, discussions held during our recent trip have indicated that there is probably approximately 0.5 ohms still existing between the connection between the two grounds and the low impedance point of the battery. This is due to the various connections and relay contacts that exist between the tie point of the two grounds and, the ground terminal of the battery.

It has been decided that this correction will be made by removing the present tie point and running the two ground wires separately back through the connectors, through the relay contacts and joined only back at the battery terminal itself. That is, no common singular wire should exist between the tie point of the mag return and the ground of the battery.

It is interesting to note that although the 3/8" probe with its high gain electronics should be the most sensitive to grounding problems and 60 cycle noise it has performed the most satisfactory. However, it is of the most recently manufacture by Marsh-McBirney and of the most recent usage by CCIW. Its grounding setups are well defined and well documented.

General Thoughts and Recommendations

The grounding problems which have been described in each of the above cases and which are shown schematically in this report are the most serious and have probably masked any other problems which may exist.

I would expect that the 60 cycle problems that are intermittantly present in all of the instruments can come about generally when long cable runs are made between an instrument base which is powered from 60 cycles and the instruments which are placed long distances in another ground plane. I would not expect 60 cycle problems to exist when both the data system and the instruments are self-contained on a platform and are run from a battery source.

When the instruments are to be used with AC power sources the use of isolation transformers and/or the changing of the grounds to eliminate third prong type ground loops is advised. Ground loops in systems are quite often difficult to find but through meticulous care to always end up with a single point ground they can nearly always be eliminated.

There is no question that due to the nature of the electromagnetic water velocity sensor it is probably more sensitive to stray electrical currents than any other sensors owned by CCIW. Therefore, it would be my recommendation that care be taken to provide more attention to the grounding as it relates to the water current meter.

Most of the data that was presented to me during my trip indicated that although there were a vast number of apparent malfunctions and problem areas, the instruments did continue to "work" during almost all of the deployment. Under these circumstances it would appear that once we have solved the basic grounding problems that exist on the systems, they should be relatively free of long term malfunctioning.

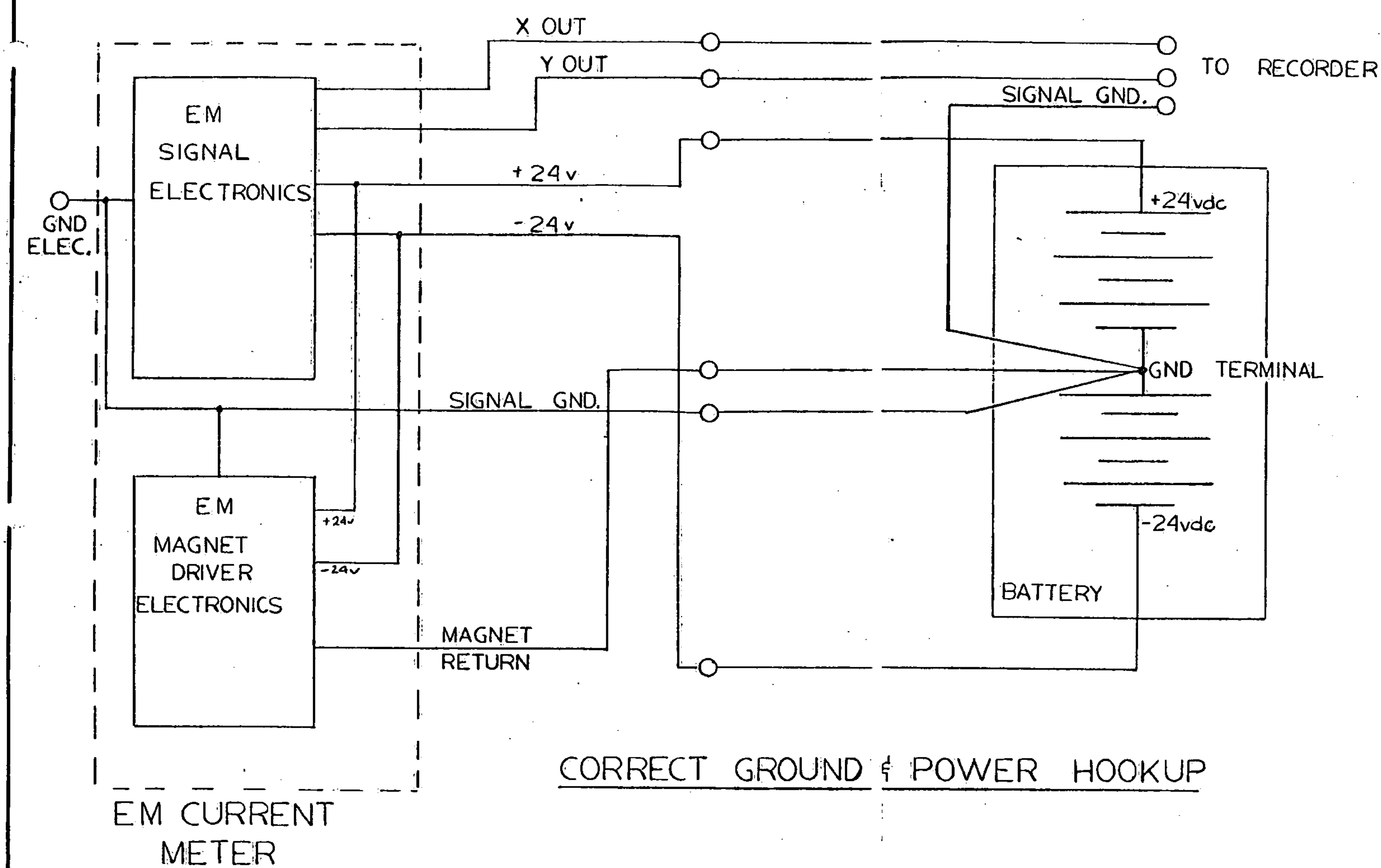
Future Achievable Accuracies

The low velocities that CCIW generally encounters in its recent programs indicate that it is desireable to achieve accuracies of the order of approximately ±1 centimeter per second. Whereas these types of accuracies are not necessarily required at the high velocities of 100 to 150 centimeters per second, it is required for the low velocities encountered in a large number of your instrumentation projects.

Once the ground loop problems have been eliminated, (as they apparently are close to being eliminated in the 3/8" diameter sensor) the long term drift of these instruments should be capable of staying within ±1 centimeter per second. This estimate is based upon experience rather than being able to be mathematically proven.

It would be my suggestion, however, that several of your instrument packages be placed out in the lake environment with appropriate shrouds covering the sensors so as to produce a zero velocity input. These outputs should then be monitored either periodically or continuously to verify the stability of the zero. Only through the proper testing can CCIW regain a confidence level that is required to deploy these instruments in your low velocity environment.

Although I feel that the instruments which have been provided to you in the past (and any that might be provided to you in the future) are capable of solving your water instrumentation jobs, it certainly has yet to be demonstrated that this can in fact happen. It is now obvious that there have been less than adequate communications between our company and CCIW and that had the proper information been conveyed to CCIW concerning grounding practices or if MMI personnel would have been present during some initial installations the various problems which have occured would have been either eliminated or at least minimized.



CORRECT GROUND & POWER HOOKUP

REVISIONS			
SYM	DESCRIPTION	DATE	BY

ITEM	QTY	DESCR.

MATERIAL

FINISH

UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES
TOLERANCES ON
2 PLACE DECIMALS = ±.030
3 PLACE DECIMALS = ±.010
REMOVE ALL BURRS AND BREAK SHARP EDGES

DRAFTSMAN	DATE
CHECKER	DATE
QA	DATE
PROJECT	DATE

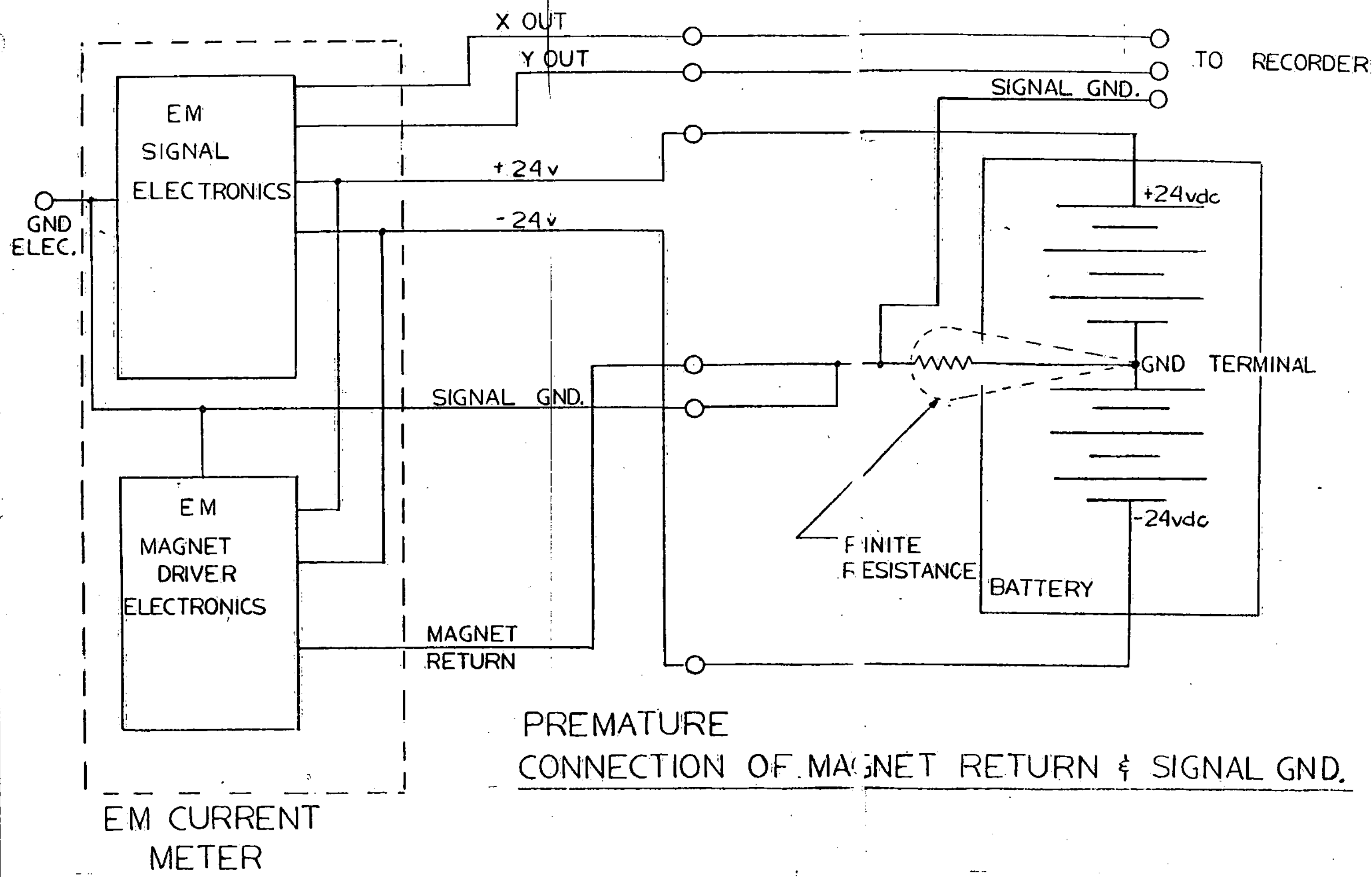
MARSH McBIRNEY
2281 LEWIS AVENUE
ROCKVILLE, MARYLAND

TITLE Fig 1

CODE

B DWG NO. REV

SCALE SHEET OF



PREMATURE
CONNECTION OF MAGNET RETURN & SIGNAL GND.

REVISIONS			
SYM	DESCRIPTION	DATE	BY

ITEM	QTY	DESCR.

MATERIAL

FINISH

UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES
TOLERANCES ON
2 PLACE DECIMALS = ±.030
3 PLACE DECIMALS = ±.010
REMOVE ALL BURRS AND BREAK SHARP EDGES

DRAFTSMAN	DATE
CHECKER	DATE
QA	DATE
PROJECT	DATE

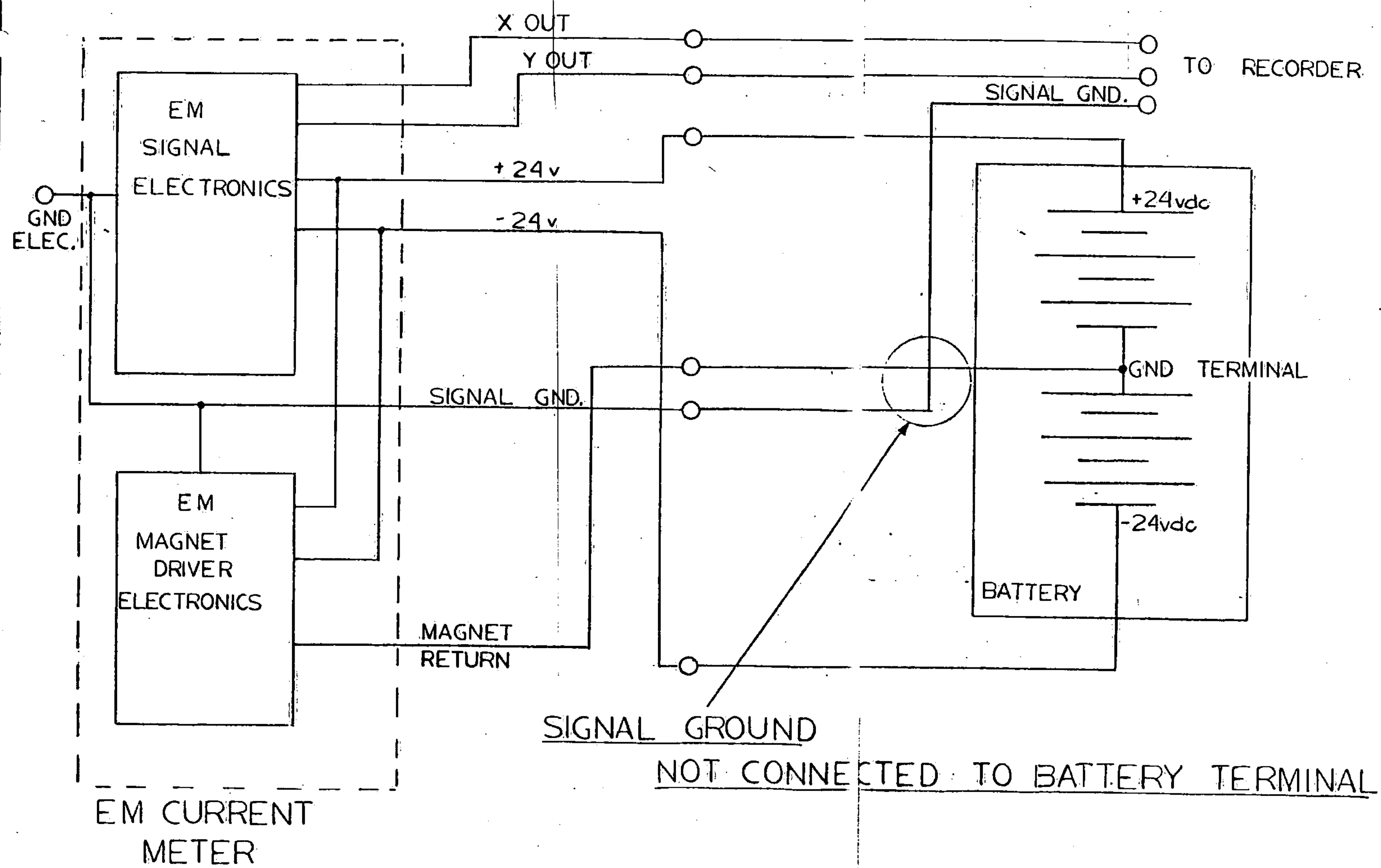
MARSH McBIRNEY
2281 LEWIS AVENUE
ROCKVILLE, MARYLAND

TITLE
Fig 2

CODE

B	DWG NO.	REV

SCALE SHEET OF



REVISIONS

SYM	DESCRIPTION	DATE	BY

ITEM	QTY	DESCR.

MATERIAL

FINISH

UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES
TOLERANCES ON
2 PLACE DECIMALS = ±.030
3 PLACE DECIMALS = ±.010
REMOVE ALL BURRS AND BREAK SHARP EDGES

DRAFTSMAN	DATE
CHECKER	DATE
QA	DATE
PROJECT	DATE

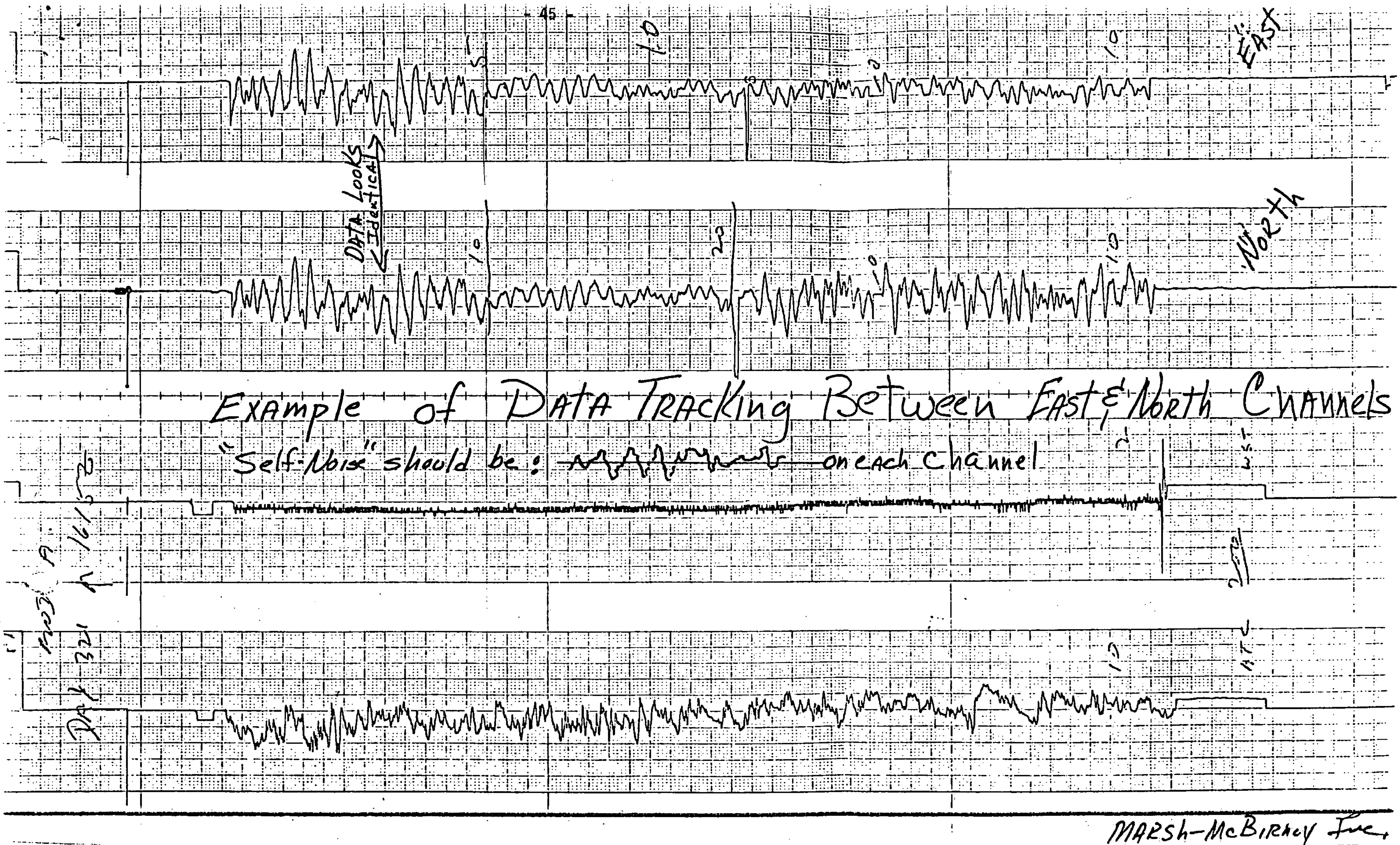
MARSH McBIRNEY
2281 LEWIS AVENUE
ROCKVILLE, MARYLAND

TITLE Fig 3

CODE

B DWG NO. REV

SCALE SHEET OF


- 45 -
DAY 321
EAST
NORTH
DATA LOOKS IDENTICAL
Example of DATA TRACKING Between EAST & NORTH CHANNELS
"Self-Noise" should be: on each channel
MARSH-McBIRNEY INC.

Sensor Calibration:

Calibration experiments at CCIW with these sensors have suffered with a variety of problems:

The CCIW towing carriage has shown short term speed fluctuations of ±10% of the mean.

The electric drive system for the carriage seems to produce signals which interfere with the functioning of the current sensors - an effect which is markedly worse with the M552B sensors than the M501.

A variety of calibration "jigs" and procedures have produced non repeatable zero offset estimates.

The rotating jig used to calibrate two axis current sensors lacks a reference standard angle indicator and an angular position sensor. This jig has been modified to have a higher rotation rate necessary for high speed calibrations - but this is inadequate for low speed calibrations - hence continuity of method in low speed calibrations has suffered. (20 s period versus 40 s)

Control over calibration data has been loose in that the responsibility for the data lies with each study team.

4.2 Fault Reports:

The memo C. Der to A.S. Watson summarizes the main report of L. Marsh who diagnosed one of the main reasons for CCIW's failure in applying EM current meters.

4.3 CCIW Recommendations

All future applications of electromagnetic current sensors should consider the following points:

4.3.1 Supply stiffness:

A battery supply using summing diodes should have capacitors to provide the low effective supply impedance needed by the sensor (eg 200 μF)

4.3.2 Grounding:

The signal ground and magnet power ground should be tied - once only - and at the power supply (capacitors above).

4.3.3 Water grounds:

The current sensor signal common should be tied to the water only by the current sensor and should be isolated from any other system water grounds by at least 100 k ohm.

4.3.4 Line coupled supplies:

Future applications requiring operation with AC power line coupled supplies should consider using either AC line phase synchronized sensors - or sensors with DC/DC convertor isolation.

4.3.5 Calibration - method:

The noise problems in the tow tank calibration set up must be resolved with isolation, shielding, improved sensor grounding as necessary.

The rotating jig should be returned to slower speed for low speed calibrations, made reversible and a reference heading sensor implemented so that vector sensing error measurements can be made.

A standard test procedure should be defined - and a central calibration history maintained.

Future calibration instrumentation should include a means to monitor the carriage speed from the displacement sensor and some reference sensor as used at NOAA-OEE-NOS-NRDC.

4.3.6 Conductivity:

Tests have shown (S4.4) that these sensors appear to operate within specification for fluid conductivities greater than 100 μ Siemen. Applications in low conductivity water bodies (mountain lakes and rivers, or under freshwater ice) should be approached with caution.

4.3.7 Sensor Types and Disposition:

The ±24 volt supply sensor type used at CCIW (either M501 - now obsolete, or M552B) has several shortcomings.

- The M501 is hydrodynamically inferior to the M552B and should not be used where significant wave orbital velocities are expected.
- The M501 sensors are suffering from attrition and are becoming uneconomic to maintain due to wiring failures in handling and repair.

- The M552B is considered a special model by the manufacturers. Maintenance, delivery times and reliability are affected by the power supply constraint which distinguishes it from Marsh McBirney's standard product.

The M552B situation provides several alternatives.

Present Status:	1 sensor in apparently good order
	1 sensor suspect
	1 sensor defective -- in need of repair
	1 sensor missing

Alternatives:

- Continue with ±24V, 6 pin specification - accepting liabilities.
- Convert to M.McB standard sensor and rework existing to this standard (new probe, component changes on magnet driver card).
- Convert to M.McB standard for new sensors and accept in-compatability.

Recommendation:
With the presumption that current sensors of the March McBirney M552 type will fill a continuing measurement need for CCIW, I suggest that the second alternative be pursued.

January 1980 update:

Three of the MMcB. Model 518 Sensors (±12 V) have been used or are on order for use in the MCATS System.
One of the four M552B sensors is still missing. The remaining three are fully functional.
The M522 miniature sensor is defective. Repair by replacing the probe head with one slightly larger (the smallest currently made by the manufacturer) is under consideration.

4.4 CCIW Analysis and Test Results

The applications of the Marsh McBirney current sensors at CCIW have raised several technical questions regarding the performance of these sensors in systems. A number of electronic tests have been conducted under the auspices of this study to resolve some of these questions. The initial work done on analysis and test of these sensors was reported in the CCIW Unpublished Report: "Evaluation Data on Solid State 2-Axis Water Velocity Sensors" (ES-511), 1976.

The results of these further tests are summarized in the following pages.

EM CURRENT SENSOR TEST SUMMARY

SENSOR TYPE: M552B
SERIAL NUMBER: C013012
DATE OF TEST: 25-31 JAN
PERFORMED BY: BF WHITE

OBJECTIVE: TO DETERMINE LIMITS OF OPERATION TO SPECIFICATION FOR CONDUCTIVITY OF WATER.

TEST METHOD: THE SENSOR WAS CONFIGURED IN THE LARGE TEST PAIL (170 ℓ). THE PAIL HAD BEEN CLEANED, RINSED AND FILLED WITH DISTILLED WATER.

THE CONDUCTIVITY WAS MEASURED USING THE CALIBRATION LAB BRIDGE BY K. MOLLON.

POTASSIUM CHLORIDE (KCl) WAS ADDED TO EFFECT CHANGES IN CONDUCTIVITY. THE WATER WAS ALLOWED TO COME TO EQUILIBRIUM THE SENSOR OPERATION MEASURED. WATER STIRRED TO ELIMINATE STRATIFICATION. OPERATION MEASURED.

NOTE: BATTERY SUPPLIES; CYD 1977 JIG; BRUSH TWO CHANNEL DIFF'L. CHART RECORDER.

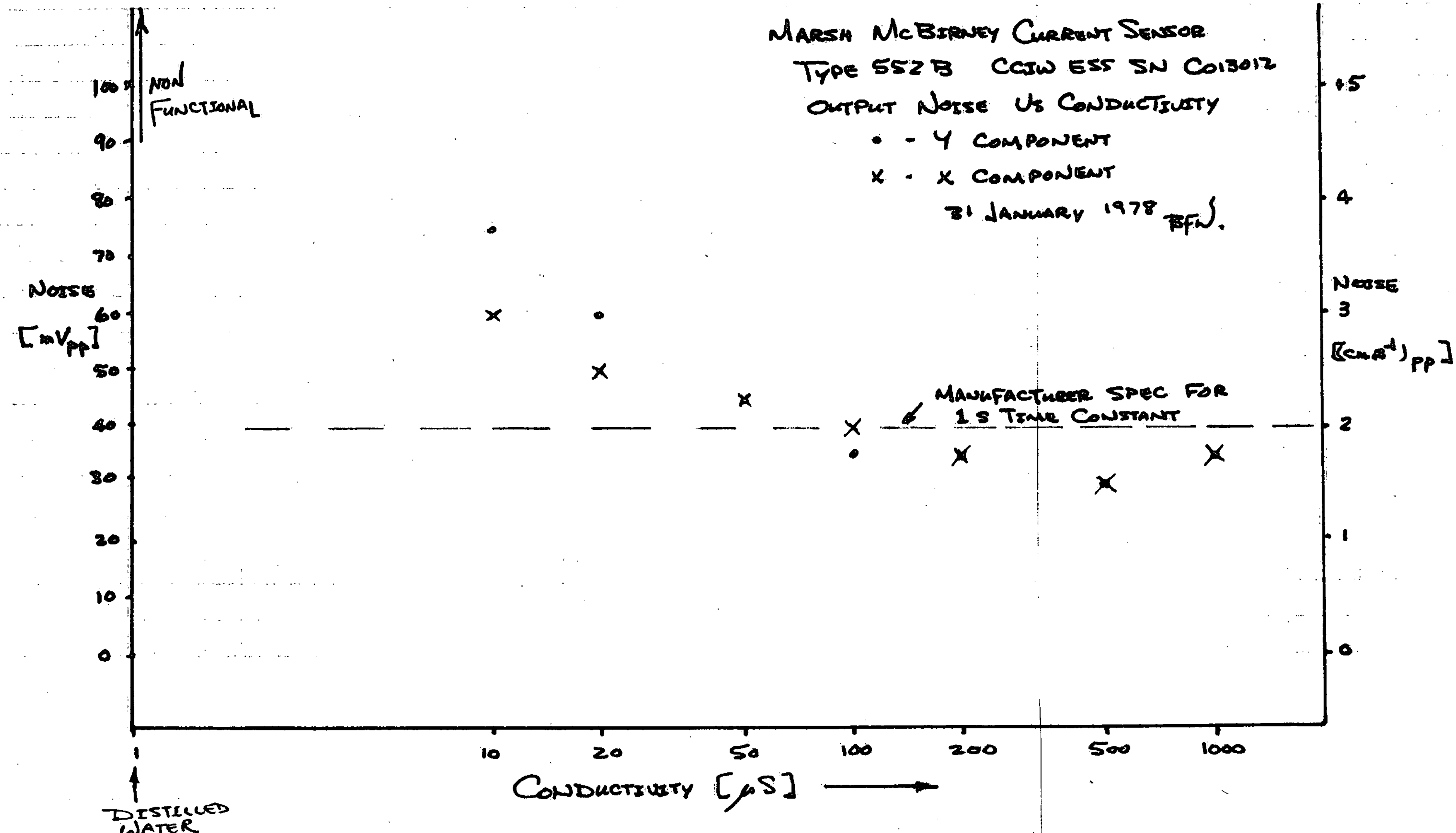
TEST RESULTS:

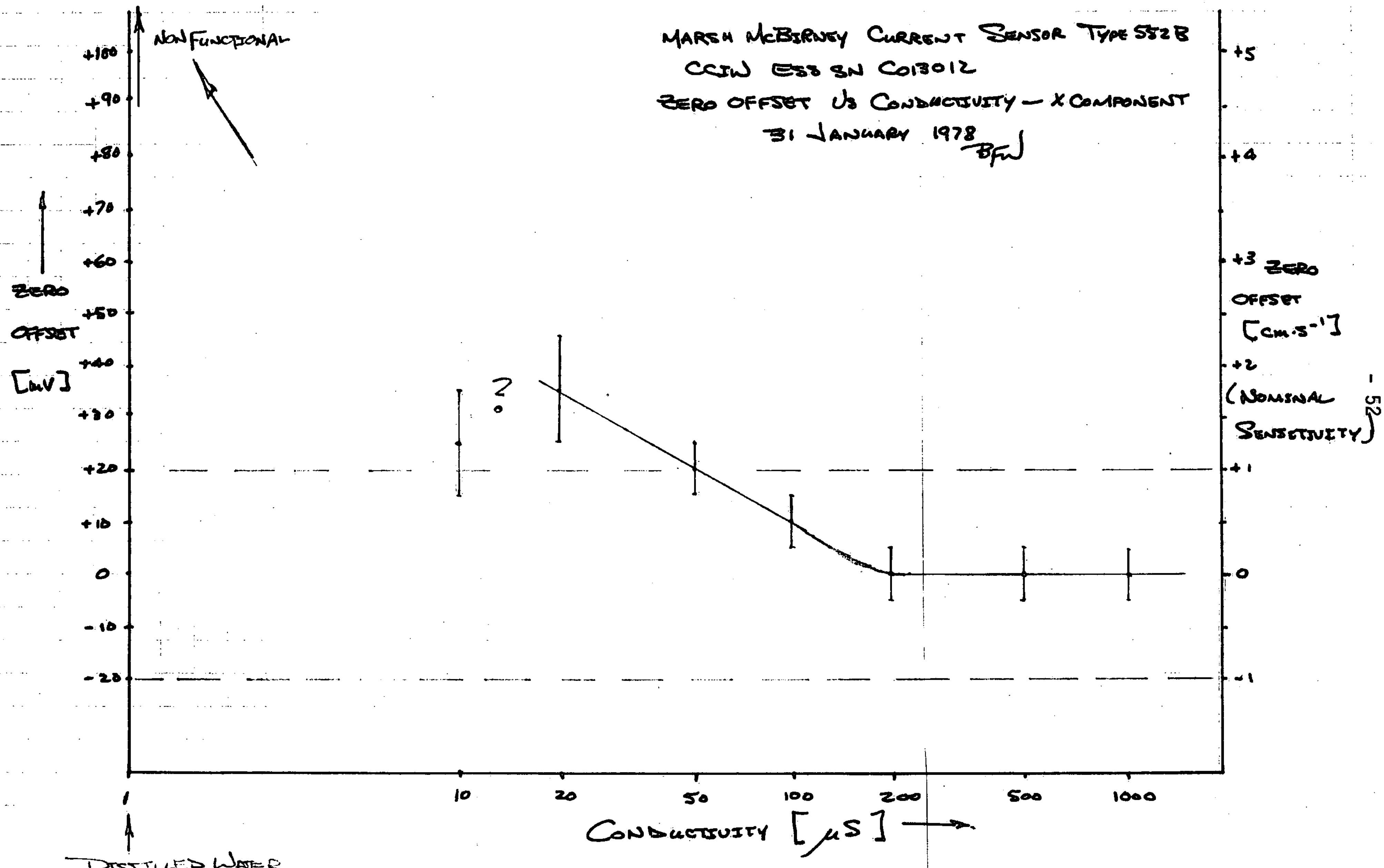
- SENSOR MALFUNCTIONED IN DISTILLED WATER - CONDUCTIVITY 1µS
- SENSOR WITHIN SPECIFICATION FOR NOISE AND OFFSET WITH CONDUCTIVITY ≥ 100µS.

CONCLUSION: APPLICATION IN WATER WITH CONDUCTIVITY ≤ 100µS MAY BE UNRELIABLE BASED ON THIS SINGLE SAMPLE TEST.

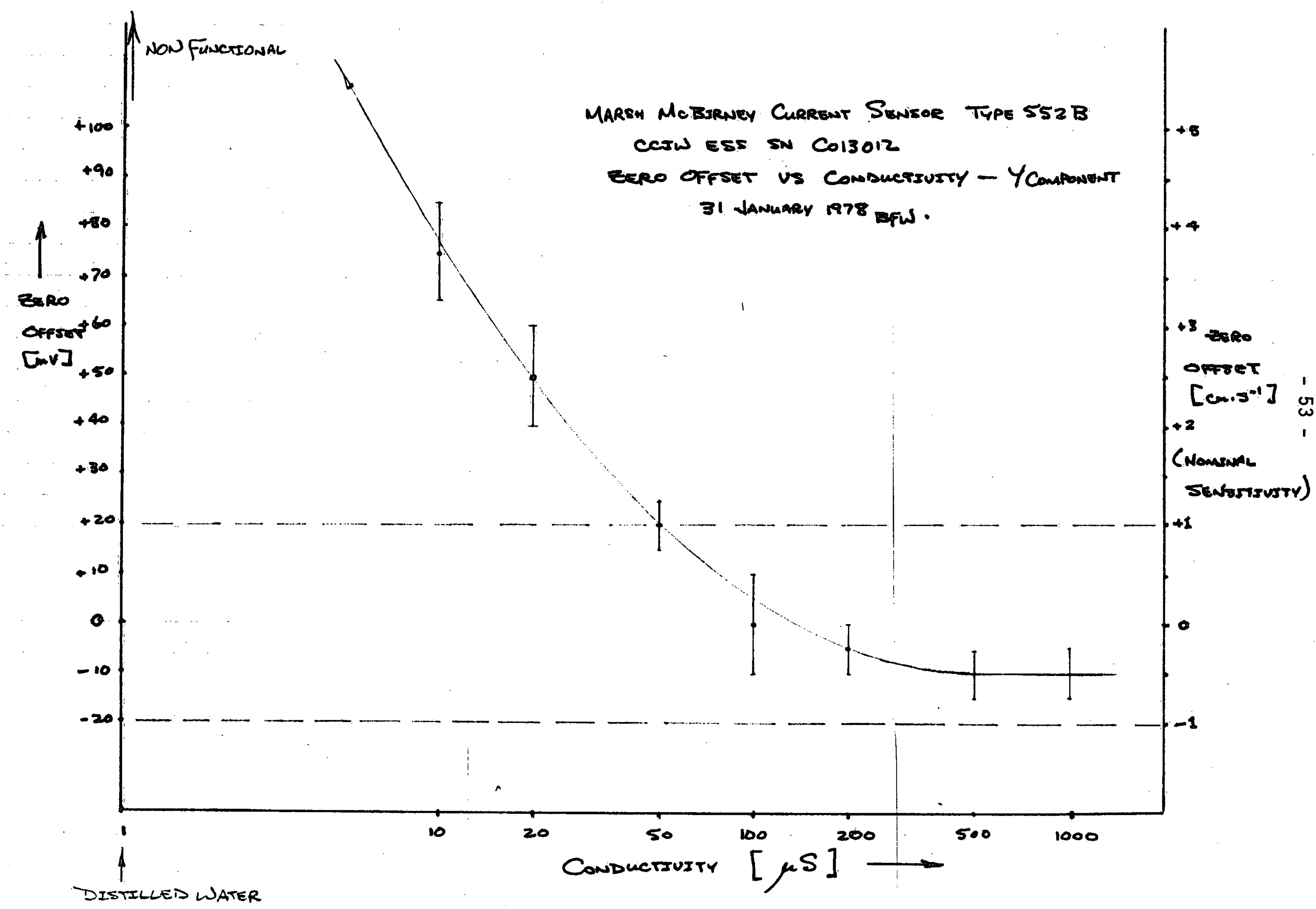
ATTACHMENTS: 3 GRAPHS.

BFW 29/3/78.


MARSH McBIRNEY CURRENT SENSOR
TYPE 552B CCIW ESS SN C013012
OUTPUT NOISE VS CONDUCTIVITY
• - Y COMPONENT
x - X COMPONENT
31 JANUARY 1978 BFW.
NOISE [mV_pp]
100%
90
80
70
60
50
40
30
20
10
0
NON FUNCTIONAL
NOISE
[(cm s^-1)_pp]
+5
4
3
2
1
0
MANUFACTURER SPEC FOR 1 S TIME CONSTANT
1
10
20
50
100
200
500
1000
CONDUCTIVITY [µS]
DISTILLED WATER



MARSH McBIRNEY CURRENT SENSOR TYPE 552B
CCIW E58 SN C013012
ZERO OFFSET Vs CONDUCTIVITY — X COMPONENT
31 JANUARY 1978
BFW
NON FUNCTIONAL
ZERO OFFSET [mV]
+100
+90
+80
+70
+60
+50
+40
+30
+20
+10
0
-10
-20
ZERO OFFSET [cm.s^-1]
(NOMINAL SENSITIVITY)
+5
+4
+3
+2
+1
0
-1
?
1
10
20
50
100
200
500
1000
CONDUCTIVITY [µS]
DISTILLED WATER


MARSH McBIRNEY CURRENT SENSOR TYPE 552B
CCIW ESS SN C013012
ZERO OFFSET VS CONDUCTIVITY — Y COMPONENT
31 JANUARY 1978 BFW.
NON FUNCTIONAL
ZERO OFFSET [mV]
+100
+90
+80
+70
+60
+50
+40
+30
+20
+10
0
-10
-20
ZERO OFFSET [cm.s⁻¹]
+5
+4
+3
+2
(NOMINAL SENSITIVITY)
+1
0
-1
1
10
20
50
100
200
500
1000
CONDUCTIVITY [μS]
DISTILLED WATER

EM CURRENT SENSOR TEST SUMMARY

SENSOR TYPE: M552B
SERIAL NUMBER: C013012
DATE OF TEST: 4 JULY 77
PERFORMED BY: CYDER

OBJECTIVE: TO DETERMINE NATURE OF TOW CARRIAGE INFLUENCE ON EM CURRENT SENSOR

TEST METHOD: SENSOR SUSPENDED FROM CARRIAGE BY INSULATING ROPE. POWER SUPPLY CONFIGURATION NOT DOCUMENTED (AC COUPLED OR BATTERY). TWO CHANNEL BRUSH DIFFERENTIAL RECORDER USED.

CARRIAGE RUN AT 2, 5, 10 $cm \cdot s^{-1}$.

ZERO SPEED CAP INSTALLED, TEST REPEATED.

TEST RESULTS: ACTUATION OF CARRIAGE CONTROLS, OPERATION AT SPEED PRODUCE LARGE TRANSIENTS IN SENSOR OUTPUTS. TRANSIENTS DO NOT HAVE SAME AMPLITUDE FOR EACH COMPONENT AND ARE SPEED DEPENDENT IN AMPLITUDE AND PERHAPS FREQUENCY OF OCCURRENCE.

ZERO SPEED CAP TESTS SHOW TRANSIENTS STILL OBSERVED. MEAN SIGNAL HAS SOME BIAS WITH SPIKES.

CONCLUSION: LACK OF POWER SUPPLY CONFIGURATION INFORMATION LIMITS CONCLUSIONS. CARRIAGE ELECTRICAL SYSTEM DOES PRODUCE INTERFERENCE — COMMON MODE OR DIFFERENTIAL POTENTIALS.

ATTACHMENTS: — SEE FILE FOR DATA.

EPW 29/3/

EM CURRENT SENSOR TEST SUMMARY

SENSOR TYPE: M552B

SERIAL NUMBER: C013012 - BELIEVED - NOT DOCUMENTED

DATE OF TEST: 5 JULY.

PERFORMED BY: CYDER

OBJECTIVE: TO IMPROVE UNDERSTANDING OF TOW CARRIAGE INTERACTION WITH EM CURRENT SENSOR

TEST METHOD:
- AC LINE COUPLED POWER (CARRIAGE OUTLET)
- ROTATING JIG MOUNT — OR SENSOR IN PAIL ON CARRIAGE WITH ~~BOTH~~ ZERO SPEED JIG.
- CARRIAGE STATIONARY WITH MANUAL CONTROL ENGAGED, ELECTRONIC CONTROL ENGAGED IN HIGH AND LOW RANGES
- CARRIAGE OPERATING AT 5, 10, 20, 50 $cm.s^{-1}$

TEST RESULTS:
- ZERO SPEED:
  - SENSOR ON ROTATING JIG:
    - MANUAL CONTROL ENGAGED — NO NOTICEABLE CHANGE IN SENSOR OUTPUTS
    - ELECTRONIC CONTROL ENGAGED, TRANSIENTS PRODUCED
  - SENSOR IN PAIL WITH ZERO SPEED CAP:
    - NO NOTICEABLE CHANGE IN SENSOR OUTPUTS FOR CONDITIONS ABOVE.
- CARRIAGE MOVING: - SENSOR IN PAIL WITH CAP SHOWS ANOMALOUS CURRENT SIGNALS UP TO 10 $cm.s^{-1}$ pk WITH MEANS $\leq$ 3 $cm.s^{-1}$

CONCLUSION:
- TOW TANK WATER GROUND INTRODUCES COUPLING TO CARRIAGE ELECTRICAL SYSTEM EVEN WHEN STATIONARY FOR ELECTRONIC CONTROL.
- CARRIAGE ELECTRICAL SYSTEM CAN INDUCE POTENTIALS AT CURRENT SENSOR IN ISOLATED ENVIRONMENT WHEN SUPPLY IS AC COUPLED.

ATTACHMENTS: SEE FILE FOR DATA

FW 29/8/78.

EM CURRENT SENSOR TEST SUMMARY

SENSOR TYPE: M552B
SERIAL NUMBER: C013012
DATE OF TEST: 28 JUNE 77
PERFORMED BY: CY DER

OBJECTIVE: TO DETERMINE SENSOR SENSITIVITY TO IMBALANCE IN THE ± POWER SUPPLIES.

TEST METHOD: SENSOR CONFIGURED IN PAIL (170ℓ) WITH AC LINE COUPLED POWER SUPPLY. POSITIVE AND NEGATIVE SUPPLIES WERE VARIED INDEPENDENTLY. SENSOR RESPONSE MEASURED ON BRUSH RECORDER.

TEST RESULTS:

ZERO OFFSETS WERE STABLE WITHIN $\pm 1 cm.s^{-1}$ (BUT NOT $\pm 0.5 cm.s^{-1}$) AS SUPPLIES VARIED FROM ~~...~~ +24 ↔ +16 / −24 ↔ −16

CONCLUSION: FOR THIS SENSOR REJECTION OF POWER SUPPLY VARIATION WAS WITHIN OVERALL ZERO DRIFT SPECIFICATION.

ATTACHMENTS: SEE FILE FOR DATA

— RW 29/3/78.

EM CURRENT SENSOR TEST SUMMARY

SENSOR TYPE: M522 (MINIATURE)
SERIAL NUMBER: ____________
DATE OF TEST: 8 JULY 77
PERFORMED BY: CY DER

OBJECTIVE: TO DETERMINE CURRENT SENSOR SENSITIVITY TO SPURIOUS SYSTEM WATER GROUNDS /LEAKAGE AND TO INJECTED DC POTENTIALS.

TEST METHOD: SENSOR CONFIGURED IN LARGE PAIL (170 ℓ) IN TAP WATER. A WIRE SEPARATELY CONNECTED TO SENSOR SIGNAL COMMON WAS INTRODUCED. THE SERIES RESISTANCE IN THE SECOND GROUND PATH WAS VARIED AND THE RESULT OBSERVED.

A DC CALIBRATOR (LINE COUPLED, BUT ISOLATED) WAS USED TO DRIVE POTENTIALS BETWEEN TWO WIRES INSERTED IN THE PAIL.

- SENSOR SUPPLY – NOT DOCUMENTED .. BELIEVED TO BE BATTERY
- BRUSH RECORDER.

TEST RESULTS:

- SPURIOUS GROUND: NO NOTICEABLE EFFECT WITH $R_s \geq 500\,k\Omega$
  NOTICEABLE EFFECT WITH $R \leq 10\,k\Omega$
  SOME DRIFT OBSERVED AS WELL AS SPATIAL (POSITION) SENSITIVITY.

- DRIVEN POTENTIALS: APPARENTLY AC COUPLING INTRODUCED SYNCHRONOUS NOISE. SENSOR BEHAVING ERRATICALLY.

CONCLUSION:

- WHEN SENSORS ARE APPLIED TO SYSTEM REQUIREMENTS SPURIOUS GROUNDS SHOULD BE AVOIDED.

ATTACHMENTS: SEE FILE FOR DATA

FPW 29/3/78

EM CURRENT SENSOR TEST SUMMARY

SENSOR TYPE: MS22 (MINIATURE)

SERIAL NUMBER: ________

DATE OF TEST: 18, 26, 27 JULY

PERFORMED BY: CYDER

OBJECTIVE: TO RESOLVE THE SPURIOUS OFFSET PERFORMANCE OBSERVED IN WAVES APPLICATION. (SPRING WAVES '77).

TEST METHOD: - THE INTENDED GROUNDING ARRANGEMENT FOR SPRING WAVES MINIATURE EM SENSOR WAS DOCUMENTED (ATT. 1).

- THE SENSOR WAS CONFIGURED IN THE LAB WITH THE INTENDED WIRING
- THE SENSOR WAS CONFIGURED AT CCIW DOCKSIDE WITH SAME WIRING
- THE SENSOR WAS CONFIGURED AT WAVES TOWER WITH ORIGINAL CABLING — SIGNAL COMMON CONNECTED & DISCONNECTED FROM POWER COMMON. — RESIDUAL OFFSETS AND DRIFT WERE MEASURED.

TEST RESULTS:

- SEE ATTACHMENTS 2, 3, 4, 5
- WITH CORRECT GROUNDING ZERO OFFSETS ARE CONSISTENT WITHIN
  - Y-AXIS ± 20 mV → $\pm 0.8\ cm.s^{-1}$ } FROM LAB TO TOWER.
  - X-AXIS $+20$ - 70 mV → $+0.8$ - $2.8\ cm.s^{-1}$ }
- DRIFT TEST WITHIN SPEC.
- NOTE! TESTS WITH AC LINE COUPLED POWER SUPPLIES SHOWED VARIABLE AND ERRATIC PERFORMANCE (BEATING OF SYNCHRONOUS NOISE WITH SENSOR OPERATION).

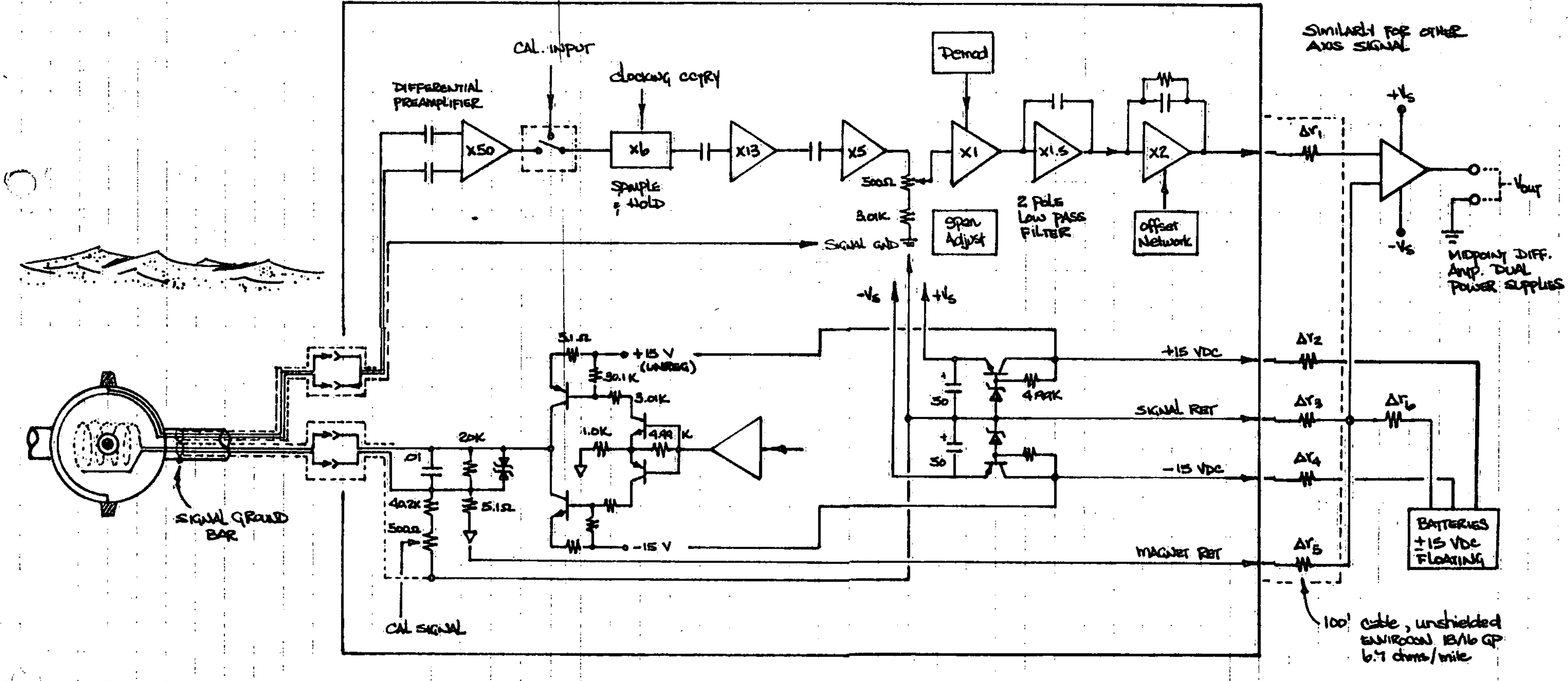
CONCLUSION: — THE INCORRECT GROUNDING USED IN WAVES APPLICATION PRODUCED THE LARGE ANOMALOUS ZERO OFFSET SHIFTS.

— AC LINE COUPLED SUPPLIES AND GROUNDED WATER PROVIDE NOISE COUPLING TO THE SENSOR WHICH RENDERS IT UNRELIABLE.

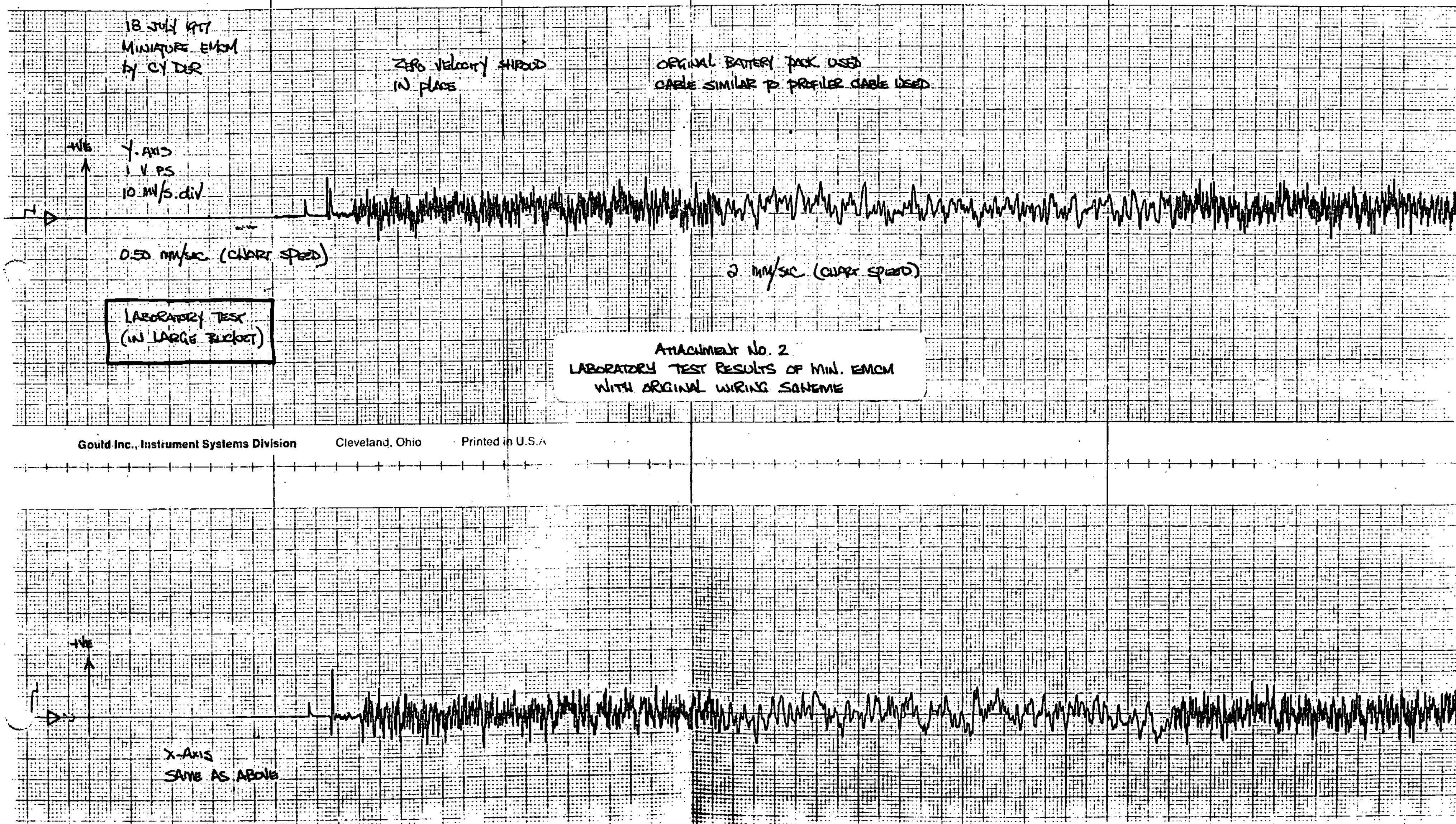
ATTACHMENTS: 6.

FW 29/8/78.

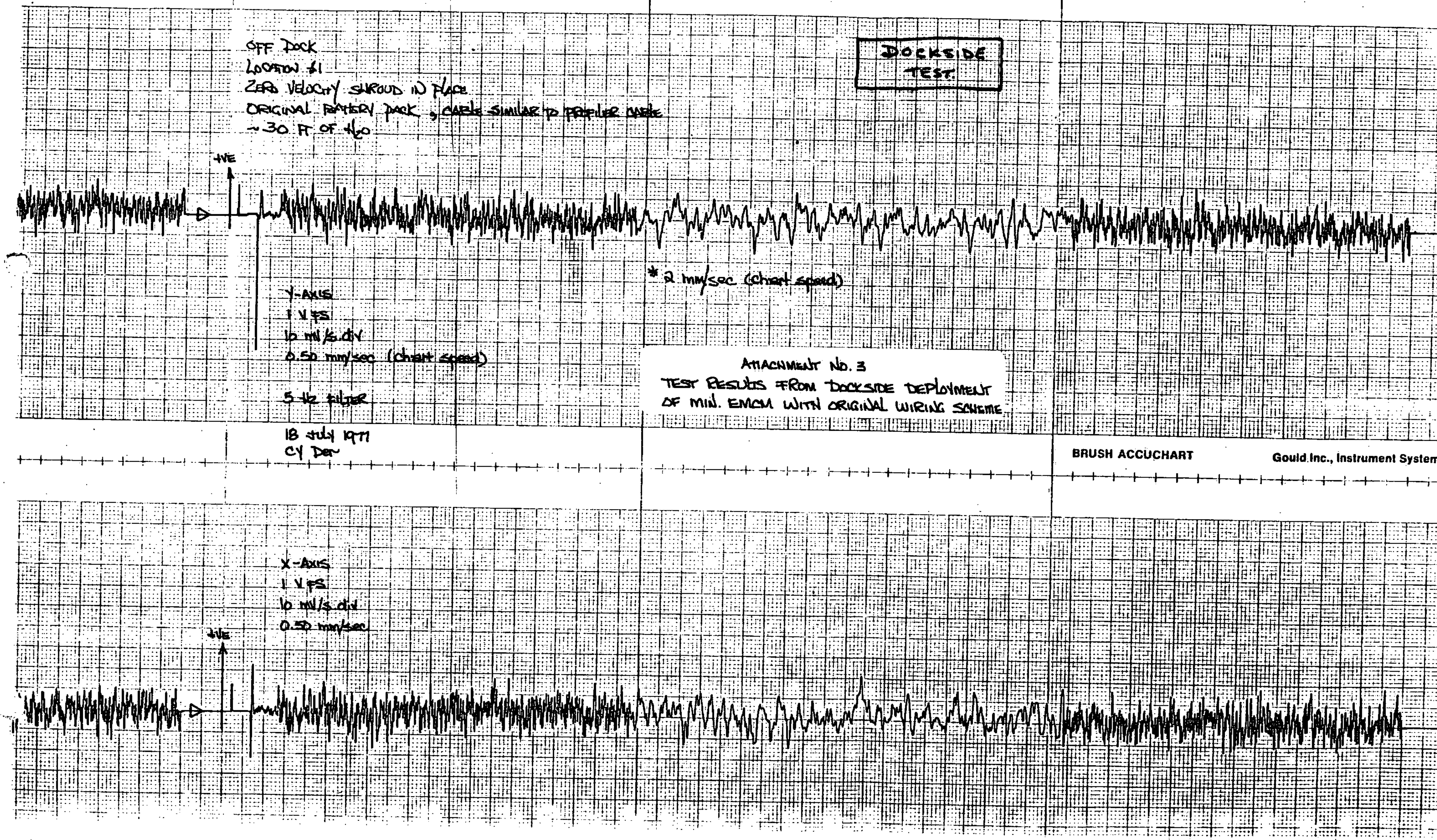
GROUNDING CONFIGURATION FOR MARSH-MCBIRNEY MINIATURE EMCM (W.A.V.E.S. DEPLOYMENT)



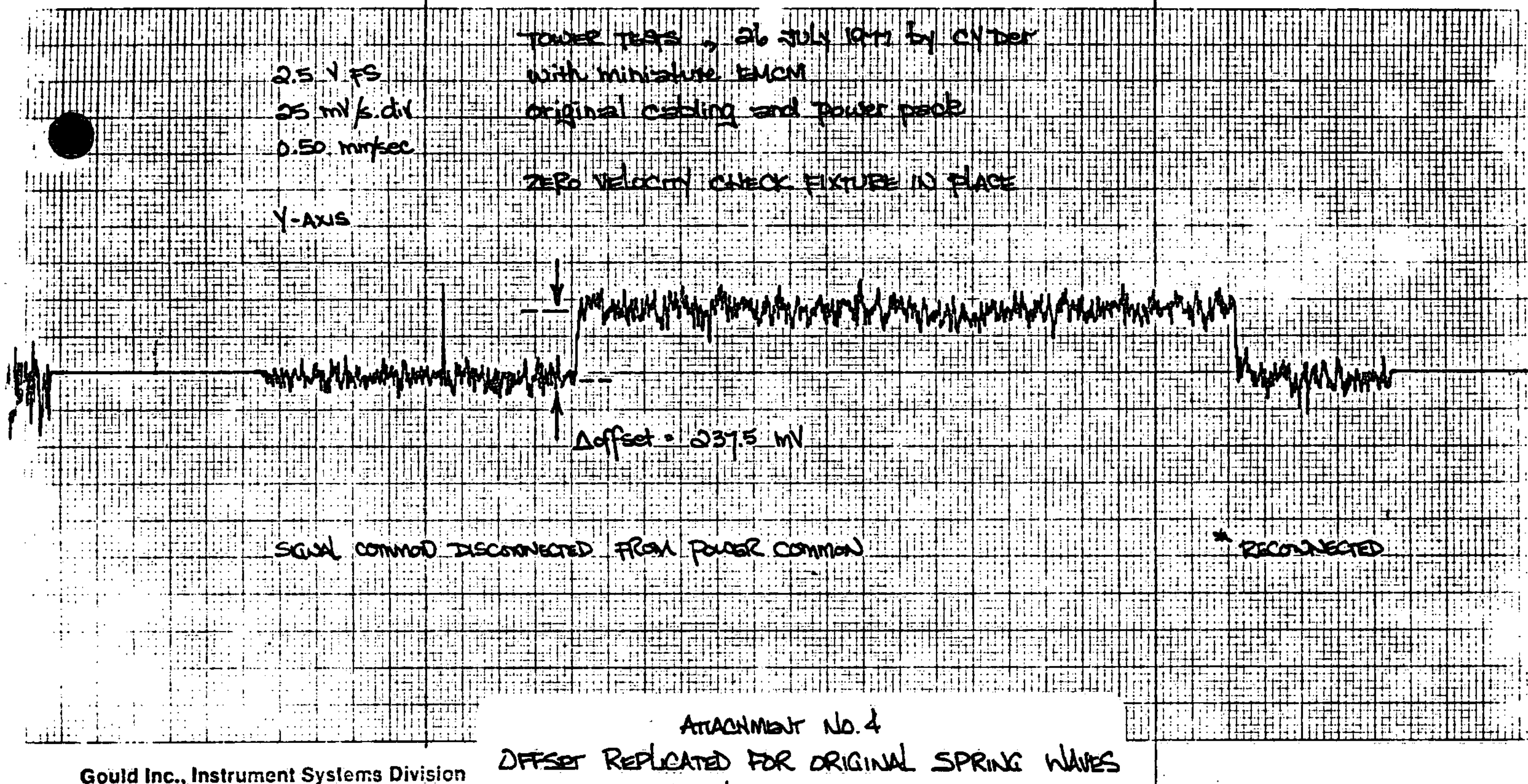
CYDER
19 July, 1977



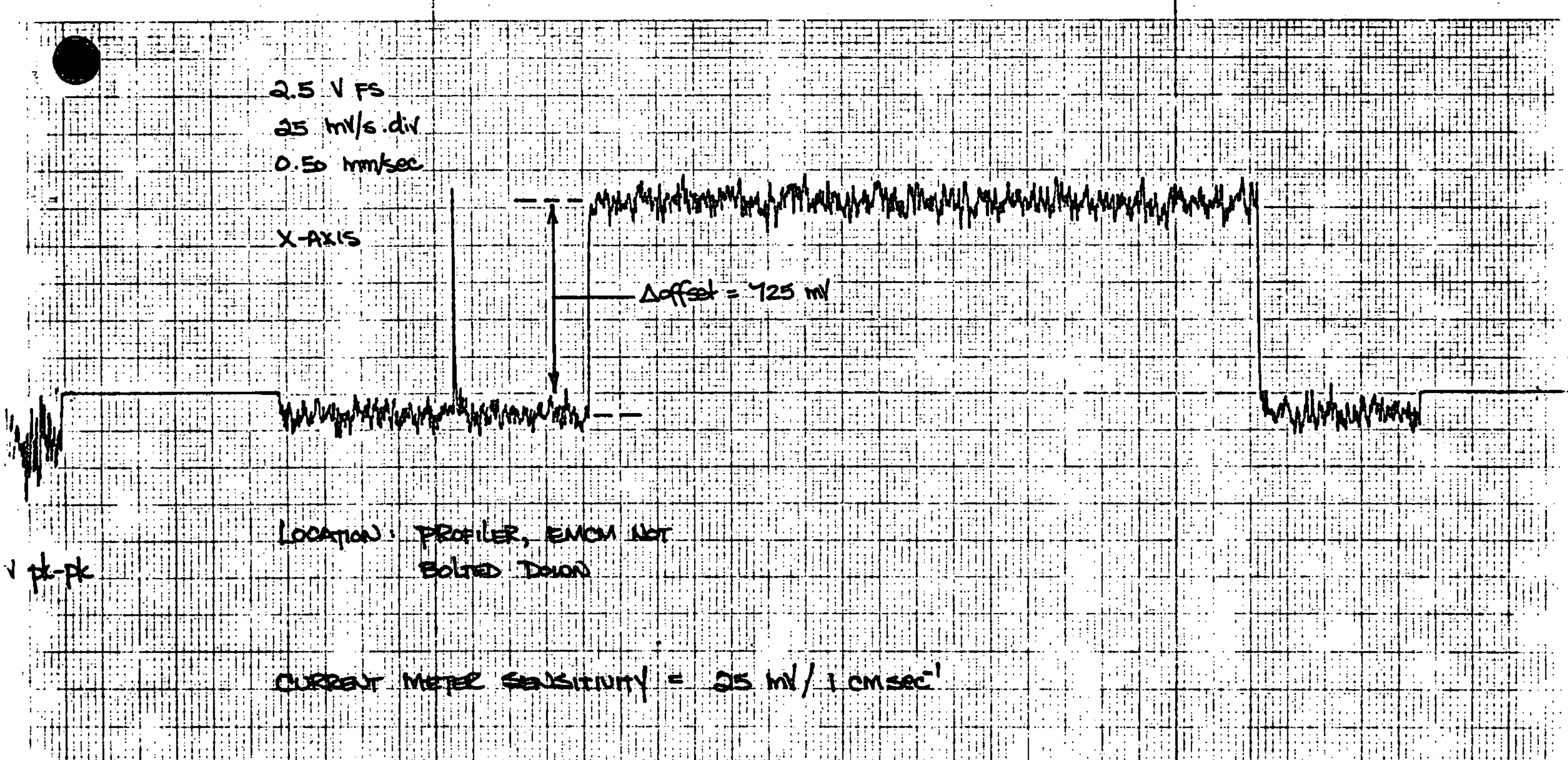
ATTACHMENT NO. 2
LABORATORY TEST RESULTS OF MIN. EMCM
WITH ORIGINAL WIRING SCHEME

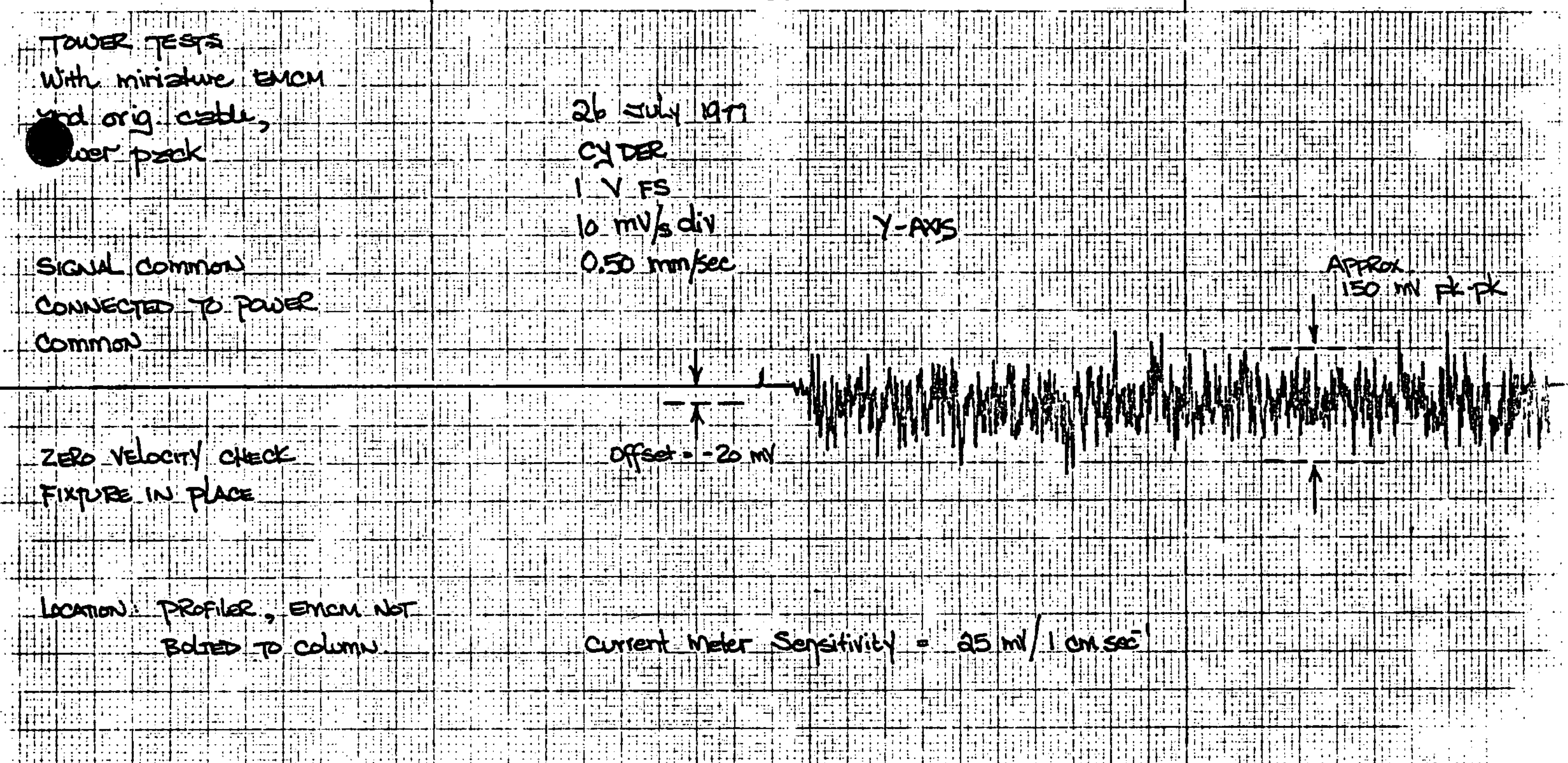


ATTACHMENT No. 3
TEST RESULTS FROM DOCKSIDE DEPLOYMENT OF MIN. EMCM WITH ORIGINAL WIRING SCHEME



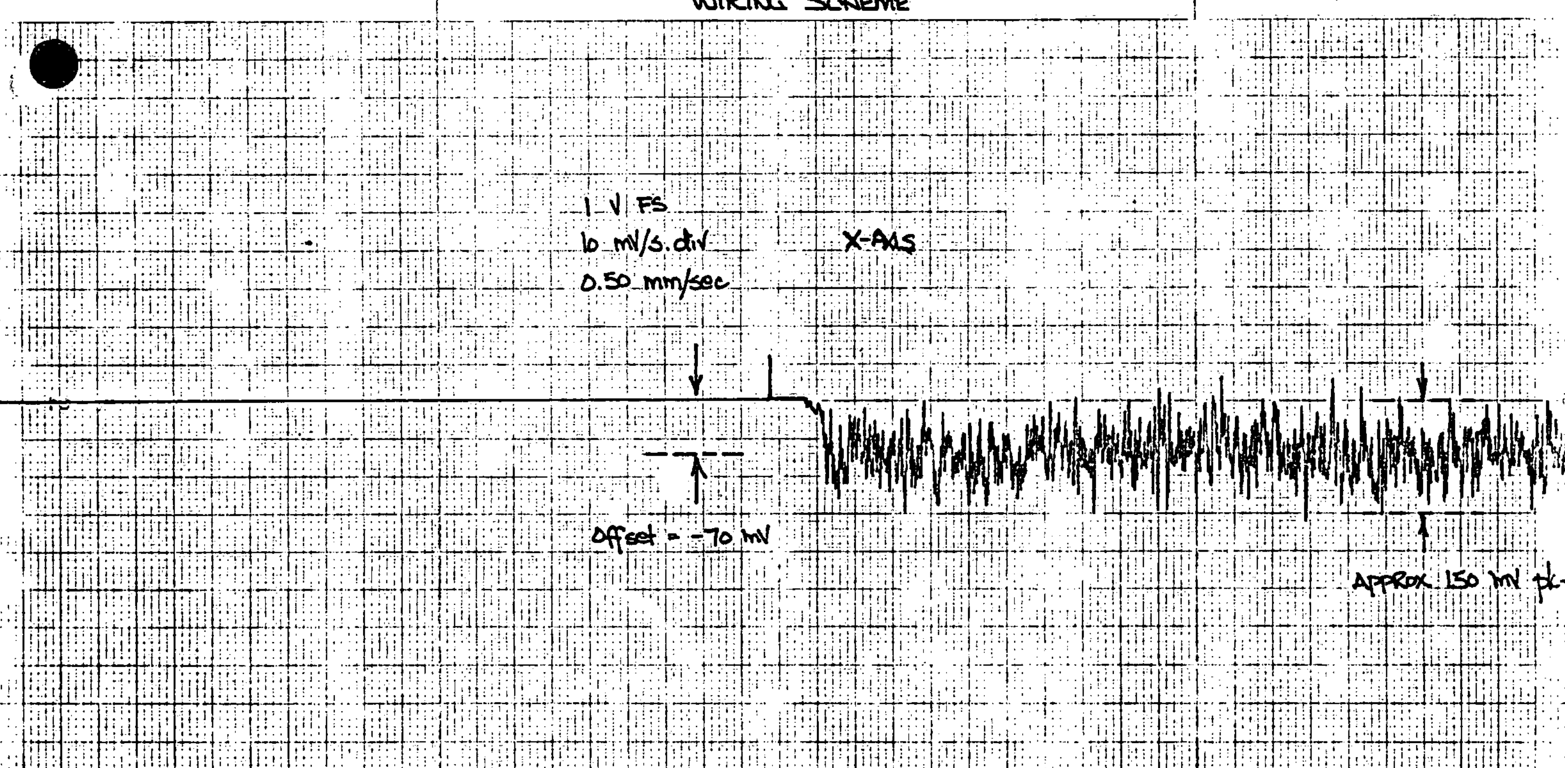
ATTACHMENT No. 4
OFFSET REPLICATED FOR ORIGINAL SPRING WAVES
WIRING SCHEME





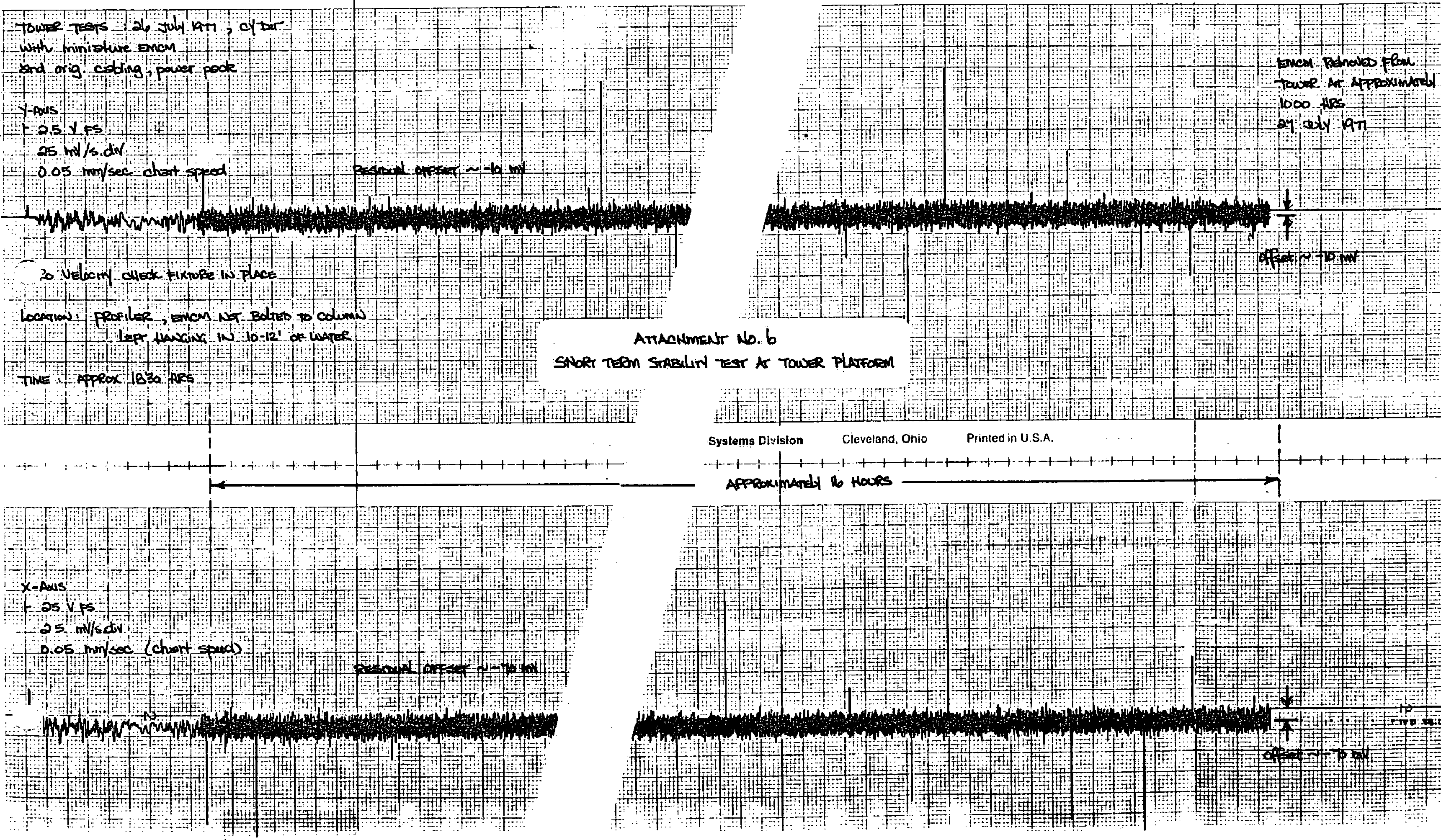
BRUSH ACCUCHART

ATTACHMENT NO. 5
RECORDED RESIDUAL OFFSETS FOR CORRECTED WIRING SCHEME



ATTACHMENT No. 6

SHORT TERM STABILITY TEST AT TOWER PLATFORM



EM CURRENT SENSOR TEST SUMMARY

SENSOR TYPE: MMS52B
SERIAL NUMBER: C013011
DATE OF TEST: 24, 27 DEC '79
PERFORMED BY: BF WHITE

OBJECTIVE: TO EVALUATE FEASIBILITY OF USING A BRINE-SOAKED CLOTH SURROUNDING AN EM CURRENT SENSOR PROBE HEAD AS A DRY ENVIRONMENT "ZERO SPEED" SIMULATION.

TEST METHOD:

- SENSOR POWERED WITH BATTERIES.
- TWO CHANNEL BRUSH RECORDER USED TO RECORD RESULTS
- 30 cm x 50 cm "TERRY" (HAND) TOWEL SOAKED IN ~ 300 ml SATURATED SALT SOLUTION (SEA SALT FROM K. MOLLOW)
- SENSOR OFFSET AND NOISE MEASURED IN LARGE PAIL AND WITH SENSOR WRAPPED IN CLOTH.
- PLASTIC BAG FITTED TO PREVENT EVAPORATION.

TEST RESULTS:

PAIL:

	ZERO OFFSET	NOISE
Y	~ +5 mV	15 mVpp
X	0 → +5 mV	~10 mVpp

BRINE, RAG:

		ZERO OFFSET	NOISE	ROTATE 180°			ON END:
PROBE HORIZONTAL	Y	~ -10 mV	15 mVpp	+35 → 40 mV	15 mVpp		
	X	~ -33 mV	~10 mVpp	+5 → 10 mV	~15 mVpp		
90°	Y	+40 → 45 mV		90°	-5 mV		+5 mV
	X	-15 mV			-35 mV		-5 mV

CONCLUSION:

TESTS INDICATE THAT SENSOR OUTPUT IS STABLE IN ANY ORIENTATION WITH BRINE + RAG SURROUND, BUT THAT ZERO OFFSET DEPENDS ON BRINE DISTRIBUTION (RELATIVE TO GND BUTTON?)

± 40 mV ≡ ± 2.4 $cm \cdot s^{-1}$ EACH COMPONENT, WORST CASE.

- ON END TEST PROMISING.

ATTACHMENTS: CHART RECORD.

2/1/80.

AR9-009A. — BFW 29/3/78.

5.0 CURRENT METER COMPARISON 1977 FIELD EXPERIMENT

The experiment was configured at the WAVES platform, which is located at the western end of Lake Ontario, in 12 m depth, 1 km offshore. The instruments were arranged as shown in Figure 5.0.1. The data return summary, Figure 5.0.2, shows that few of the instruments were available, or operated without failure for the experiment duration. The Plessey MO21 current meters sufferred battery failures. The Aanderaa RCM-4 meters were not properly prepared for the field work. CATS 1 was recovered and redeployed to diagnose a monitoring problem. The CATS 2 upper current sensor was damaged by an anchor cable. The VAPS - CMI current sensor was available for only the latter portions of the experiment period.

As is shown in the following subsections, the Aanderaa performance observed is not up to that expected from a properly prepared instrument, and the Plessey 9021 current meter had poor compass performance. The current data from the CATS systems was studied exhaustively. As is reported in Section 5.6, the CATS 1 data was processed to compensate for spurious responses identified as systematic errors. The data from the WAVES system M501 Electromagnetic Current Sensor is not considered useable.

5.1 Low Flow Case: 16 - 23 February 1977

The period 16 - 23 February was selected as an interval for which there were no sustained events of current speed greater than 10 $cm.s^{-1}$. Figures 5.1.1.a, b compare the speed records for Plessey MO21 current meters at 3 and 5 m depths. Figures 5.1.1.c, d compare the direction records for these same instruments. The data suggest that the combined effect of low mean velocity and occasional orbital velocity combine with synergism to cause significant uncertainty in the current direction.

The processed CATS 1 data (Section 5.6) is compared to the West 3 m Plessey MO21 in Figures 5.1.2.a,b,c,d. The CATS data show no speeds greater than 10 $cm.s^{-1}$. One may suggest that the duration and intensities of current events were insufficient to allow mixing to the CATS 1 sensor depth to generate a uniform velocity distribution. As well, the tendency of the Plessey to overspeed in the presence of orbital

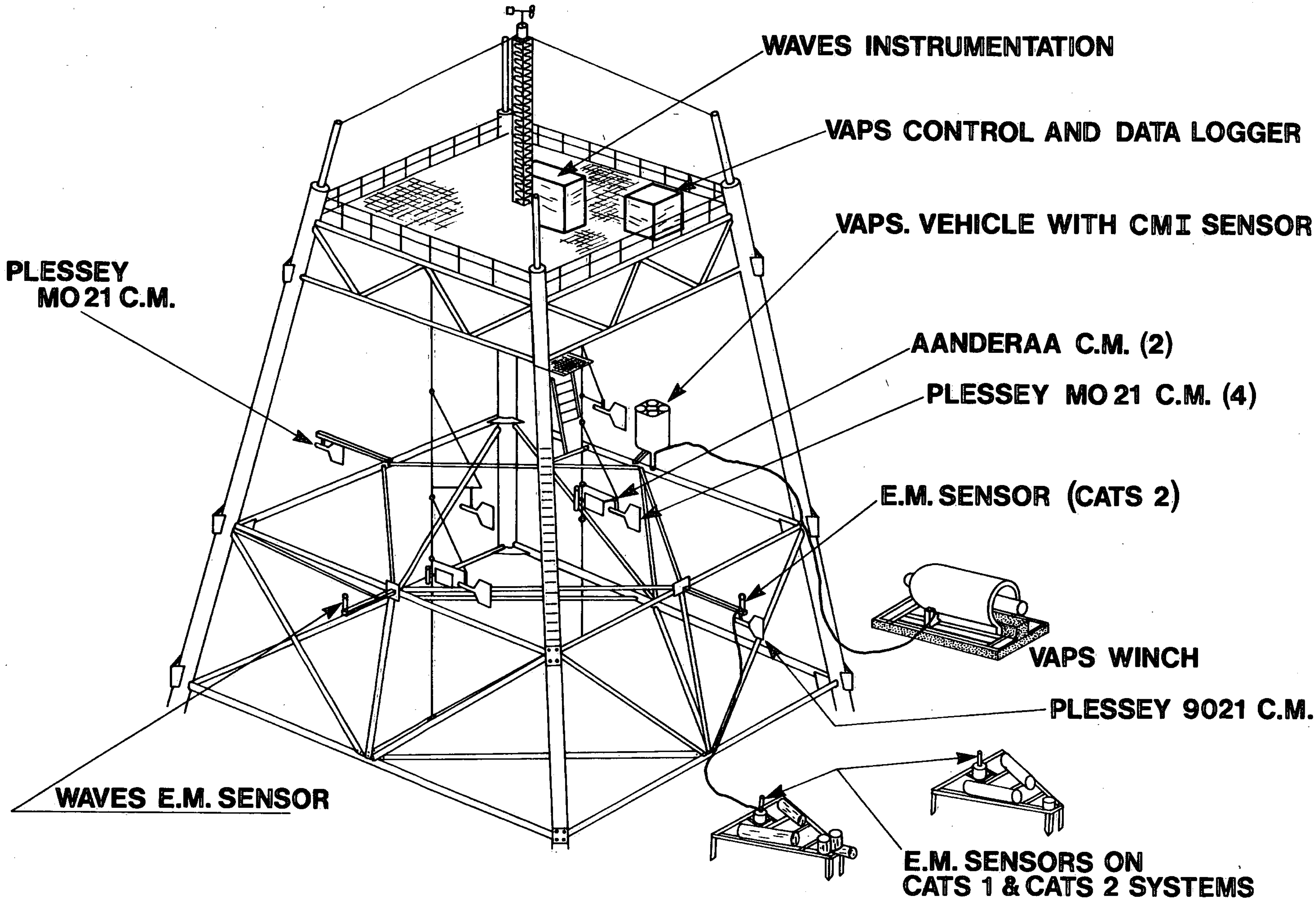

WAVES INSTRUMENTATION
VAPS CONTROL AND DATA LOGGER
VAPS. VEHICLE WITH CMI SENSOR
PLESSEY MO21 C.M.
AANDERAA C.M. (2)
PLESSEY MO 21 C.M. (4)
E.M. SENSOR (CATS 2)
VAPS WINCH
PLESSEY 9021 C.M.
WAVES E.M. SENSOR
E.M. SENSORS ON CATS 1 & CATS 2 SYSTEMS

Figure 5.0.1

DATA RETURN SUMMARY

Current Meter	Tower Side	Depth	Comments
Plessey M021	N	5 m	(NO DATA — NOT TRANSLATABLE)
Plessey M021	E	3 m	(FIRST DEPLOYMENT FAILED)
Plessey M021	E	5 m	
Plessey M021	W	3 m	
Plessey M021	W	5 m	(LOSS OF TIMING)
Plessey 9021	S	6 m	
Aanderaa RCM 10	E	6 m	
Aanderaa RCM 10	W	6 M	(NO DATA — BATTERY FAILURE)
WAVES EM Sensor	W	5 m	(DATA AVAILABLE BUT NOT ACCEPTABLE) ?
VAPS CMI Sensor	E	5 m	(INSTALLATION DELAYED)
CATS 1 EM Sensor	S	12 m	
CATS 2 EM Sensor	S	5 m	
CATS 2 EM Sensor	S	12 M	

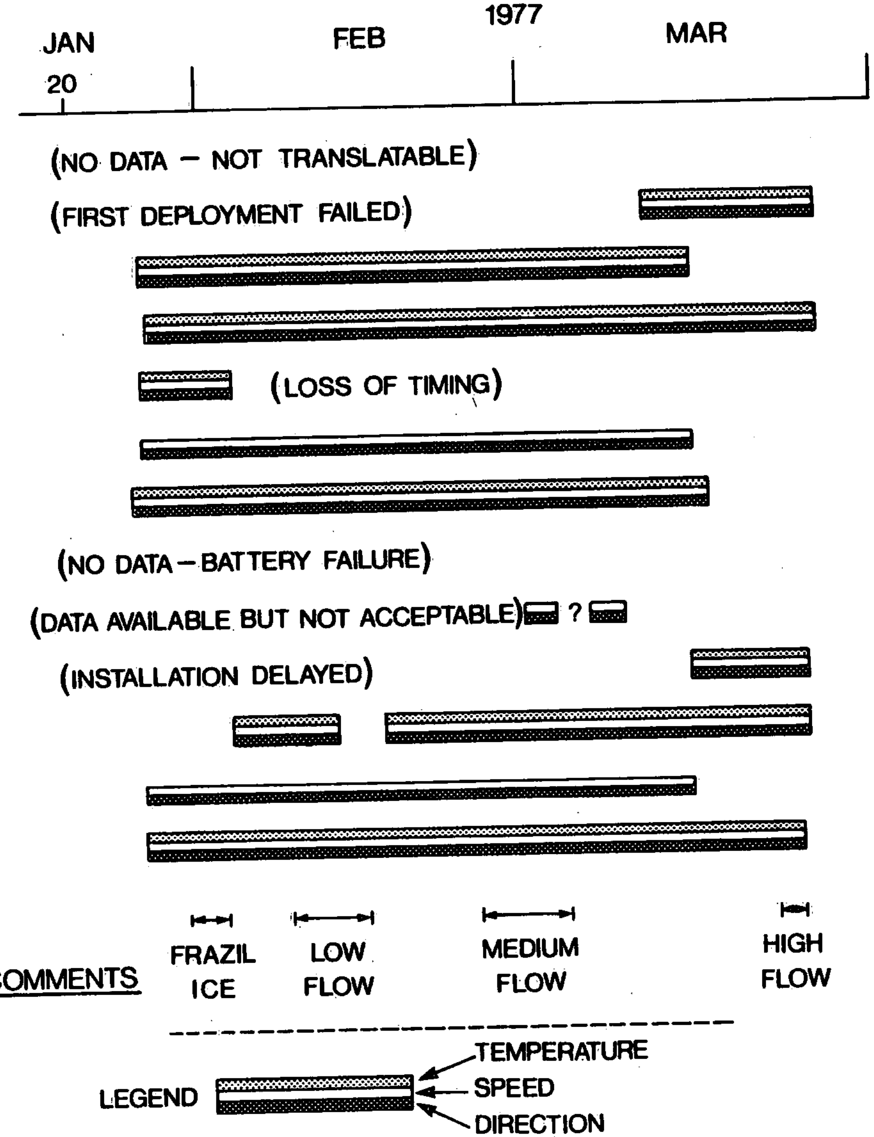


Figure 5.0.2

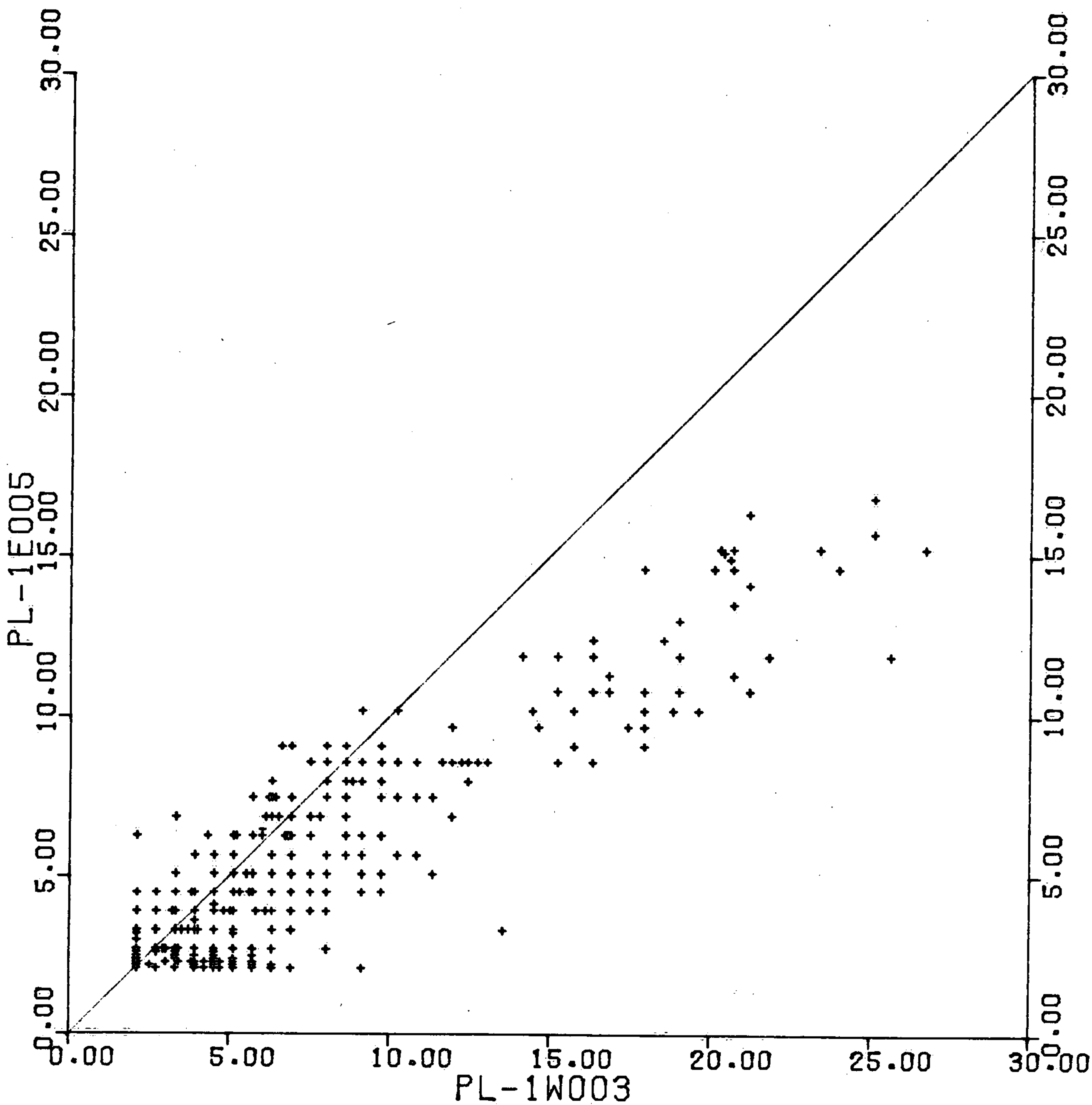
motion would support the data. The Plessey M021 transfer function imposes a 2.1 $cm.s^{-1}$ threshold value, which is readily observed in the scatter plots.

The comparison data for the Plessey 9021 is given in Figures 5.1.3.a, b,c,d. The direction data shows that the Plessey 9021 compass was unreliable. Subsequent testing has shown that the original equipment compass in the 9021 has inadequate roll and pitch gimbal limits. The manufacturer has developed a modification to improve on this limitation.

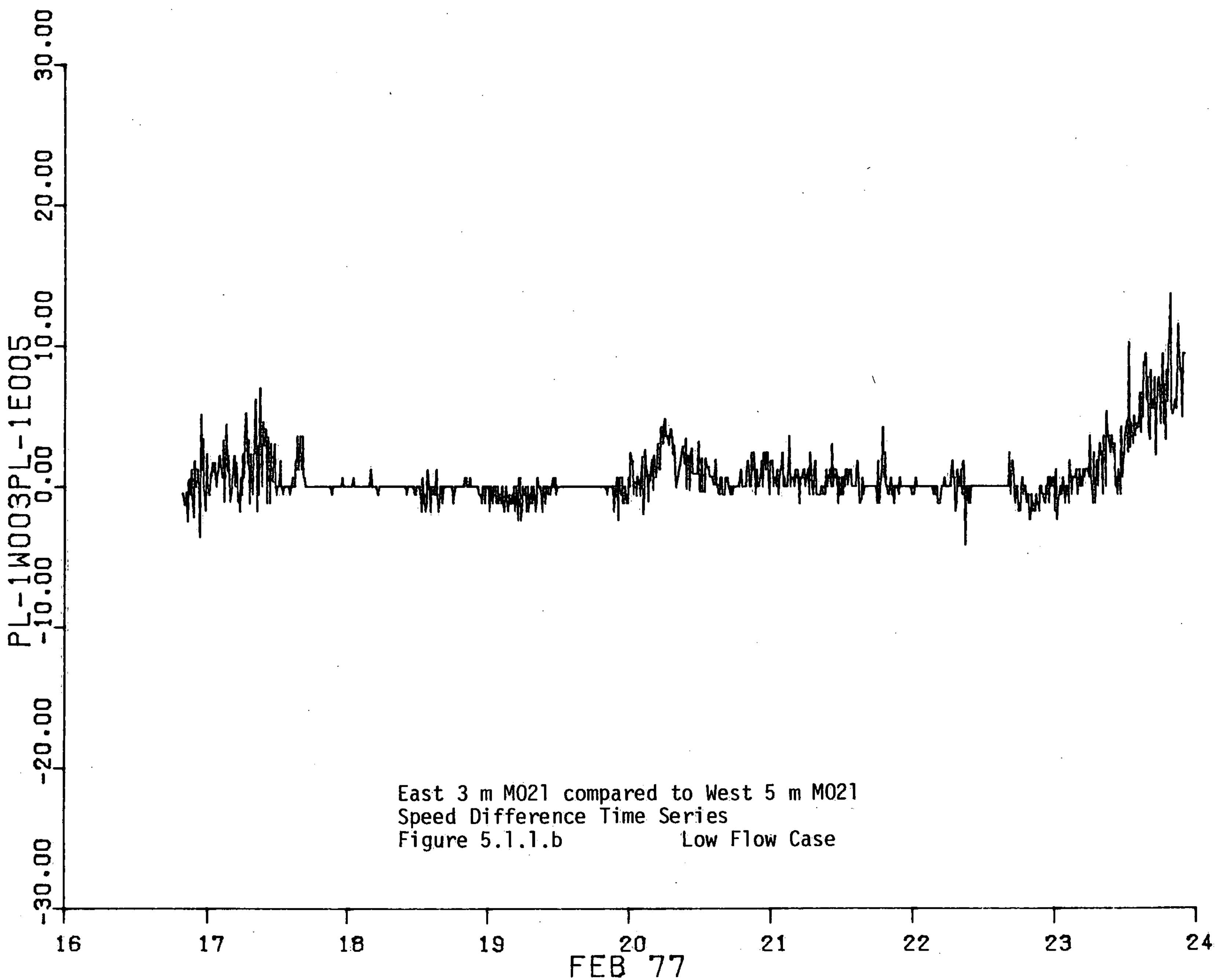
At this point, it is useful to compare Figures 5.1.1.b, 2.b, 3.b -- the speed difference time series. All three show, other than for threshold effects, apparent coherence. In particular, the negative speed differences on 19 February, the trend and transient on the 20th, and the trends at the start and end of the time series stand out. The negative speed differences suggest that the 3m M021 may have had a threshold problem or may have been influenced by orbital motion to underspeed. The 3 and 5 m M021 meters show a direction difference of approximately 30° on 19 February. The CATS 1 direction data agrees more with the 3 m M021 than the 5 m instrument.

The East 6 m Aanderaa comparisons are plotted in Figures 5.1.4.a, b, c,d. The speed data shows that the Aanderaa meter overspeeds, presumably due to wave orbital motion, as compared to the 3 m Plessey M021. As well, the threshold for the instrument used appears to be 8 - 10 $cm.s^{-1}$.

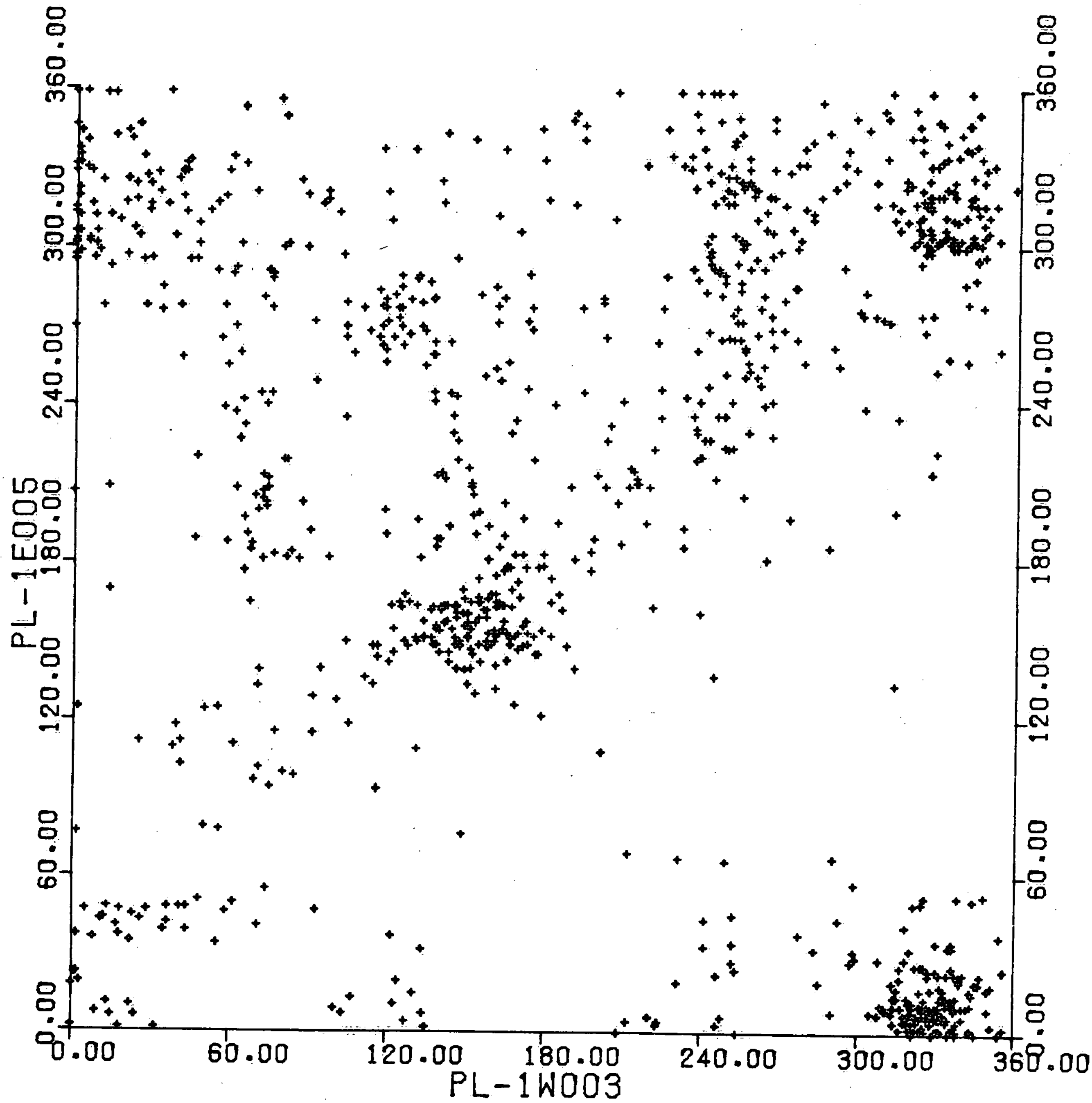
Statistical analyses were performed on the time series data to produce the Kinetic Energy Spectral Density Plots, Coherence and Phase Plots in Figures 5.1.5.a, b,c,d,e and 5.1.6.a, b,c,d. The Kinetic Energy Plots are variously scaled, hence comparison must be executed with caution. Comparing the total K.E. spectral density for the 3 and 5 m M021's shows that the 3 m instrument indicates energy spectral densities greater by approximately 50% than the 5 m instrument for periods greater than 20 hours. The local maximum at a period of 5 hours is 300% greater for the 3 m instrument versus the 5 m.



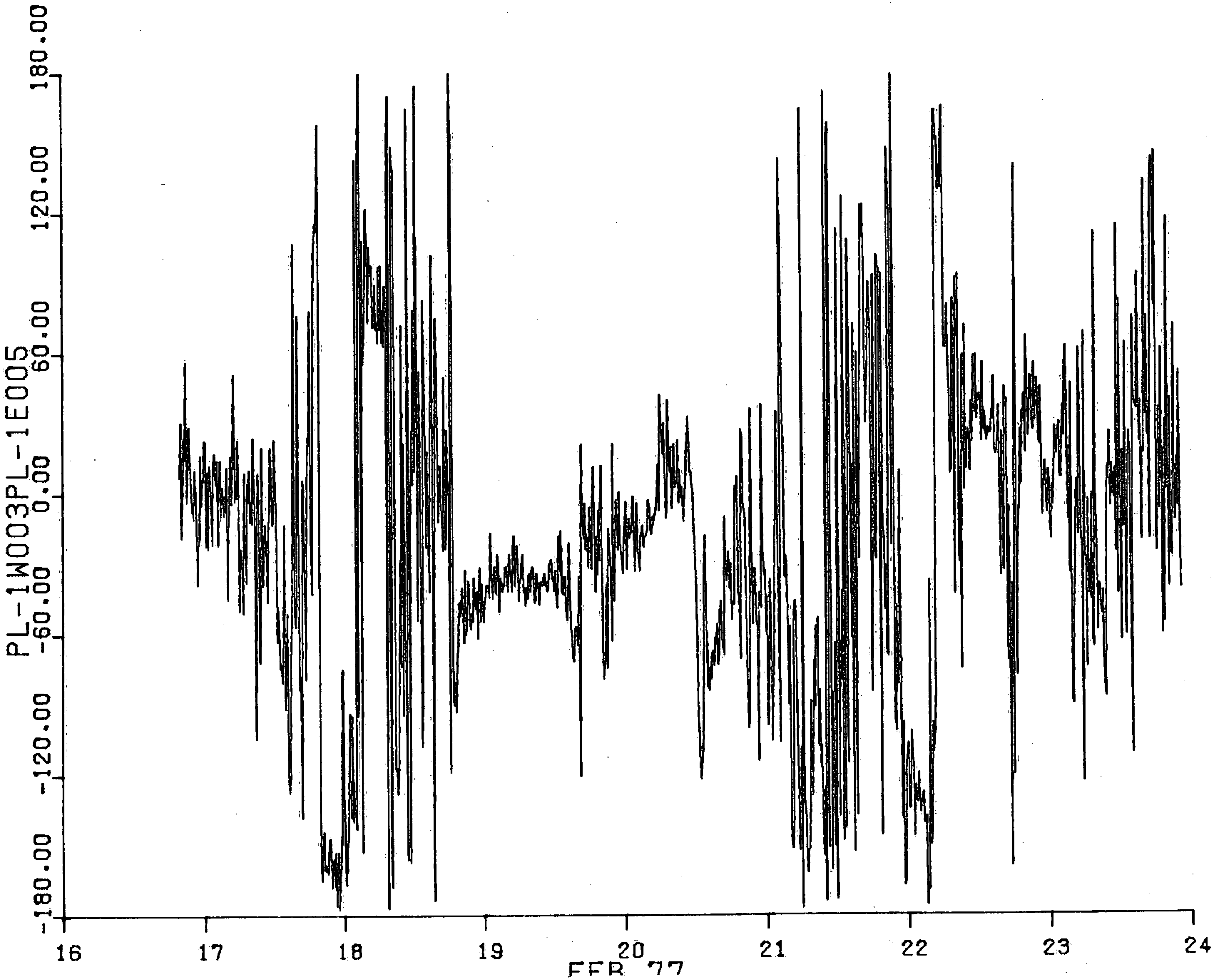
East 5 m M021 compared to West 3 m M021
Speed Comparison
Figure 5.1.1.a   Low Flow Case



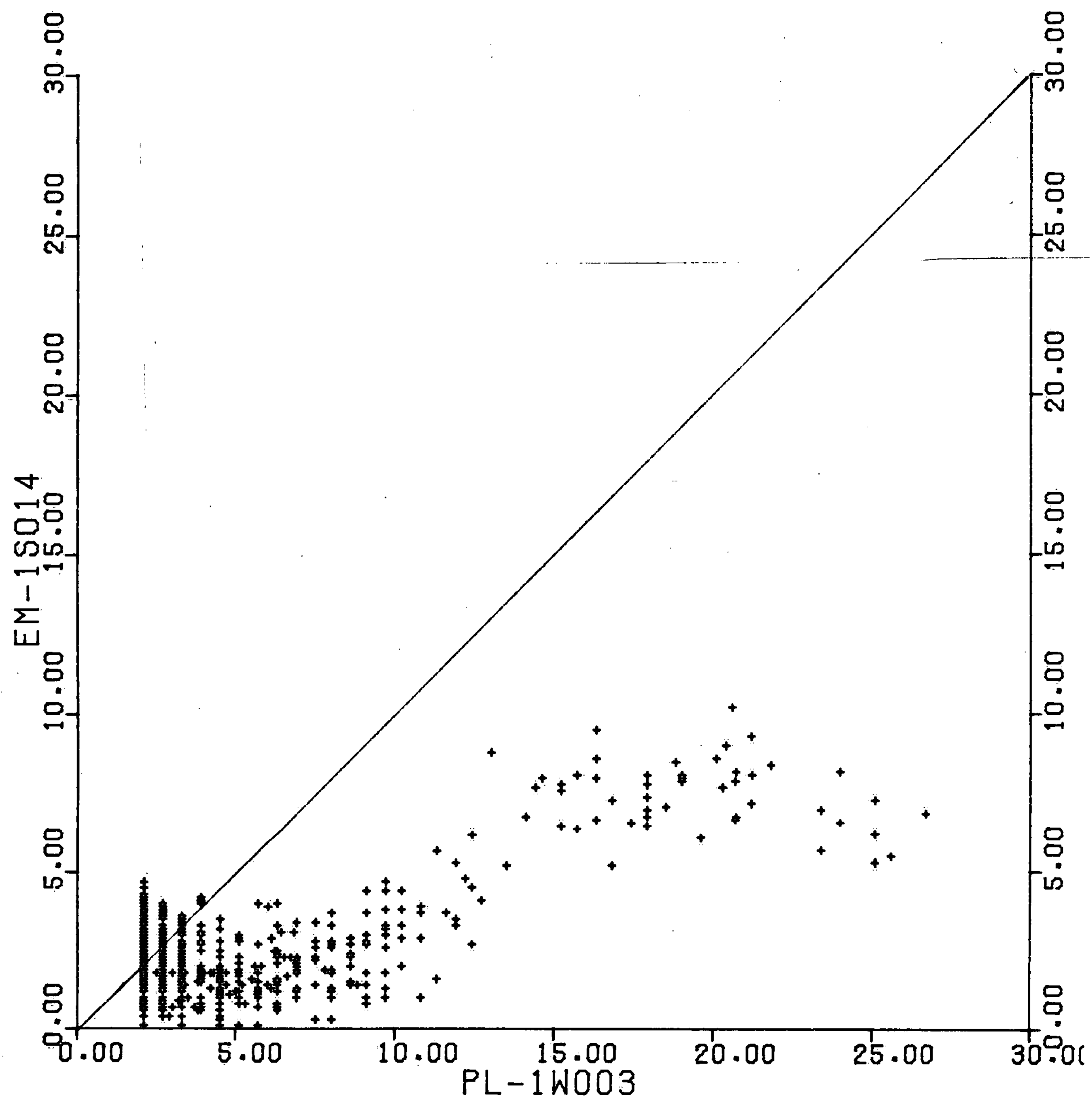
East 3 m M021 compared to West 5 m M021
Speed Difference Time Series
Figure 5.1.1.b Low Flow Case



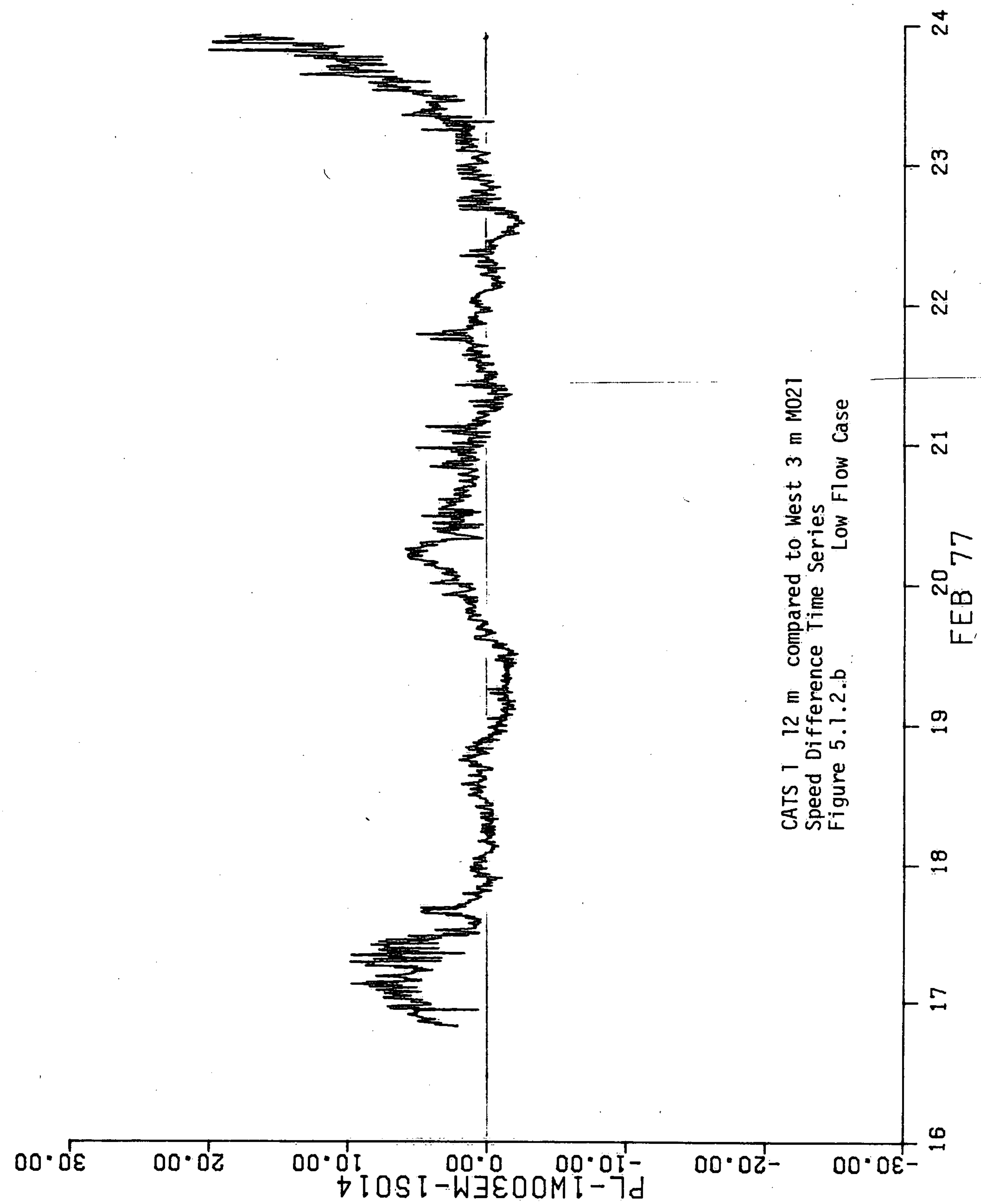
East 5 m M021 compared to West 3 m M021
Direction Comparison
Figure 5.1.1.c		Low Flow Case



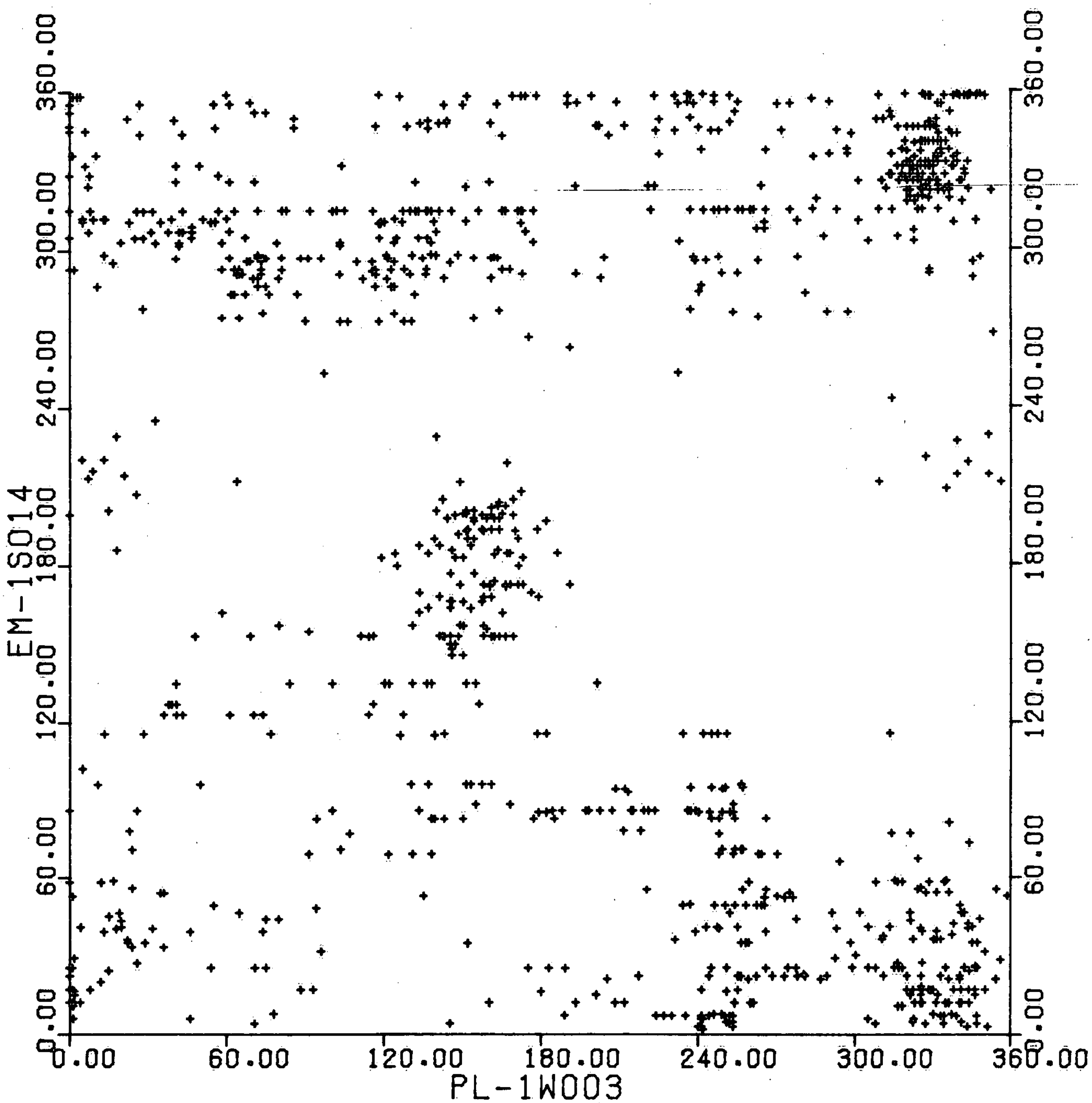
East 5 m M021 compared to West 3 m M021
Direction Difference Time Series
Figure 5.1.1.d Low Flow Case



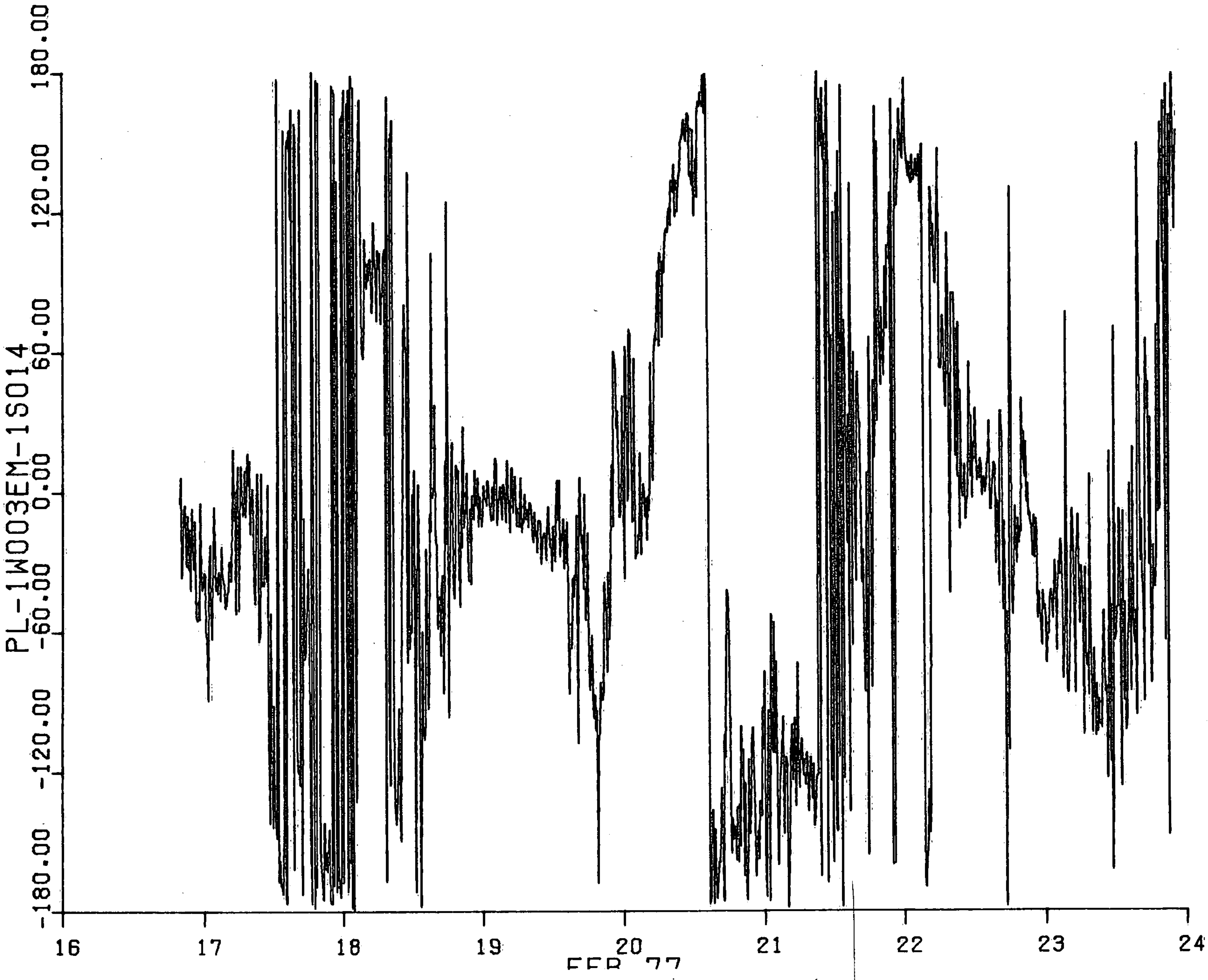
CATS 1 12 m compared to West 3 m M021
Speed Comparison
Figure 5.1.2.a Low Flow Case



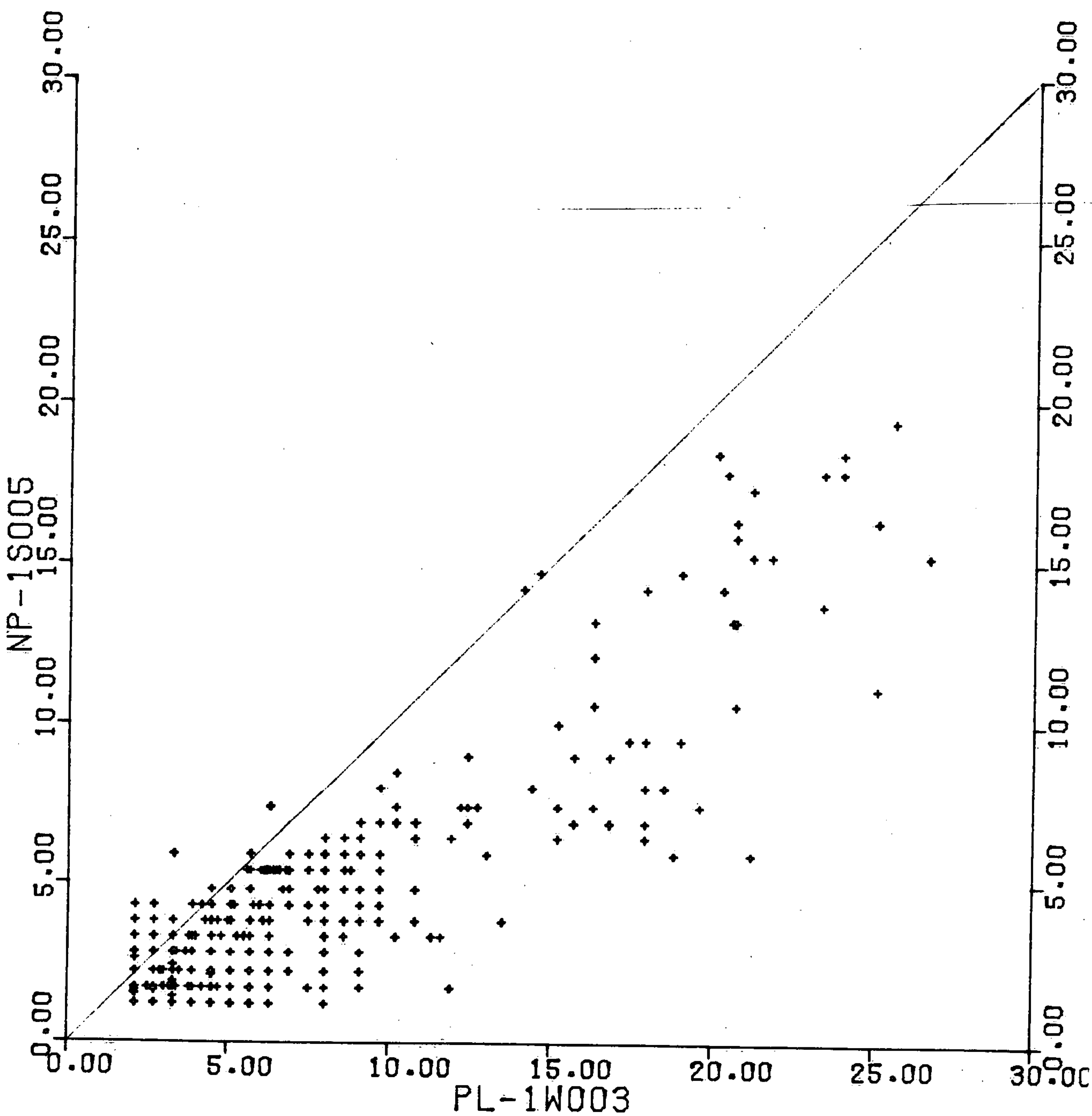
CATS 1 12 m compared to West 3 m M021
Speed Difference Time Series
Figure 5.1.2.b Low Flow Case



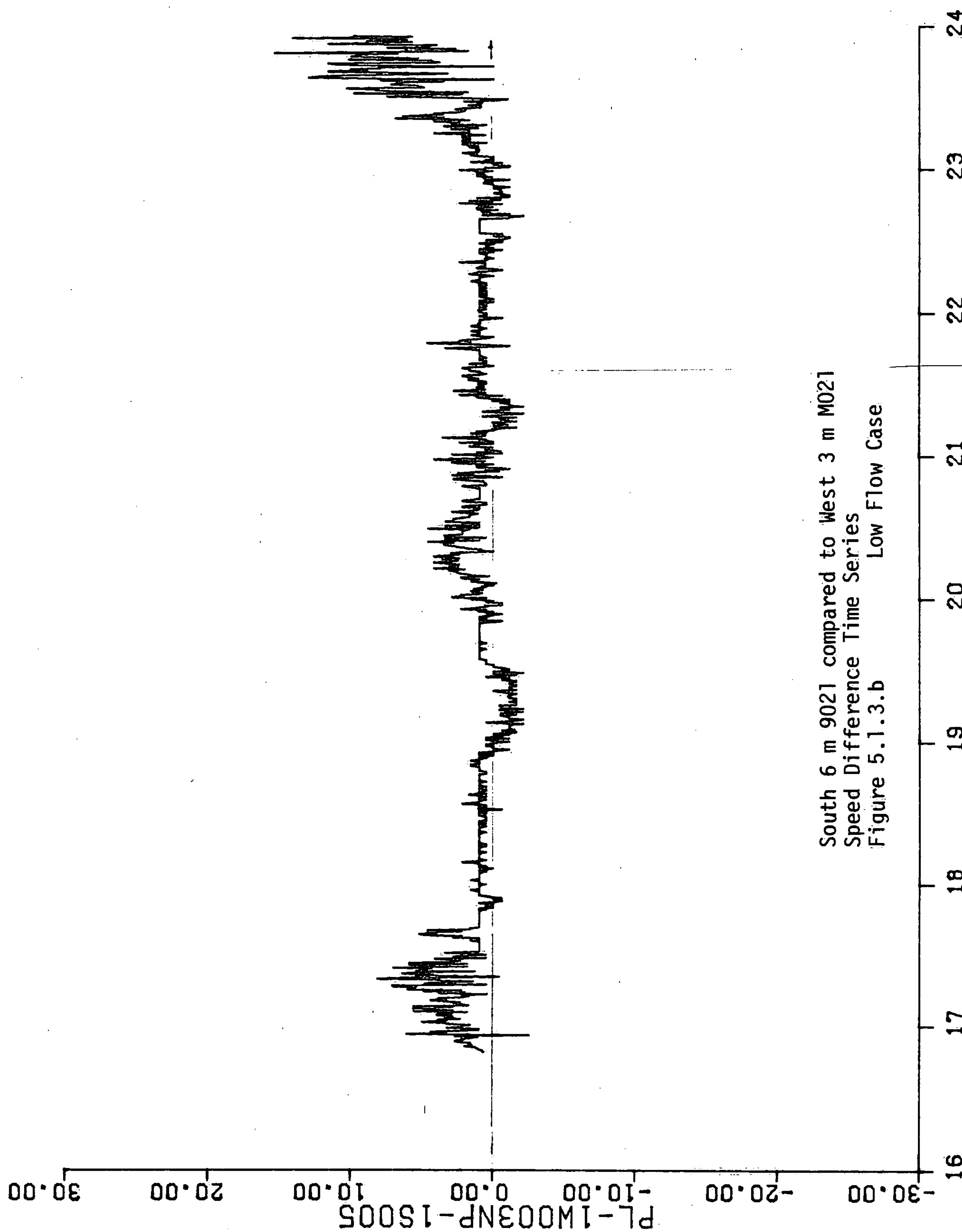
CATS 1 12 m compared to West 3 m Plessey
Direction Comparison
Figure 5.1.2.c Low Flow Case



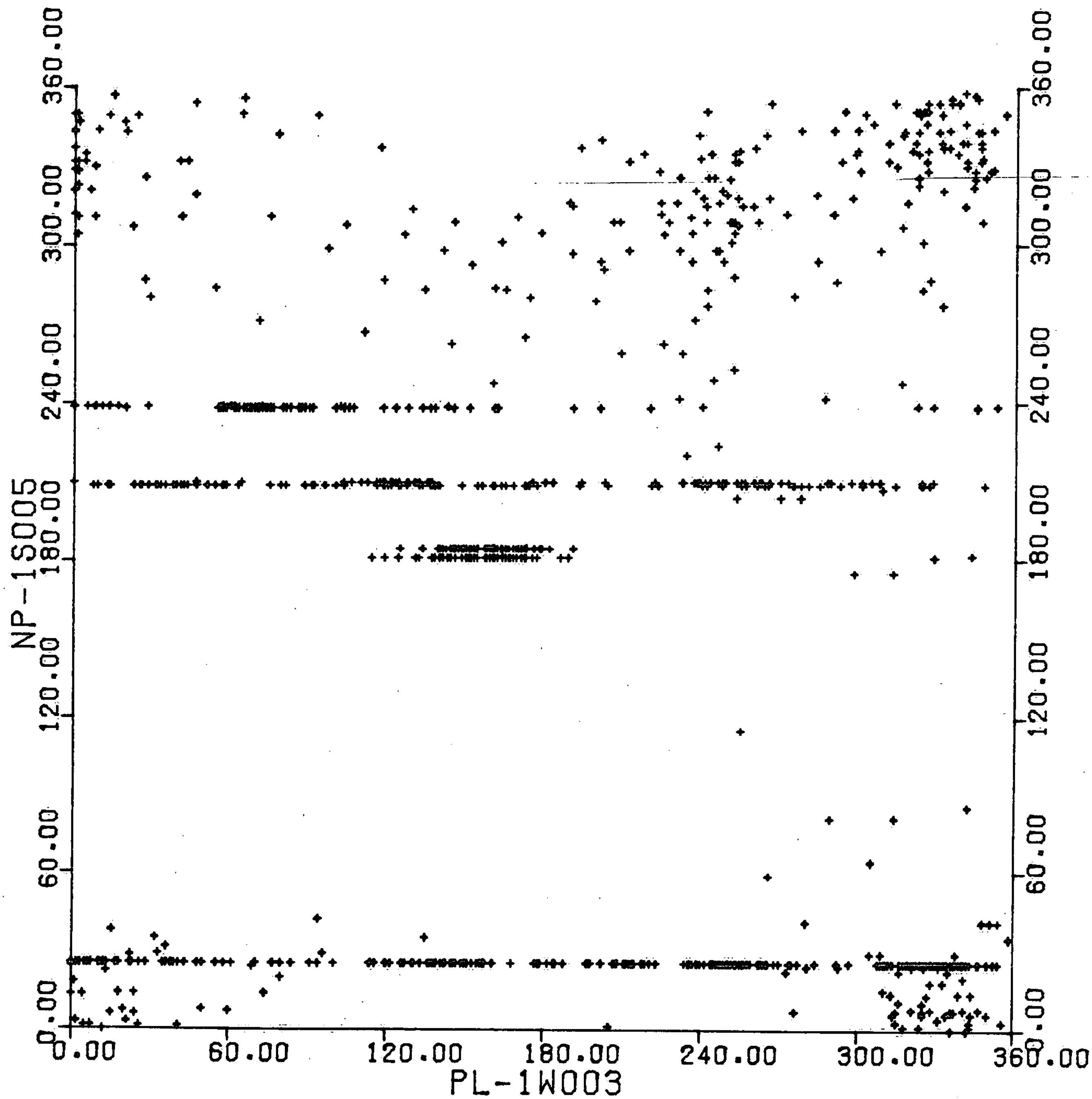
CATS 1 12 m compared to West 3 m M021
Direction Difference Time Series
Figure 5.1.2.d Low Flow Case



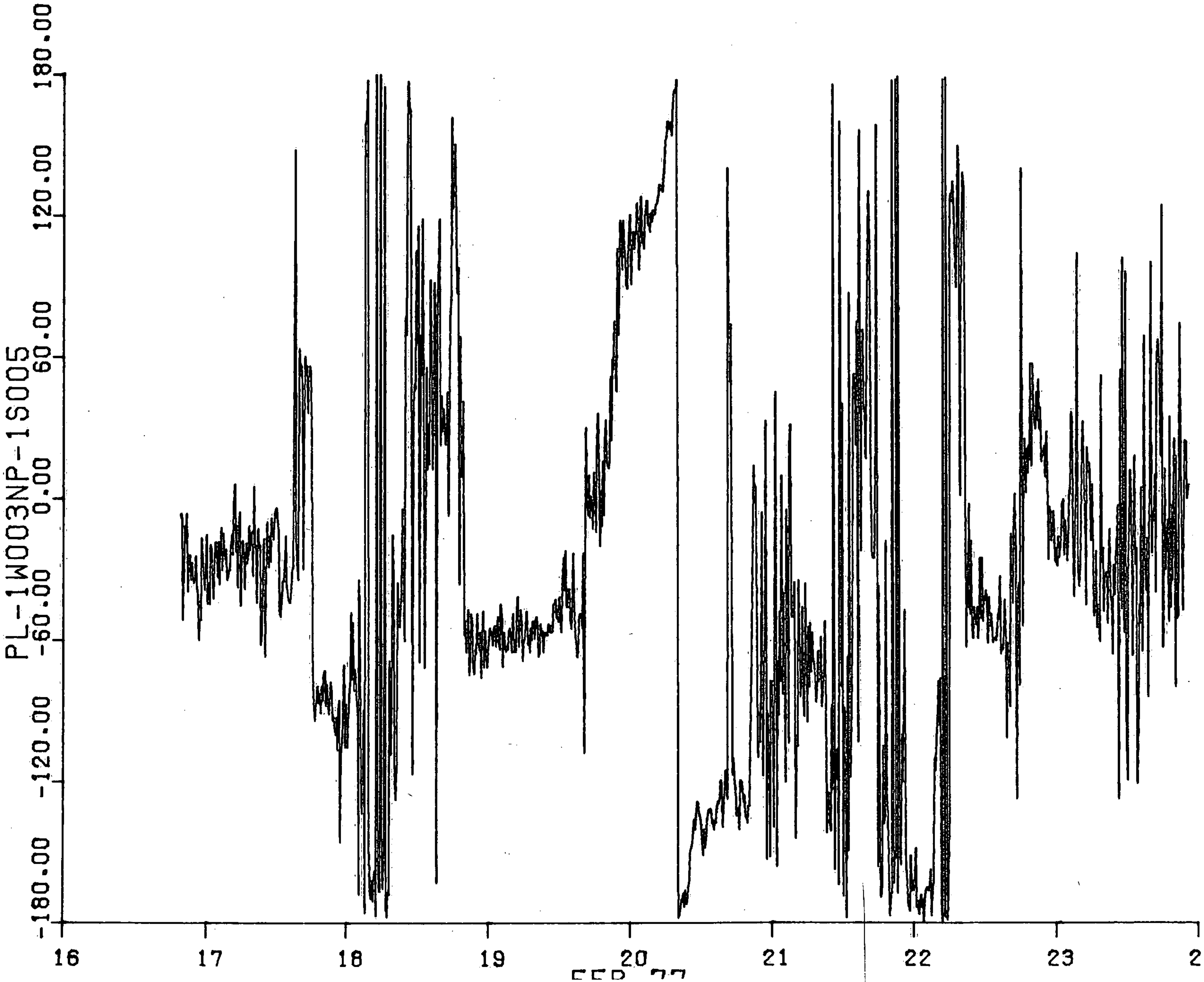
South 6 m 9021 compared to West 3 m M021
Speed Comparison
Figure 5.1.3.a Low Flow Case



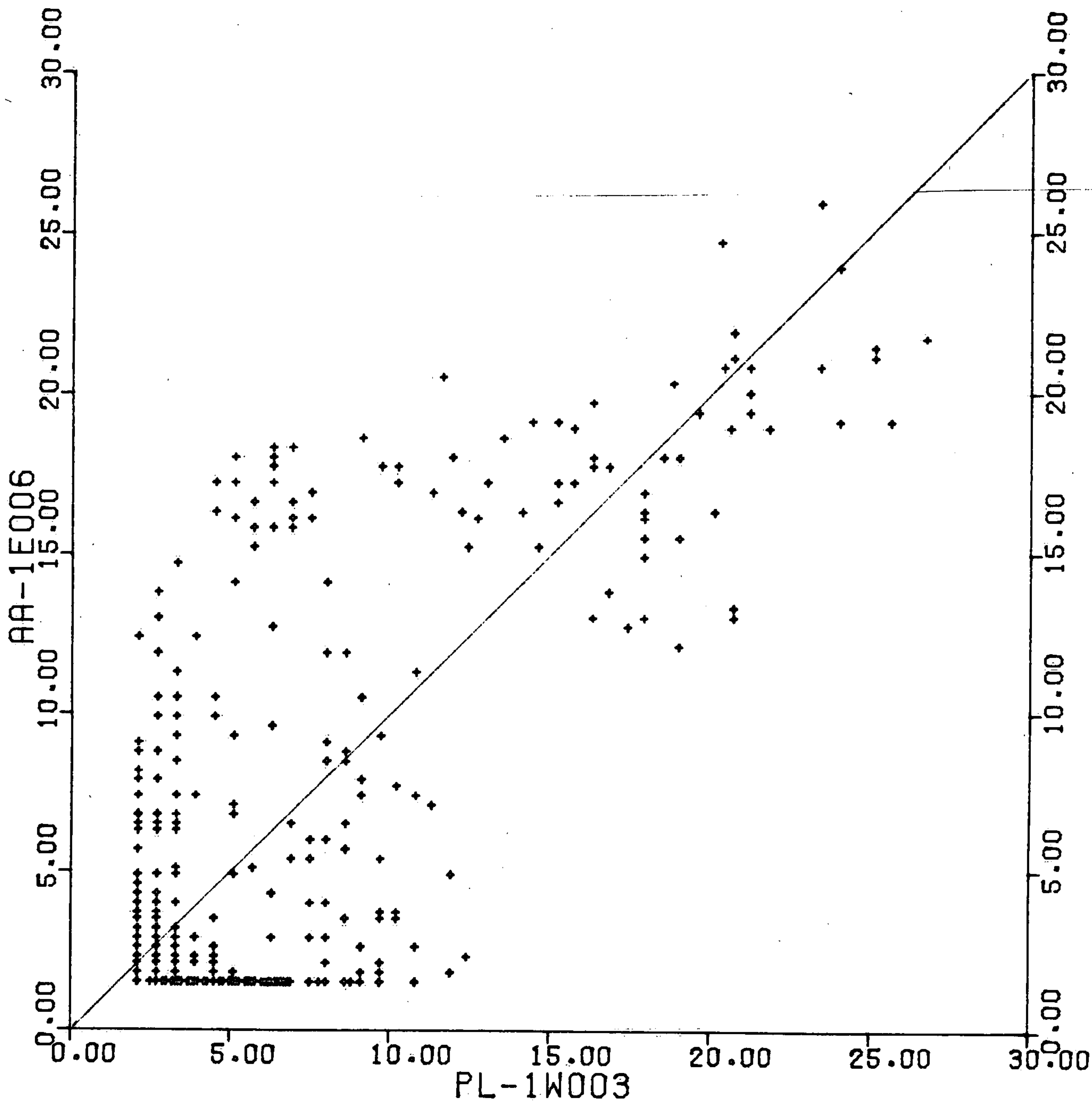
South 6 m 9021 compared to West 3 m M021
Speed Difference Time Series
Figure 5.1.3.b Low Flow Case



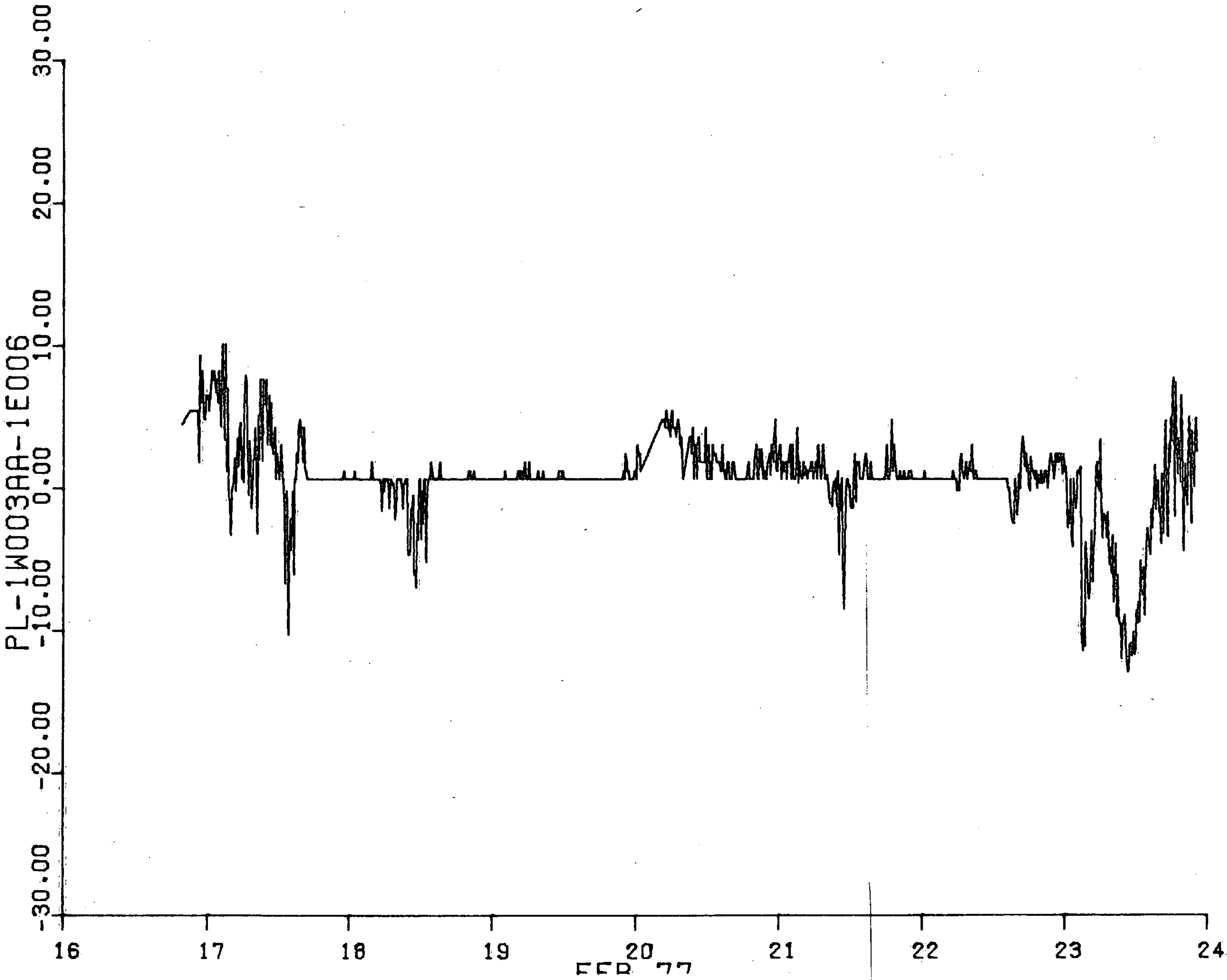
South 6 m 9021 compared to West 3 m M021
Direction Comparison
Figure 5.1.3.c Low Flow Case



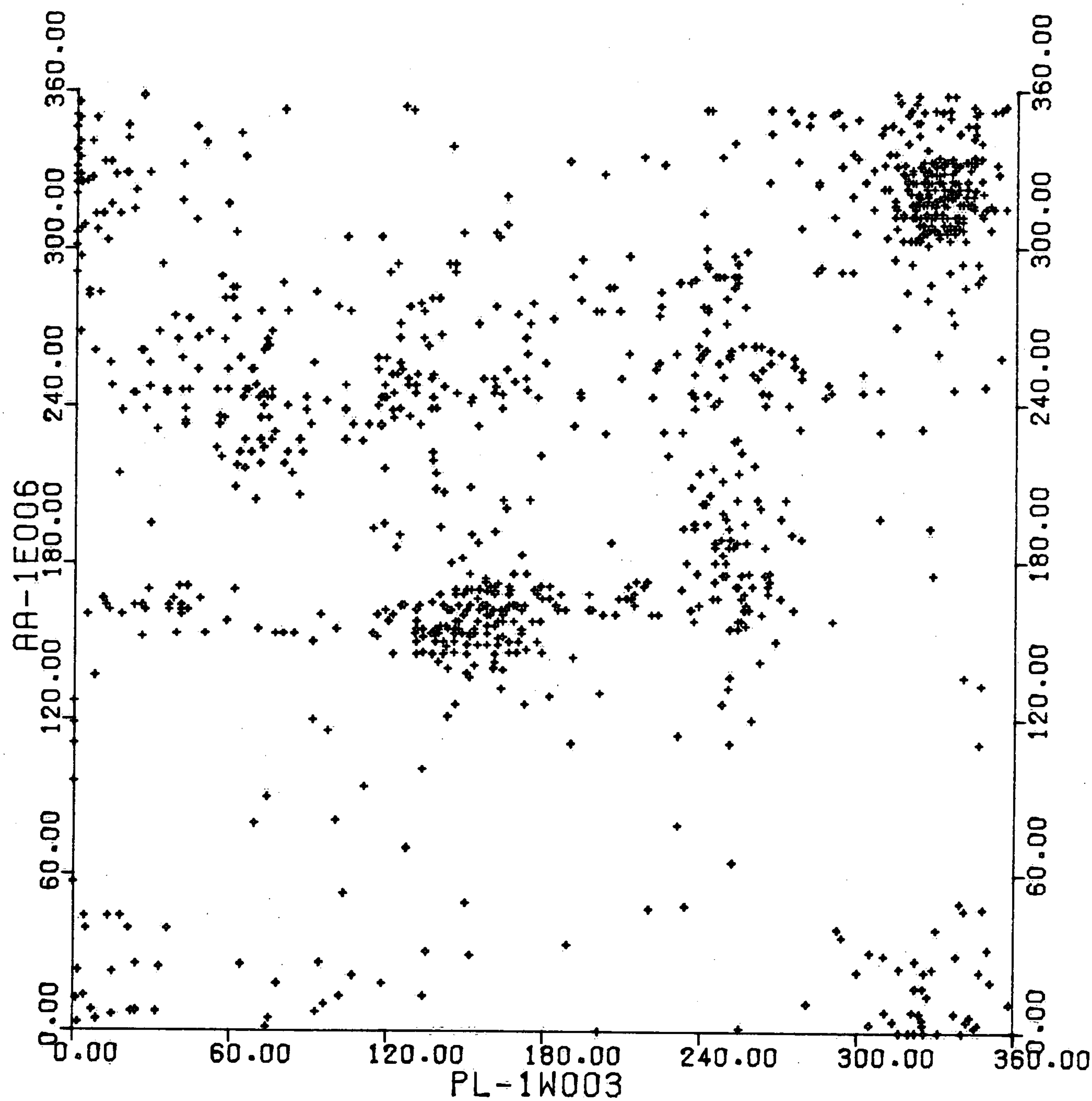
South 6 m 9021 compared to West 3 m M021
Direction Difference Time Series
Figure 5.1.3.d Low Flow Case



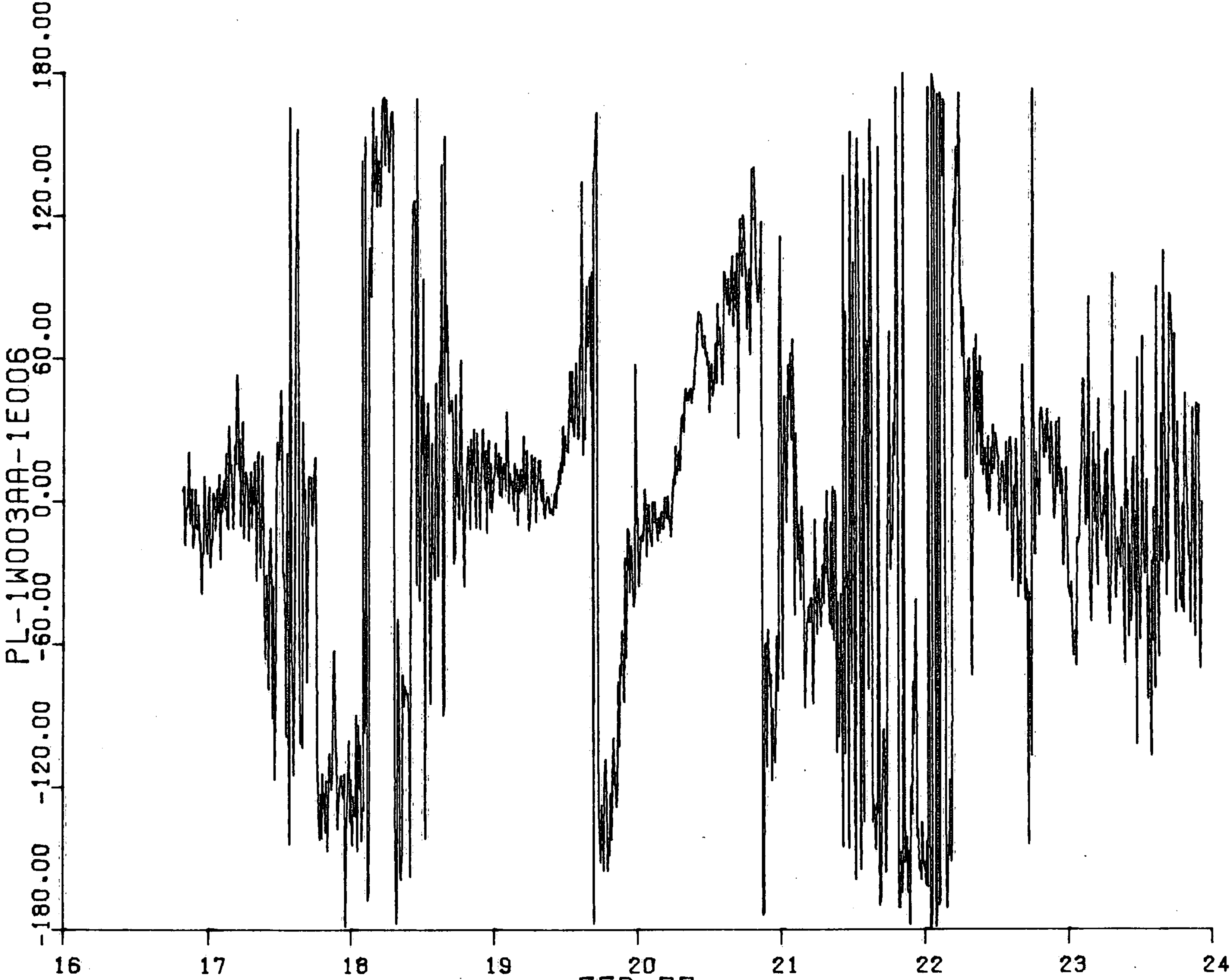
East 6 m Aanderaa compared to West
3 m M021 -- Speed Comparison
Figure 5.1.4.a Low Flow Case



East 6 m Aanderaa compared to West 3 m
M021 -- Speed Difference Time Series
Figure 5.1.4.b Low Flow Case



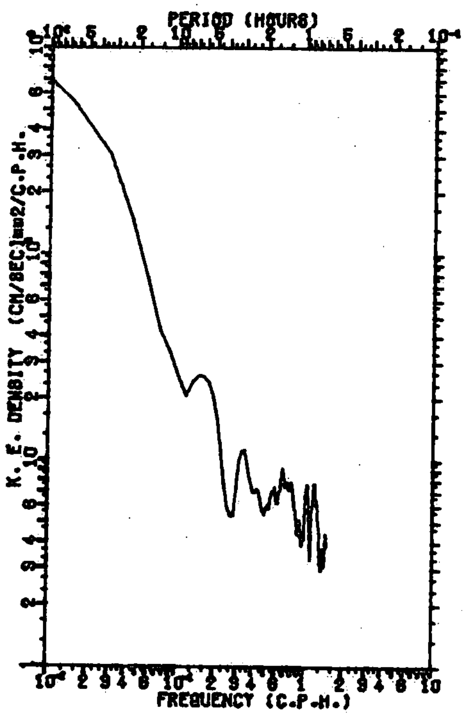
East 6 m Aanderaa compared to West
3 m M021 -- Direction Comparison
Figure 5.1.4.c   Low Flow Case



East 6 m Aanderaa compared to West 3m
Plessey
Direction Difference Time Series
Figure 5.1.4.d Low Flow Case

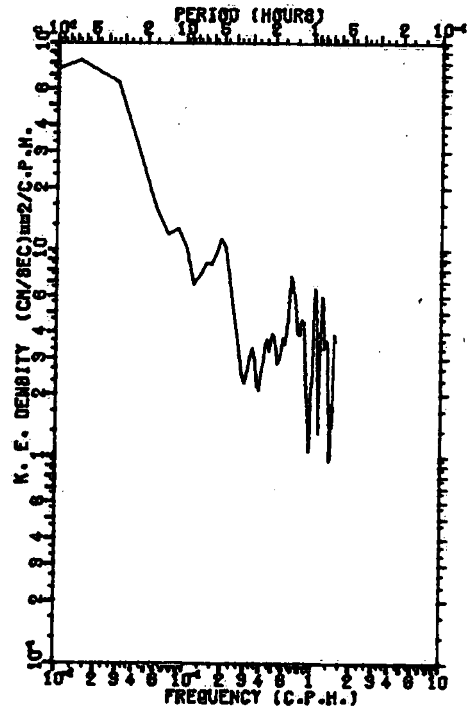
TOTAL KE FOR M021-3

FEB 16 TO 23



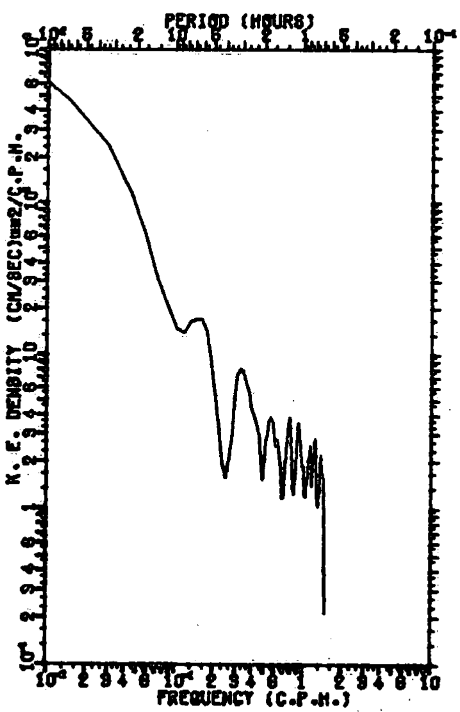
KE EAST COMPONENT M021-3

FEB 16 TO 23



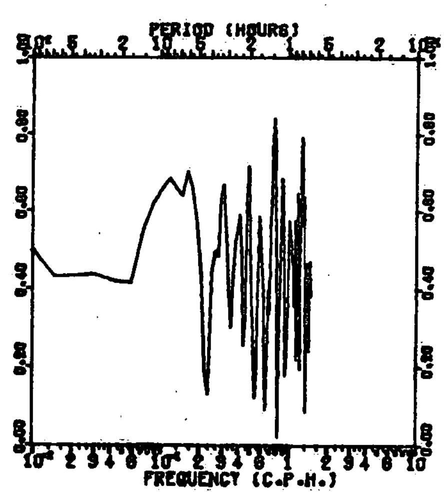
KE NORTH COMPONENT M021-3

FEB 16 TO 23



COHERENCE M021-3 NORTH AND EAST

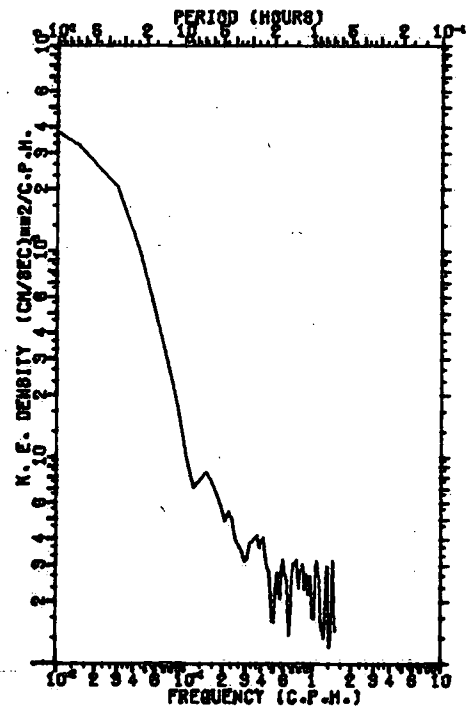
FEB 16 TO 23



West 3 m M021
Low Flow Case
Figure 5.1.5.a

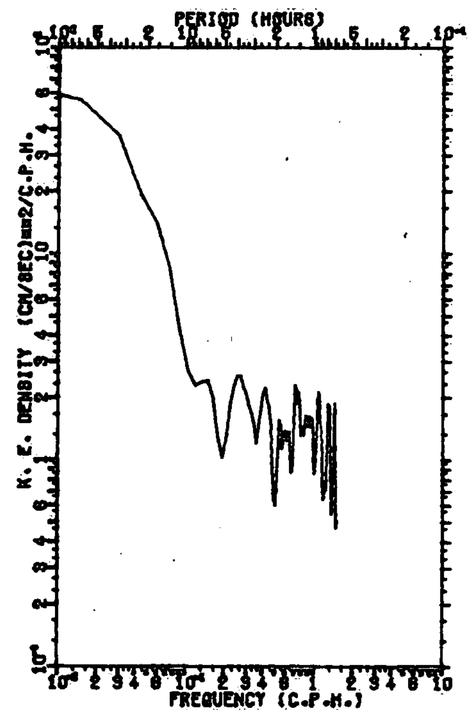
TOTAL KE FOR M021-5

FEB 16 TO 23



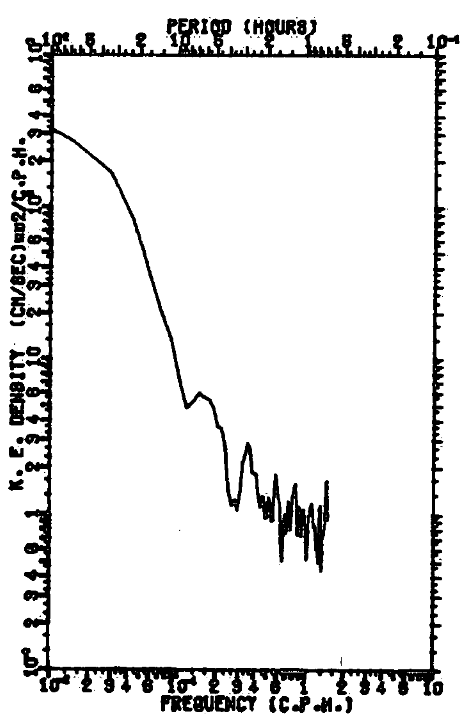
KE EAST M021-5

FEB 16 TO 23



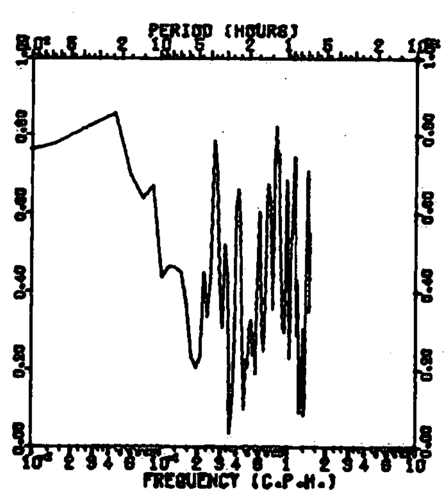
KE NORTH M021-5

FEB 16 TO 23



COHERENCE M021-5 NORTH AND EAST

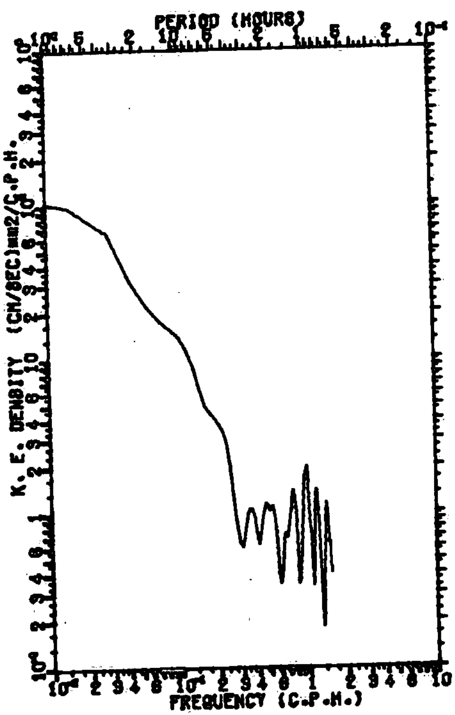
FEB 16 TO 23



East 5 m M021
Low Flow Case
Figure 5.1.5.b

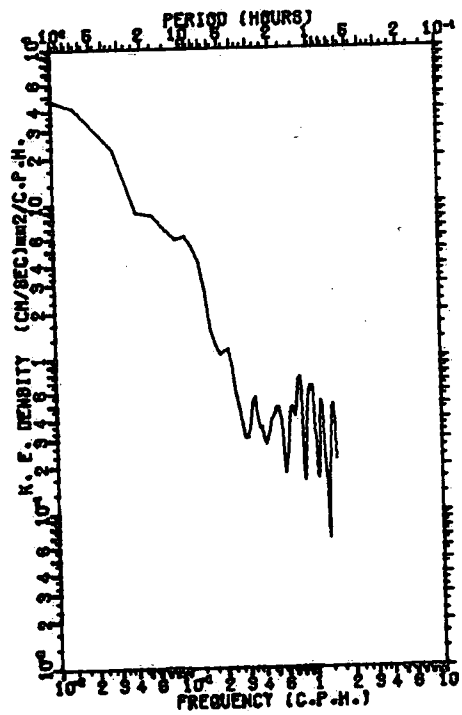
TOTAL KE FOR CATS1

FEB 16 TO 23



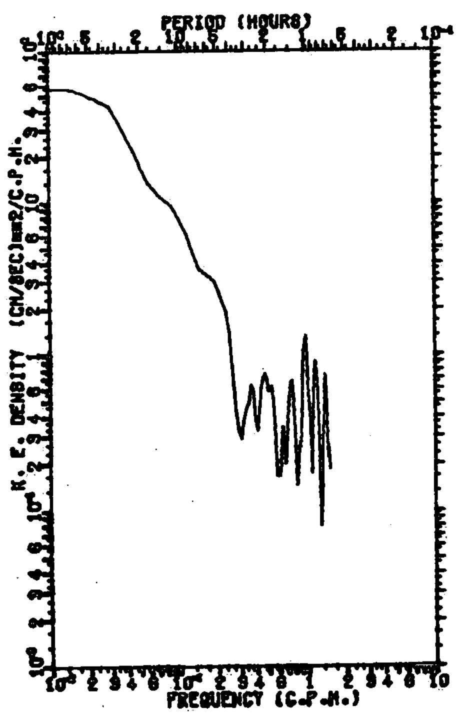
KE EAST CATS1

FEB 16 TO 23



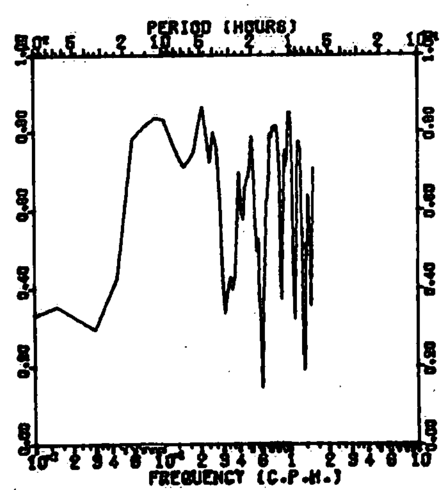
KE NORTH CATS1

FEB 16 TO 23



COHERENCE CATS1 NORTH AND EAST

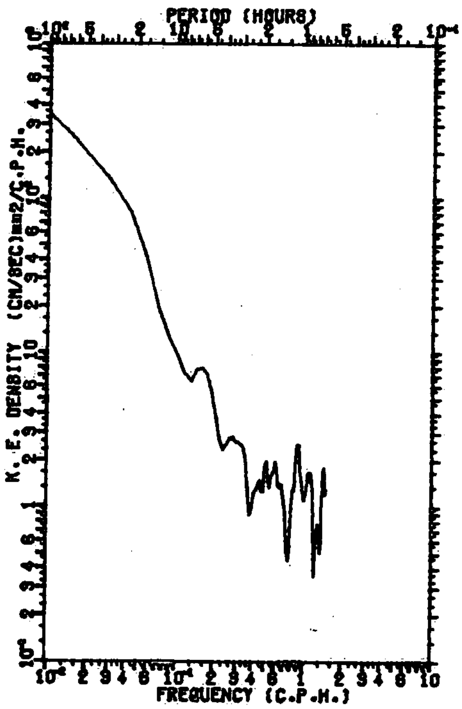
FEB 16 TO 23



CATS 1 12 m
Low Flow Case
Figure 5.1.5.c

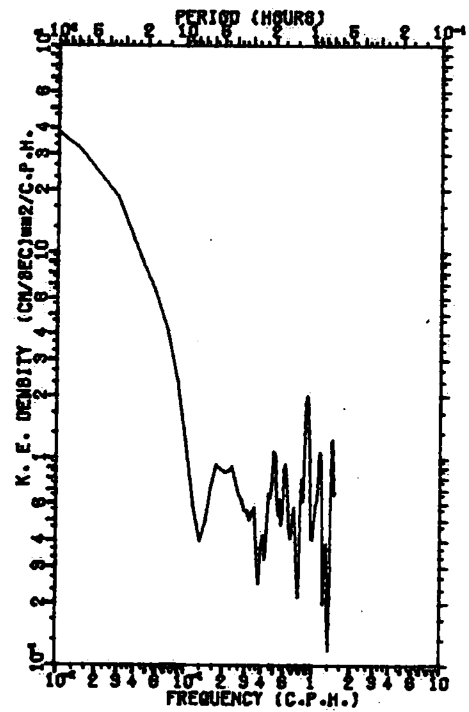
TOTAL KE FOR 9021

FEB 16 TO 23



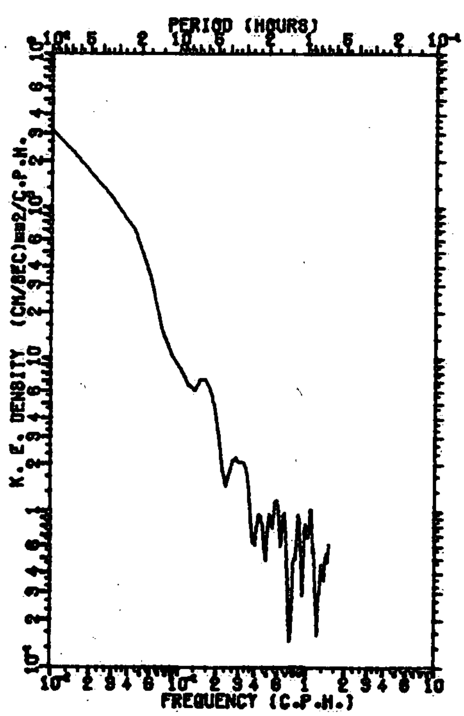
KE EAST COMPONENT 9021

FEB 16 TO 23



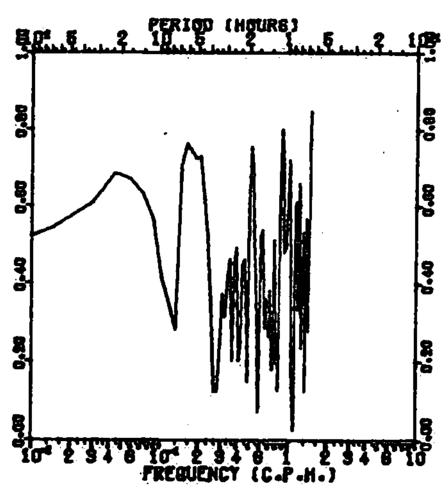
KE NORTH COMPONENT 9021

FEB 16 TO 23

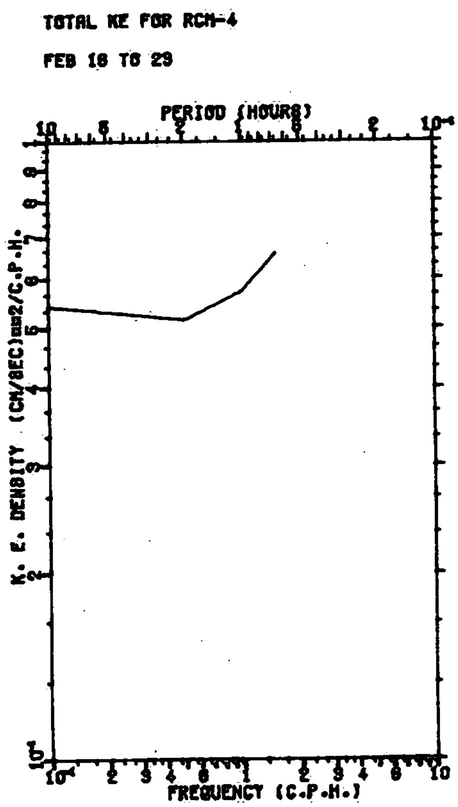


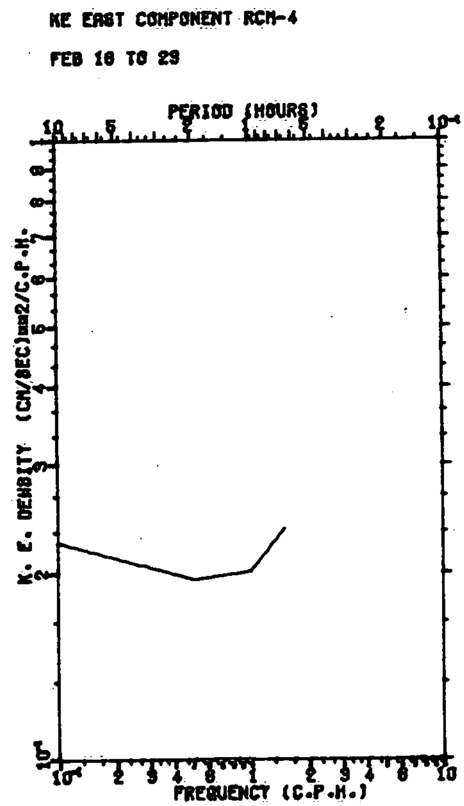
COHERENCE 9021 NORTH AND EAST

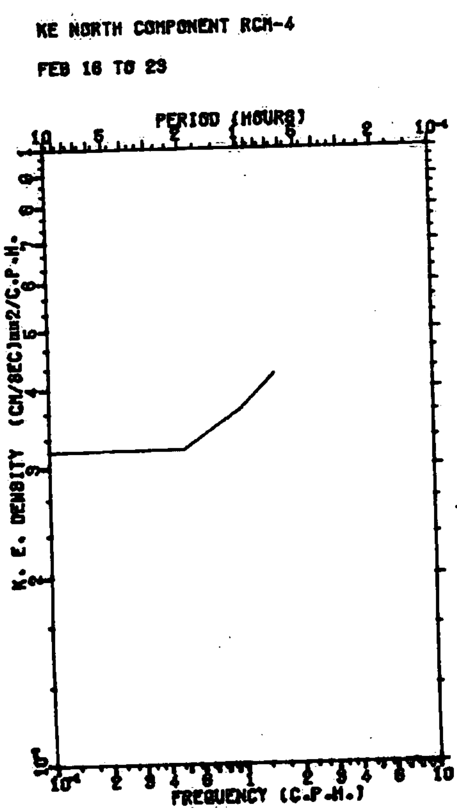
FEB 16 TO 23

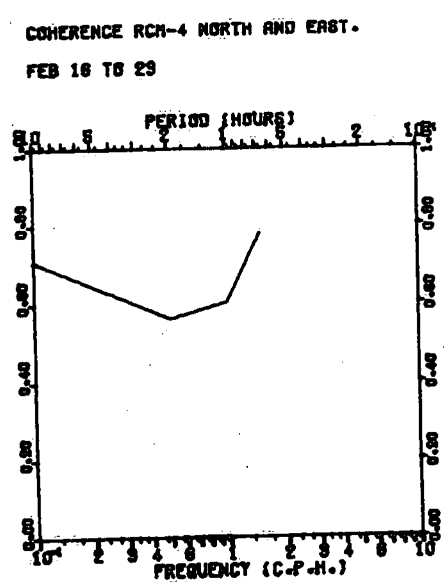


South 6 m 9021
Low Flow Case
Figure 5.1.5.d





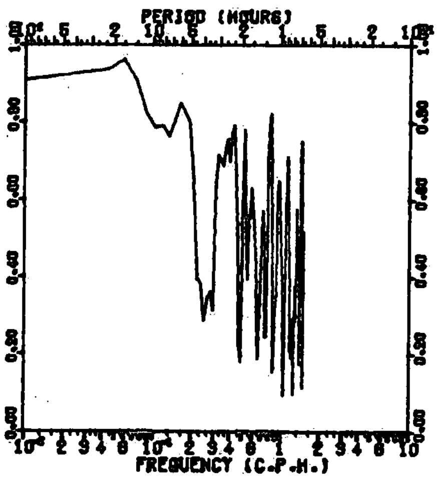




East 6 m Aanderaa
Low Flow Case
Figure 5.1.5.e

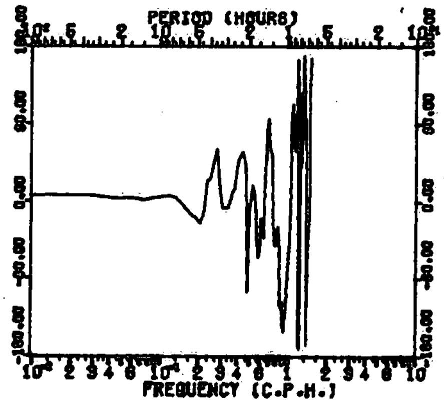
COHERENCE MO21-5 AND MO21-3 NORTH

FEB 16 TO 29



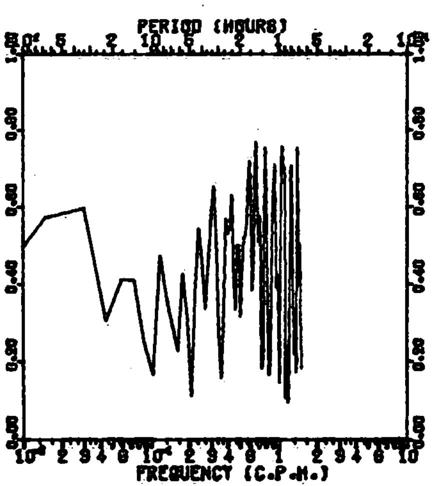
PHASE MO21-5 AND MO21-3 NORTH

FEB 16 TO 29



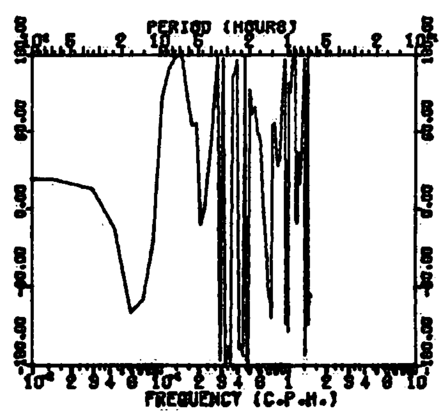
COHERENCE MO21-5 AND MO21-3 EAST

FEB 16 TO 29

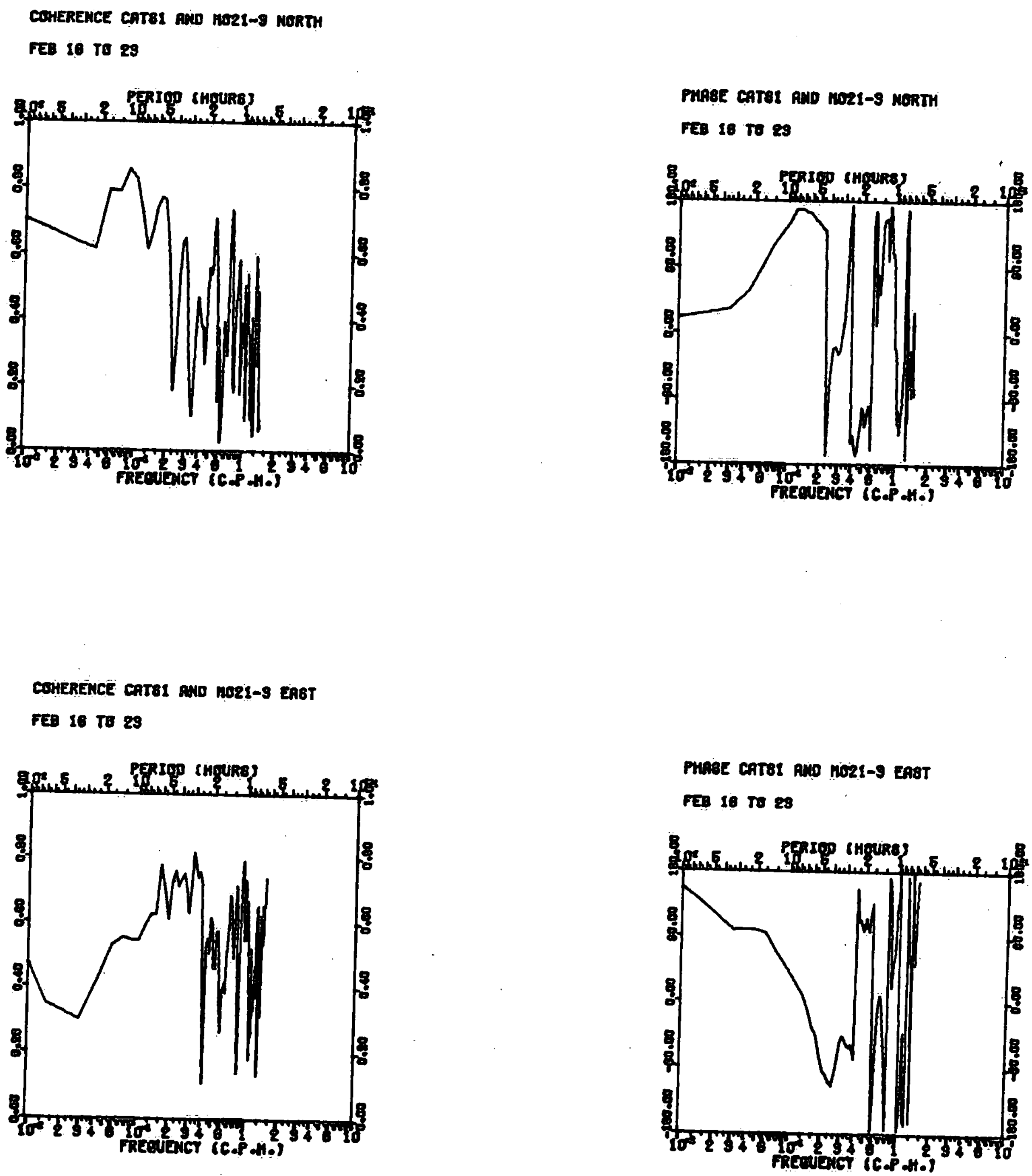


PHASE MO21-5 AND MO21-3 EAST

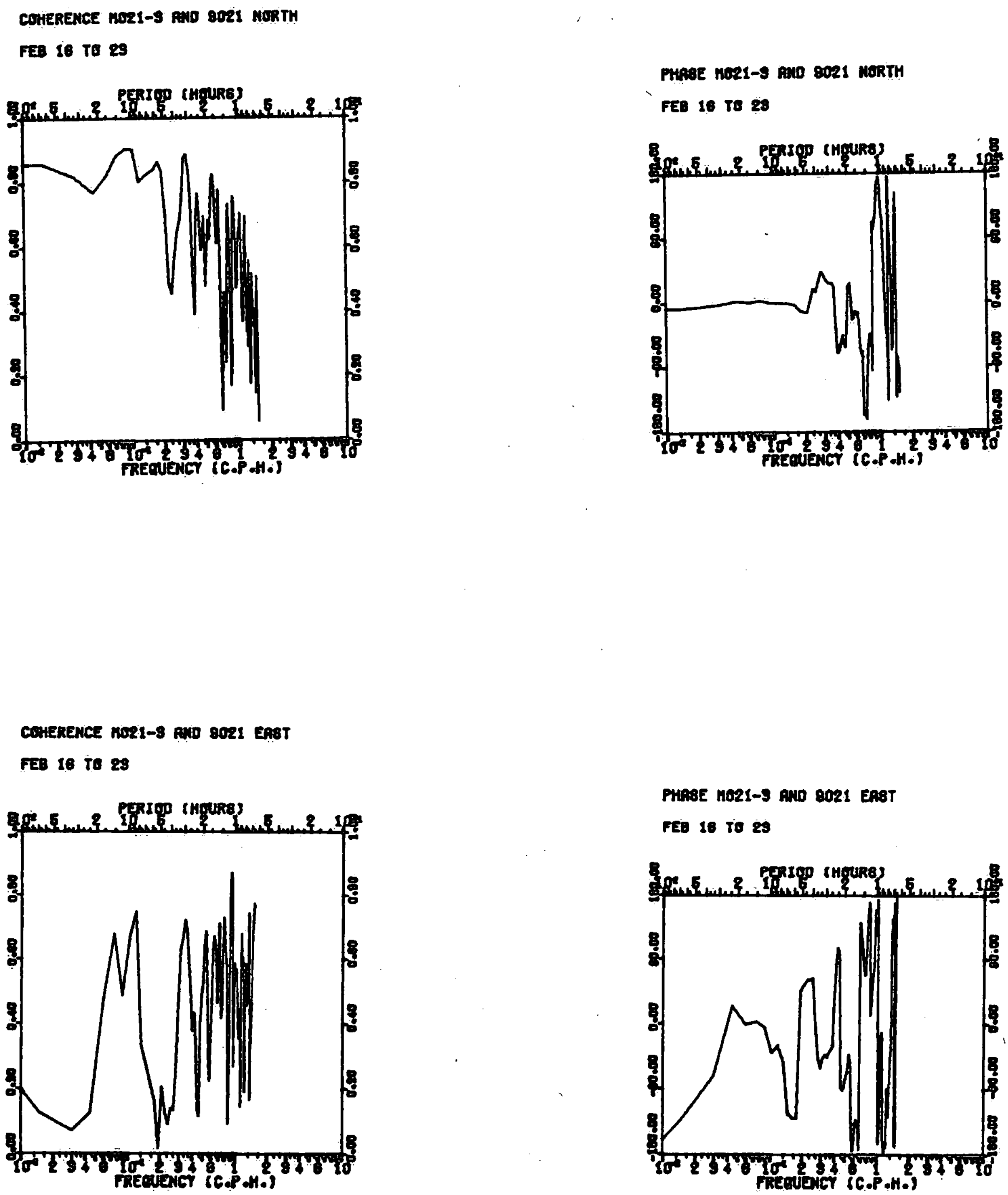
FEB 16 TO 29



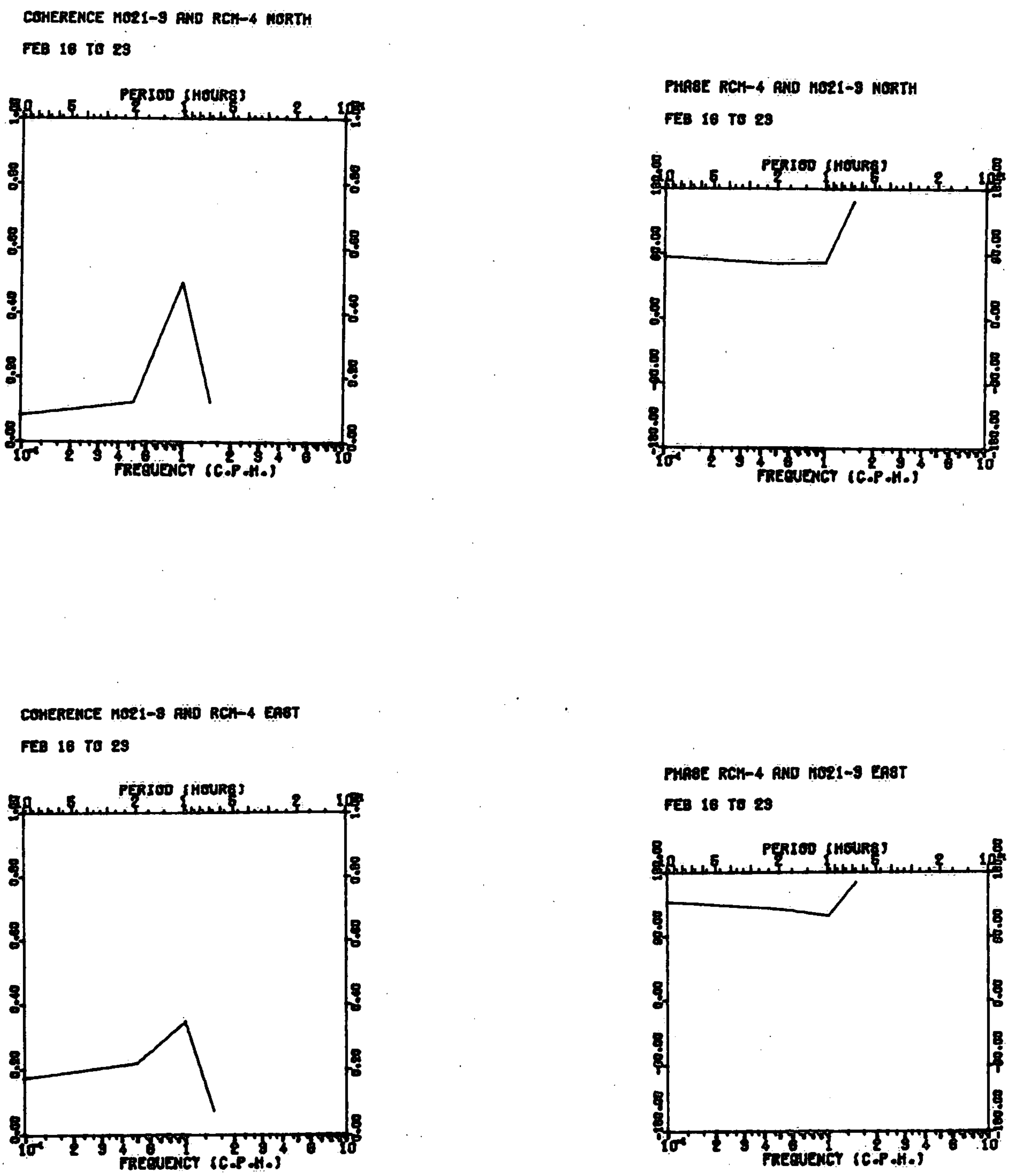
East 5 m MO21 compared to West 3m MO21
Low Flow Case
Figure 5.1.6.a



12 m CATS 1 compared to West 3 m M021
Low Flow Case
Figure 5.1.6.b



South 6 m S021 compared to West 3m M021
Low Flow Case
Figure 5.1.6.c



East 6 m Aanderaa compared to West 3m
M021 -- Low Flow Case
Figure 5.1.6.d

Comparing Figures 5.1.5.b, d (watch the scaling) shows excellent agreement between the 5 m M021 and 6 m 9021. Figure 5.1.5.e indicates that the Aanderaa data is highly suspect. The CATS 1 data in Figure 5.1.5.c shows lower total Kinetic Energy Spectral Density estimates than the 3, 5 m instruments for periods greater than 12 hours. Comparing to the 9021 estimate shows a factor of 3 - 4 for long periods. The absence of stratification in the experiment period leads one to suspect less current shear over the 5 to 12 m depth than this indicates.

The coherence and phase plots for the North and East components in Figures 5.1.6.a, b,c,d are included for completeness, but are not discussed.

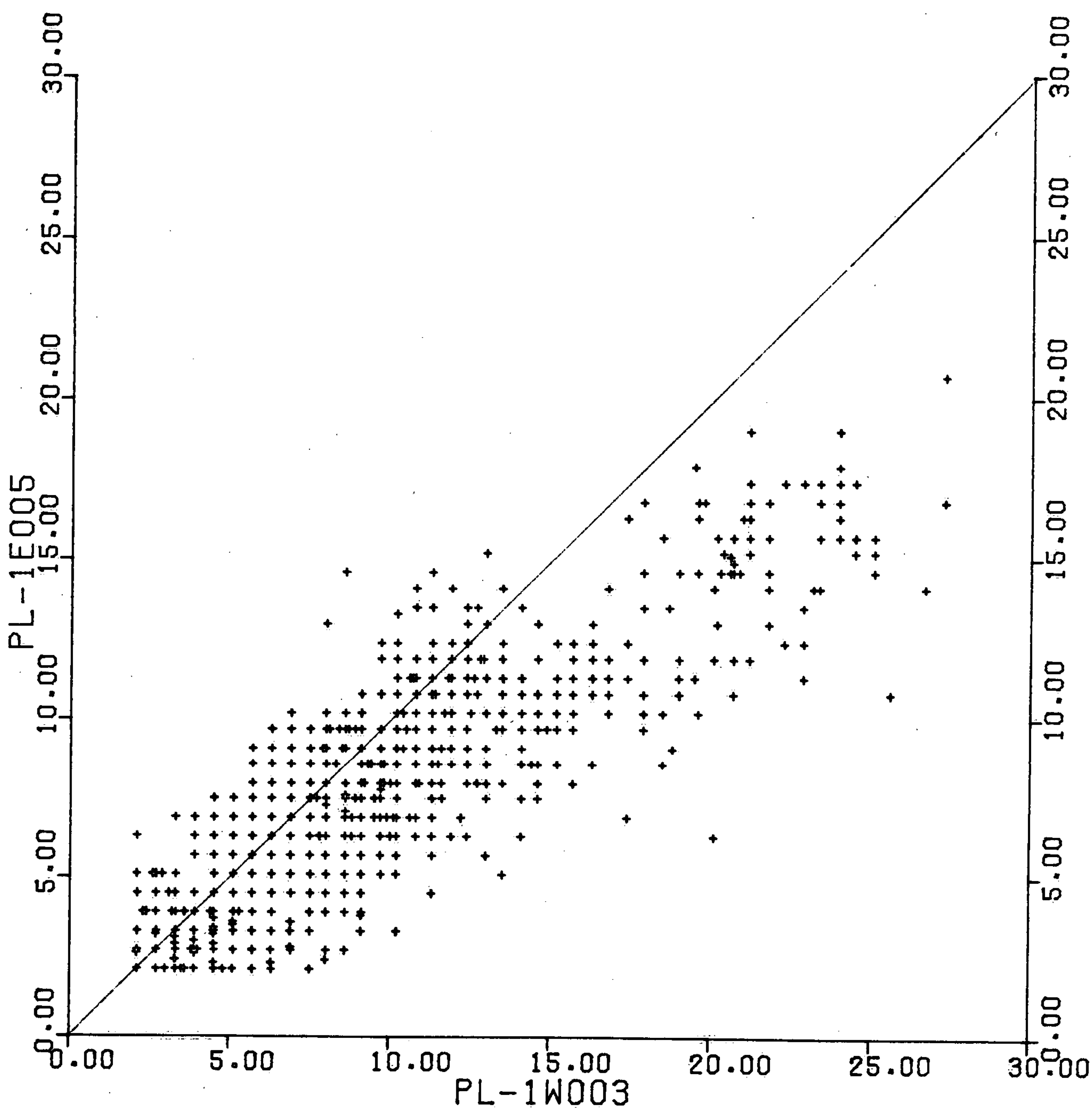
5.2 Medium Flow Case: 23 February - 3 March 1977

The medium flow case period of 23 February to 3 March was selected as a more energetic period for comparison. Figures 5.2.1.a - d, 5.2.4.a - d show the similar plots as in Section 5.1. The 3 m M021 indicates higher speeds than the 5 m instruments. The speed difference plots for the 9021, Figure 5.2.3.b and for the CATS 1, Figure 5.2.2.b show similarity. The 5 m M021 speed difference does not show the same structure (5.2.1.b).

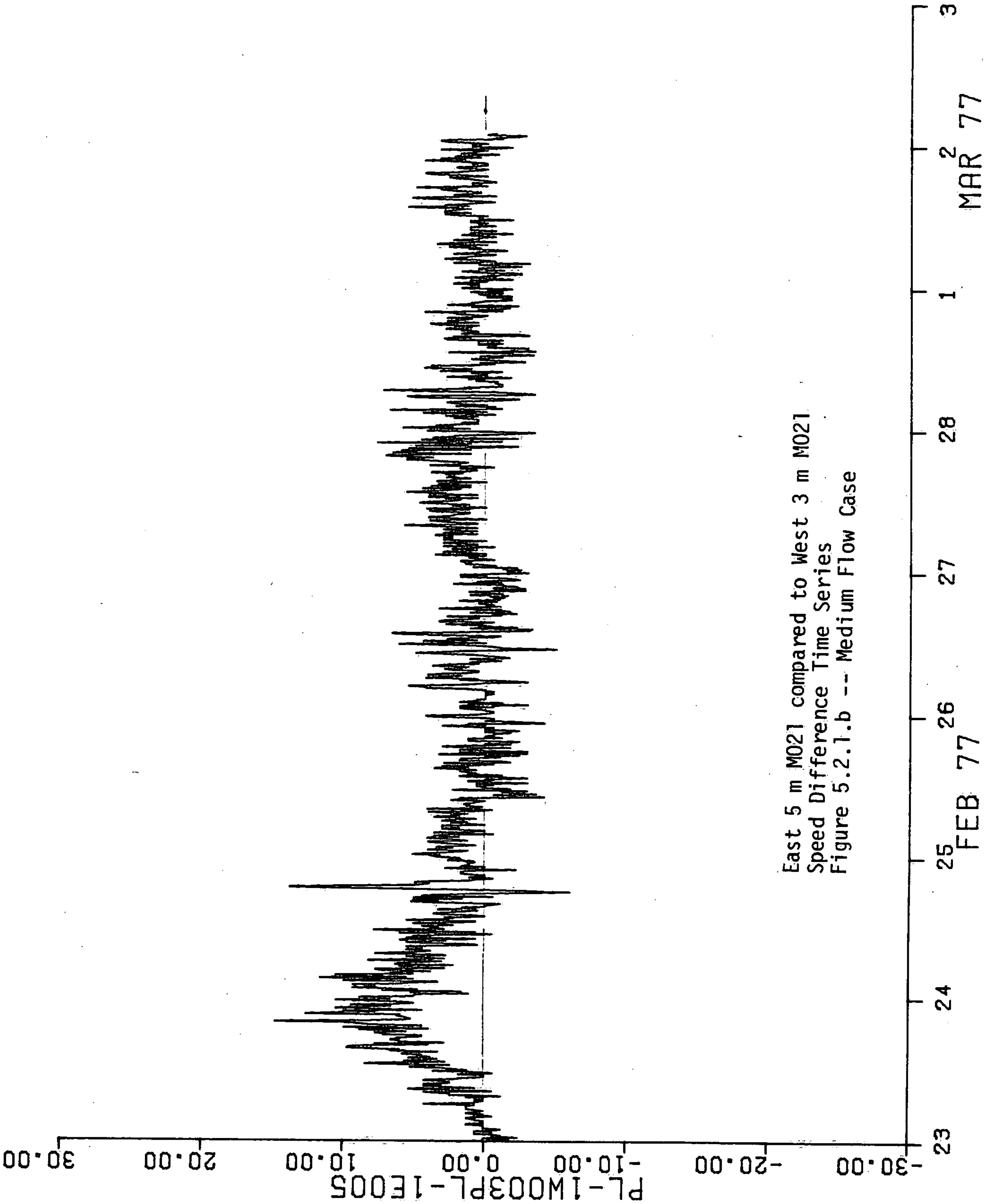
The Aanderaa instrument again shows overspeeding, compared to the 3 m Plessey M021, Figure 5.2.4.a. The direction differences are difficult to evaluate for the medium and low flow cases. An alternative comparison method would seem to be necessary.

Statistical analyses of the time series are provided in Figures 5.2.5.a to e and 5.2.6.a to d. The total kinetic energy spectral density plots again show higher values for the 3 m M021 at long periods than the 5 m M021. The 9021 data indicates long period values a factor of 3 lower than the 5 m M021. The CATS 1 data gives total K.E. spectral densities approximately half of the 9021 data results.

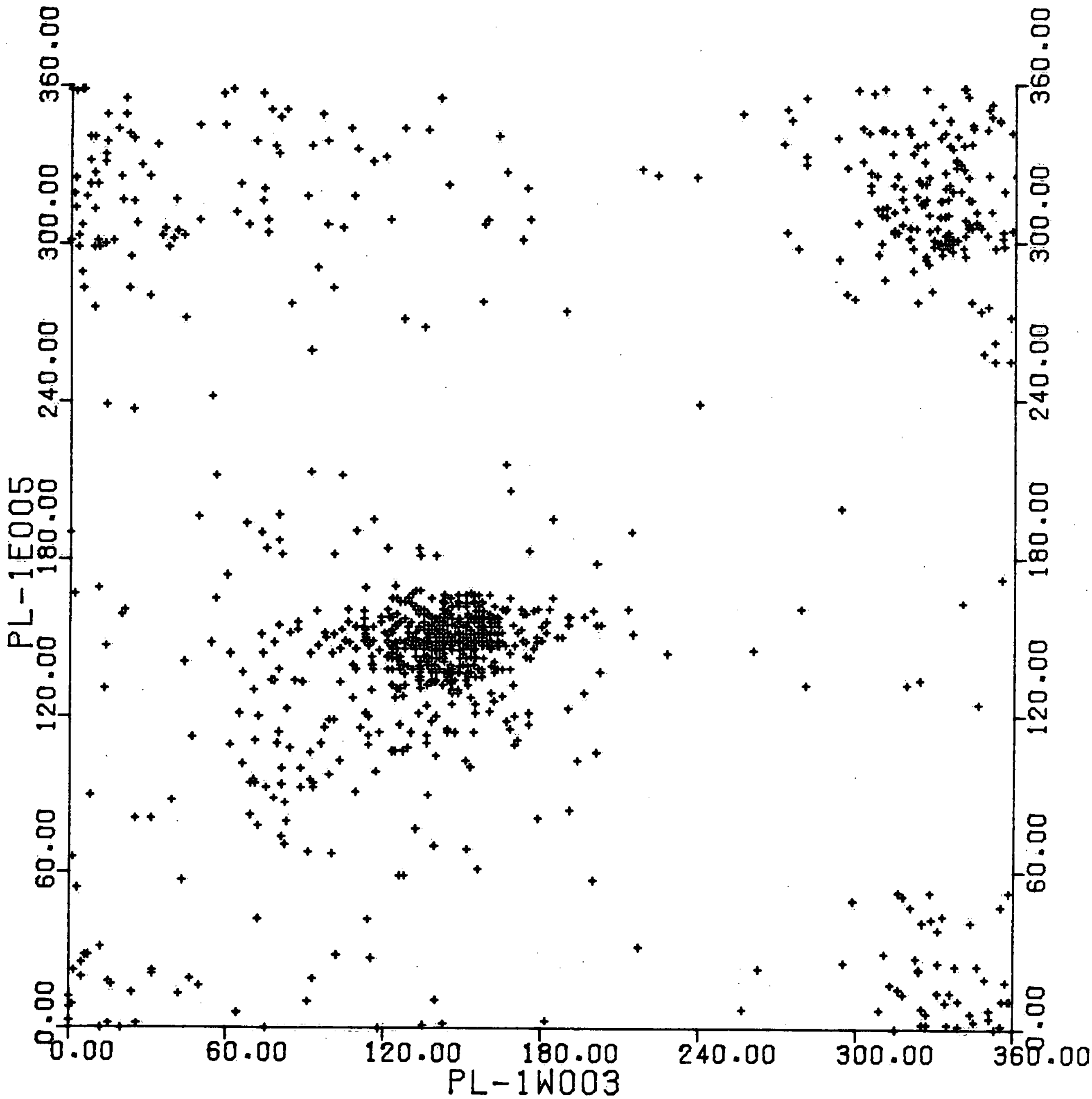
The short period (high frequency) end of the total K.E. spectral density plots show the 9021 and CATS 1 data to have similar values, while the



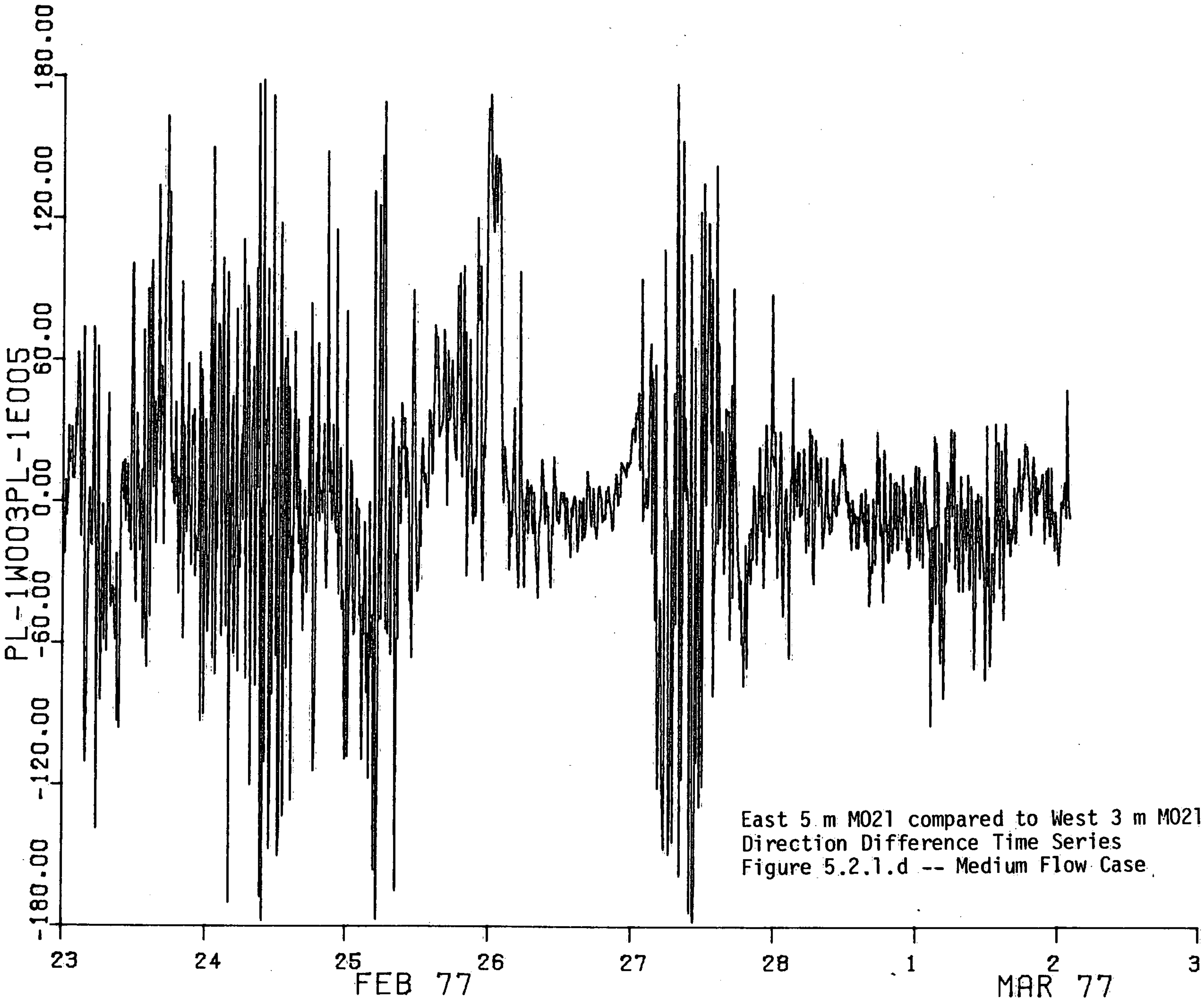
East 5 m M021 compared to West 3m Plessey
Speed Comparison
Figure 5.2.1.a -- Medium Flow Case



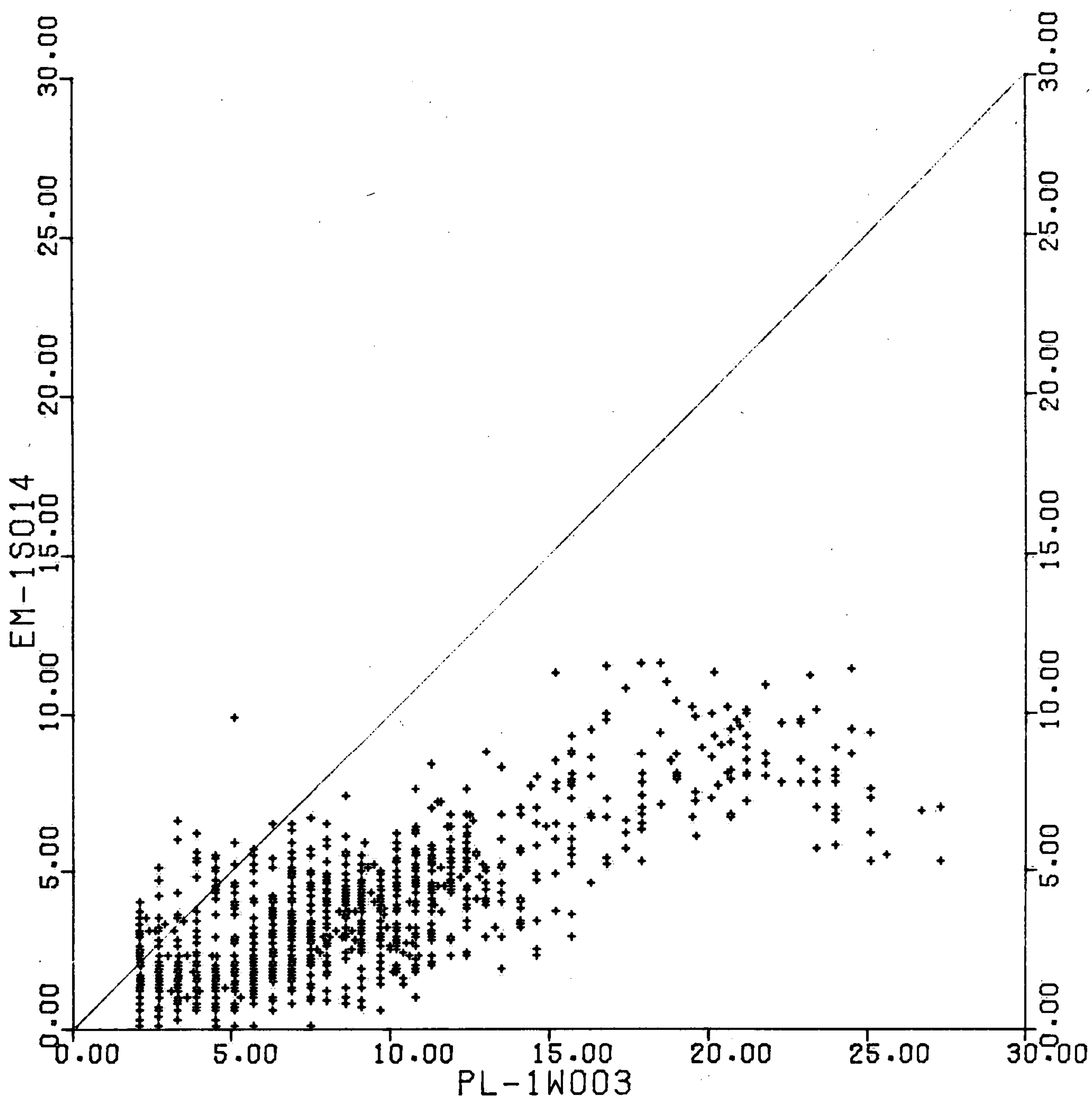
East 5 m M021 compared to West 3 m M021
Speed Difference Time Series
Figure 5.2.1.b -- Medium Flow Case



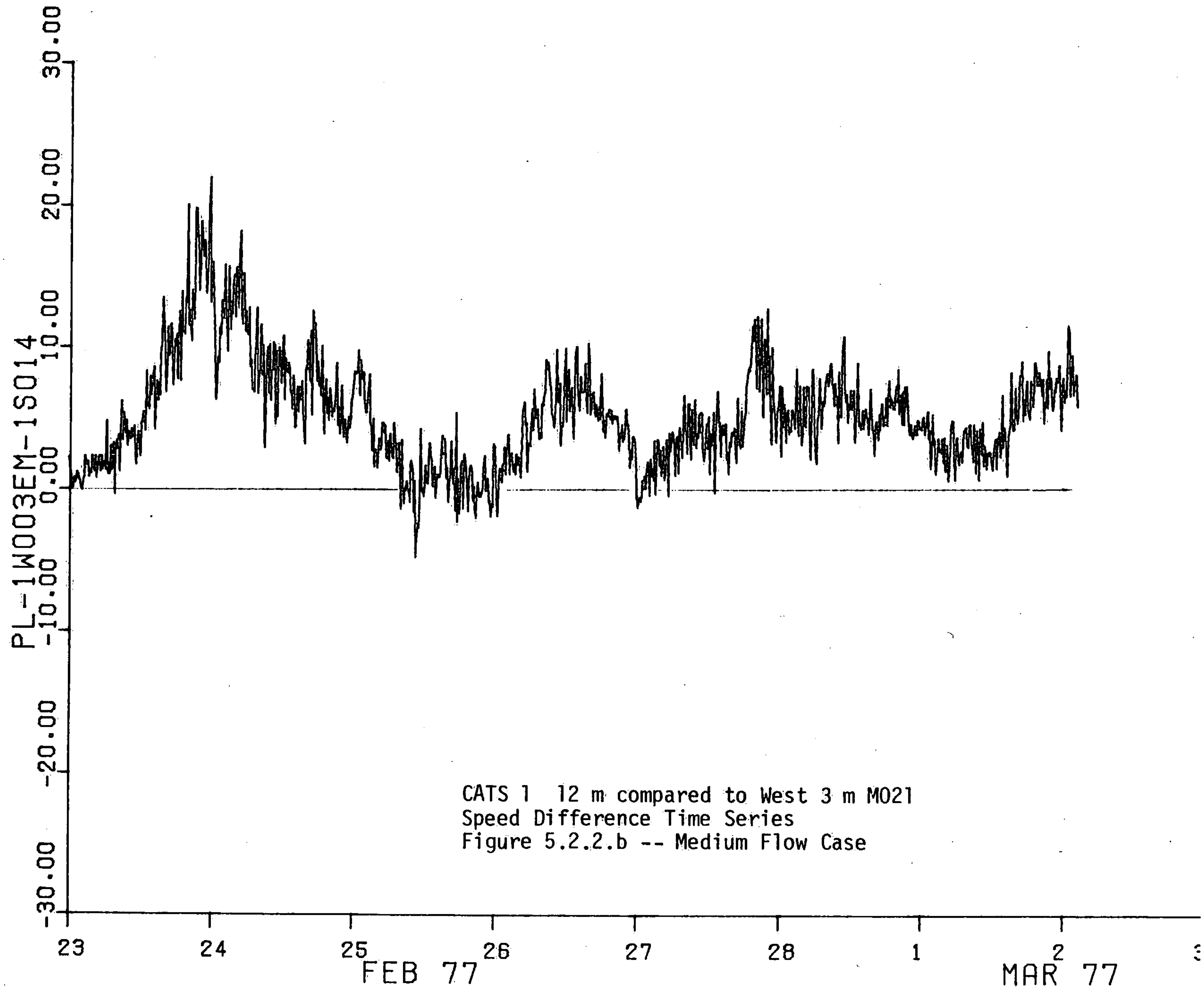
East 5 m M021 compared to West 3m M021
Direction Comparison
Figure 5.2.1.c -- Medium Flow Case



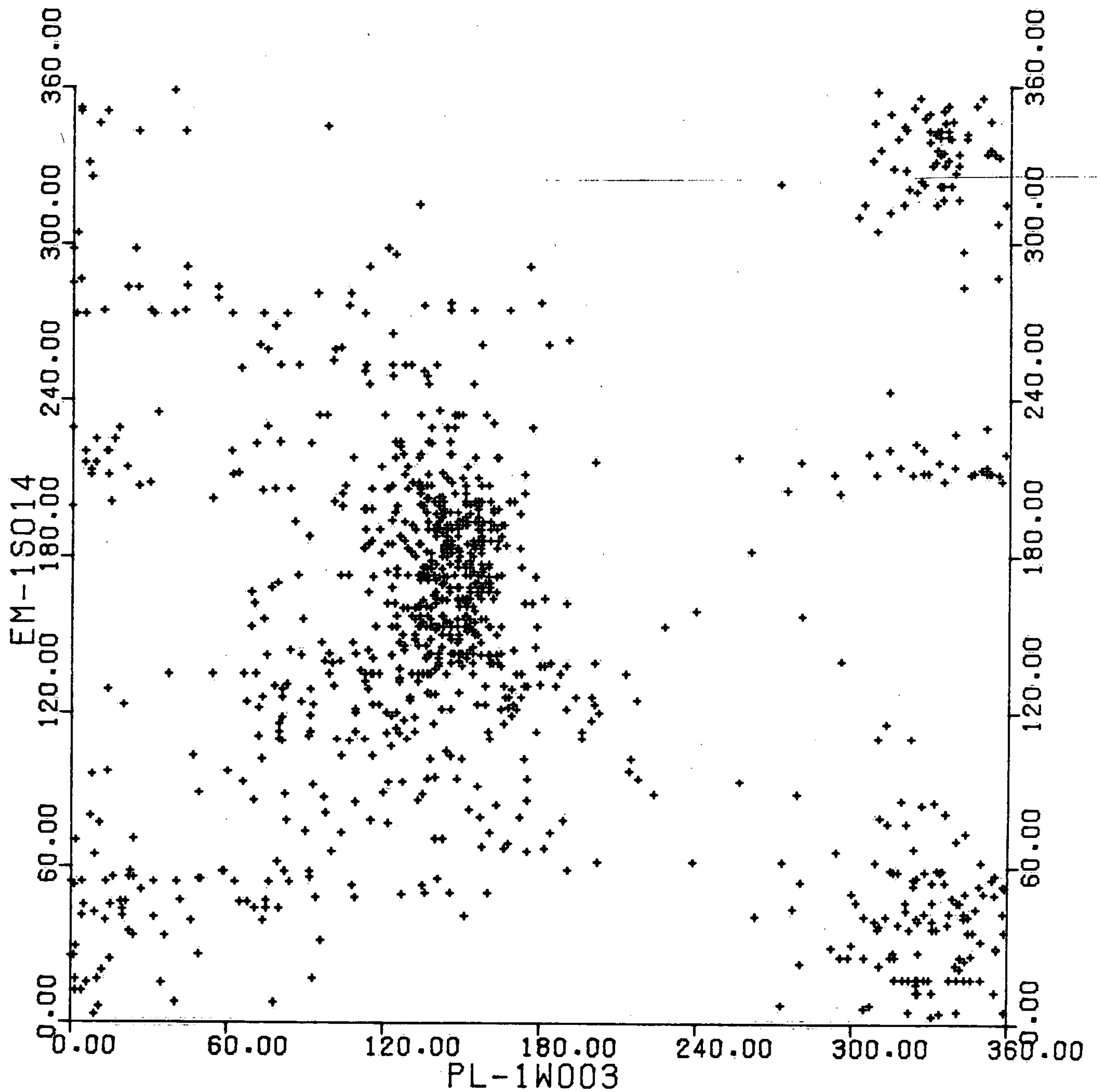
East 5 m M021 compared to West 3 m M021
Direction Difference Time Series
Figure 5.2.1.d -- Medium Flow Case



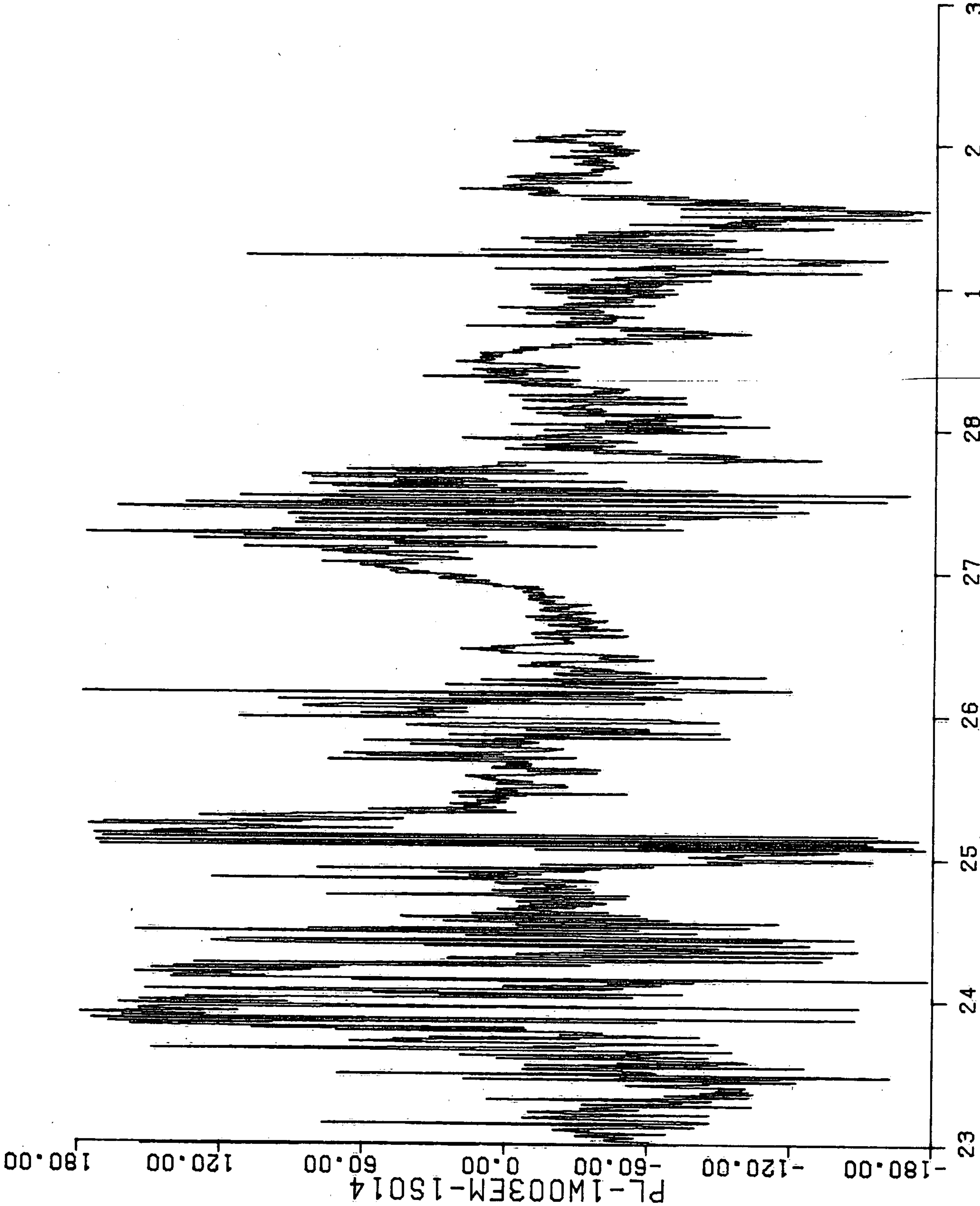
CATS 1 12 m compared to West 3 m M021
Speed Comparison
Figure 5.2.2.a -- Medium Flow Case



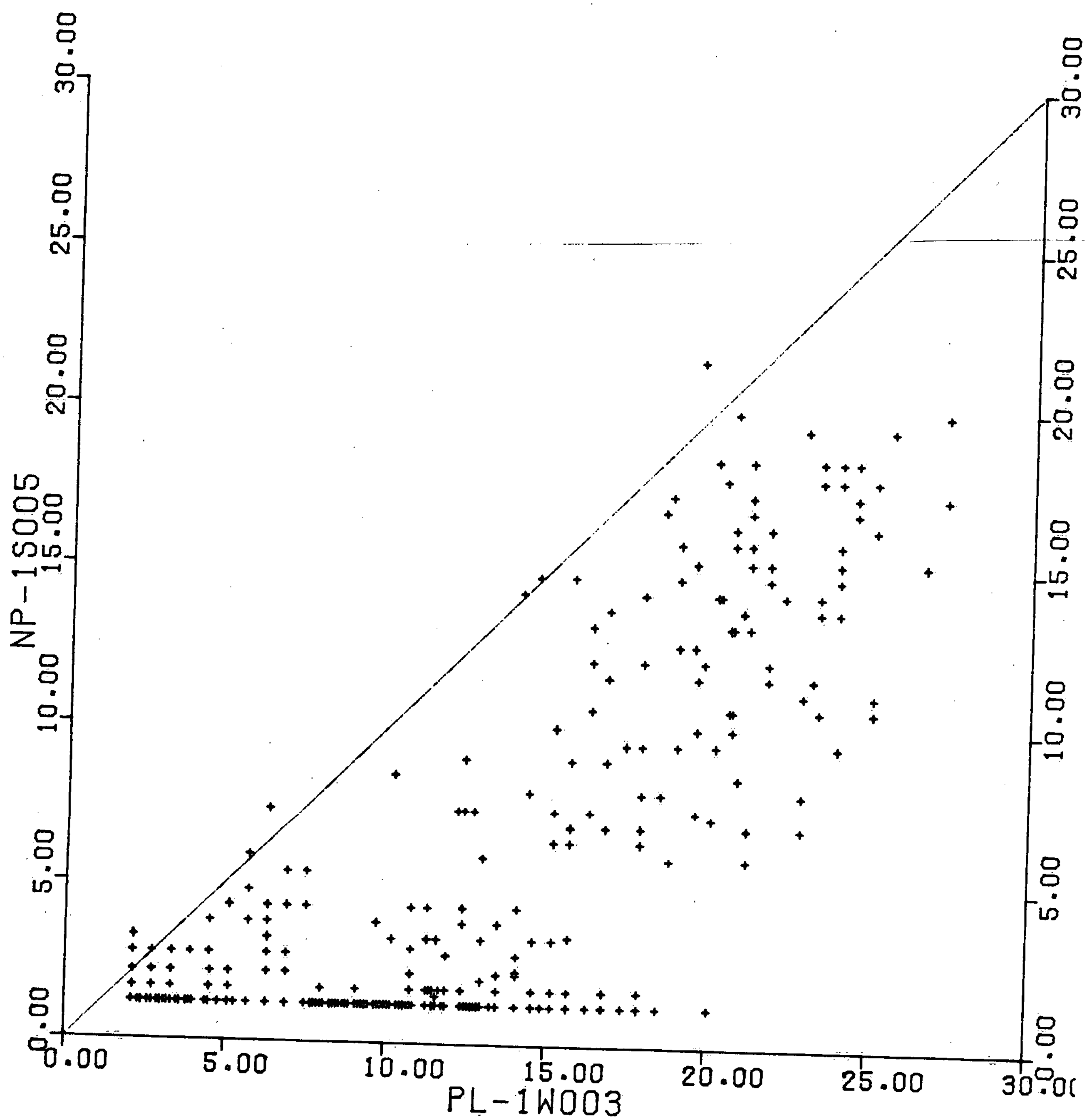
CATS 1 12 m compared to West 3 m M021
Speed Difference Time Series
Figure 5.2.2.b -- Medium Flow Case



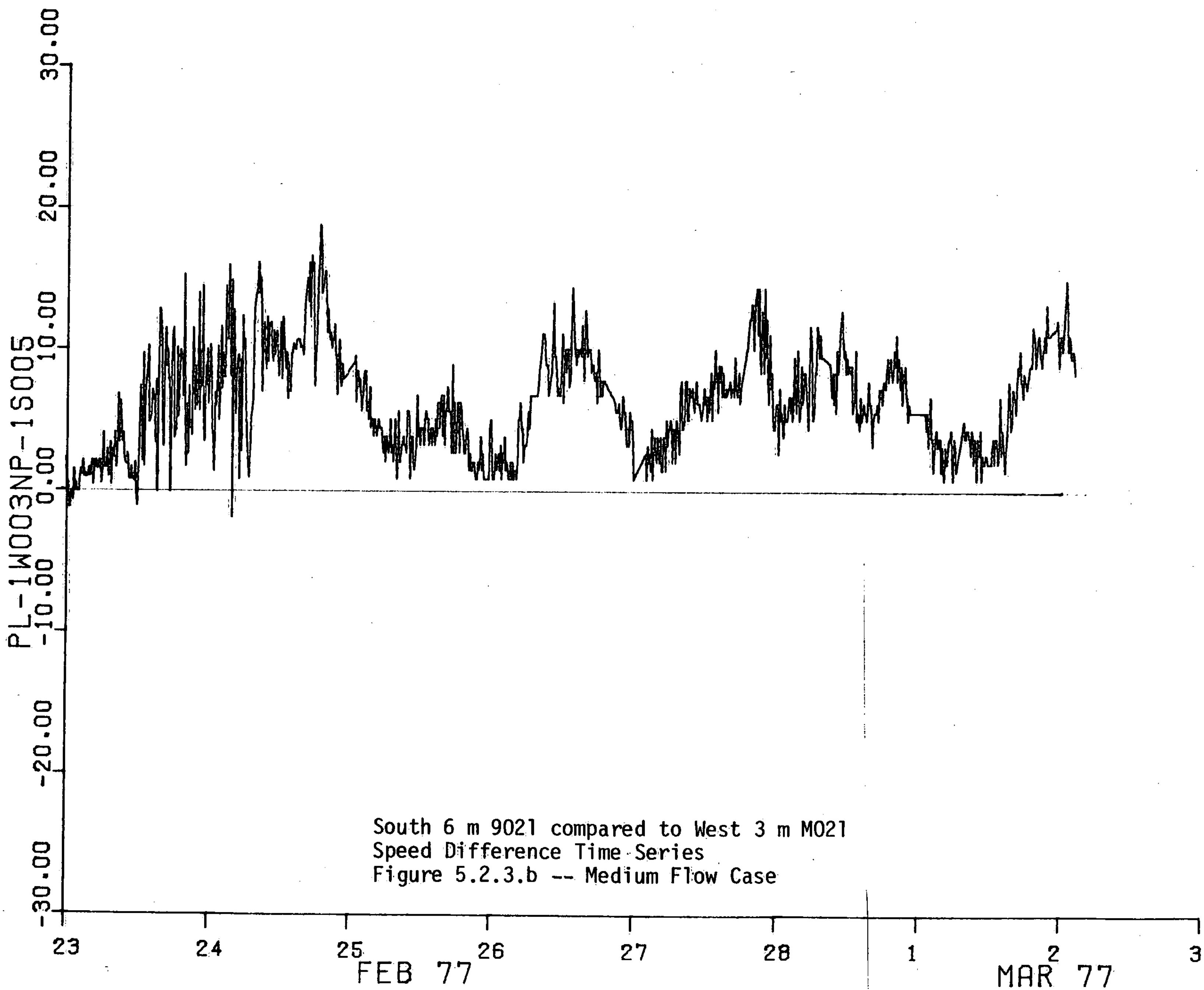
CATS 1 12 m compared to 3 m M021
Direction Comparison
Figure 5.2.2.c -- Medium Flow Case



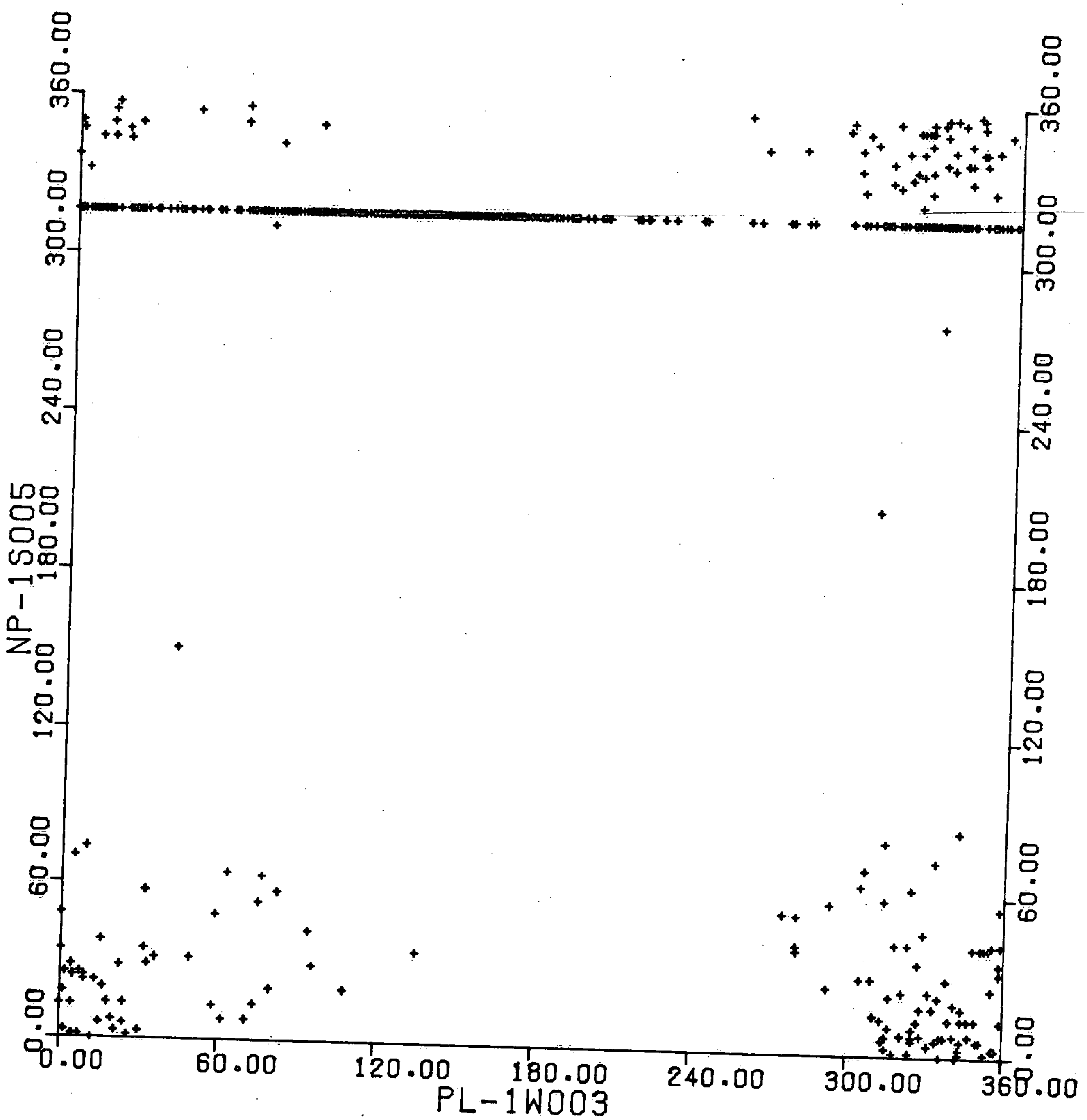
CATS 1 12 m compared to West 3 m M021
Direction Difference Time Series
Figure 5.2.2.d -- Medium Flow Case



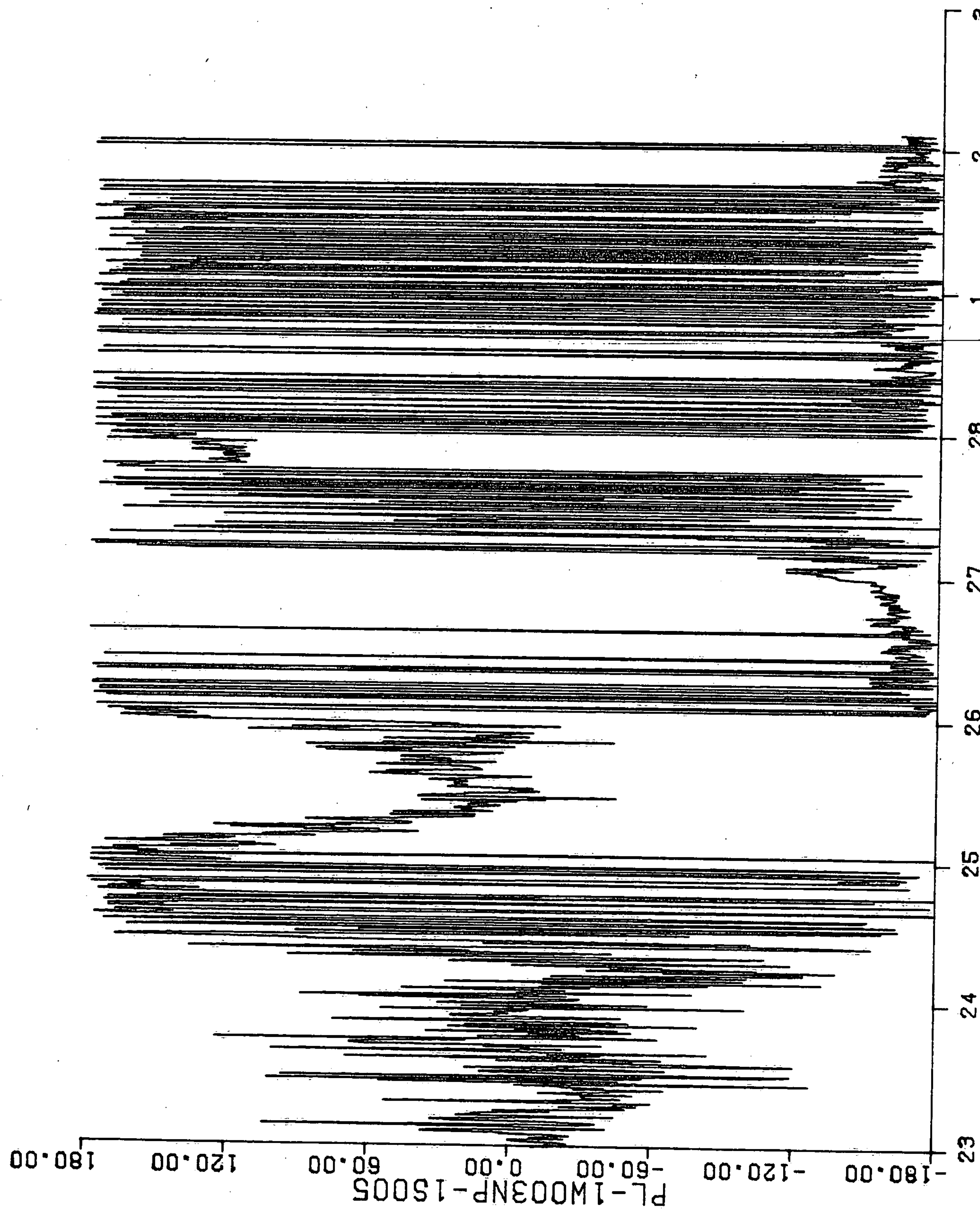
South 6 m 9021 compared to West 3 m M021
Speed Comparison
Figure 5.2.3.a -- Medium Flow Case



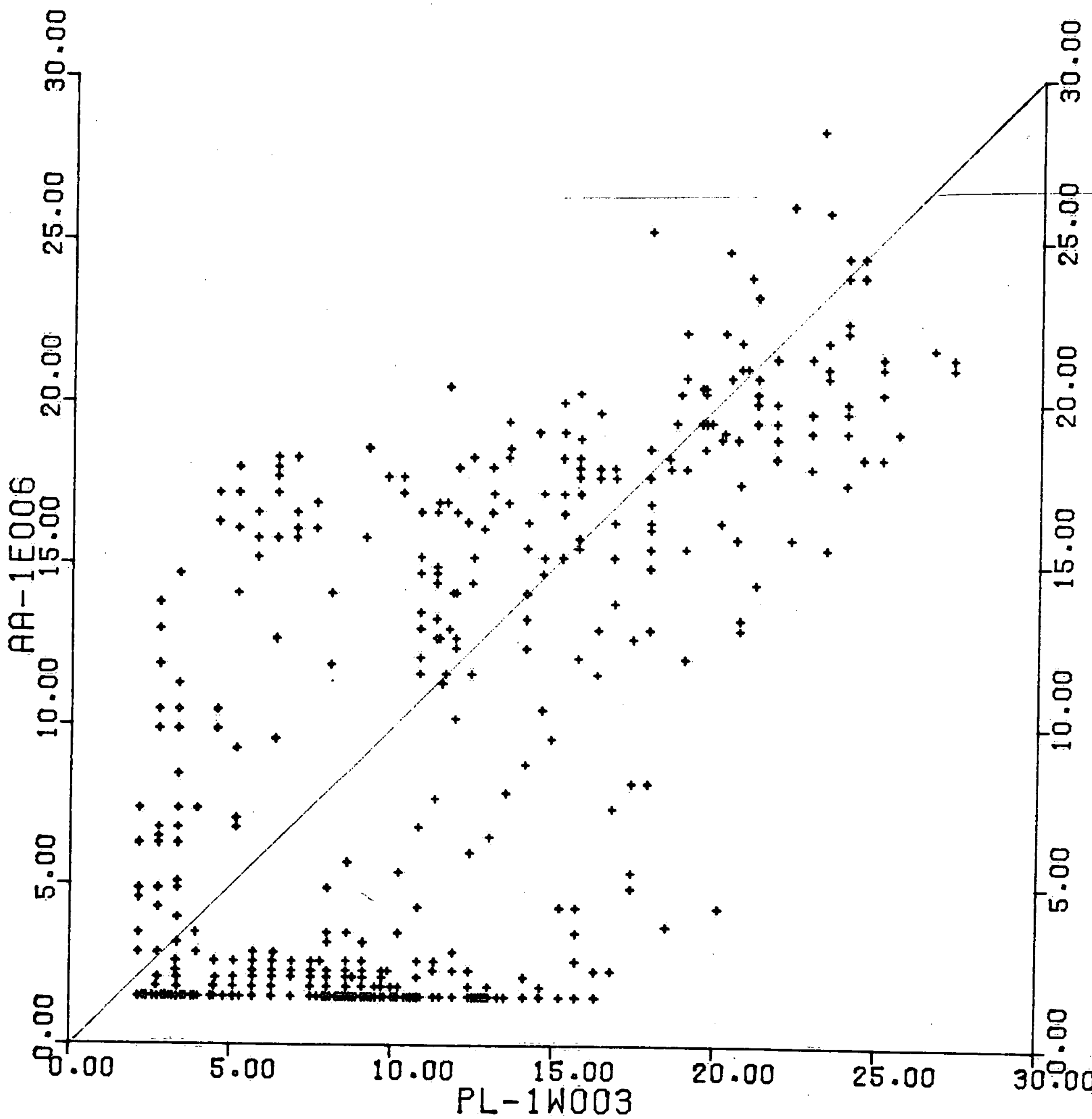
South 6 m 9021 compared to West 3 m M021
Speed Difference Time Series
Figure 5.2.3.b -- Medium Flow Case



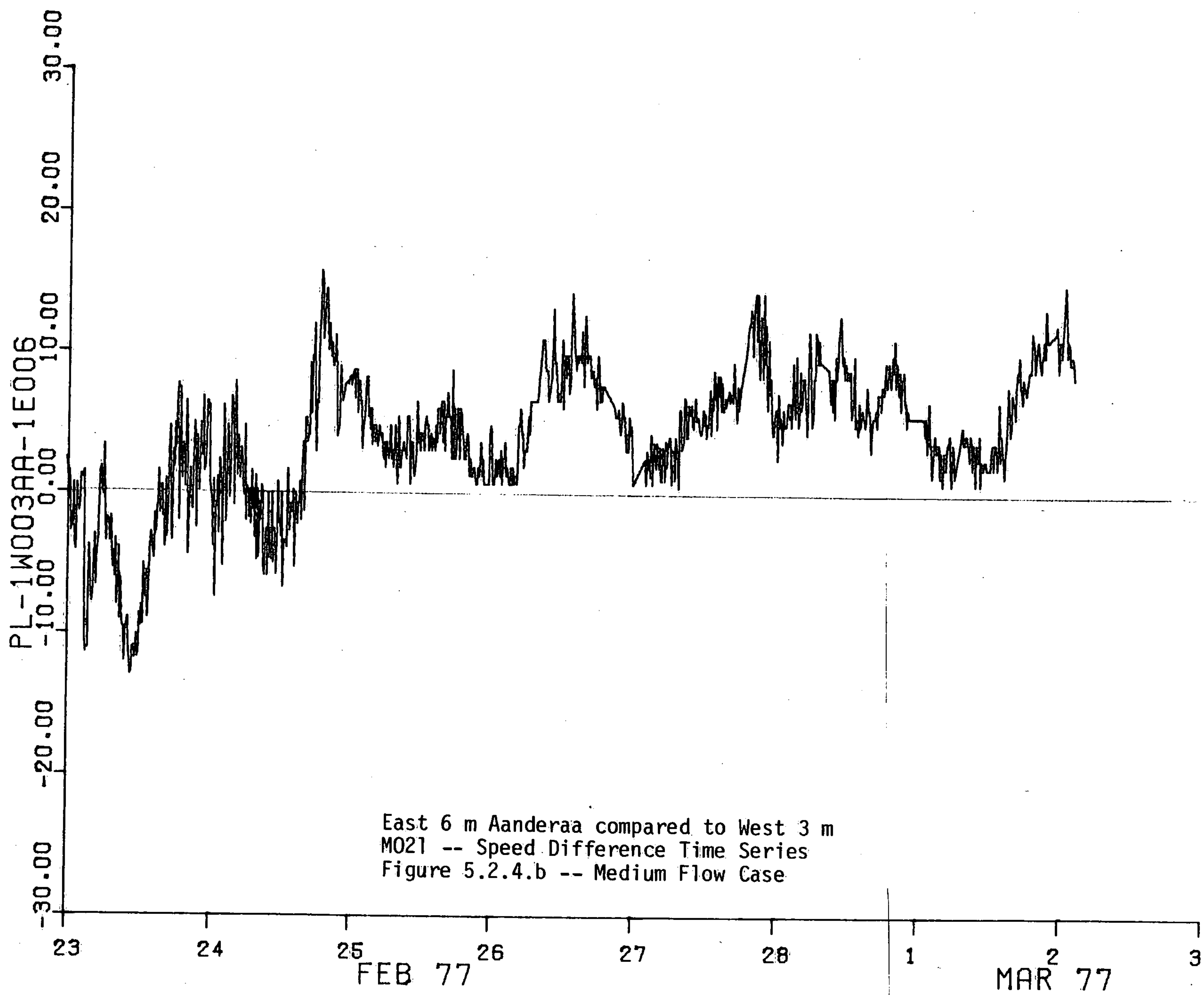
South 6 m 9021 compared to West 3 m M021
Direction Comparison
Figure 5.2.3.c -- Medium Flow Case



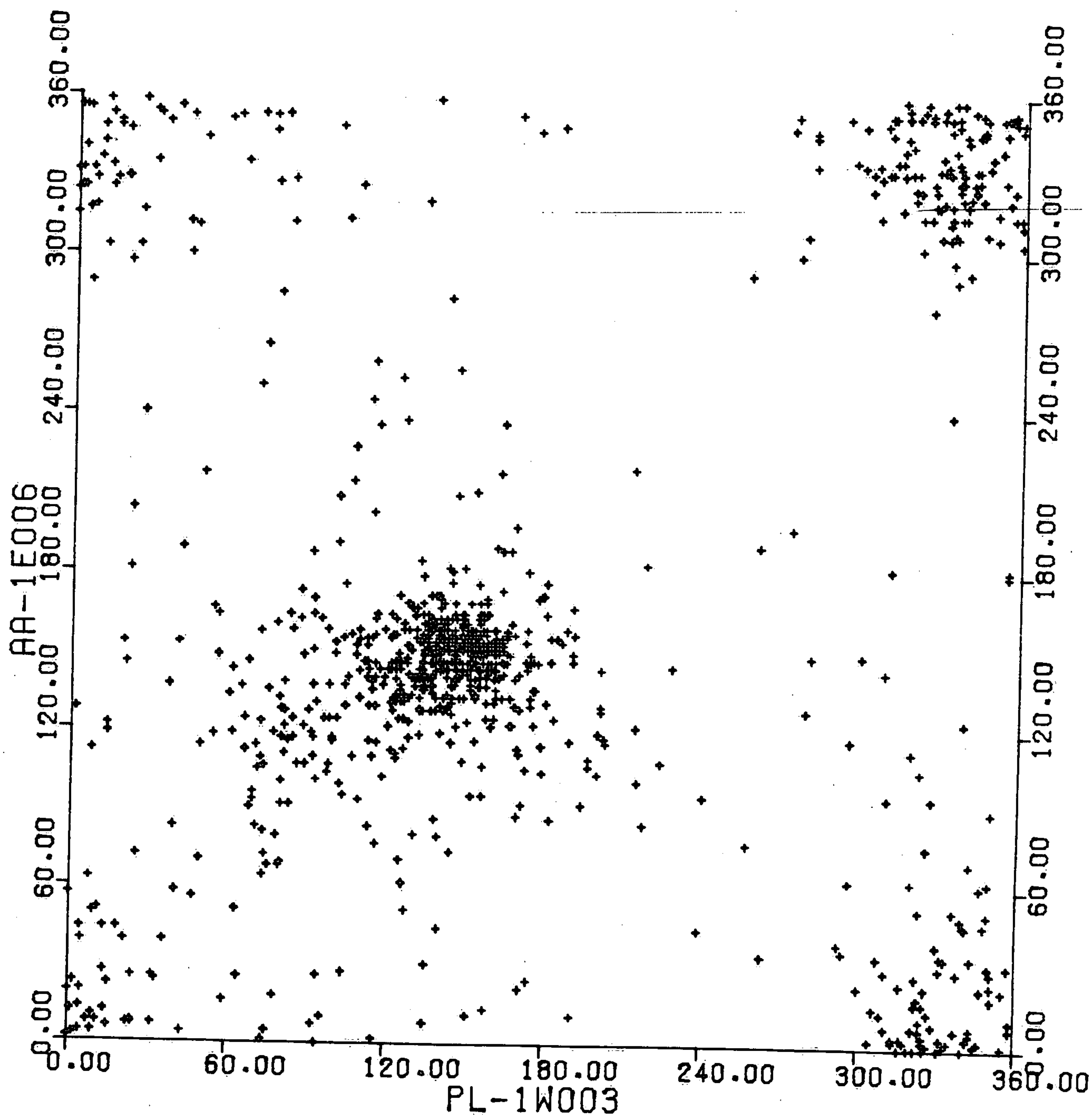
South 6 m 9021 compared to West 3 m M021
Direction Difference Time Series
Figure 5.2.3.d -- Medium Flow Case



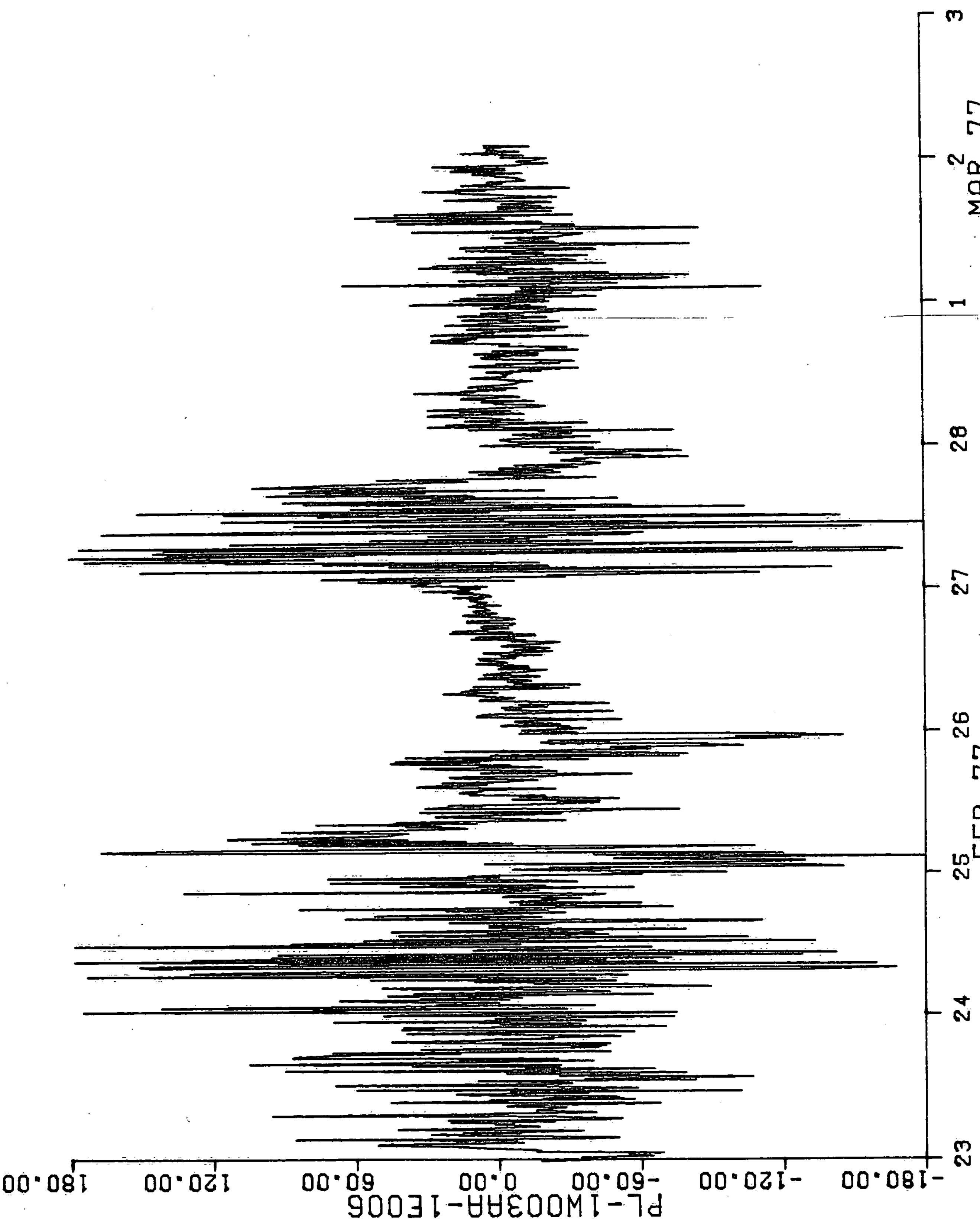
East 6 m Aanderaa compared to West 3 m
M021 -- Speed Comparison
Figure 5.2.4.a -- Medium Flow Case



East 6 m Aanderaa compared to West 3 m
M021 -- Speed Difference Time Series
Figure 5.2.4.b -- Medium Flow Case



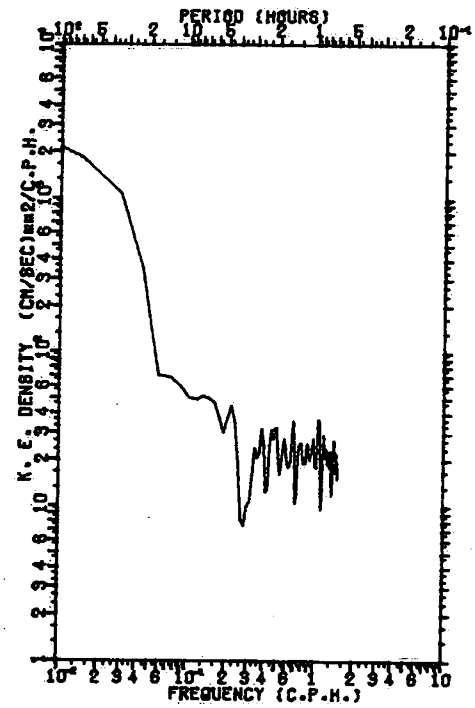
East 6 m Aanderaa compared to West 3 m
M021 -- Direction Comparison
Figure 5.2.4.c -- Medium Flow Case



East 6 m Aanderaa compared to West 3 m
M021 -- Direction Difference Time Series
Figure 5.2.4.d -- Medium Flow Case

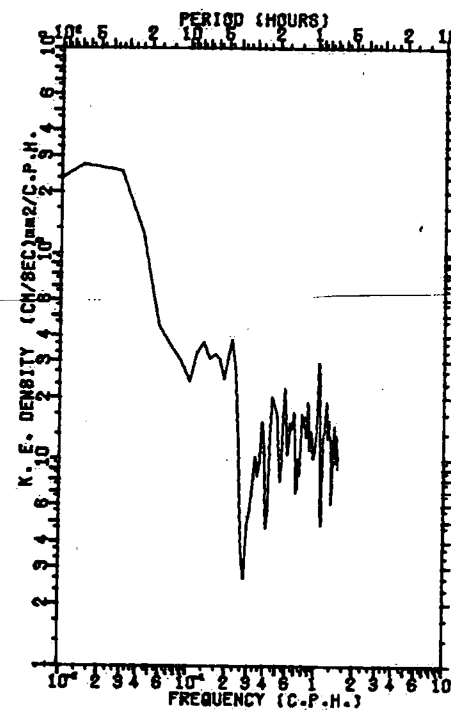
TOTAL KE FOR M021-3

FEB23 TO MAR 3



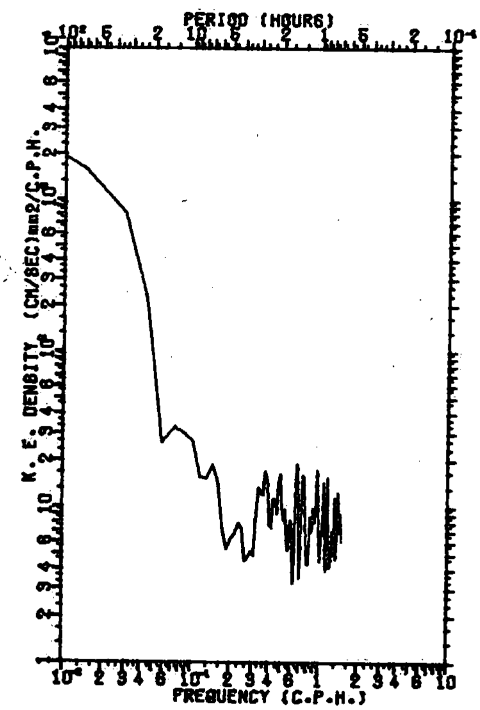
KE EAST COMPONENT M021-3

FEB23 TO MAR 3



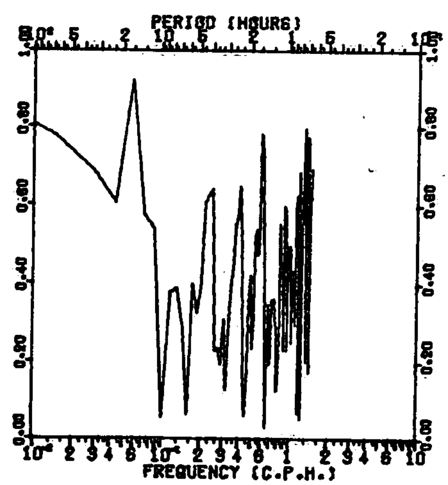
KE NORTH COMPONENT M021-3

FEB23 TO MAR 3

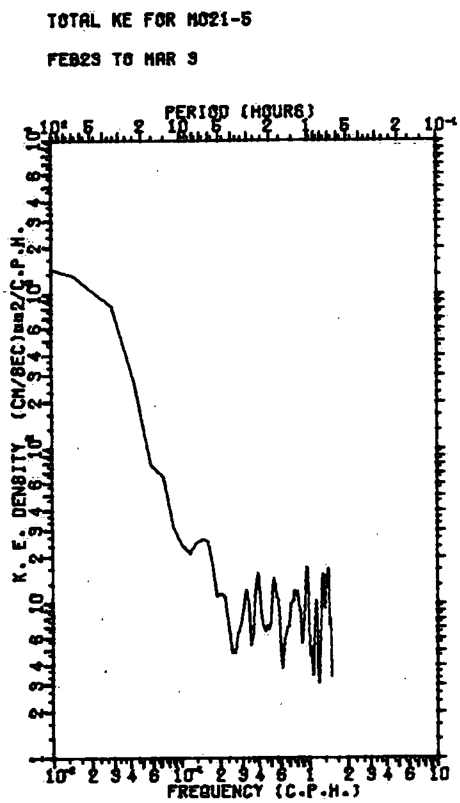


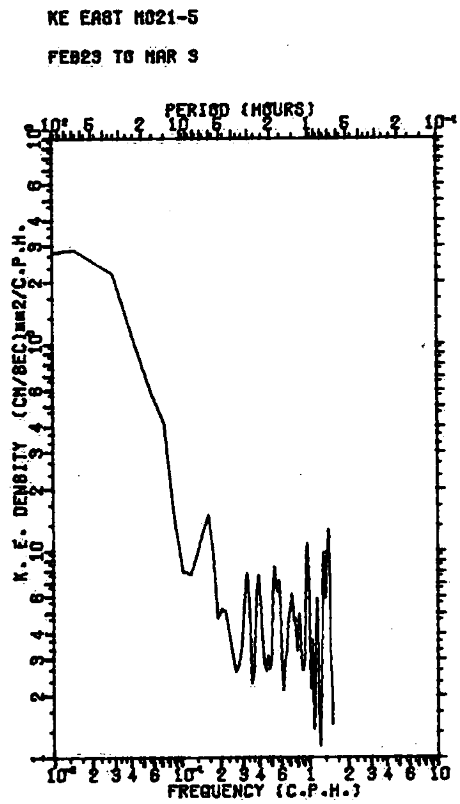
COHERENCE M021-3 NORTH AND EAST

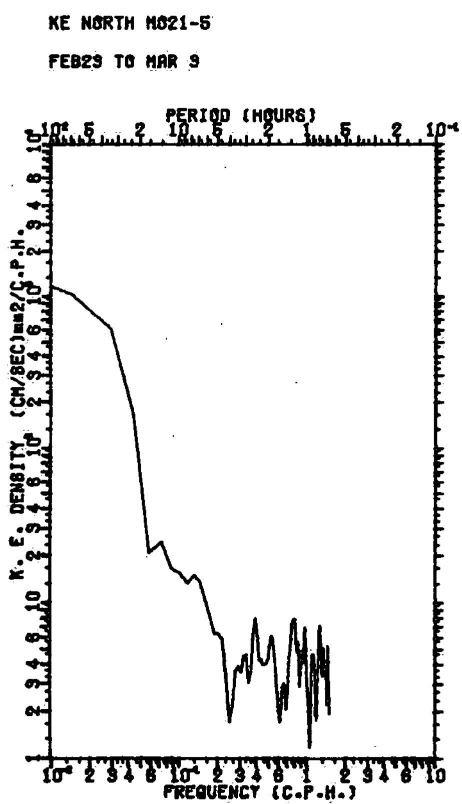
FEB23 TO MAR 3

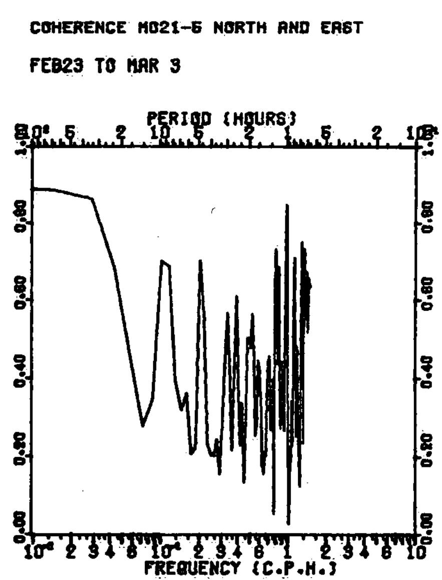


West 3 m M021
Medium Flow Case
Figure 5.2.5.a





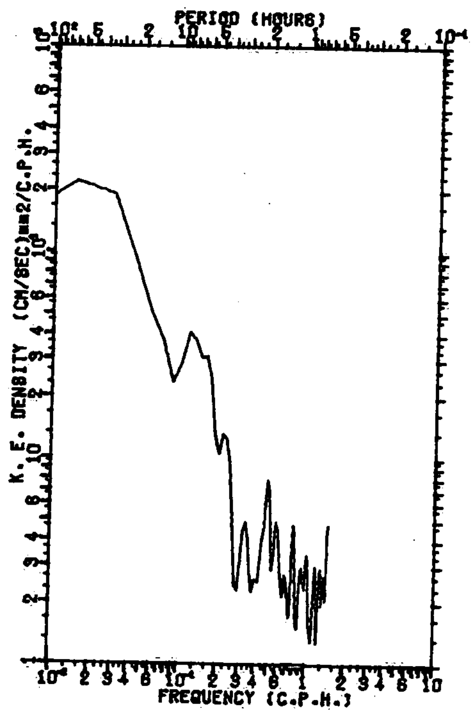




East 5 m M021
Medium Flow Case
Figure 5.2.5.b

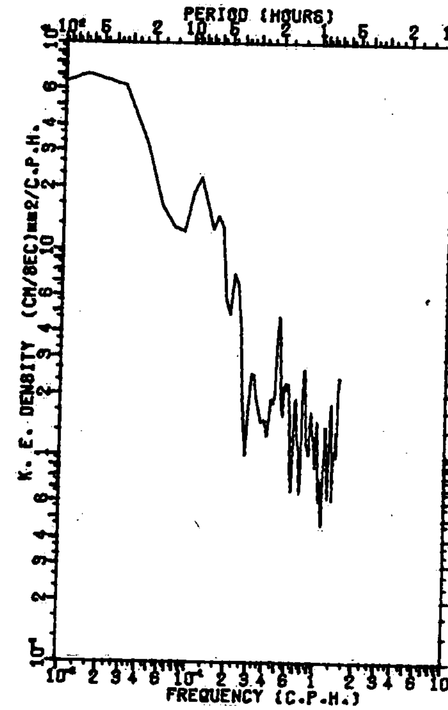
TOTAL KE FOR CATS1

FEB23 TO MAR 3



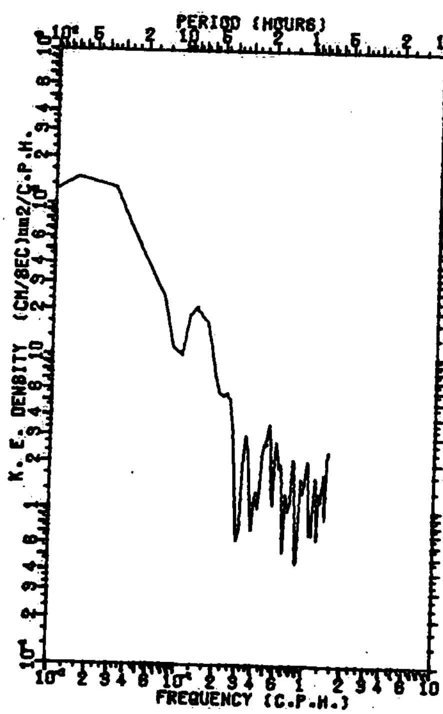
KE EAST CATS1

FEB23 TO MAR 3



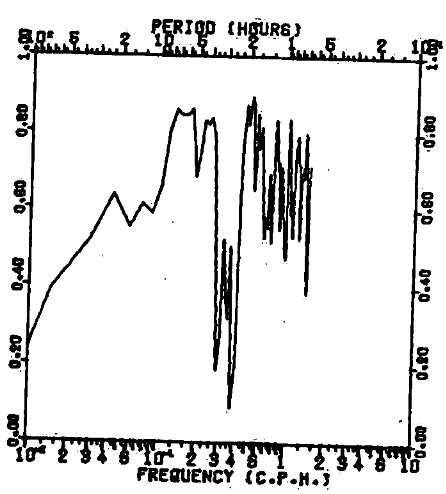
KE NORTH CATS1

FEB23 TO MAR 3

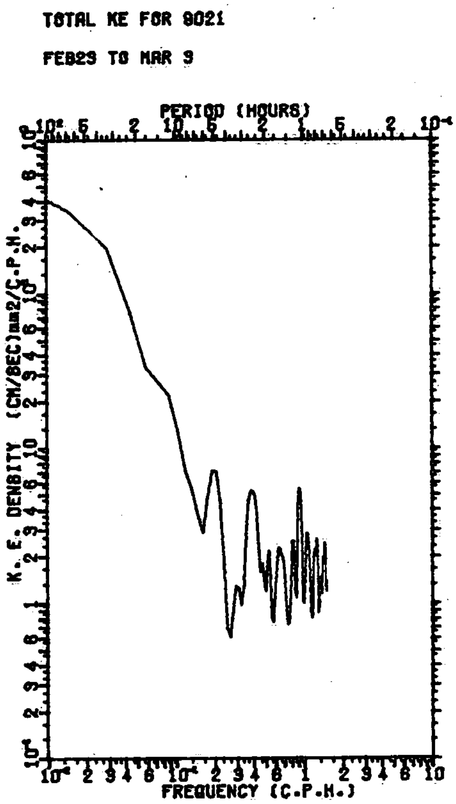


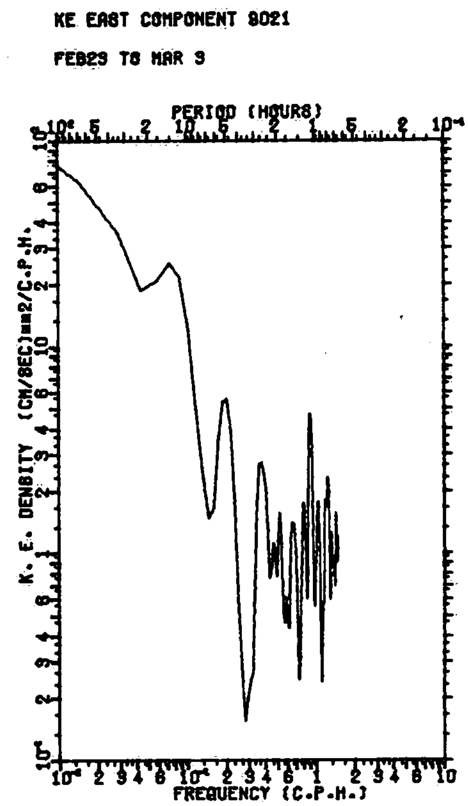
COHERENCE CATS1 NORTH AND EAST

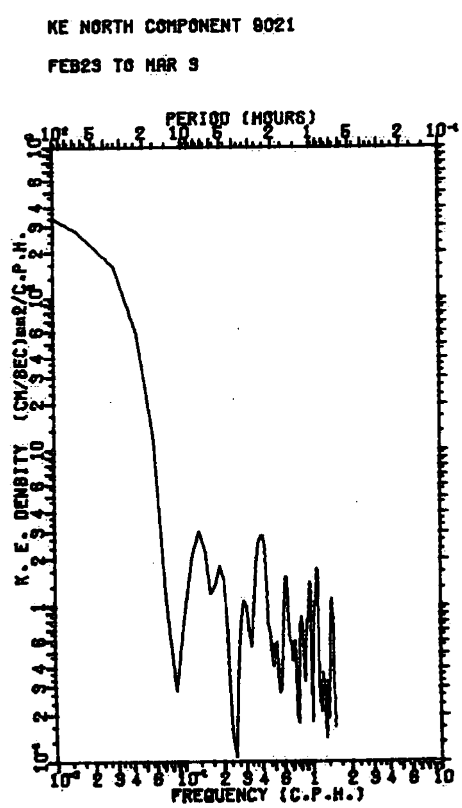
FEB23 TO MAR 3

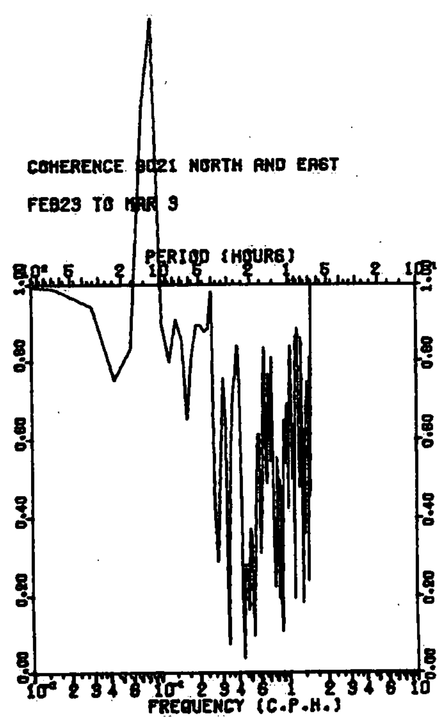


CATS 1 12 m
Medium Flow Case
Figure 5.2.5.c





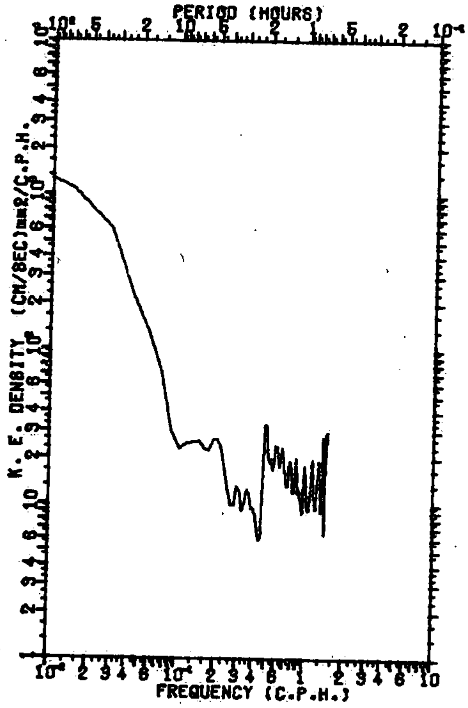




South 6 m 9021
Medium Flow Case
Figure 5.2.5.d

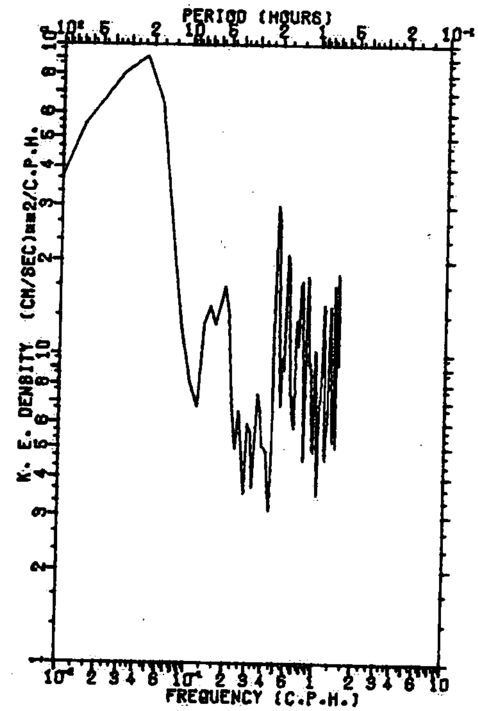
TOTAL KE FOR RCM-4

FEB29 TO MAR 3



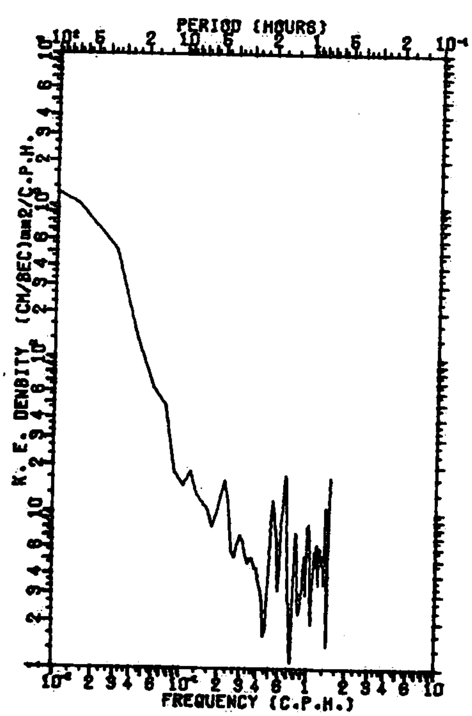
KE EAST COMPONENT RCM-4

FEB29 TO MAR 3



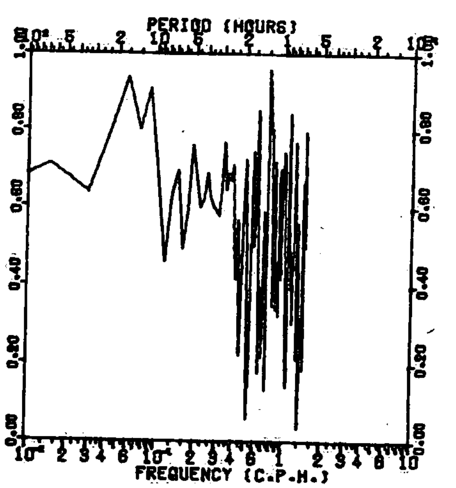
KE NORTH COMPONENT RCM-4

FEB29 TO MAR 3

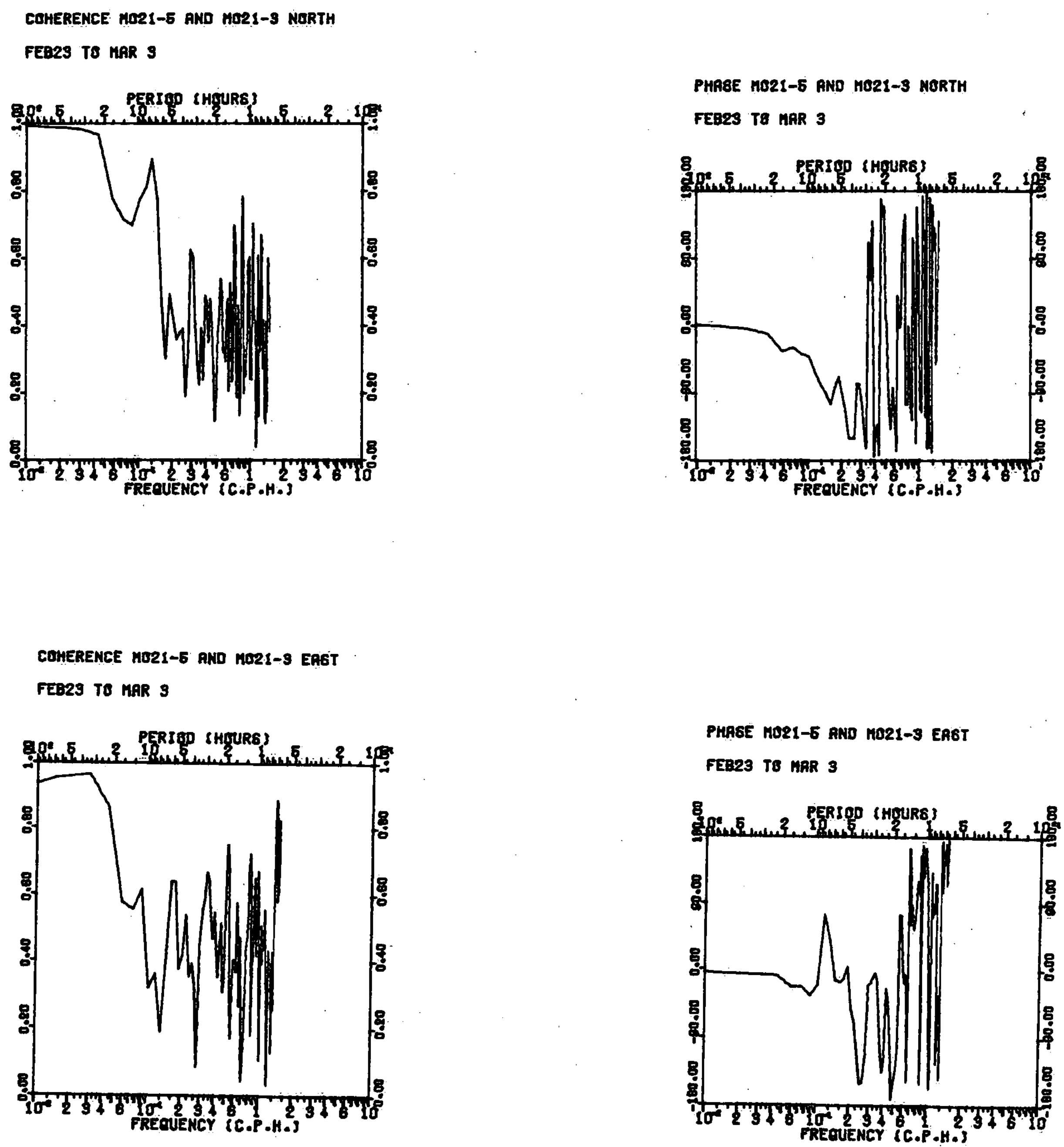


COHERENCE RCM-4 NORTH AND EAST.

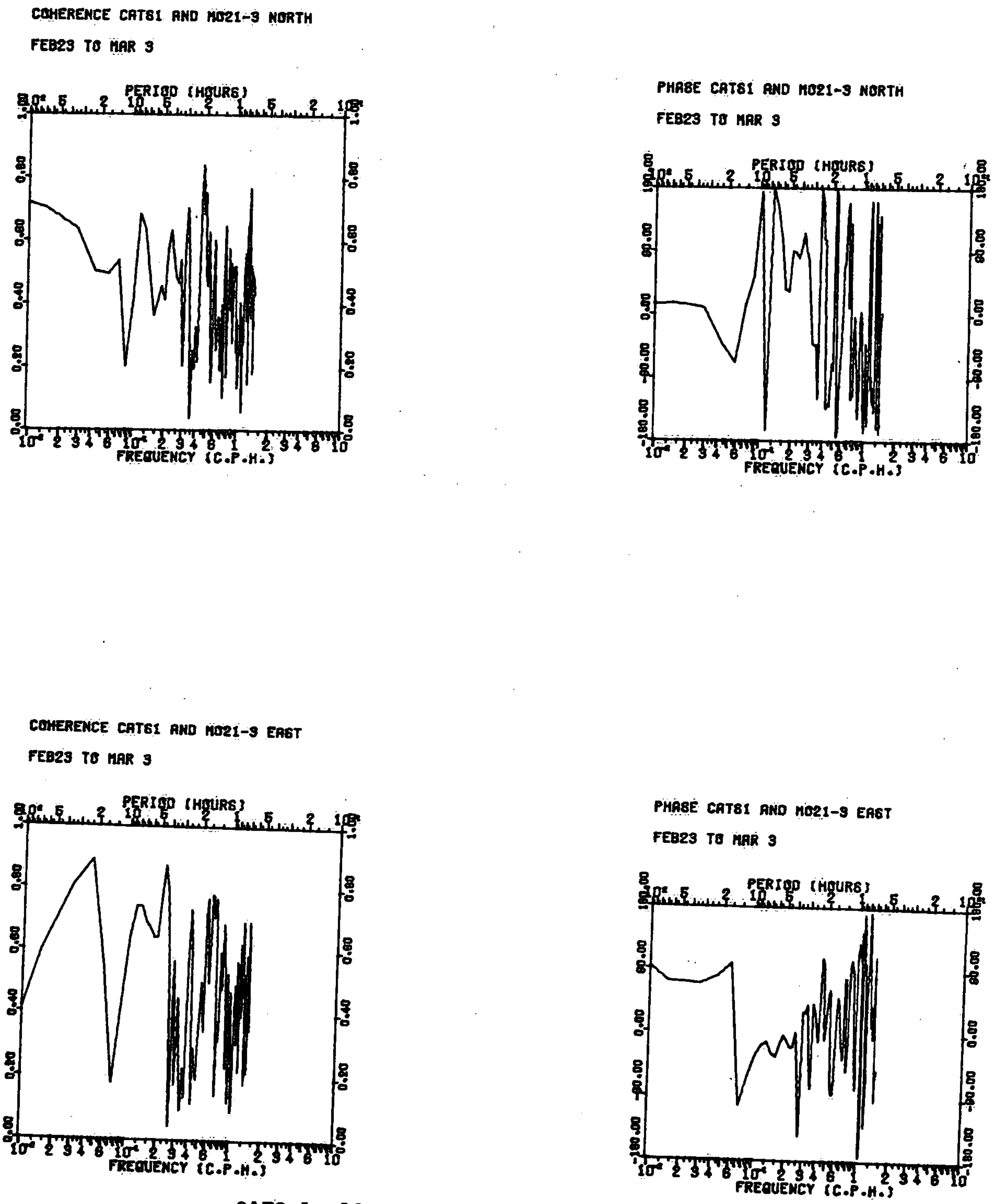
FEB29 TO MAR 3



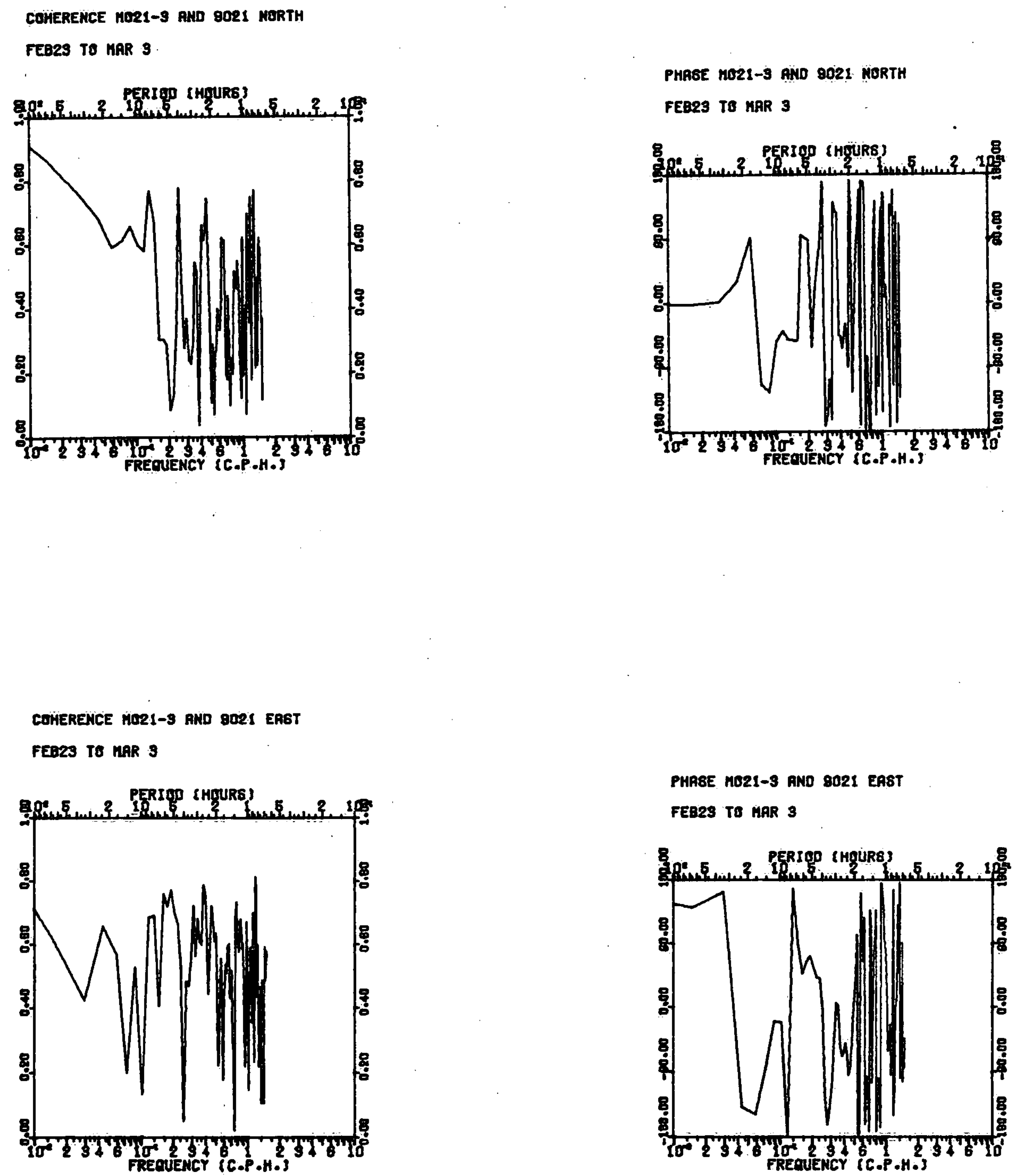
East 6 m Aanderaa
Medium Flow Case
Figure 5.2.5.e



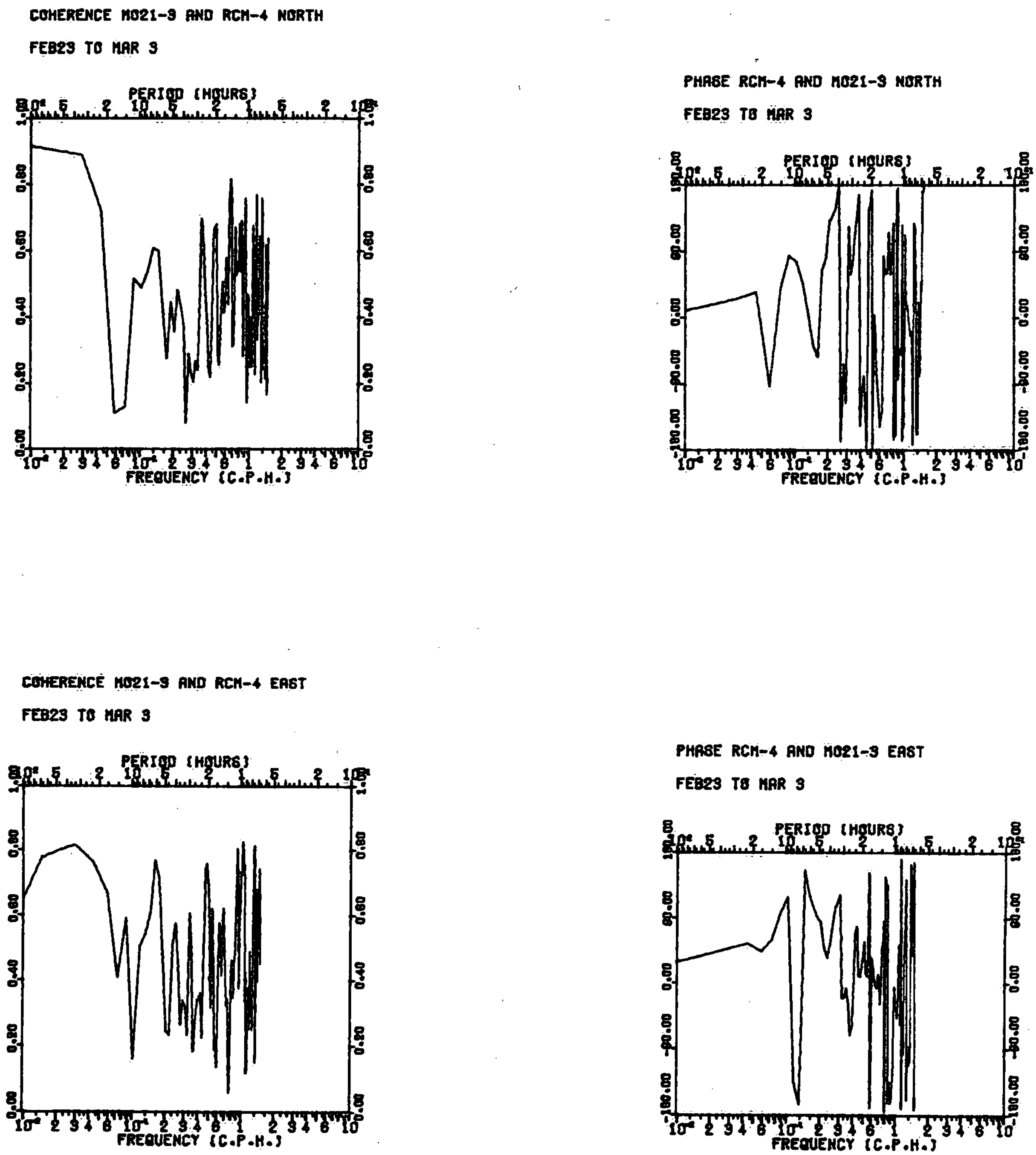
East 5 m M021 compared to West 3 m M021
Medium Flow Case
Figure 5.2.6.a



CATS 1 12 m compared to West 3 m M021
Medium Flow Case
Figure 5.2.6.b



South 6 m 9021 compared to West 3 m M021
Medium Flow Case
Figure 5.2.6.c



East 6 m Aanderaa compared to West 3 m
M021 -- Medium Flow Case
Figure 5.2.6.d

5 m M021 gives 3 to 5 times the 9021 result, and the 3 m M021 about 10 times the 9021 result. The 6 m Aanderaa current meter total kinetic energy spectral density result agrees well with the 5 m M021 for this case.

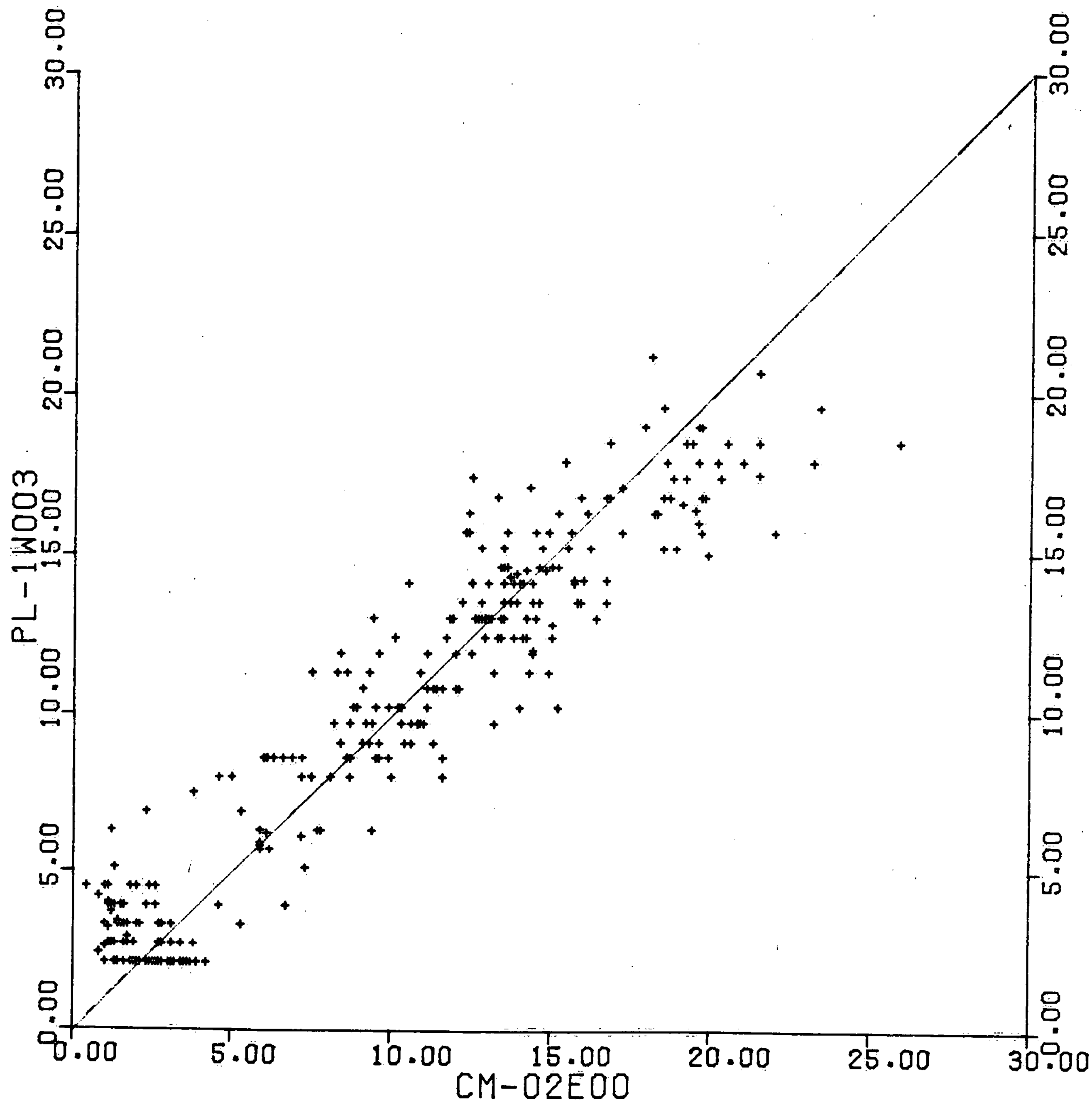
5.3 Mixed Flow Case: 16 - 25 March 1977

By the middle of March, the ensemble of functioning instruments available for comparison had changed. A second 3 m Plessey M021, on the east side of the platform was introduced. The 5 m M021, 6 m 9021, and 6 m Aanderaa each failed by this point. The Kootenay VAPS/CMI sensor was introduced for two portions of this period. The data sets are compared against the VAPS/CMI sensor for the two intervals 15 to 17 March and 21 to 23 March in Figures 5.3.1.a, b,c,d through 5.3.3.a to d and 5.3.4.a to d through 5.3.6.a to d.

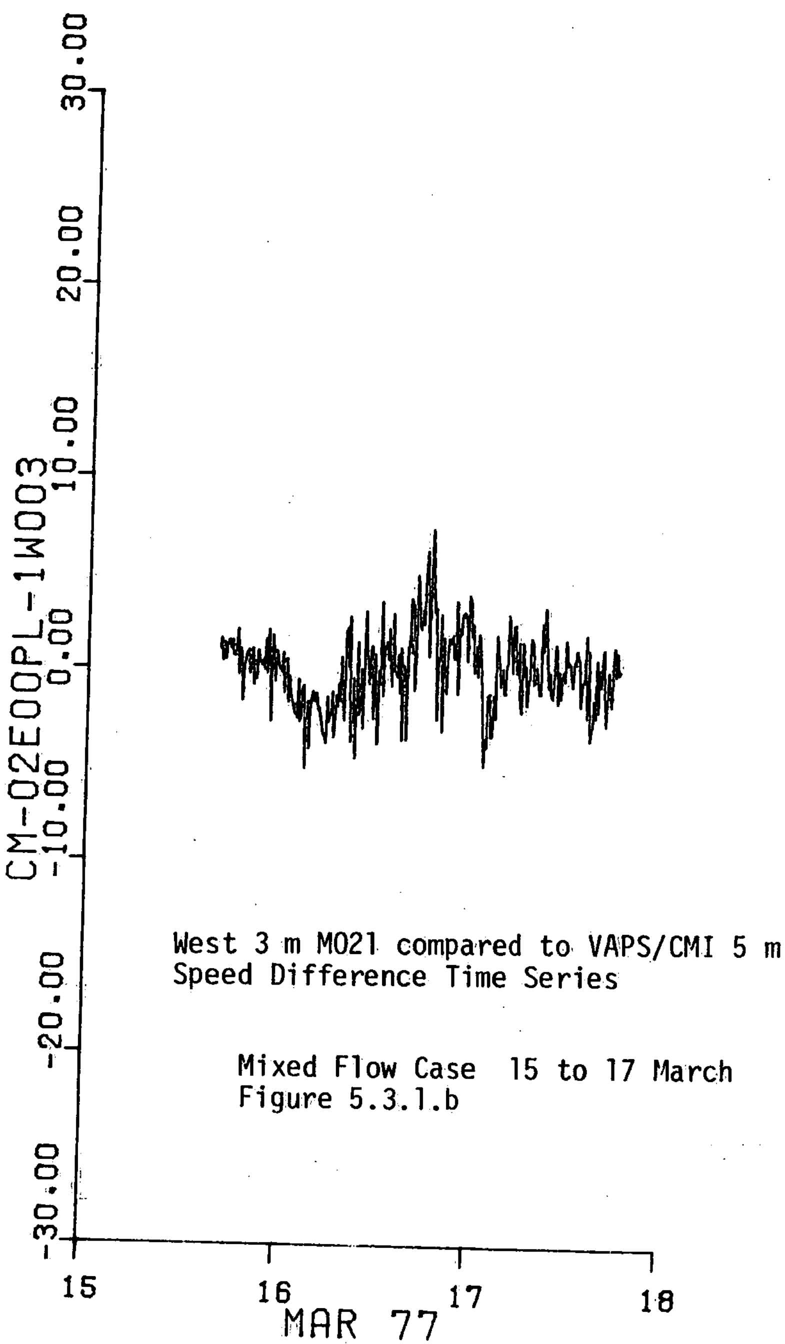
The data for the first set shows the M021 current meters to compare quite favourably to the VAPS/CMI in speed and less well with direction. There appears to be both bias and dynamic differences between the comparisons of direction for the two 3 m M021 meters. The CATS 1 meter shows lower speeds than the instruments higher in the water column.

The second interval in the mixed flow period shows the 3 m M021 instruments to have recorded much higher speeds than the VAPS/CMI sensor. Comparing Figures 5.3.4.b, 5.b, 6.b -- the speed difference time series shows that the M021 are near replicates, and that the CATS 1 difference plot shows similar characteristics up to 1900 on 22 March. It is interesting to note that the direction difference time series stabilize after this time (Figures 5.3.4.d, 5.d, 6.d).

The statistical analysis results for the two 3 m M021 current meters and the CATS 1 are presented in Figures 5.3.7.a to c, and 5.3.8.a and b. The total kinetic energy spectral density plots for the 3 m M021 current meters are near replicates, as are those for the north components. The east components differ by a factor of 2. The total K.E. spectral density for the CATS 1 data is a factor of 5 smaller than that for the

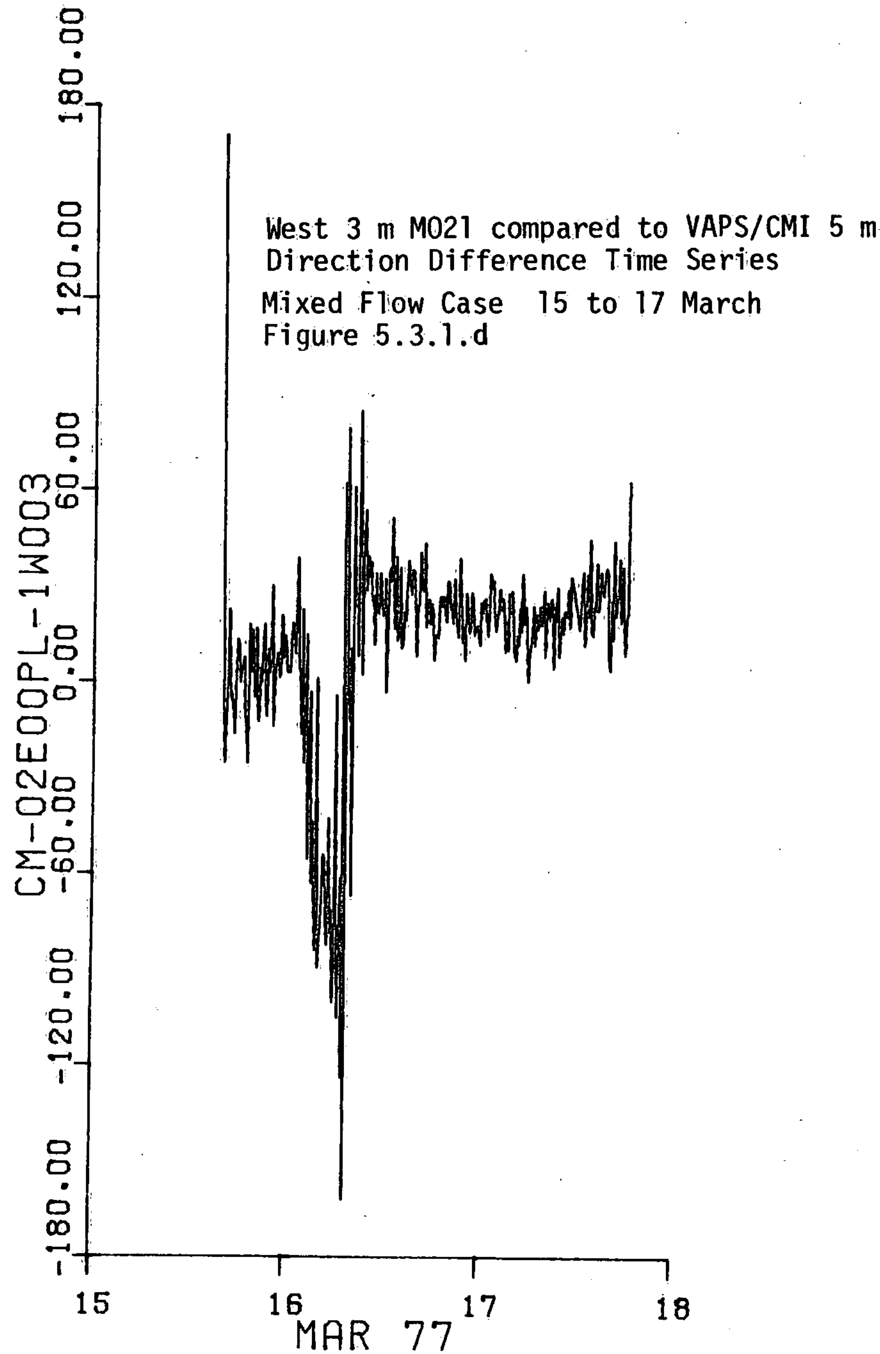


West 3 m M021 compared to VAPS/CMI 5 m
Mixed Flow Case 15 to 17 March
Figure 5.3.1.a -- Speed Comparison



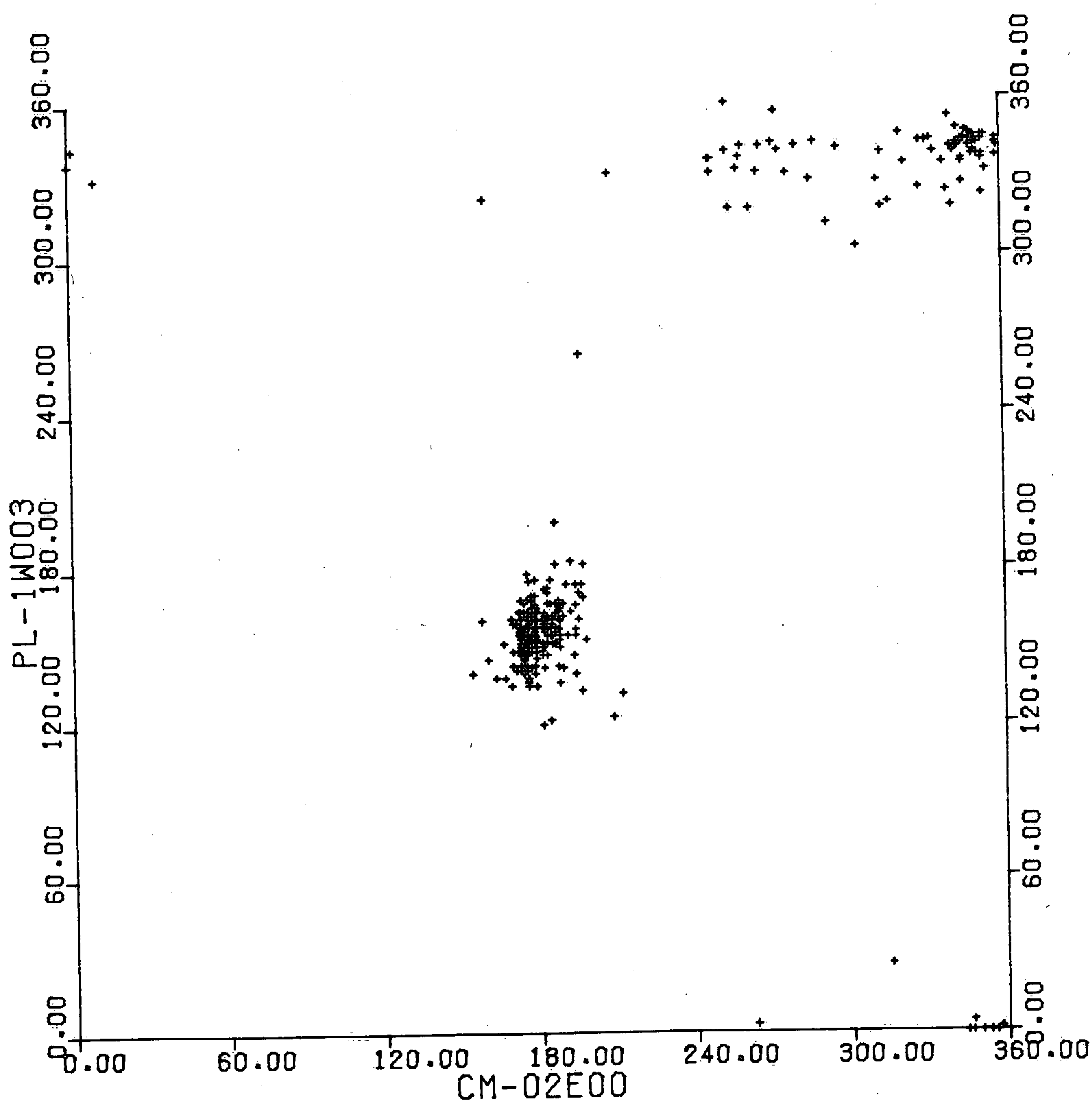
West 3 m M021 compared to VAPS/CMI 5 m
Speed Difference Time Series

Mixed Flow Case 15 to 17 March
Figure 5.3.1.b

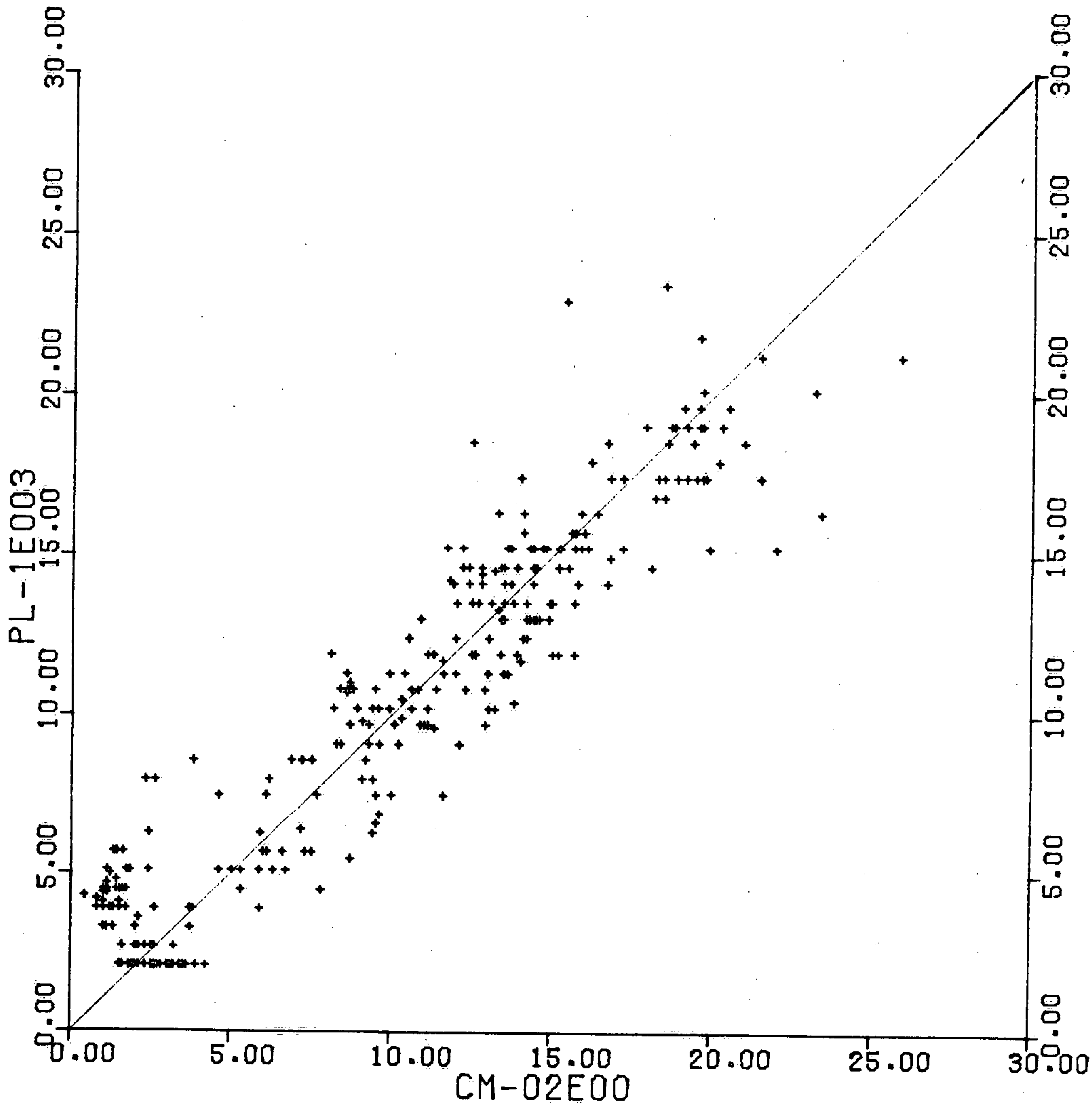


West 3 m M021 compared to VAPS/CMI 5 m
Direction Difference Time Series

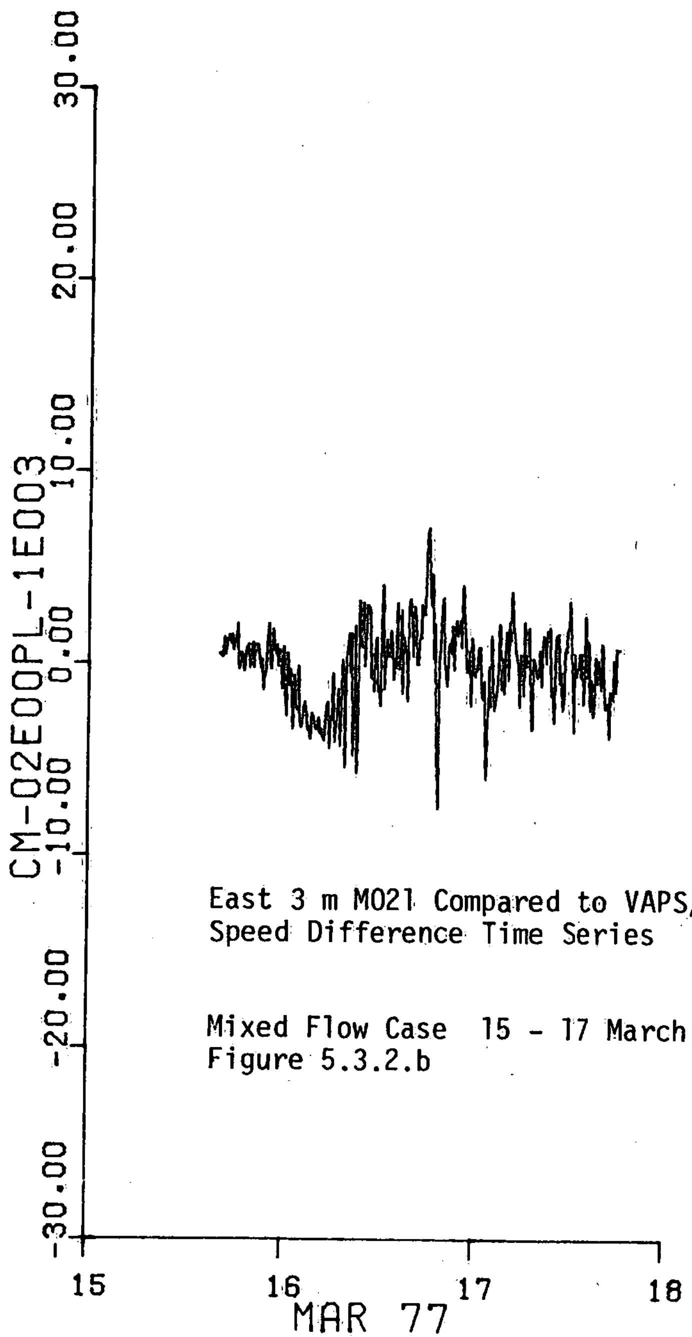
Mixed Flow Case 15 to 17 March
Figure 5.3.1.d



West 3 m M021 compared to VAPS/CMI
Mixed Flow Case 15 - 17 March
Figure 5.3.1.c -- Direction Comparison

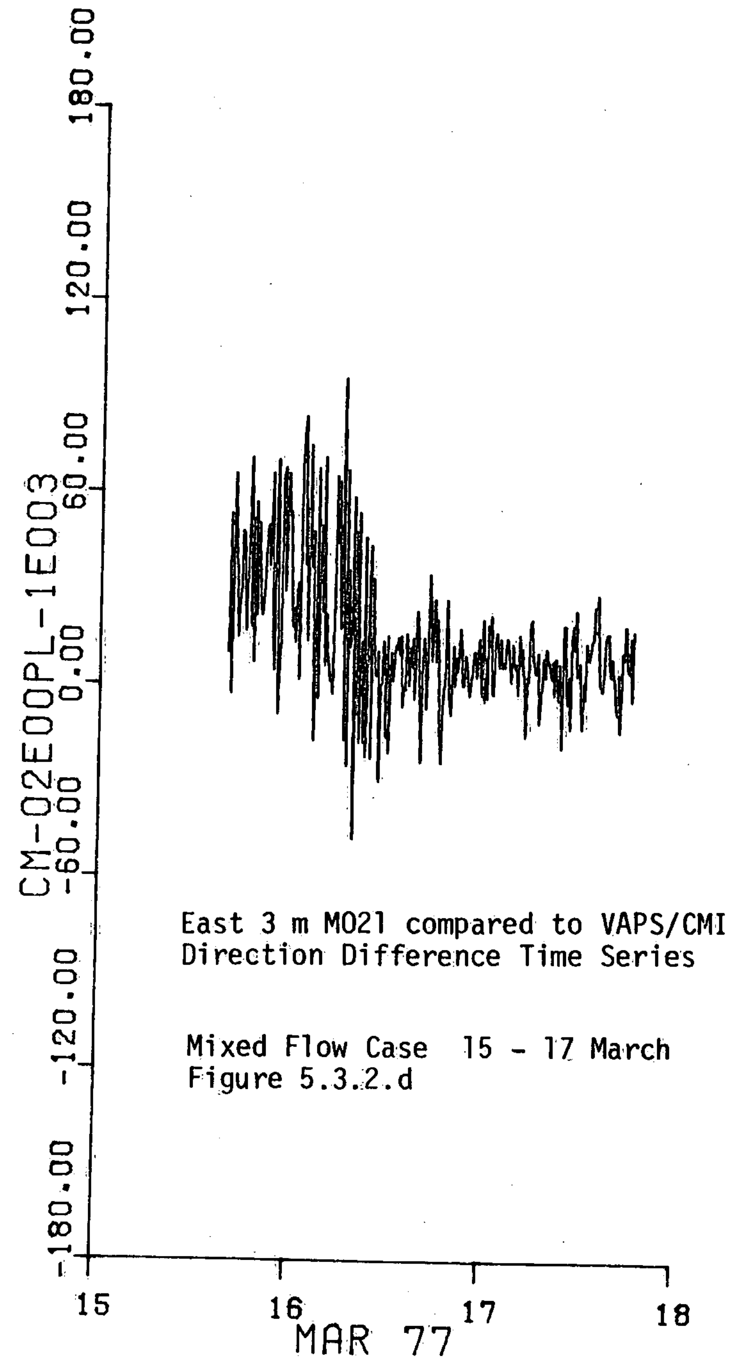


East 3 m M021 compared to VAPS/CMI
Mixed Flow Case 15 - 17 March
Figure 5.3.2.a -- Speed Comparison



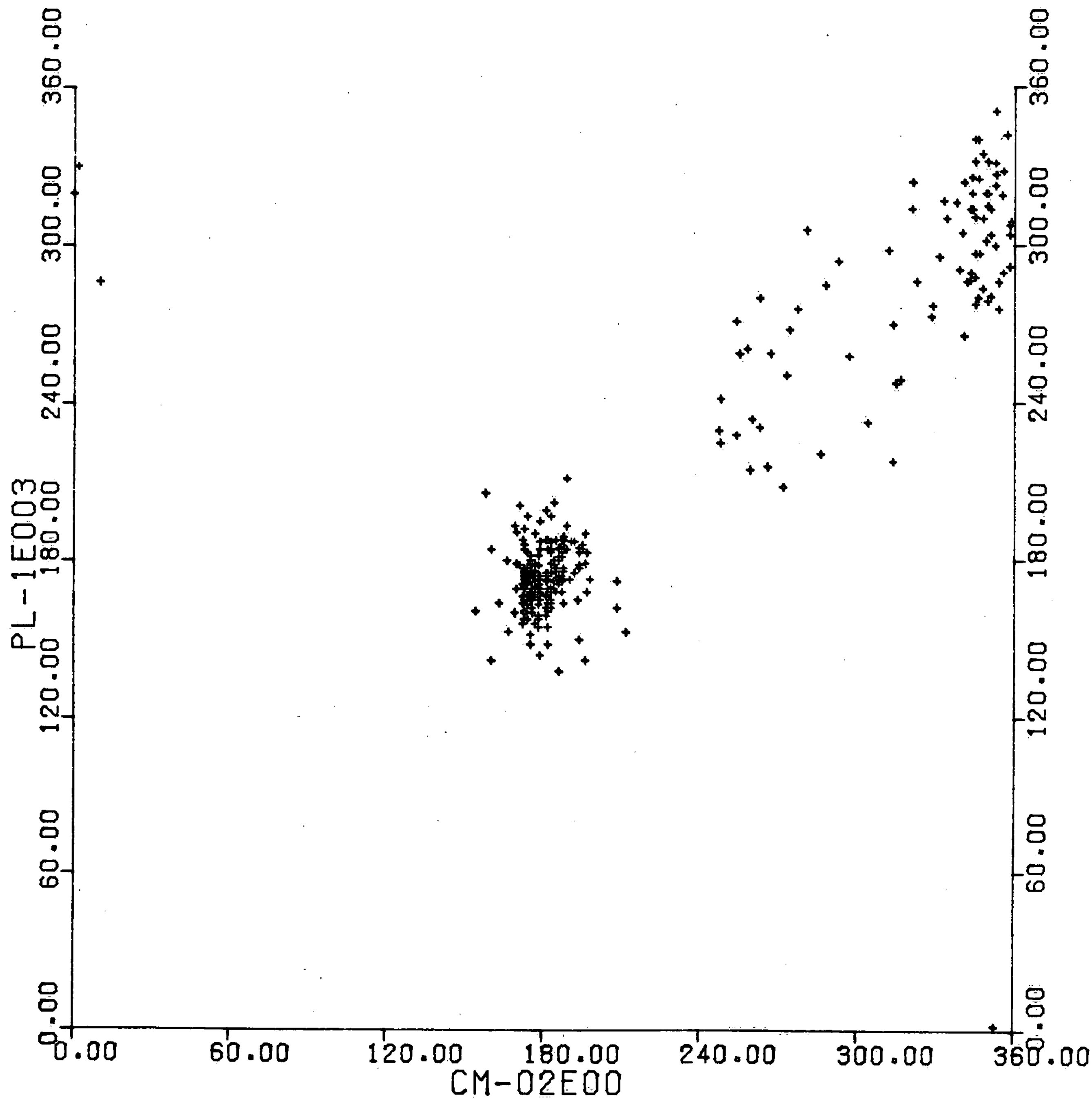
East 3 m M021 Compared to VAPS/CMI
Speed Difference Time Series

Mixed Flow Case 15 - 17 March
Figure 5.3.2.b

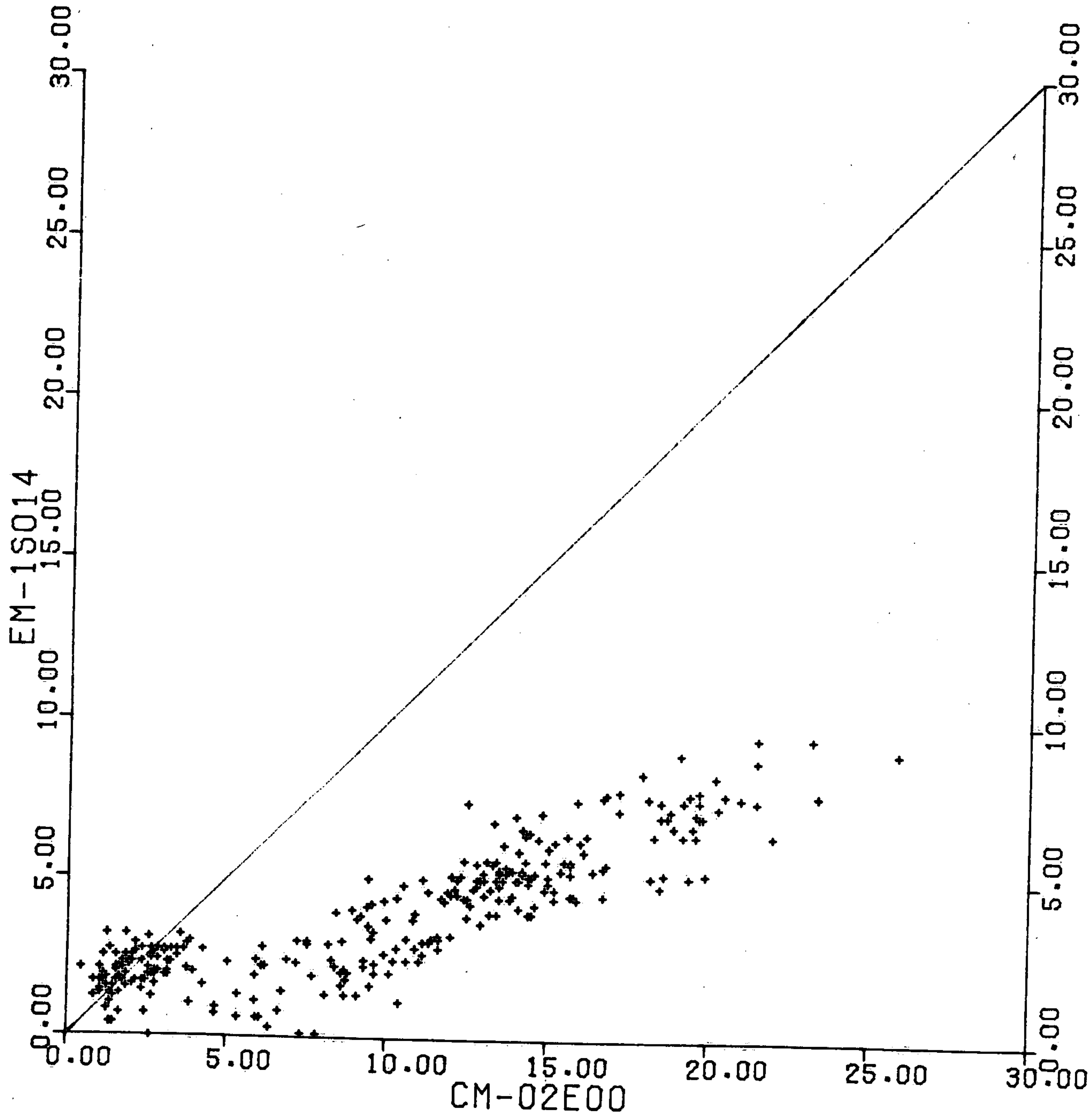


East 3 m M021 compared to VAPS/CMI
Direction Difference Time Series

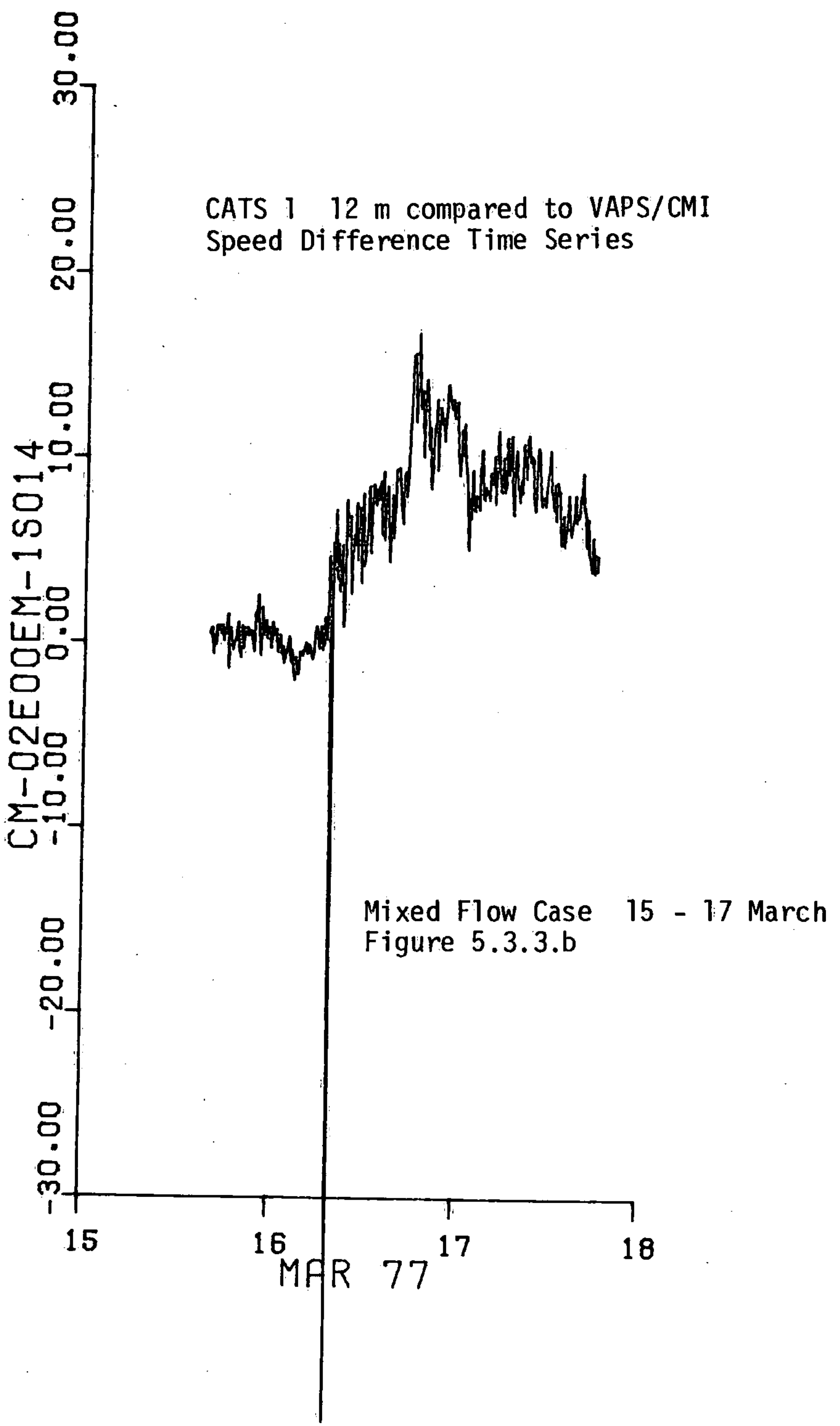
Mixed Flow Case 15 - 17 March
Figure 5.3.2.d



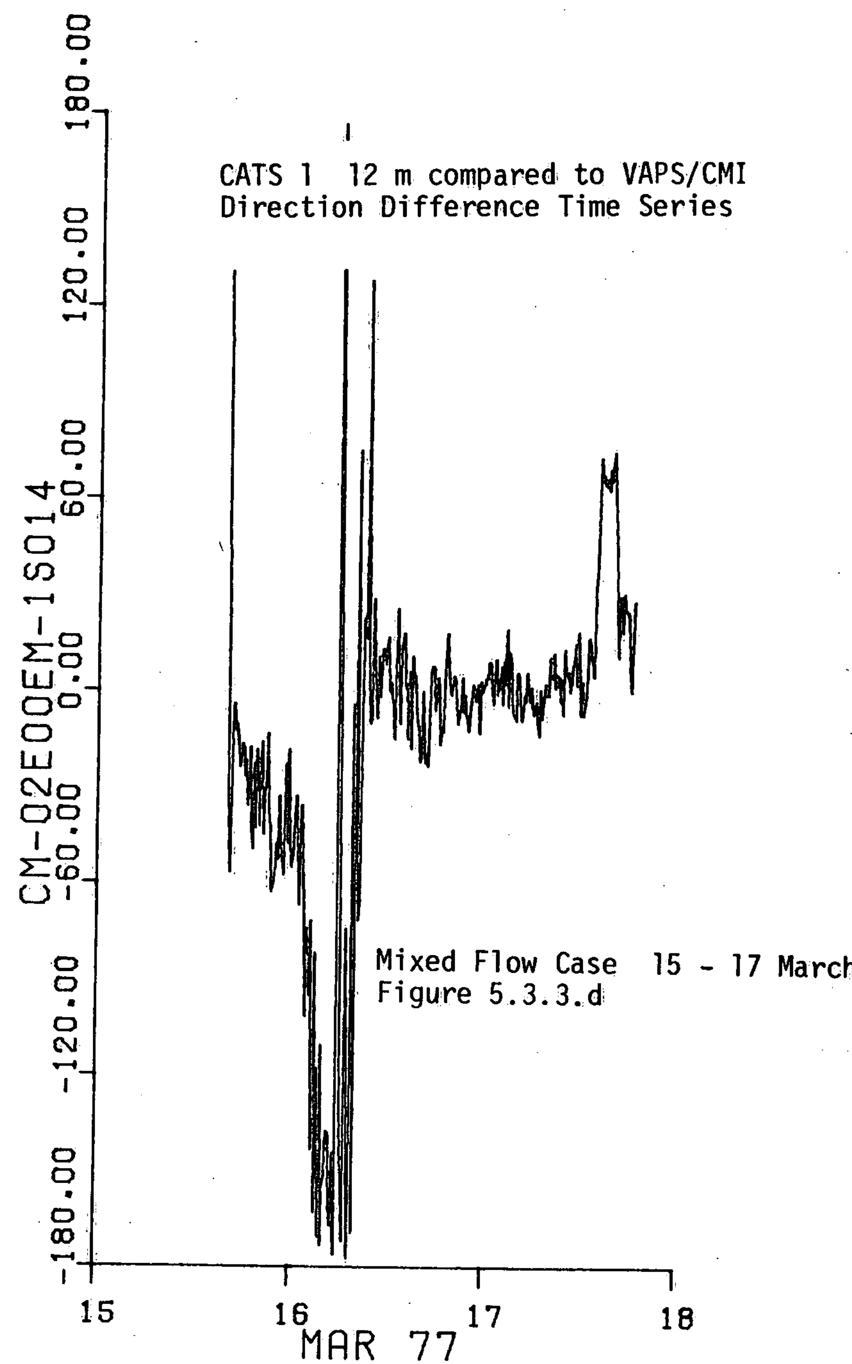
East 3 m M021 compared to VAPS/CMI
Mixed Flow Case 15 - 17 March
Figure 5.3.2.c -- Direction Comparison



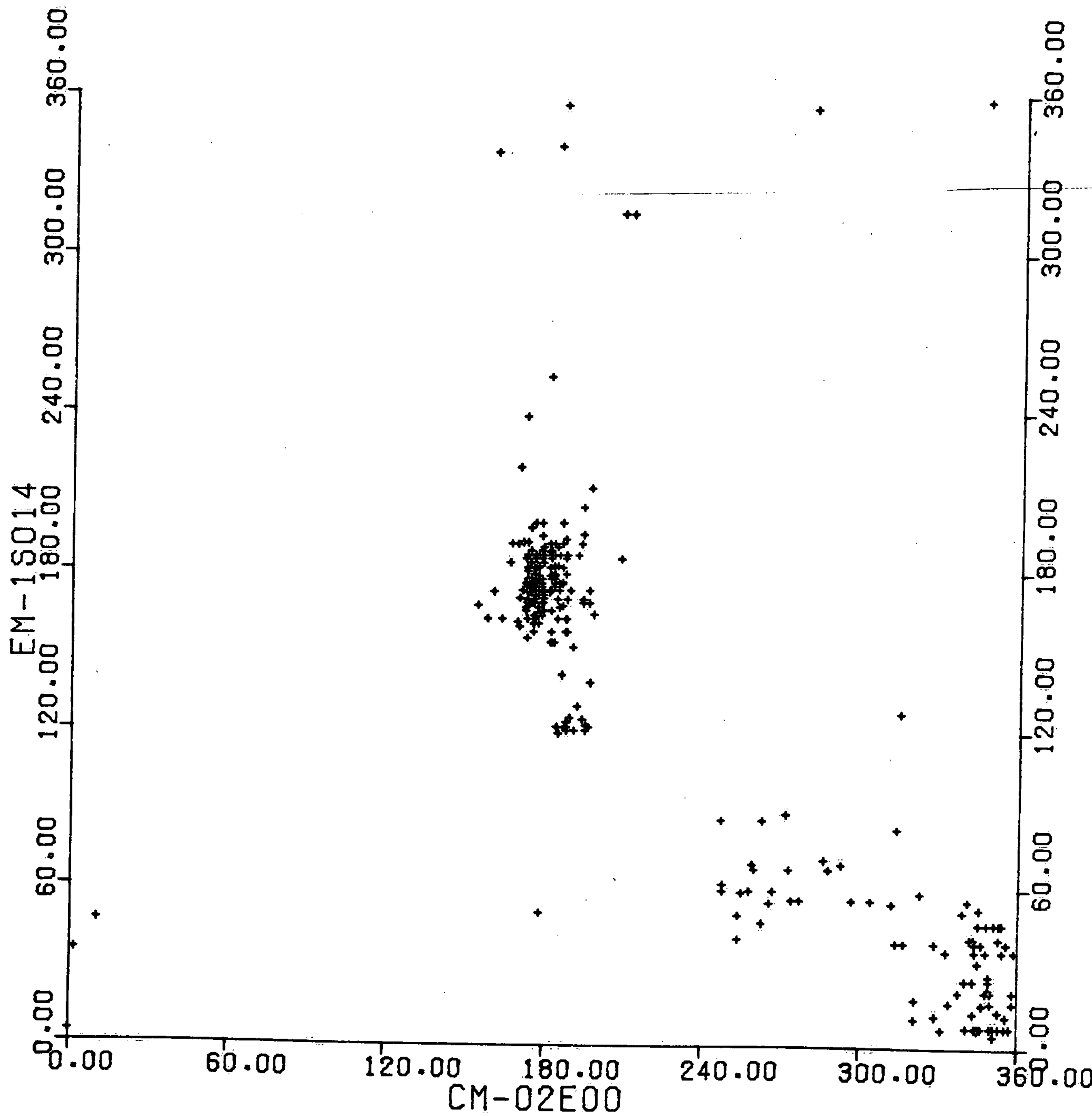
CATS 1 12 m compared to VAPS/CMI
Mixed Flow Case 15 - 17 March
Figure 5.3.3.a -- Speed Comparison



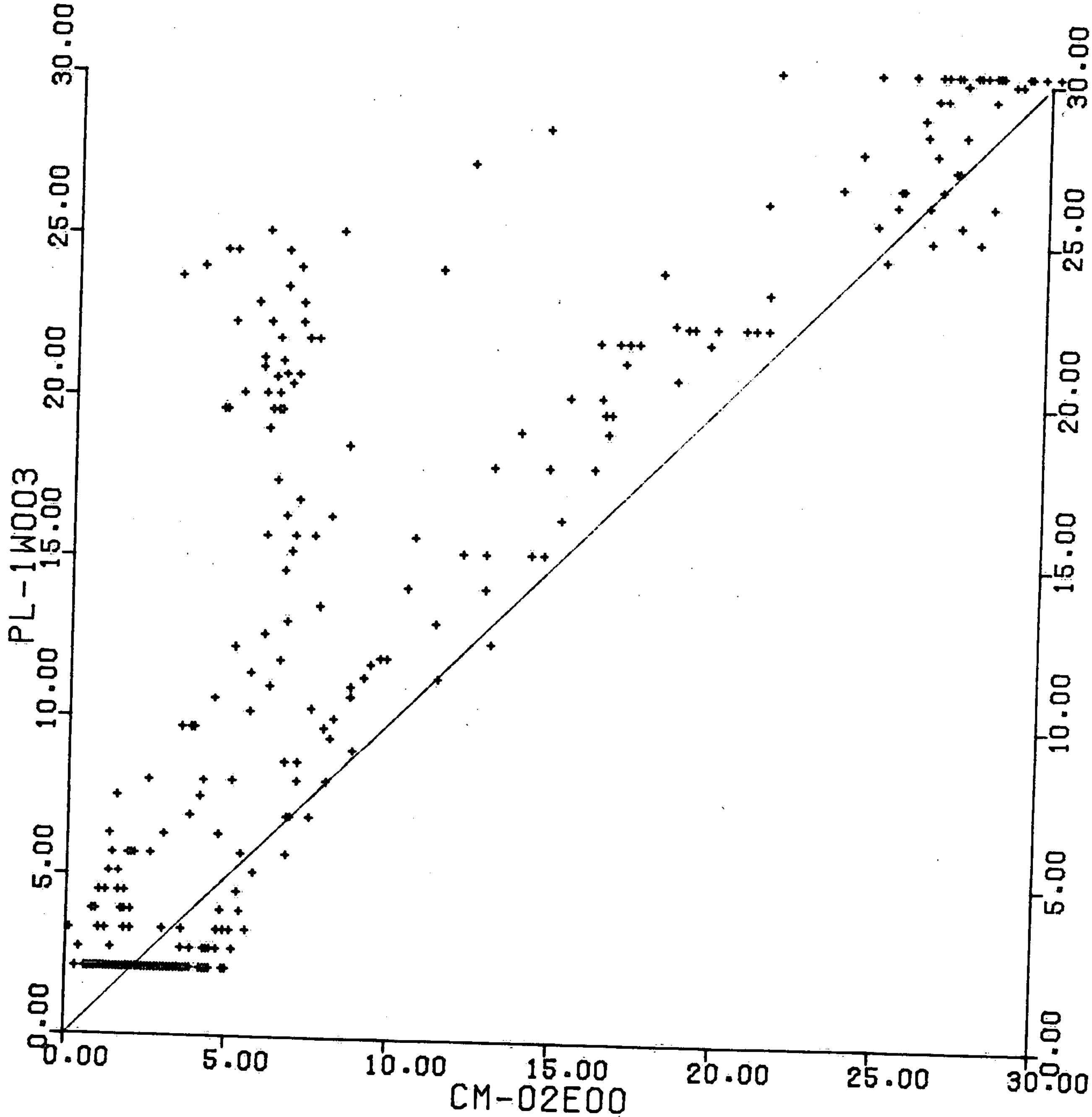
Mixed Flow Case 15 - 17 March
Figure 5.3.3.b



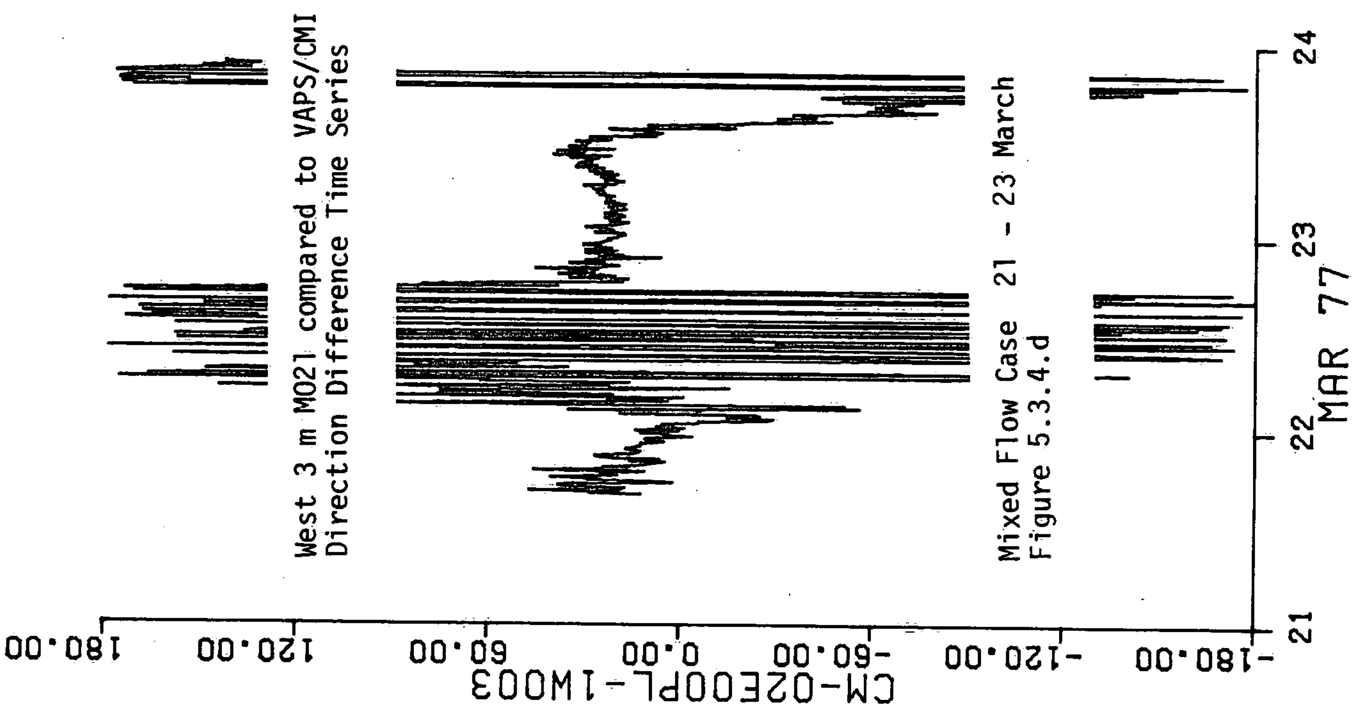
Mixed Flow Case 15 - 17 March
Figure 5.3.3.d

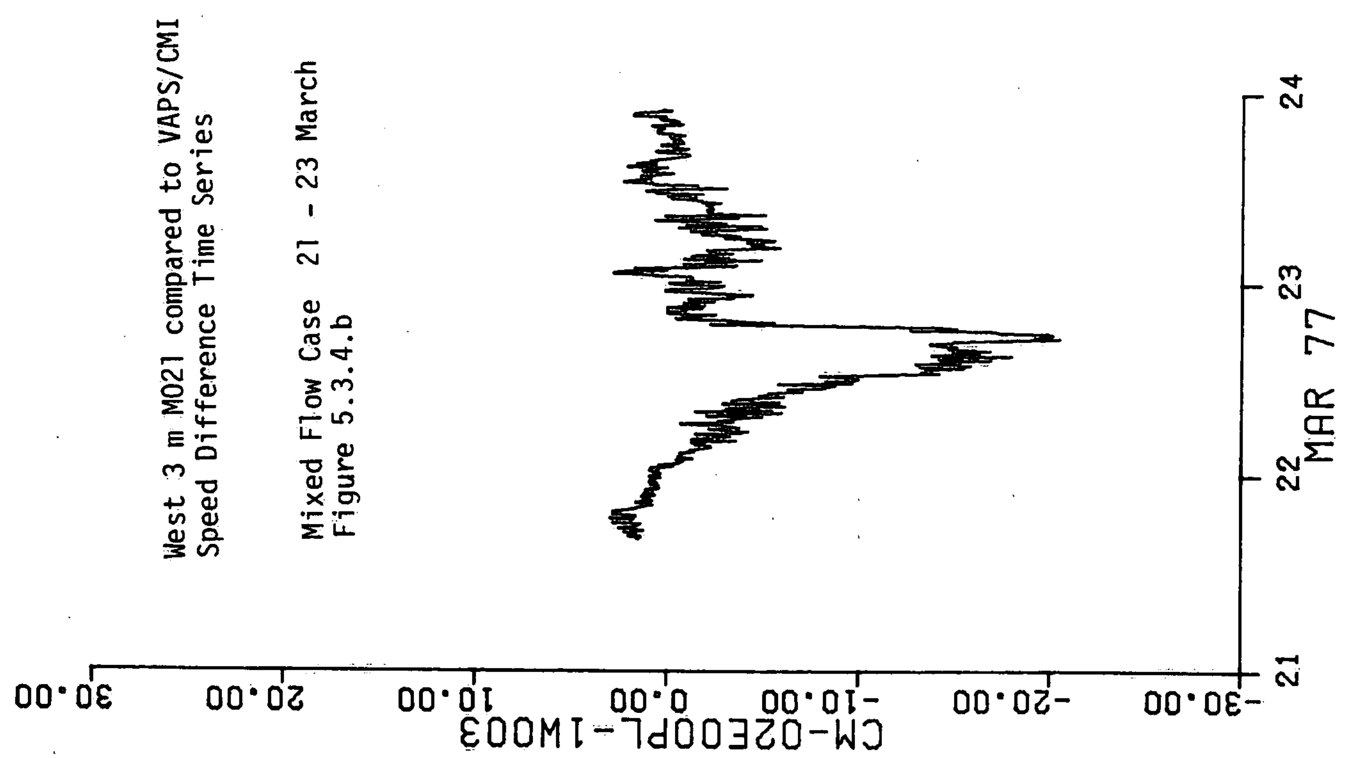


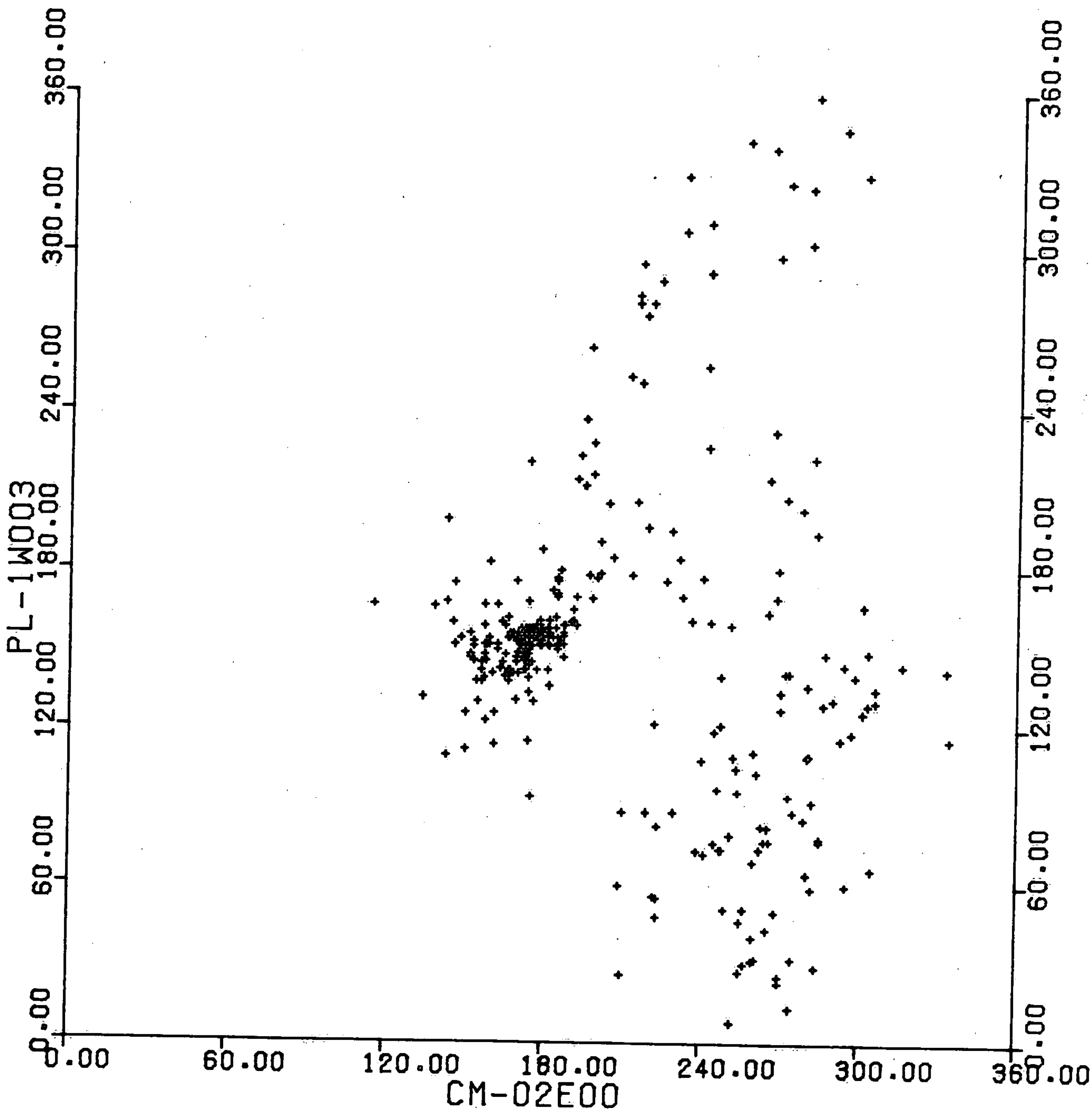
CATS 1 12 m compared to VAPS/CMI
Mixed Flow Case 15 - 17 March
Figure 5.3.3.c -- Direction Comparison



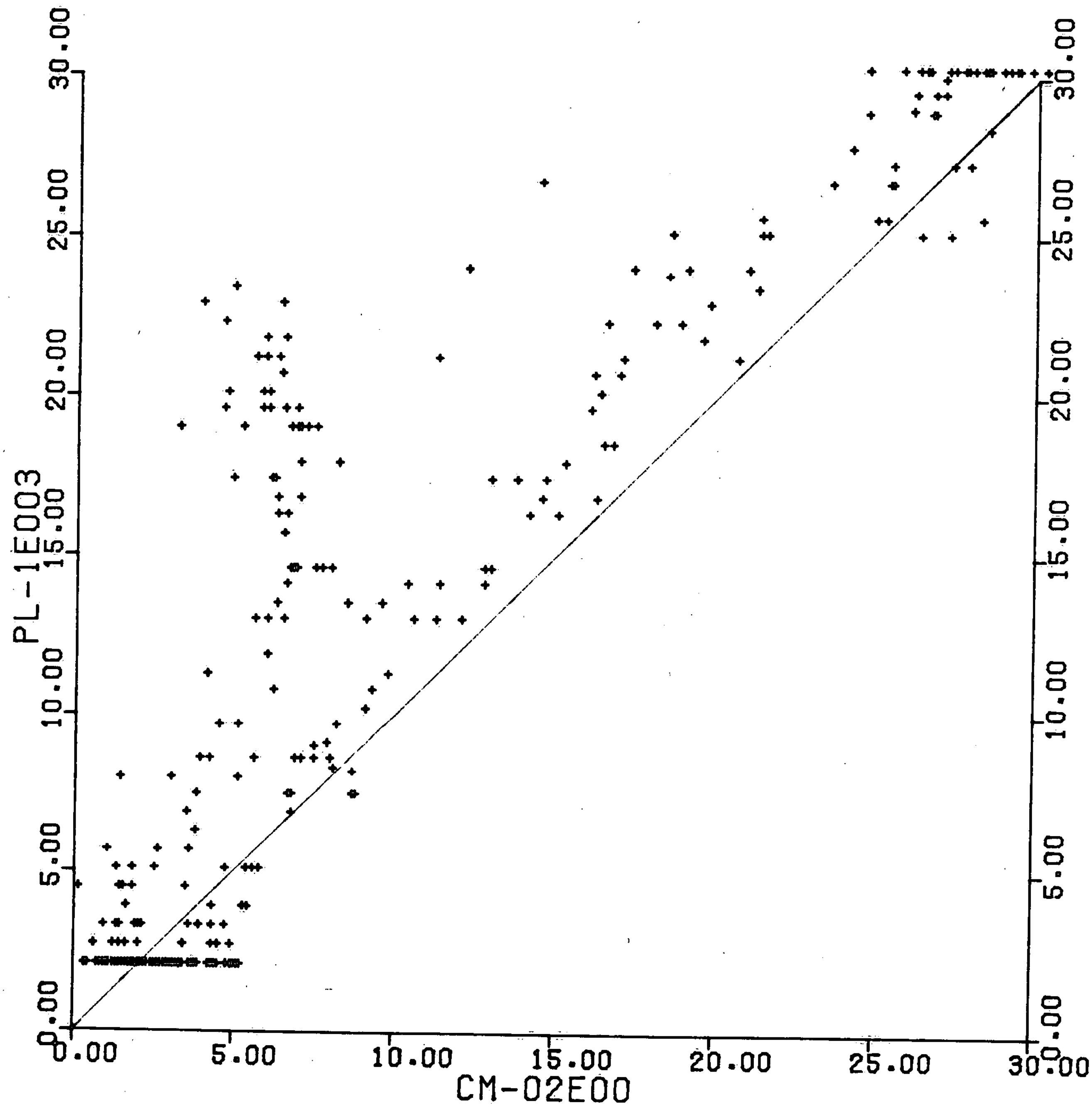
West 3 m M021 compared to VAPS/CMI 5 m
Mixed Flow Case 21 to 23 March
Figure 5.3.4.a -- Speed Comparison


West 3 m M021 compared to VAPS/CMI
Direction Difference Time Series
Mixed Flow Case 21 - 23 March
Figure 5.3.4.d
CM-02E00PL-1W003
180.00
120.00
60.00
0.00
-60.00
-120.00
-180.00
21
22
23
24
MAR 77

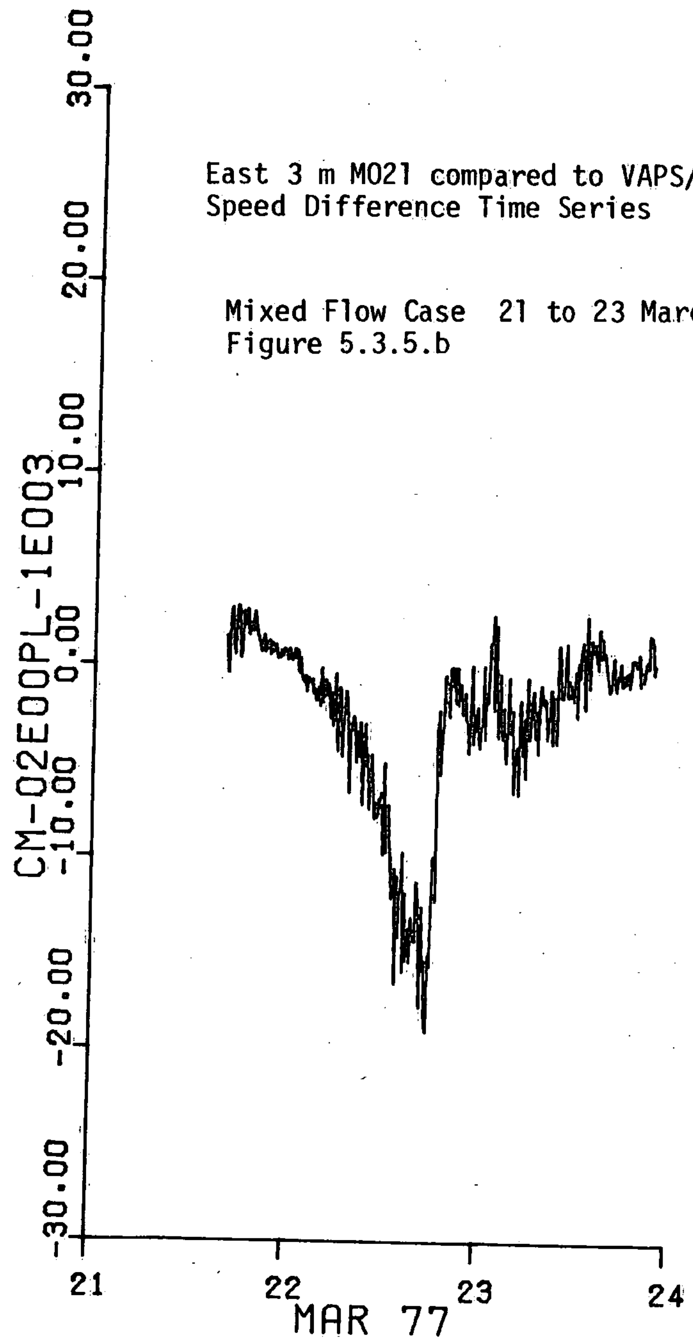

West 3 m M021 compared to VAPS/CMI
Speed Difference Time Series
Mixed Flow Case 21 - 23 March
Figure 5.3.4.b
CM-02E00PL-1W003
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
21
22
23
24
MAR 77



West 3 m M021 compared to VAPS/CMI
Mixed Flow Case 21 - 23 March
Figure 5.3.4.c -- Direction Comparison

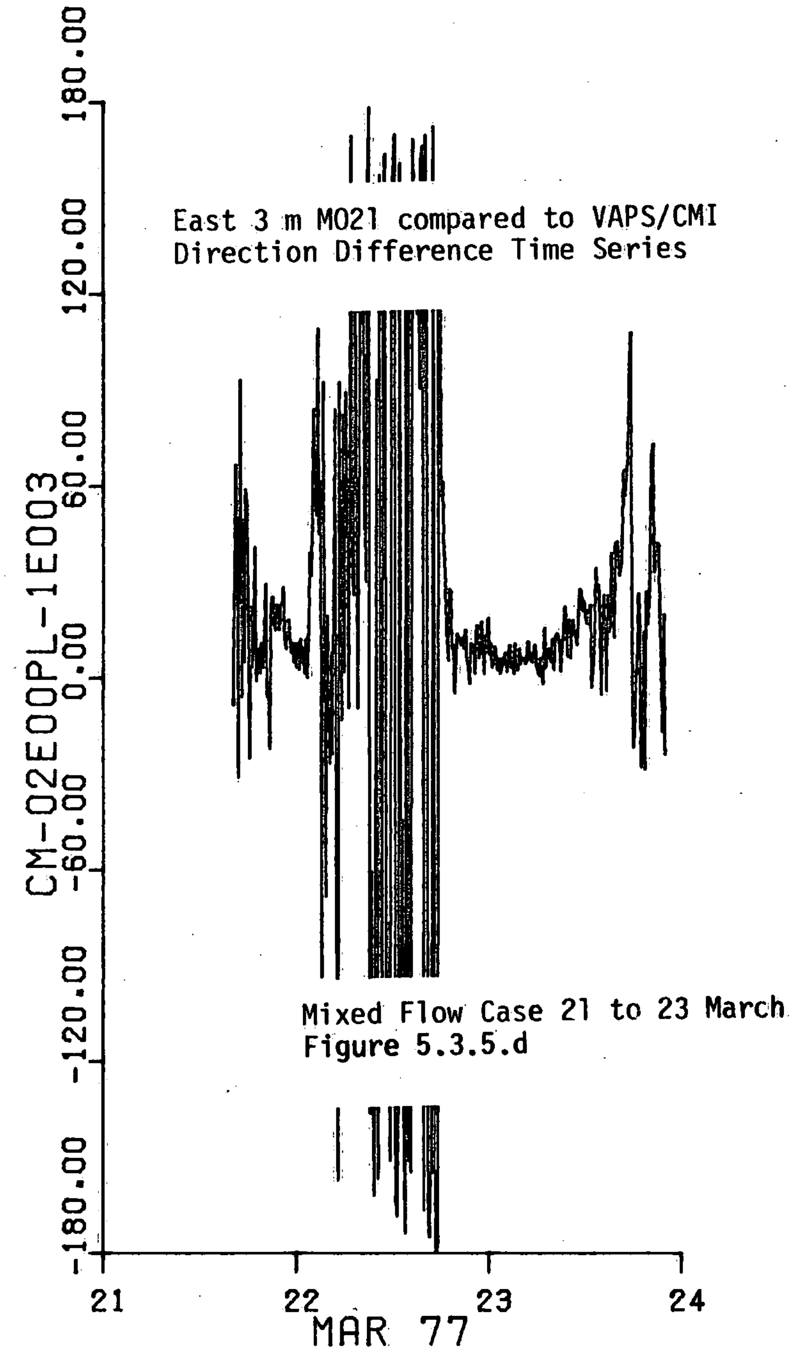


East 3 m M021 compared to VAPS/CMI
Mixed Flow Case 21 to 23 March
Figure 5.3.5.a -- Speed Comparison



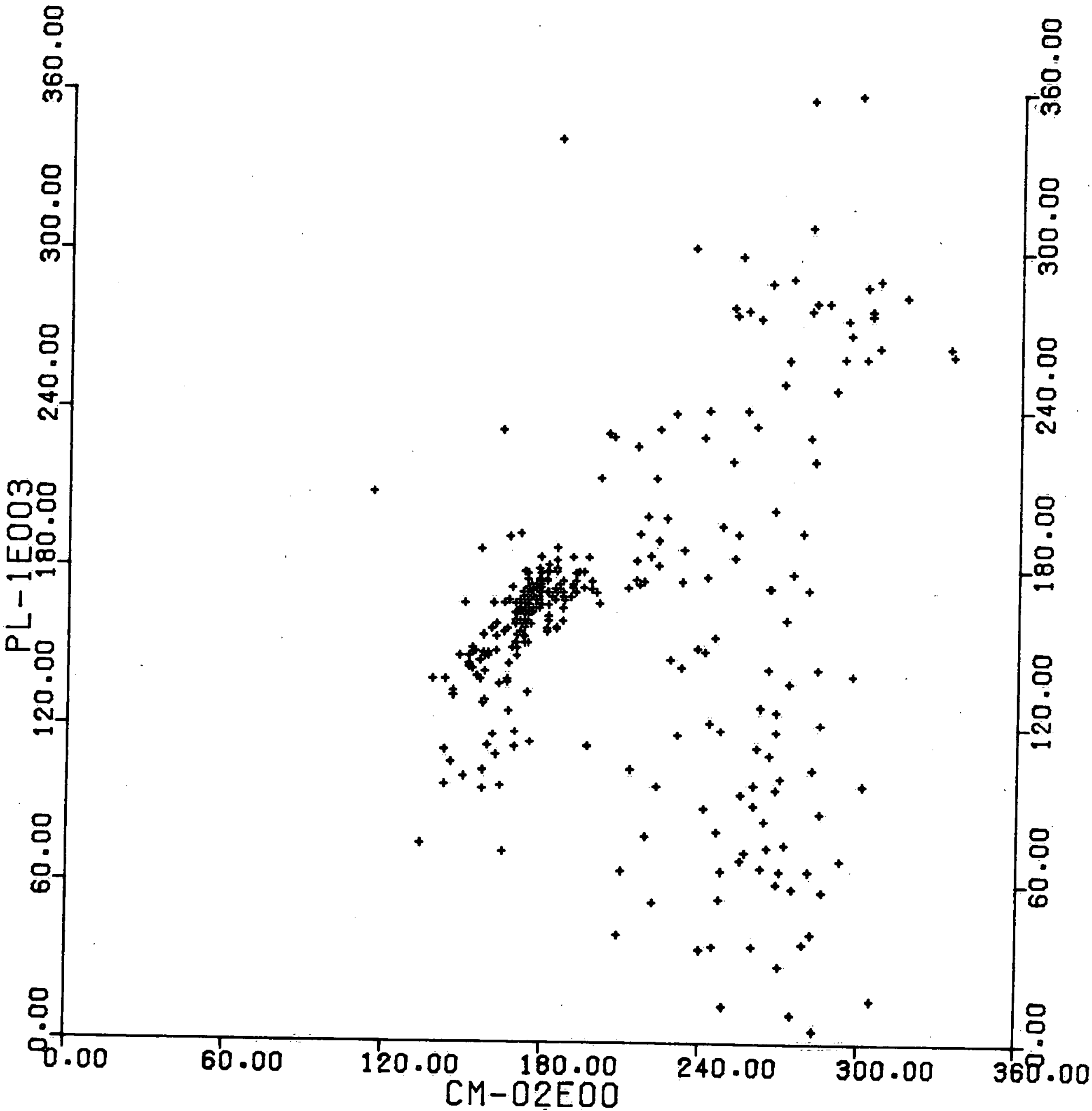
East 3 m M021 compared to VAPS/CMI
Speed Difference Time Series

Mixed Flow Case 21 to 23 March
Figure 5.3.5.b

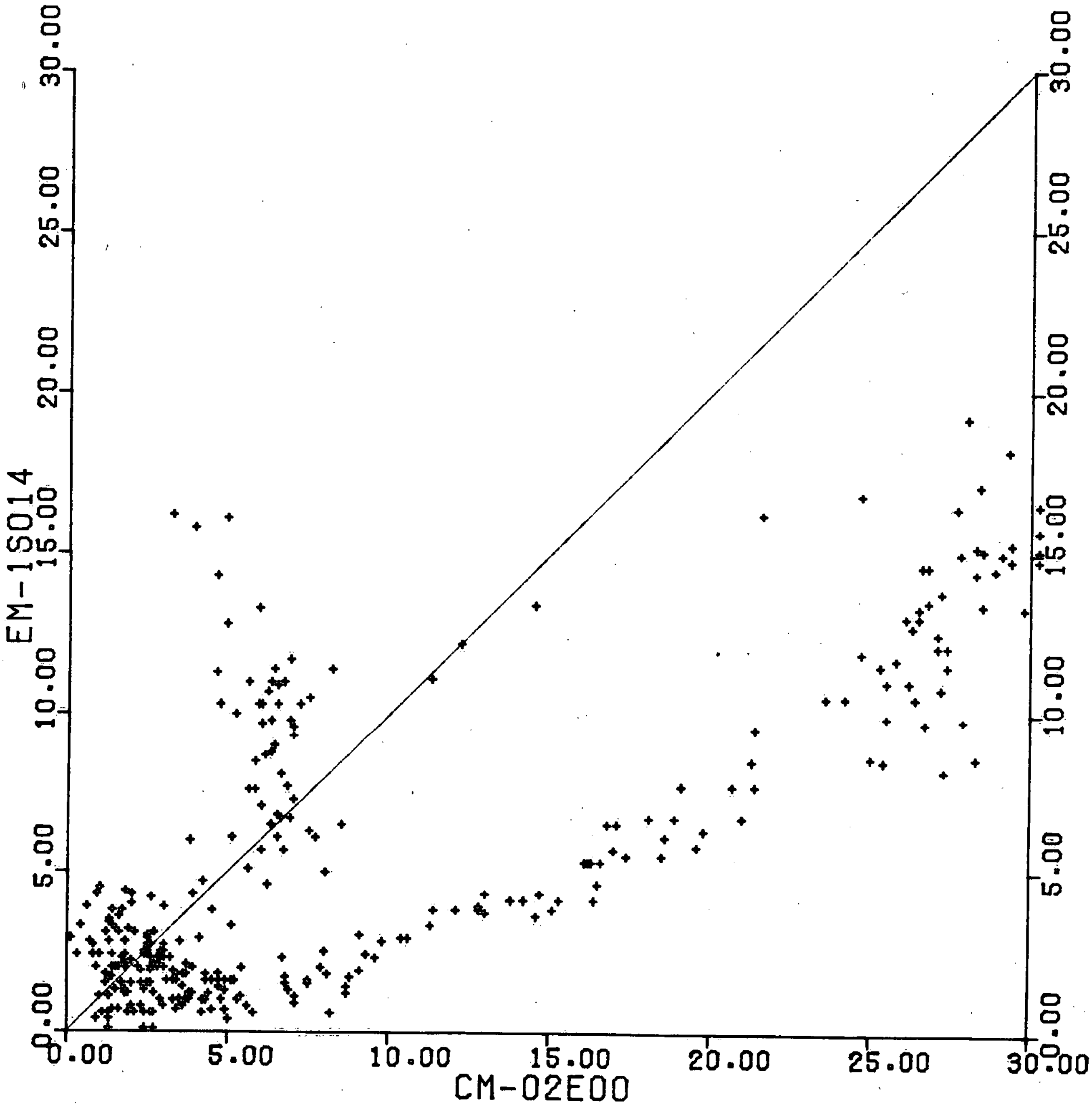


East 3 m M021 compared to VAPS/CMI
Direction Difference Time Series

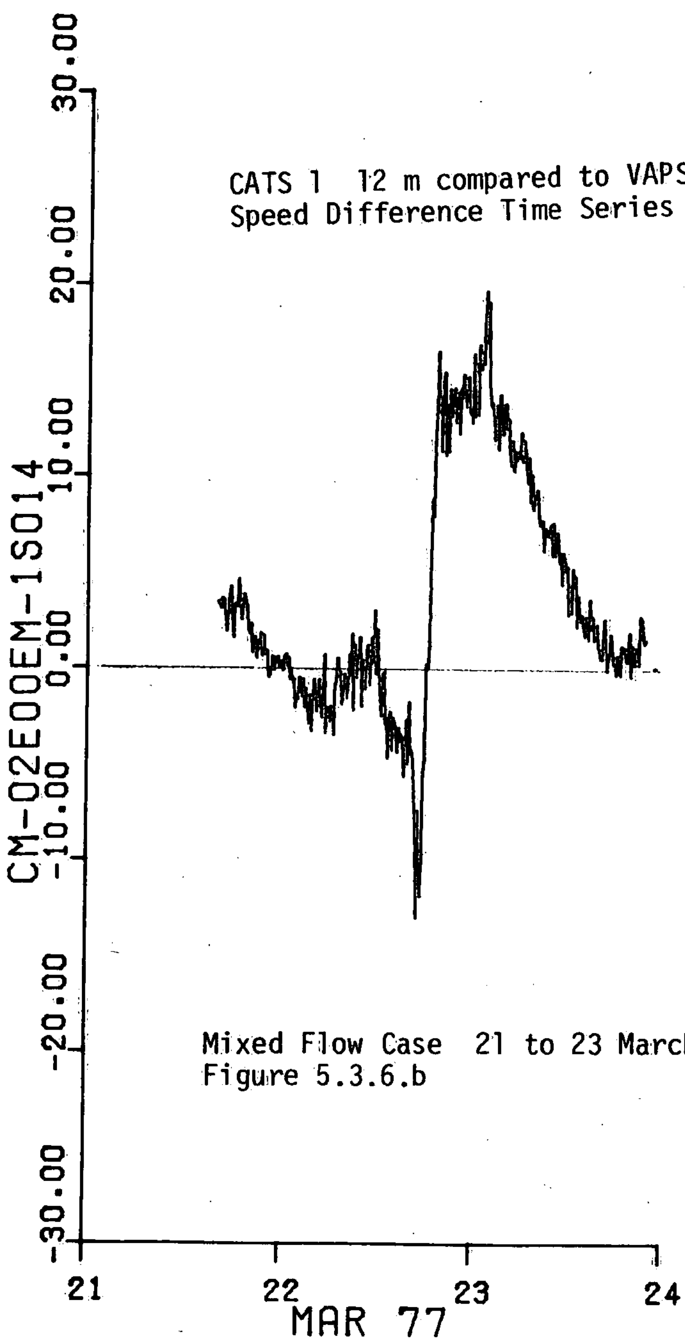
Mixed Flow Case 21 to 23 March
Figure 5.3.5.d



East 3 m M021 Compared to VAPS/CMI
Mixed Flow Case 21 - 23 March
Figure 5.3.5.c -- Direction Comparison

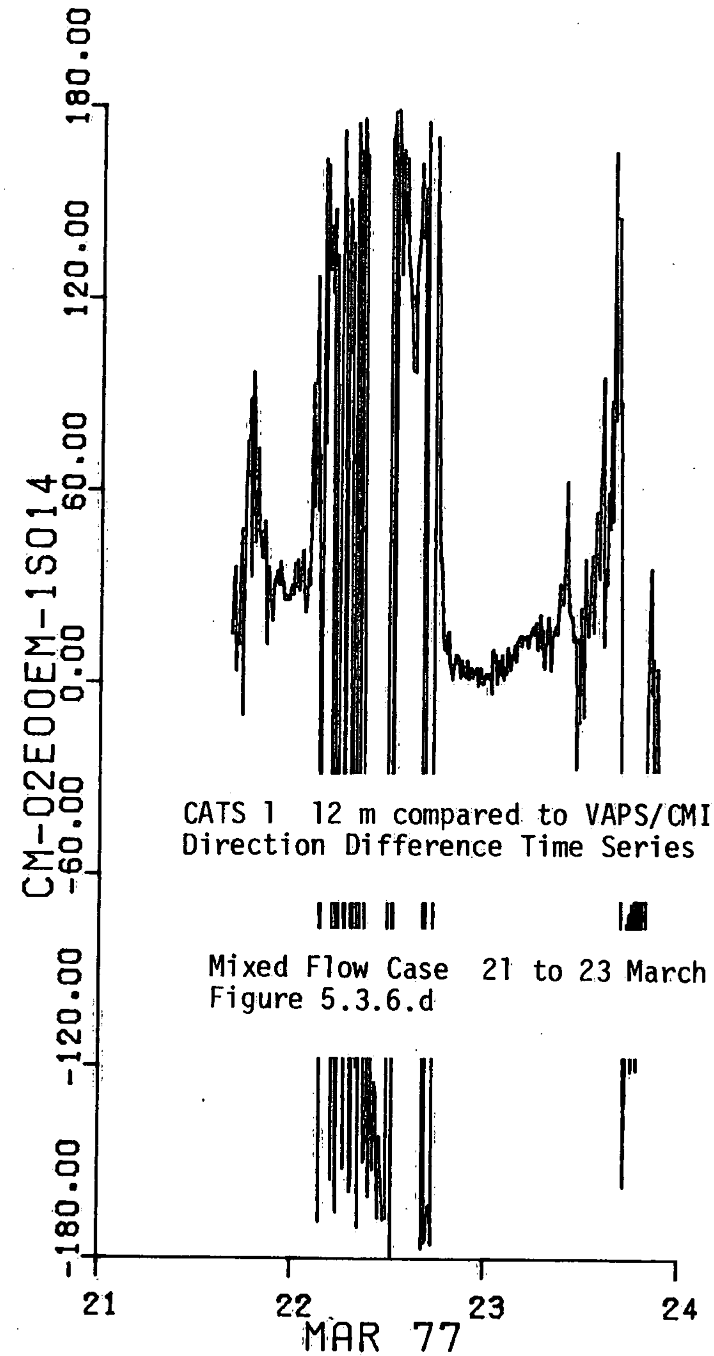


CATS 1 12 m compared to VAPS/CMI
Mixed Flow Case 21 to 23 March
Figure 5.3.6.a -- Speed Comparison



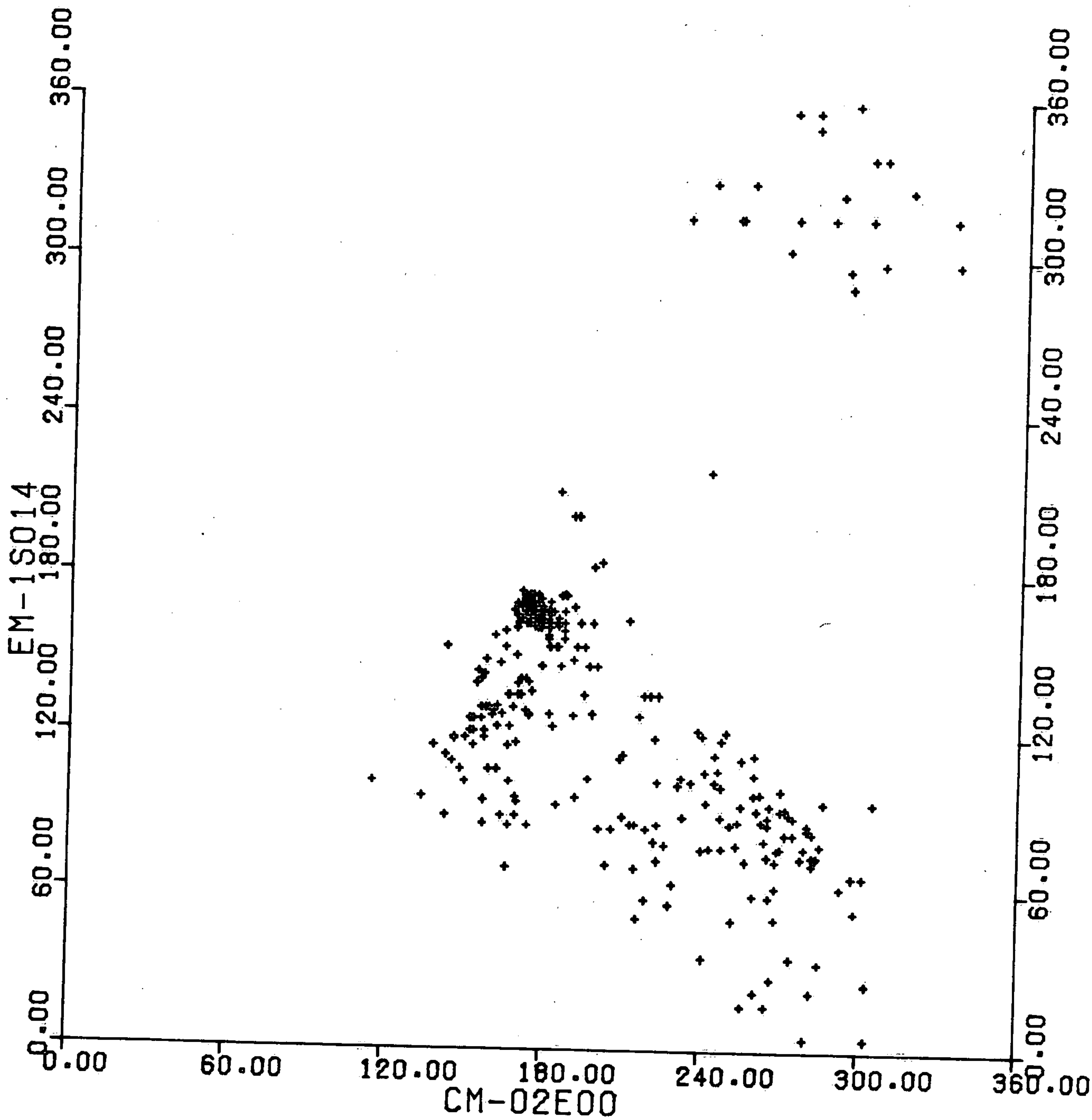
CATS 1 12 m compared to VAPS/CMI
Speed Difference Time Series

Mixed Flow Case 21 to 23 March
Figure 5.3.6.b



CATS 1 12 m compared to VAPS/CMI
Direction Difference Time Series

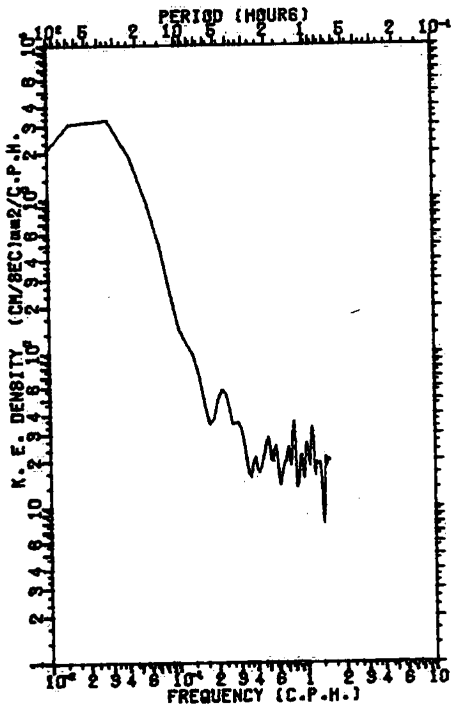
Mixed Flow Case 21 to 23 March
Figure 5.3.6.d



CATS 1 12 m compared to VAPS/CMI
Mixed Flow Case 21 to 23 March
Figure 5.3.6.c -- Direction Comparison

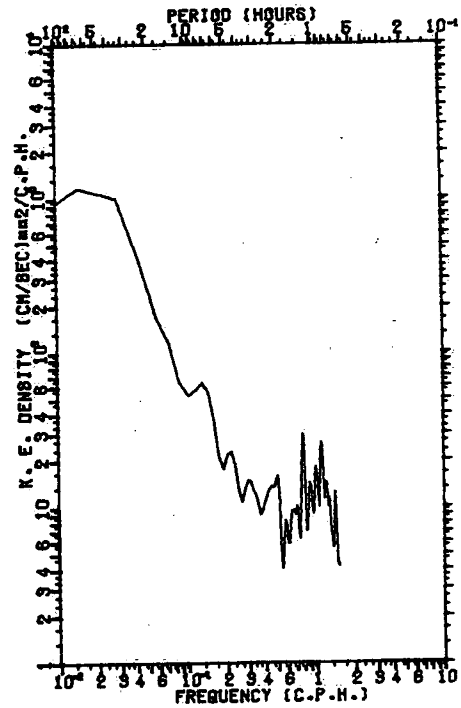
TOTAL KE FOR M021-3

MAR 16 TO 23



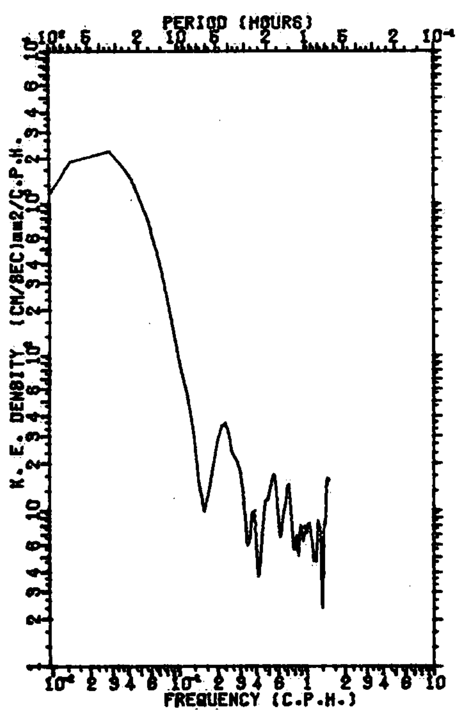
KE EAST COMPONENT M021-3

MAR 16 TO 23



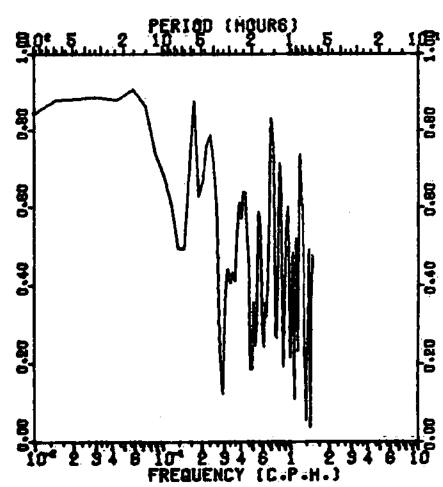
KE NORTH COMPONENT M021-3

MAR 16 TO 23



COHERENCE M021-3 NORTH AND EAST

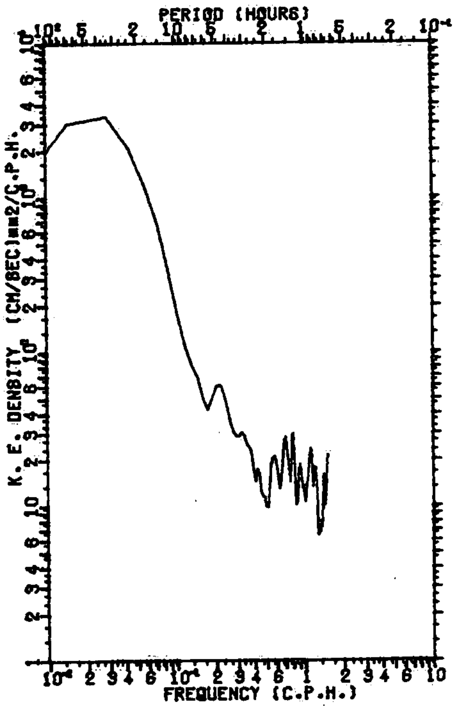
MAR 16 TO 23



West 3 m M021
Mixed Flow Case
Figure 5.3.7.a

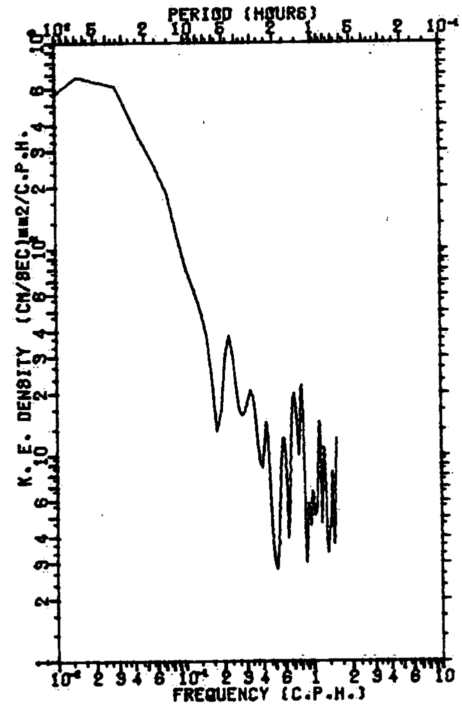
TOTAL KE FOR M021-6

MAR 16 TO 23



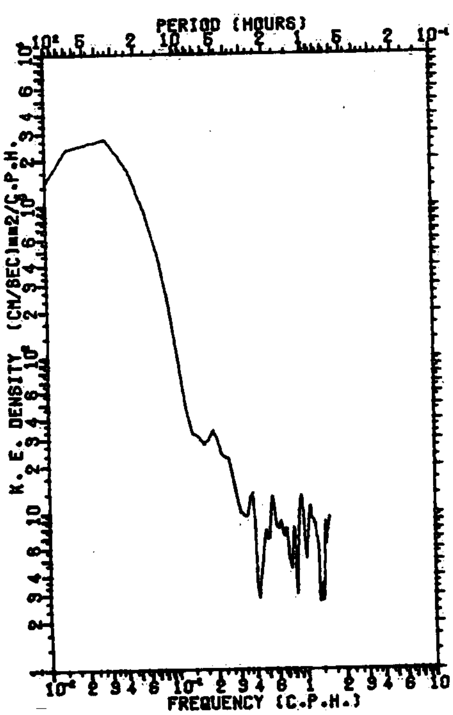
KE EAST M021-6

MAR 16 TO 23



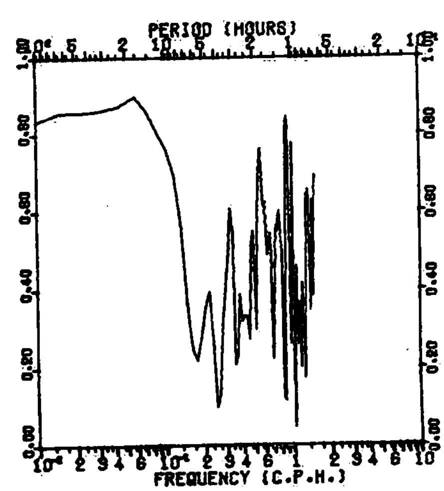
KE NORTH M021-6

MAR 16 TO 23

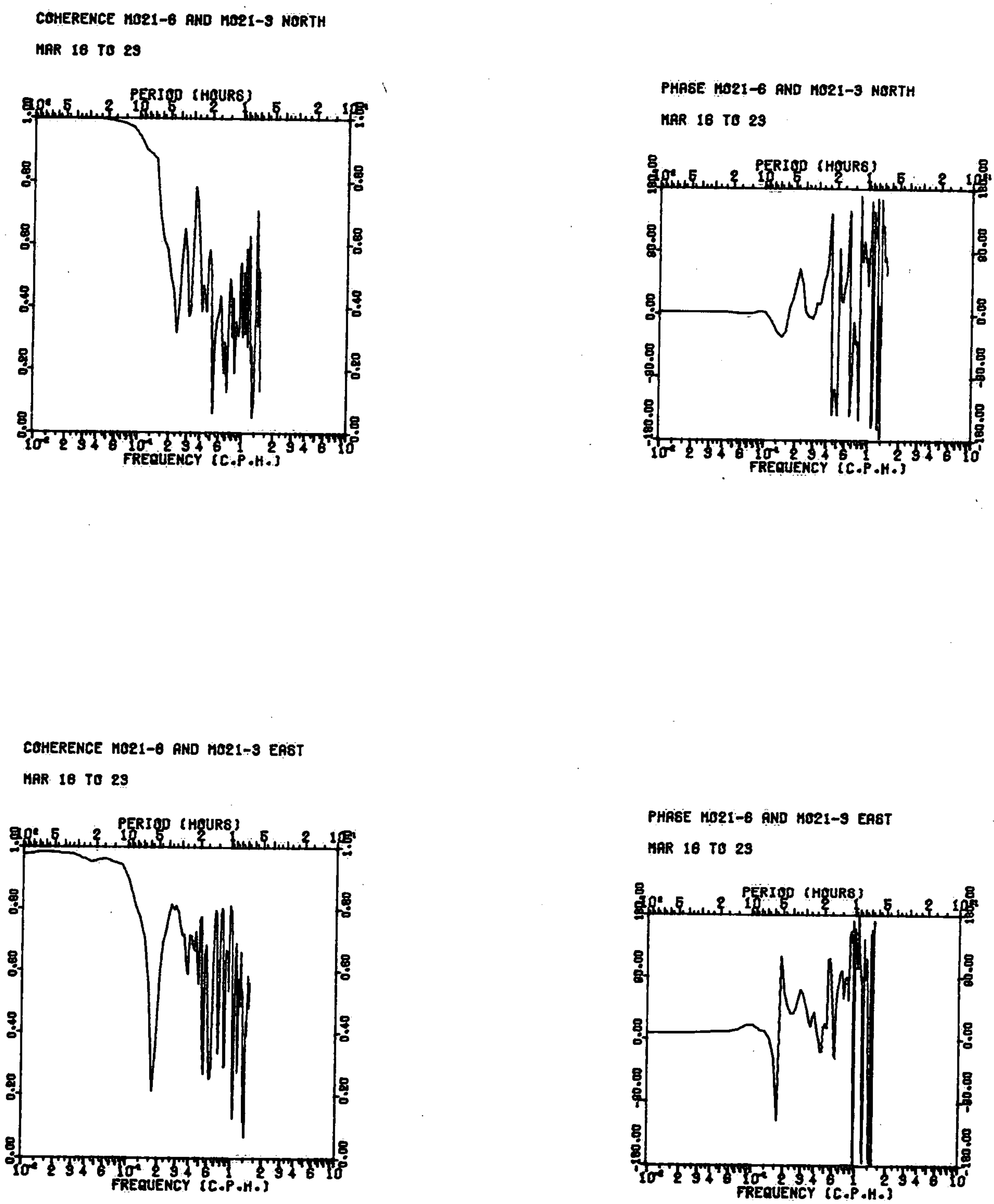


COHERENCE M021-6 NORTH AND EAST

MAR 16 TO 23



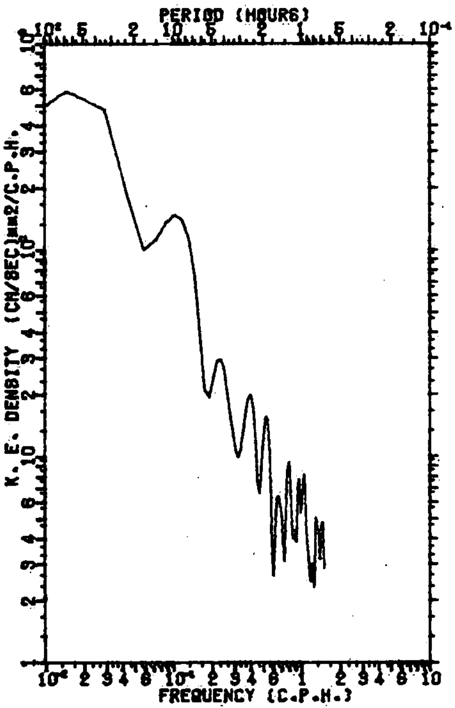
East 3 m M021
Mixed Flow Case
Figure 5.3.7.b



West and East 3 m M021's
Mixed Flow Case
Figure 5.3.8.a

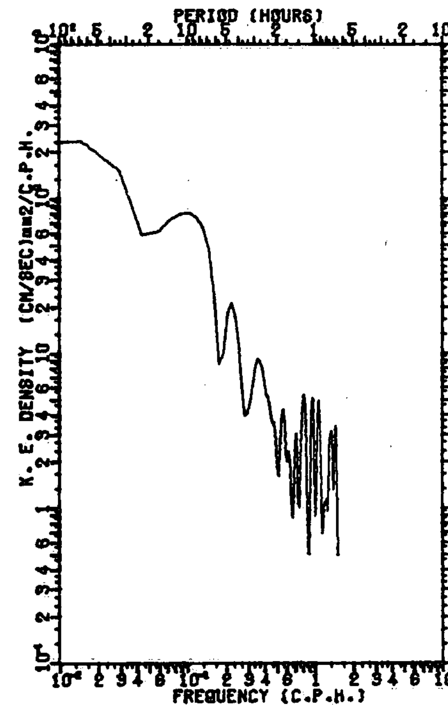
TOTAL KE FOR CATS1

MAR 16 TO 23



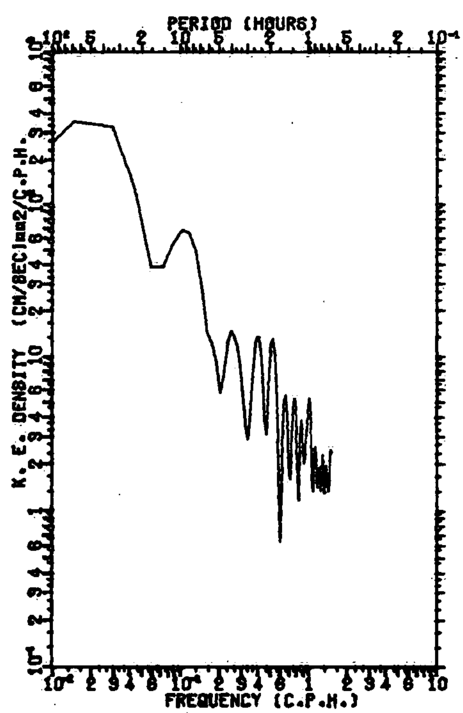
KE EAST COMPONENT CATS 1

MAR 16 TO 23



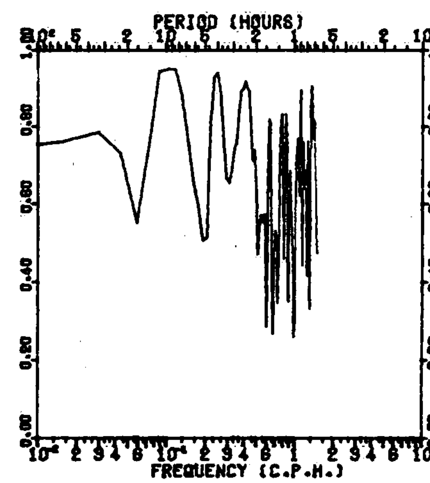
KE NORTH COMPONENT CATS1

MAR 16 TO 23

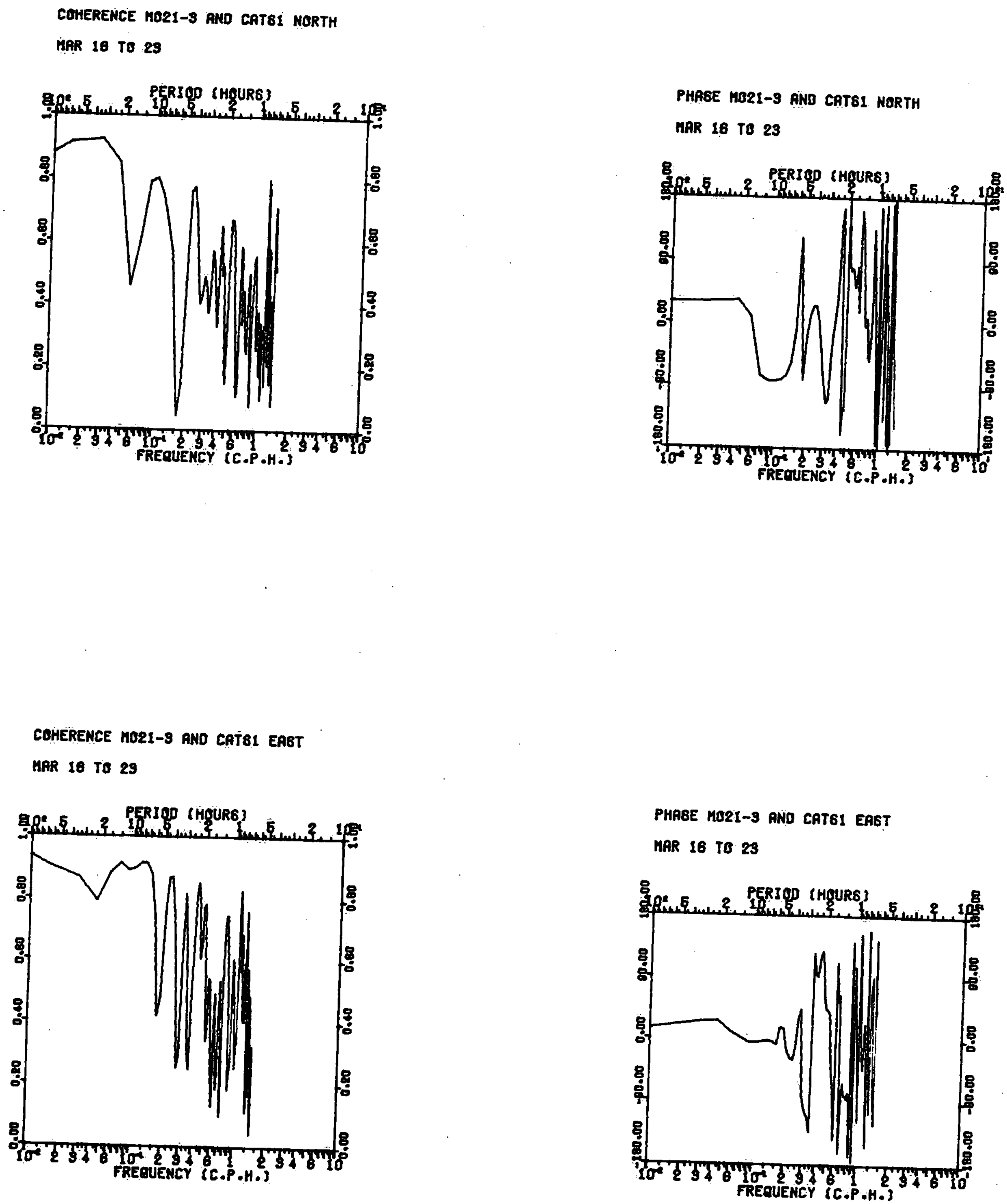


COHERENCE CATS1 NORTH AND EAST

MAR 16 TO 23



CATS 1 12 m
Mixed Flow Case
Figure 5.3.7.c



CATS 1 12 m compared to West 3 m M021
Mixed Flow Case
Figure 5.3.8.b

M021 data. The CATS 1 data shows a separated spectral feature with a period of 8 - 10 hours with a spectral density value comparable to that of the M021's for this period, although they do not resolve the feature.

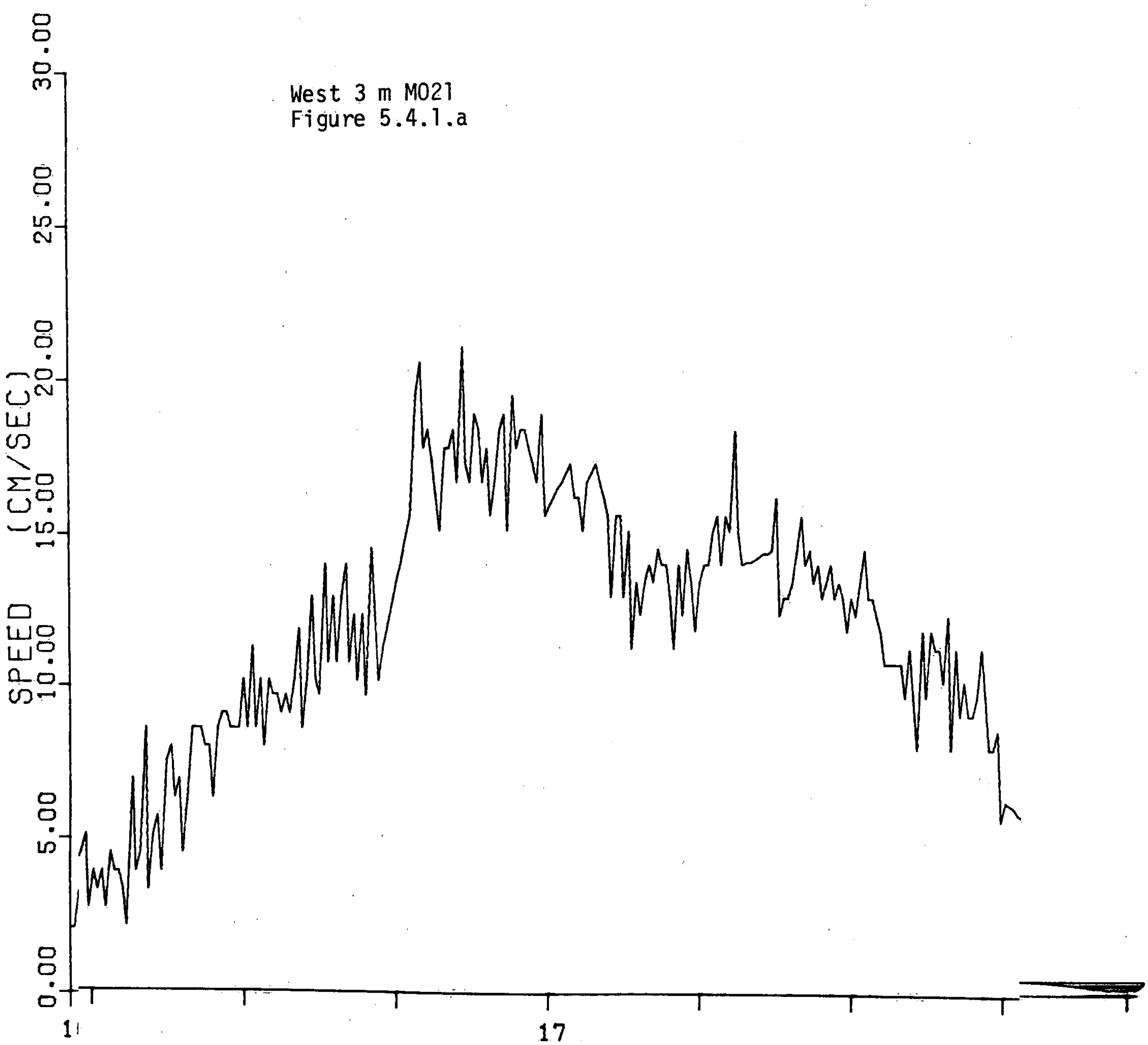
5.4 Special Events

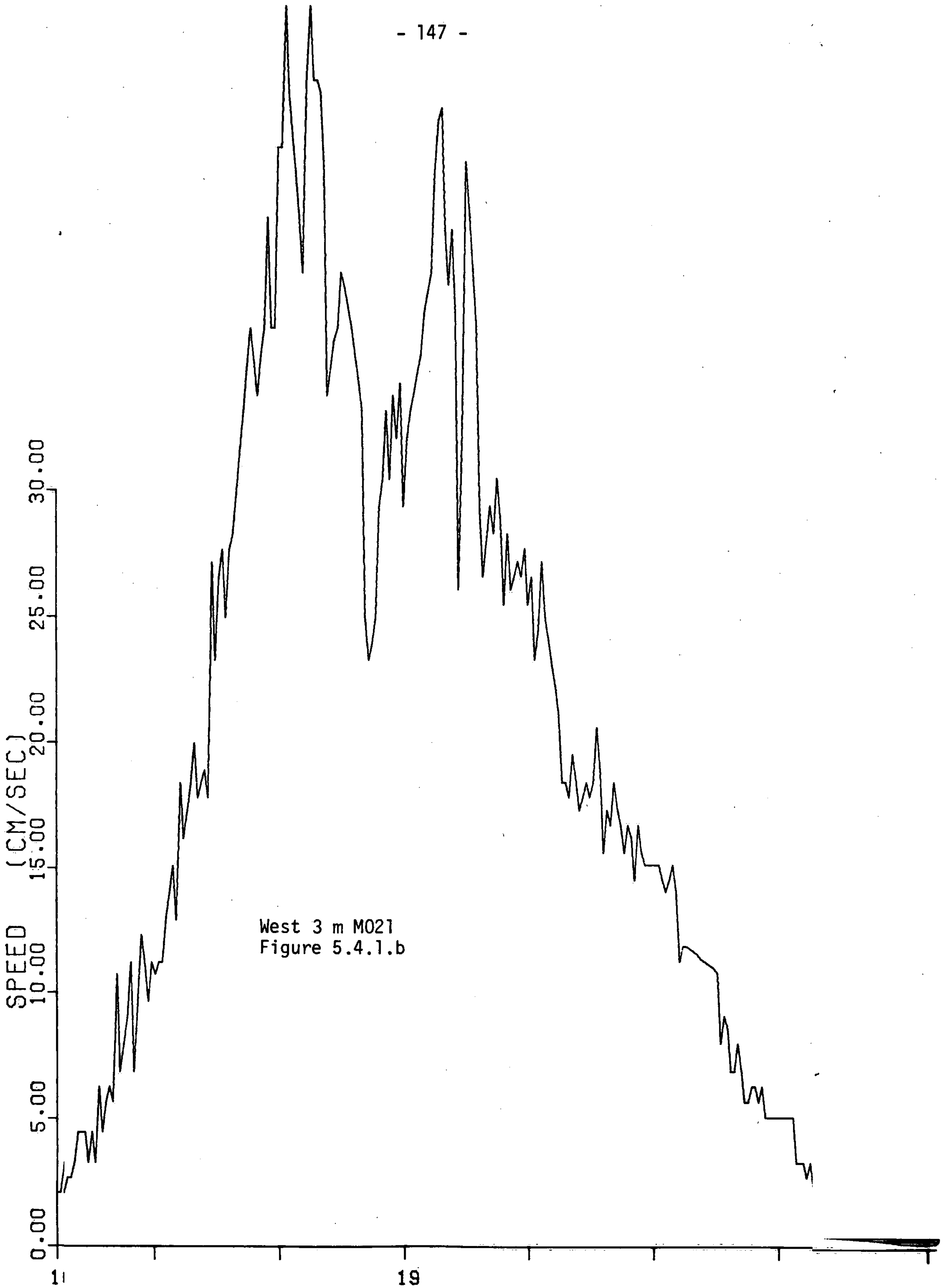
The period of January 29 - February 2 is identified as a special event, due to the observation of frazil ice formation in the water inside the legs of the WAVES platform. It is presumed that very small mean flow speeds must have been present for the frazil ice to form. The Plessey data shows threshold speeds for the period. Unfortunately, CATS 1 was not installed, and CATS 2 appears to have been generating unstable zero offsets.

The current events on 16 - 17 March, 18 - 19 March and 22 - 23 March were the largest flow events in the experiment. The VAPS/CMI Acoustic current sensor was installed for a portion of the first and the last of these. The speed time series for the West 3 m Plessey MO-21: Figure 5.4.1.a, b,c; the East 3 m M021: Figure 5.4.2.a, b,c; the CATS 1 system: Figure 5.4.3.a, b,c; and the VAPS/CMI: Figure 5.4.4.a, c provide a means of comparing these systems with high resolution. The M021 meters show sustained speeds of 18 to 20 $cm.s^{-1}$ for the first episode, 40 - 50 $cm.s^{-1}$ for the second, and 30 - 35 $cm.s^{-1}$ for the third.

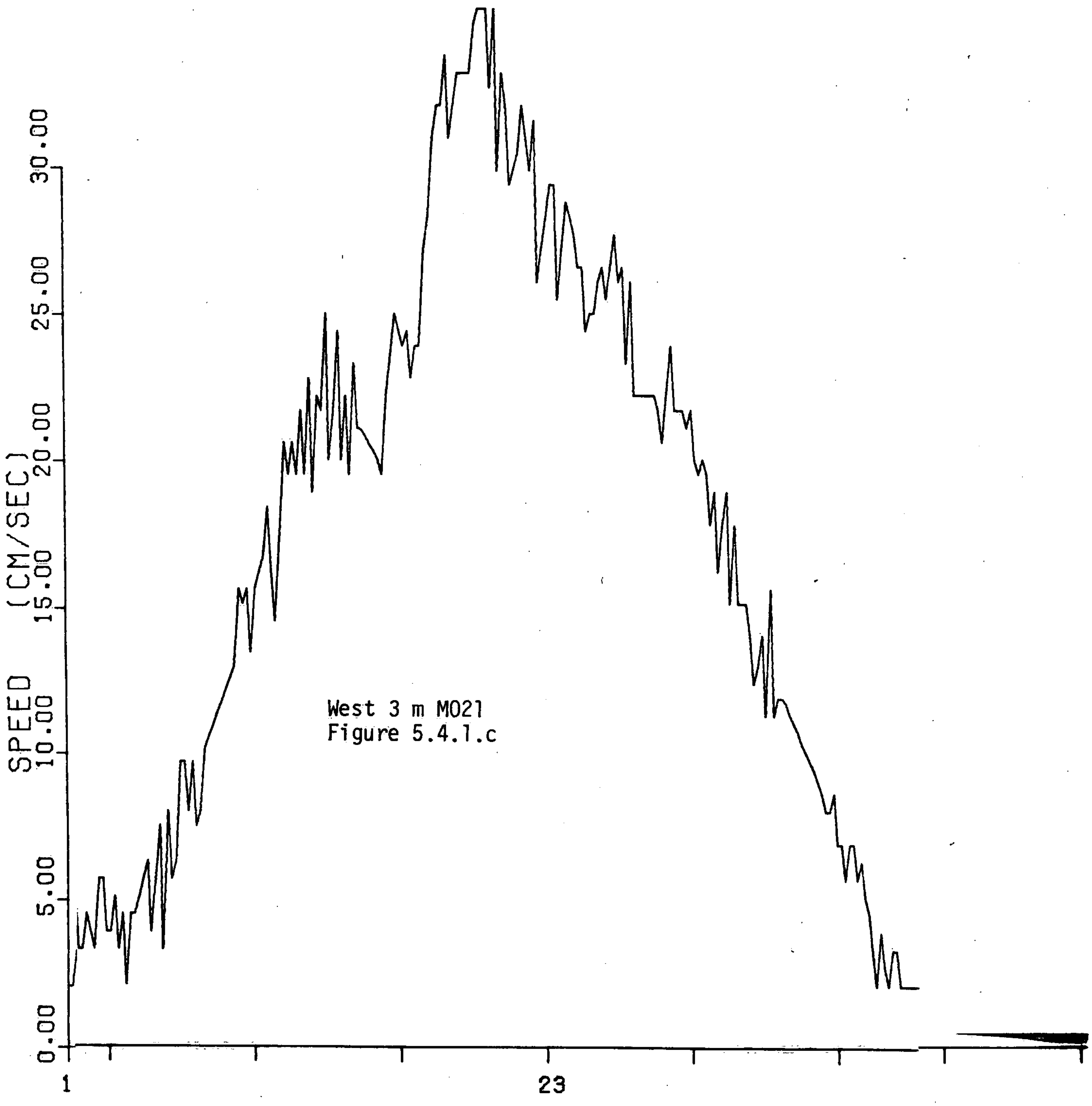
The CATS 1 system at 12 m shows lower sustained currents of 8 $cm.s^{-1}$, 30 $cm.s^{-1}$, and 15 $cm.s^{-1}$ for the same episodes. Many of the dynamic features for the three speed records are synchronous, although the amplitude and phases are not always in the same relationships between the three systems.

The VAPS/CMI data for the first episode shows good agreement with the M021 data, although the VAPS/CMI does indicate higher speeds at 1800 hours. The absence of the VAPS/CMI from the apparently most energetic episode is unfortunate. The March 22 - 23 event has a most interesting characteristic. The VAPS/CMI sensor shows the mean speed increasing by 20 $cm.s^{-1}$ in less than one hour. The M021 data shows a more gradual increase in speed and generally higher speeds than the VAPS/CMI. One

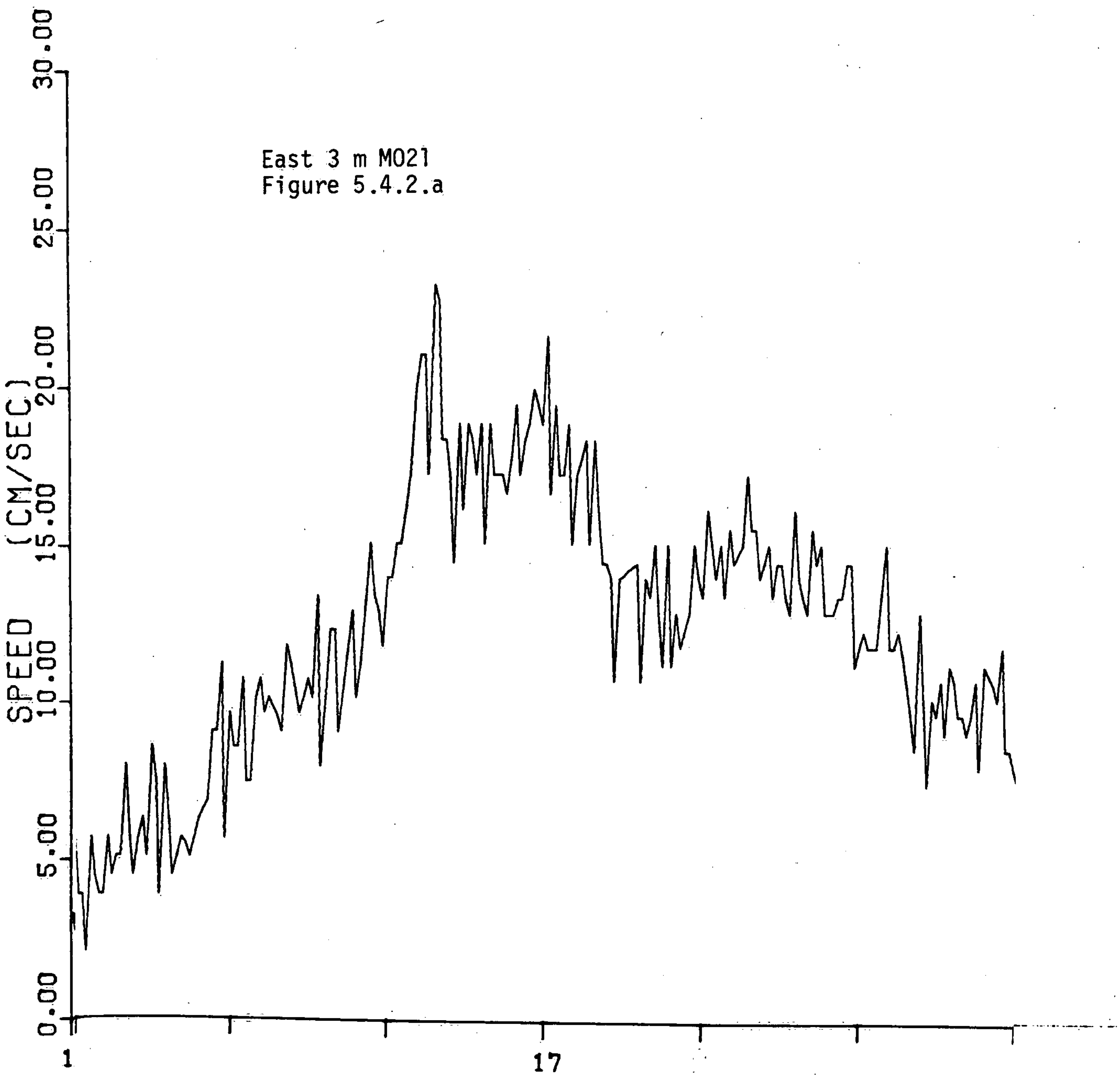

West 3 m M021
Figure 5.4.1.a
SPEED (CM/SEC)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1
17

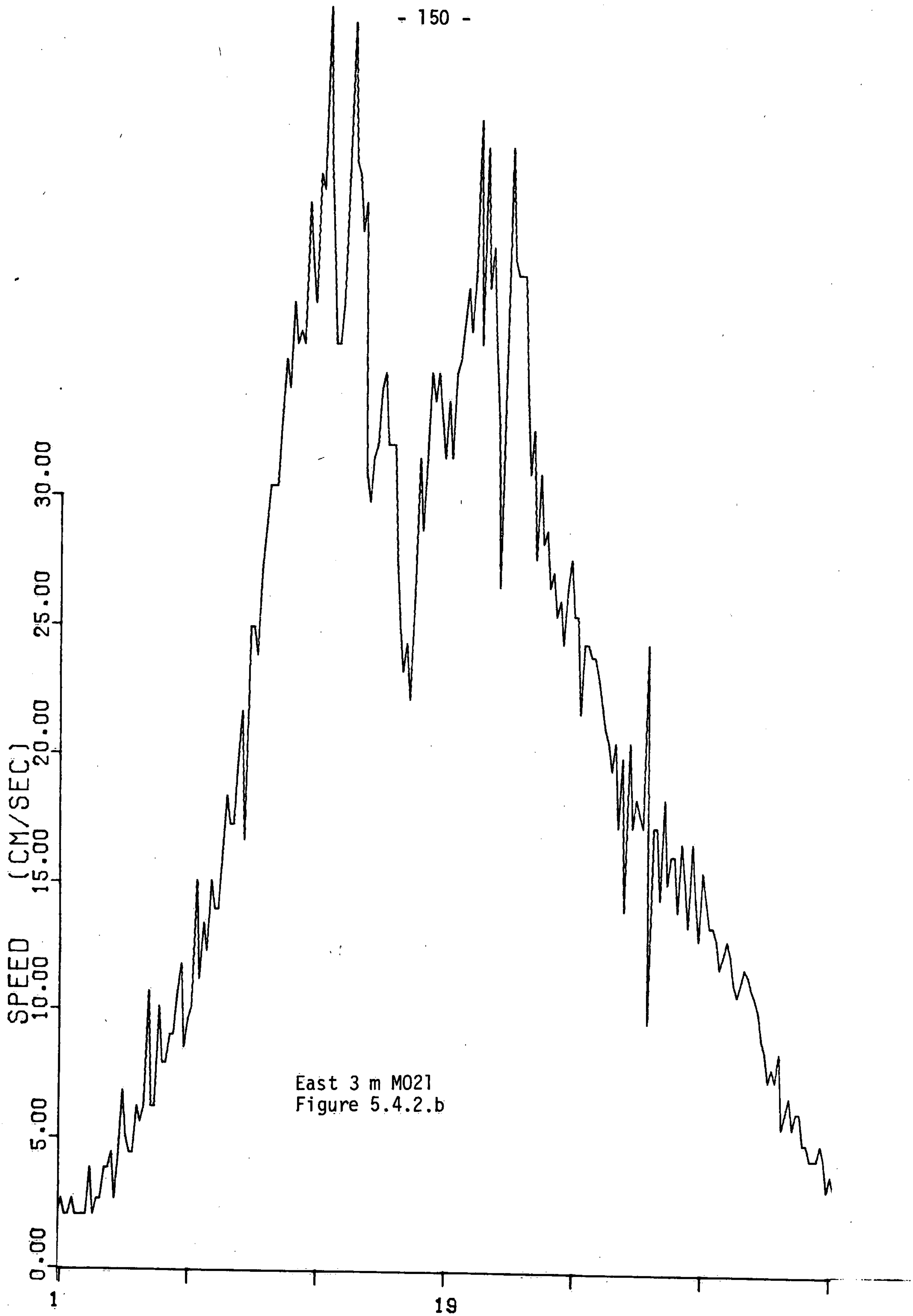


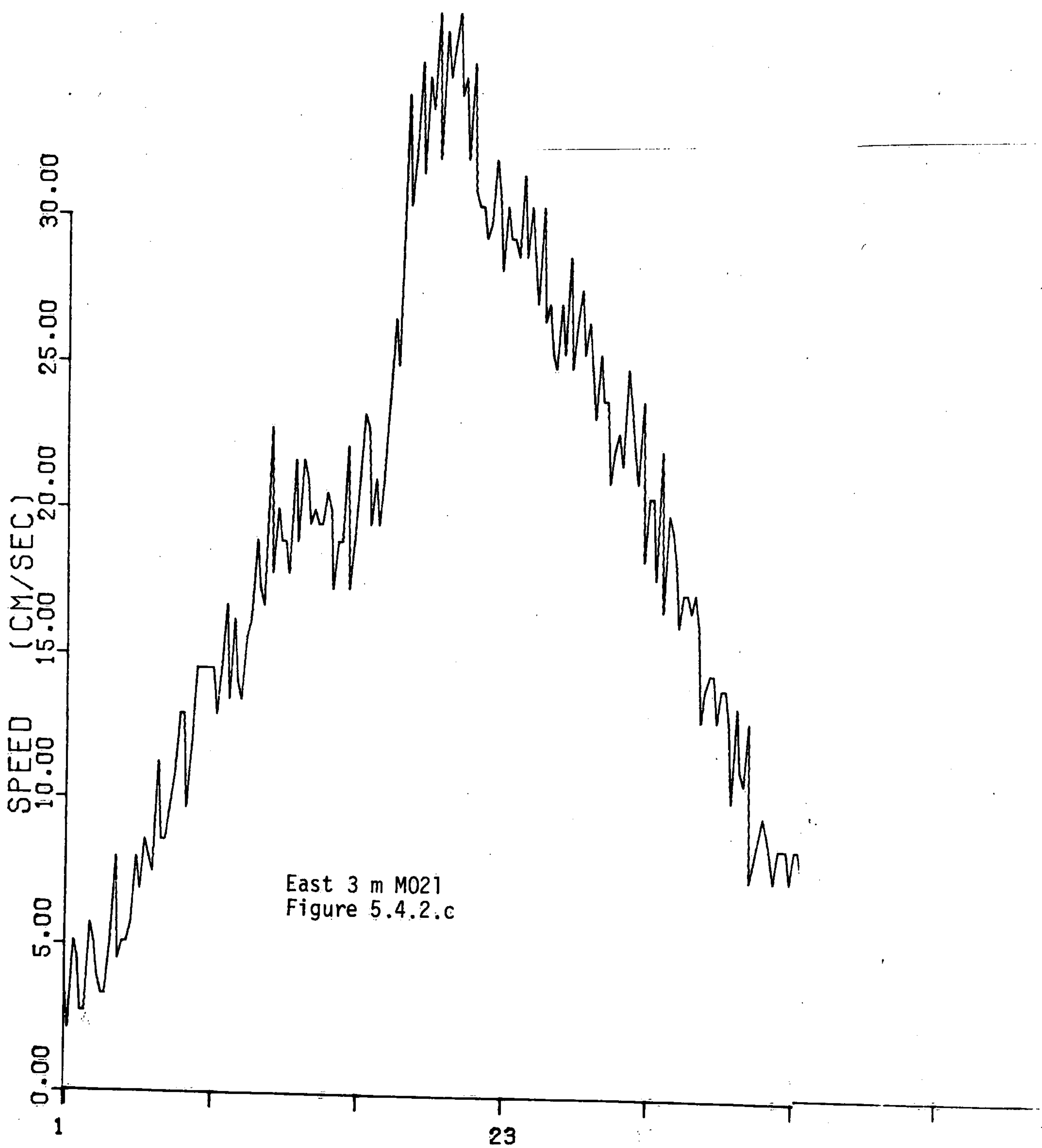
West 3 m M021
Figure 5.4.1.b



West 3 m M021
Figure 5.4.1.c


East 3 m M021
Figure 5.4.2.a
SPEED (CM/SEC)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1
17

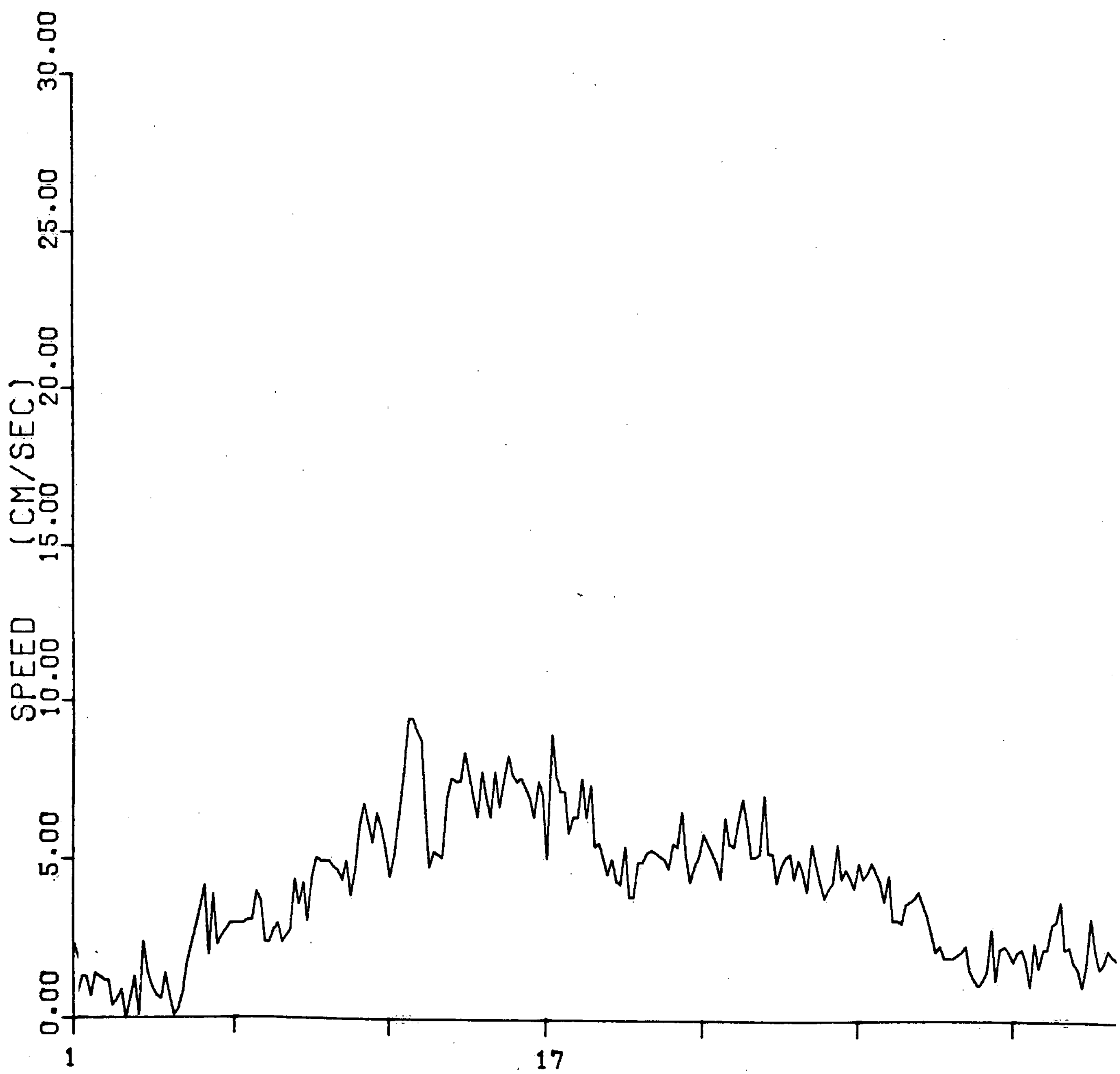

SPEED (CM/SEC)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
1
19
East 3 m M021
Figure 5.4.2.b



East 3 m M021
Figure 5.4.2.c

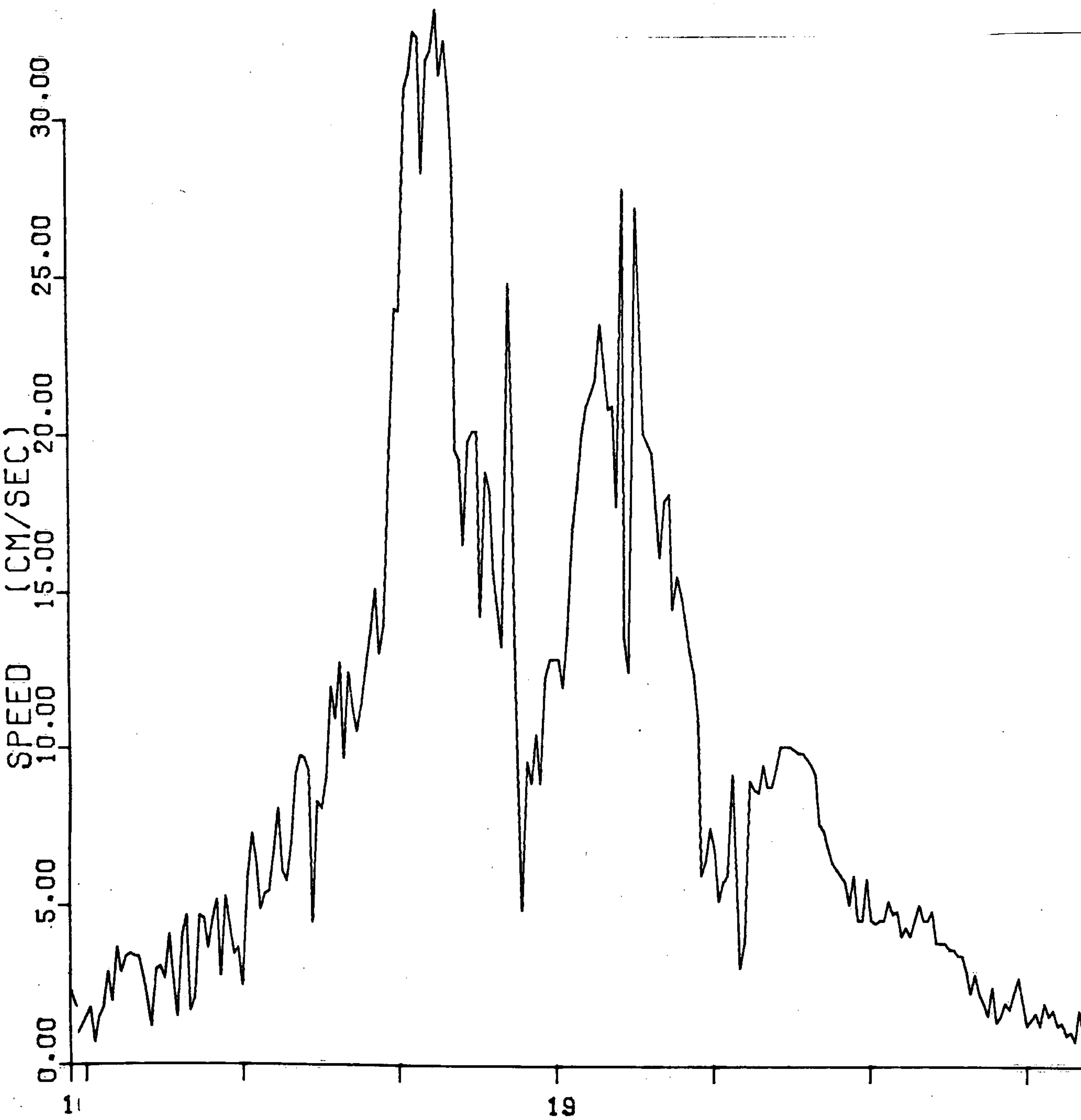
77-OC-01S014

CATS 1 12 m
Figure 5.4.3.a



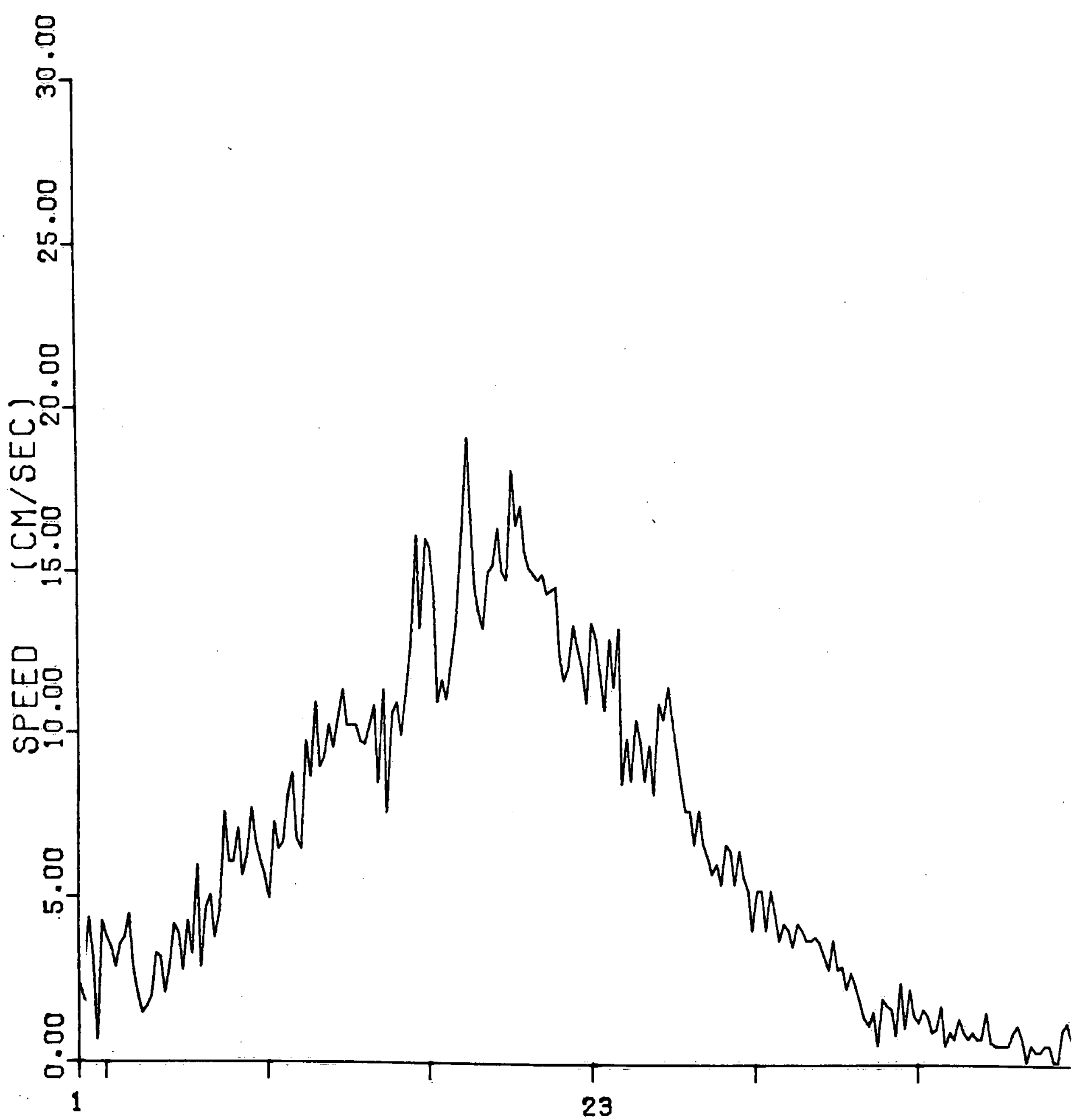
77-OC-01S014

CATS 1 12 m
Figure 5.4.3.b

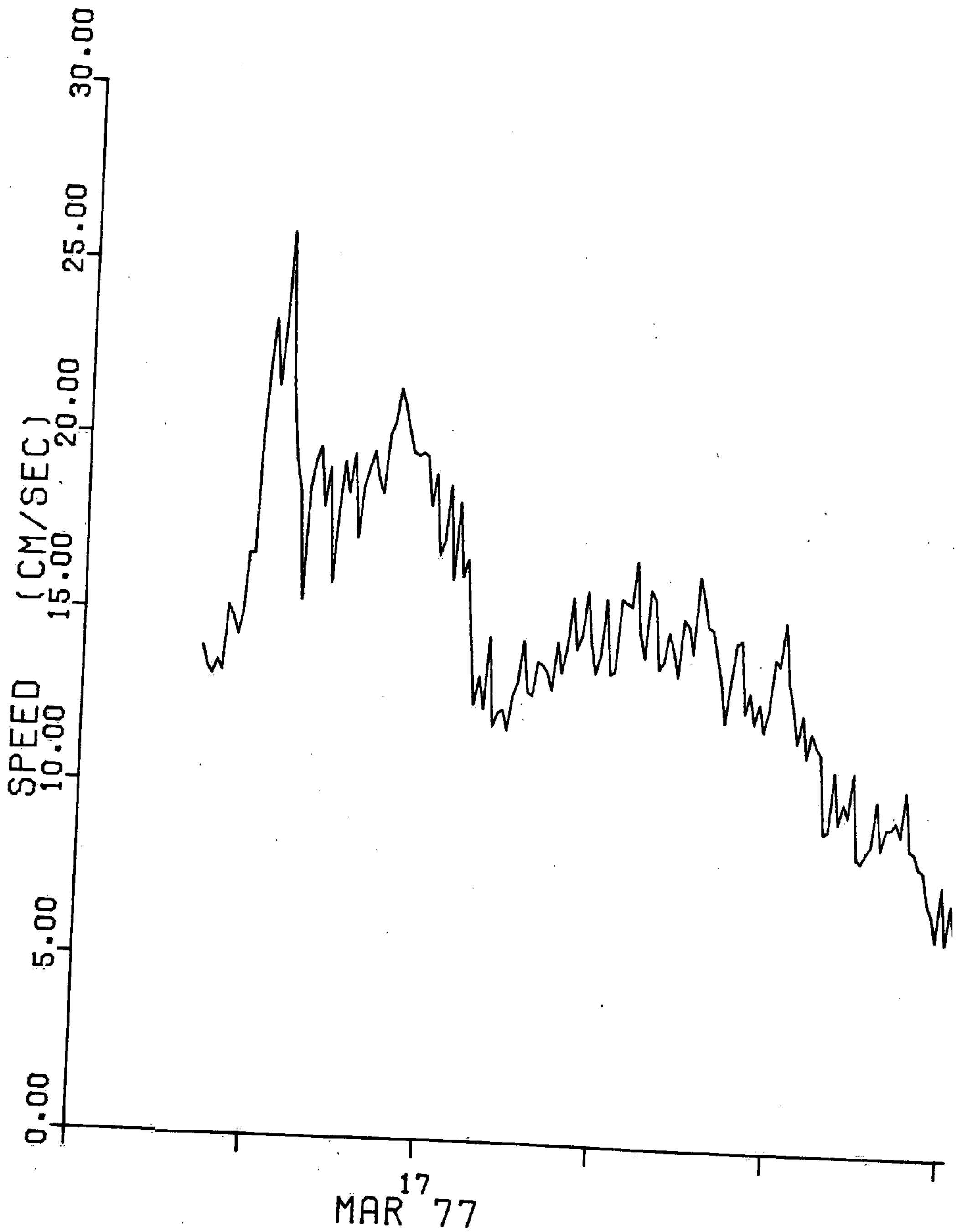


77-OC-01S014

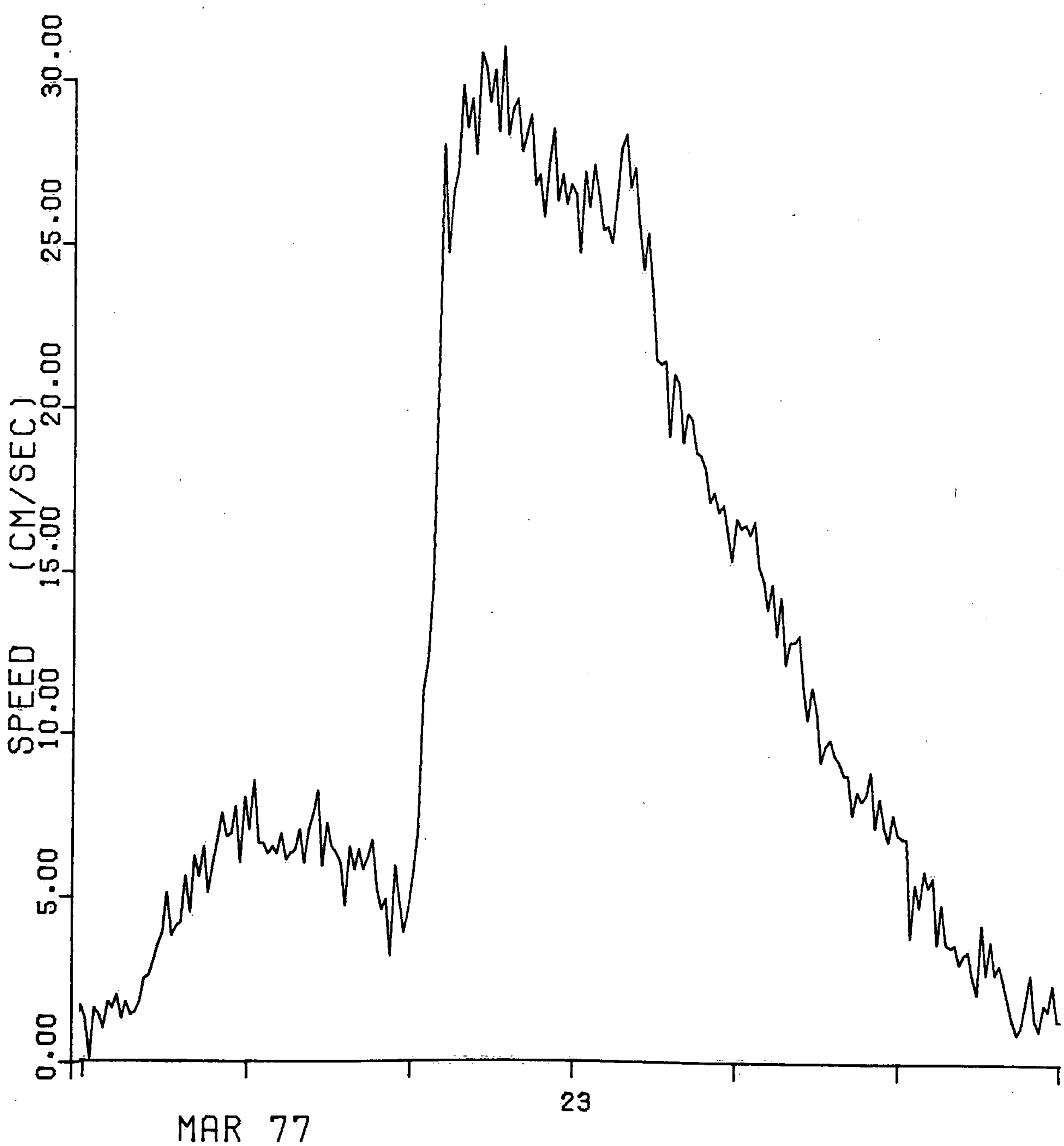
CATS 1 12 m
Figure 5.4.3.c



VAPS/CMI 5 m
Figure 5.4.4.a



VAPS/CMI
Figure 5.4.4.c



hypothesis for this discrepancy is that discussed in Section 6, regarding the sensing of mean current in the presence of orbital motion. It is suggested that the Plessey M021 overspeeds with the orbital motion until the mean currents are sufficiently large to enable the meter to respond more linearly.

The CATS 1 response for this same period indicates higher mean speeds than the VAPS/CMI from 1200 - 1900 hours on 22 March, despite the depth difference. This suggests that either the CATS 1 system is aliasing orbital motions or that the CMI sensor underestimates the mean speed for the hydrodynamic conditions prevailing. Both hypotheses are supportable in that the CATS 1 electromagnetic current sensors have demonstrated nonlinear sensitivity, and the CMI sensor has been shown to underestimate for some conditions (McCullough - see Section 6, Appendix II). These hypotheses cannot be pursued in any more than a qualitative manner, due to the form of the VAPS/CMI sensor vehicle assembly used in this experiment and the now obsolete configuration of the CATS system.

An interesting diversion is that P.F. Hamblin reports that spectral analysis of the high sample rate VAPS/CMI current sensor data shows evidence of the WAVES platform vibration frequencies predicted and previously measured.

5.5 Summary

The Current Meter Comparison Experiment of January - March, 1977, was the first experience at CCIW with a medium-large scale field comparison experiment. The Plessey M021 failures were ascribed to the delay in recovering the maintenance skills and experience following the return of the maintenance program to inhouse staff from industry, and the low reliability of the Kalium batteries. The Aanderaa meters were apparently not properly serviced prior to deployment. The Plessey 9021 meter suffers from an intrinsic design defficiency in the compass. Plessey offer a retrofit modification to improve performance. The CATS systems were principally limited by incorrect system integration methods, as identified in Sections 4.1, 4.3.

With the limited data ensemble available, one is not inclined to make strong conclusions. The 3 m M021 instruments showed symptoms of overspeeding, due to wave orbital motion, when compared to the 5 m M021, 9021 and VAPS/CMI. The 6 m Aanderaa showed a high threshold and overspeeding. The Plessey 9021 gave lower mean speed estimates than the M021 at the same depth. This would suggest that the hydrodynamics of the Roberts impellor mounting are better on the 9021 than the M021. This is consistent with the observation that the impellor is close to the blunt bulkhead of the pressure case on the M021 and hence cannot respond as well to reversing flows as that on the 9021, which is mounted further forward with a faired bulkhead.

5.6 CATS Systems

The CATS systems deployed in the 1977 field experiment were representative of the systems deployed at Byng Inlet (Georgian Bay) in FY 76. These systems have been under development since 1975. As this report has been delayed, some aspects of the CATS systems design have been changed, significantly improving their performance. The role played by the analysis of the CMC experiment data in this development is worthy of note.

Prior to the CMC experiment, current data collected with the CATS systems was considered unrepresentative of the expected currents in the deployment sites, despite some "current like" variability. This experiment provided a data set with independent information about the flow conditions which served to aid study of the CATS data.

The two systems had the following form: CATS 1, a single current sensor at 12 m; CATS 2, a current sensor at 12 m and one at 5 m. There were no other instruments at 12 m. The data were scrutinized by plotting the North and East flow components time series. Comparison with a similar time series for a 5 m Plessey identified periods of low or steady or unsteady flow. It was evident from inspection that the CATS systems were sensing current, but that the current was masked by relatively large zero offsets on the components. Figure 5.6.1 shows an example of this data. The cause for the offset behaviour is discussed in Section 4.

The offsets were found to be consistent for CATS 1 in any deployment, although they changed when the system was recovered and redeployed, due to a monitoring problem. CATS 2 showed greater variability in zero offset than CATS 1. When the estimated zero offsets were subtracted from the original time series, substantial portions of the CATS data were recovered, and correlation with the Plessey data improved markedly. Figure 5.6.2 summarizes the offset history for the CATS systems.

The offset corrected CATS data were plotted against each other, and the Plessey components, as in Figure 5.6.3. It is evident that the lower CATS sensors have a direction anomaly. No systematic resolution of this apparent 180 degrees rotation has been identified. On the strength of this empirical result, the CATS 1 data was rotated to agree with the 5 meter Plessey and CATS 2. This corrected CATS 1 data set was supplied for the comparison work of the previous subsections.

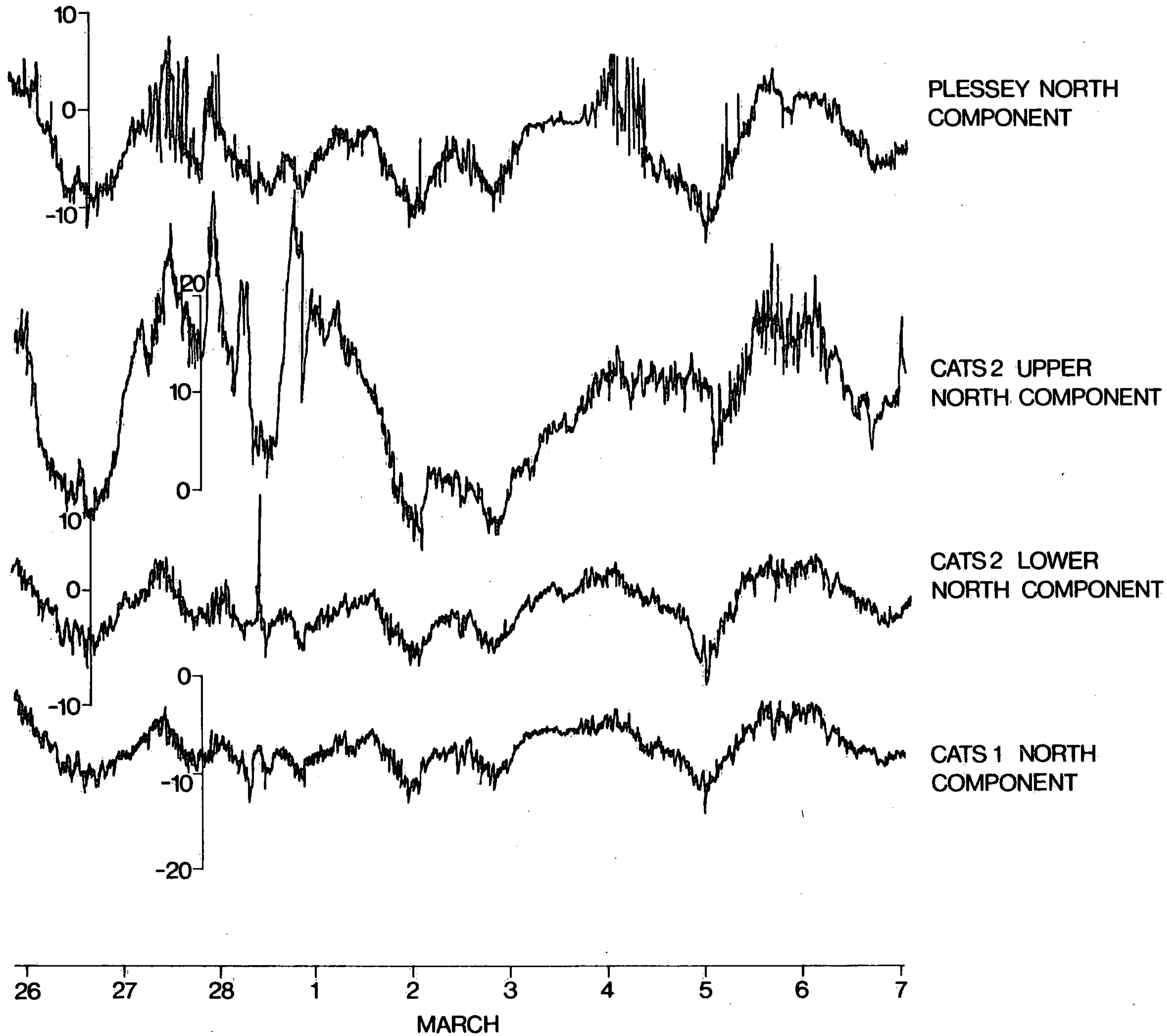


Figure 5·6·1 CMC COMPONENT TIME SERIES, VERTICAL SCALES ARE $cm \cdot s^{-1}$

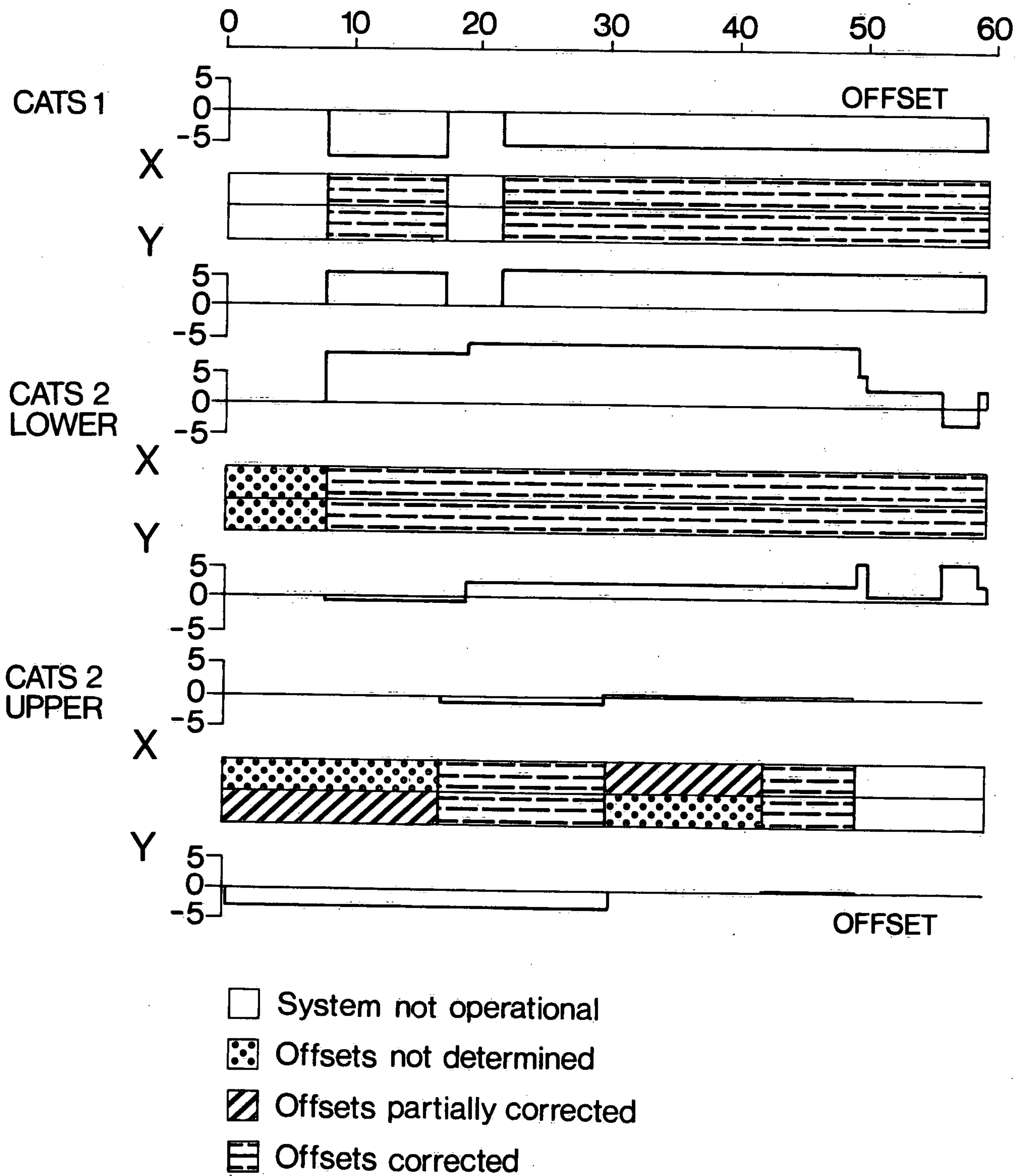


Figure 5·6·2 CMC CATS OFFSET BEHAVIOUR

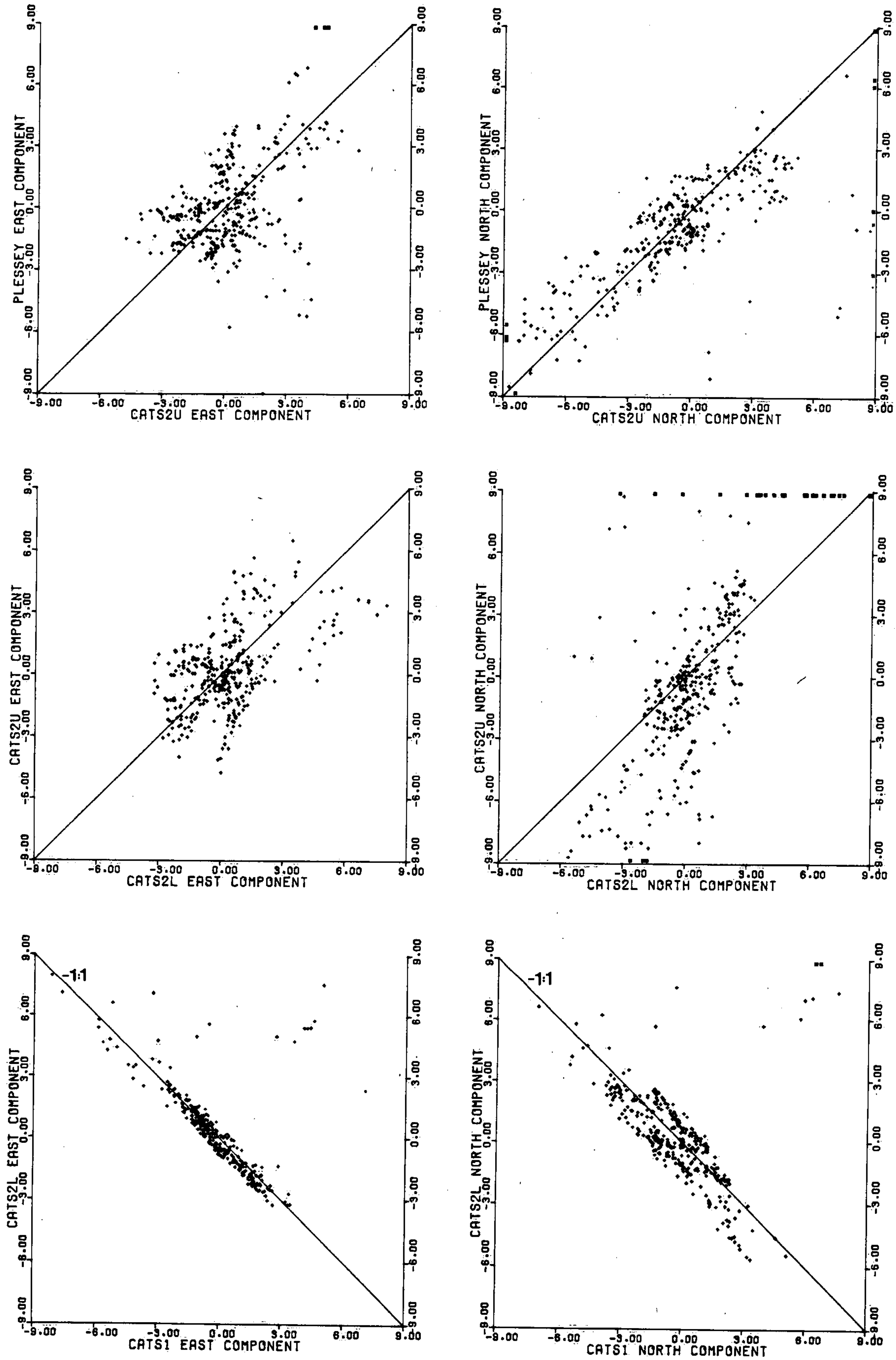


Figure 5·6·3 CMC PLESSEY, CATS SCATTER PLOTS – CATS1 IS ROTATED ?

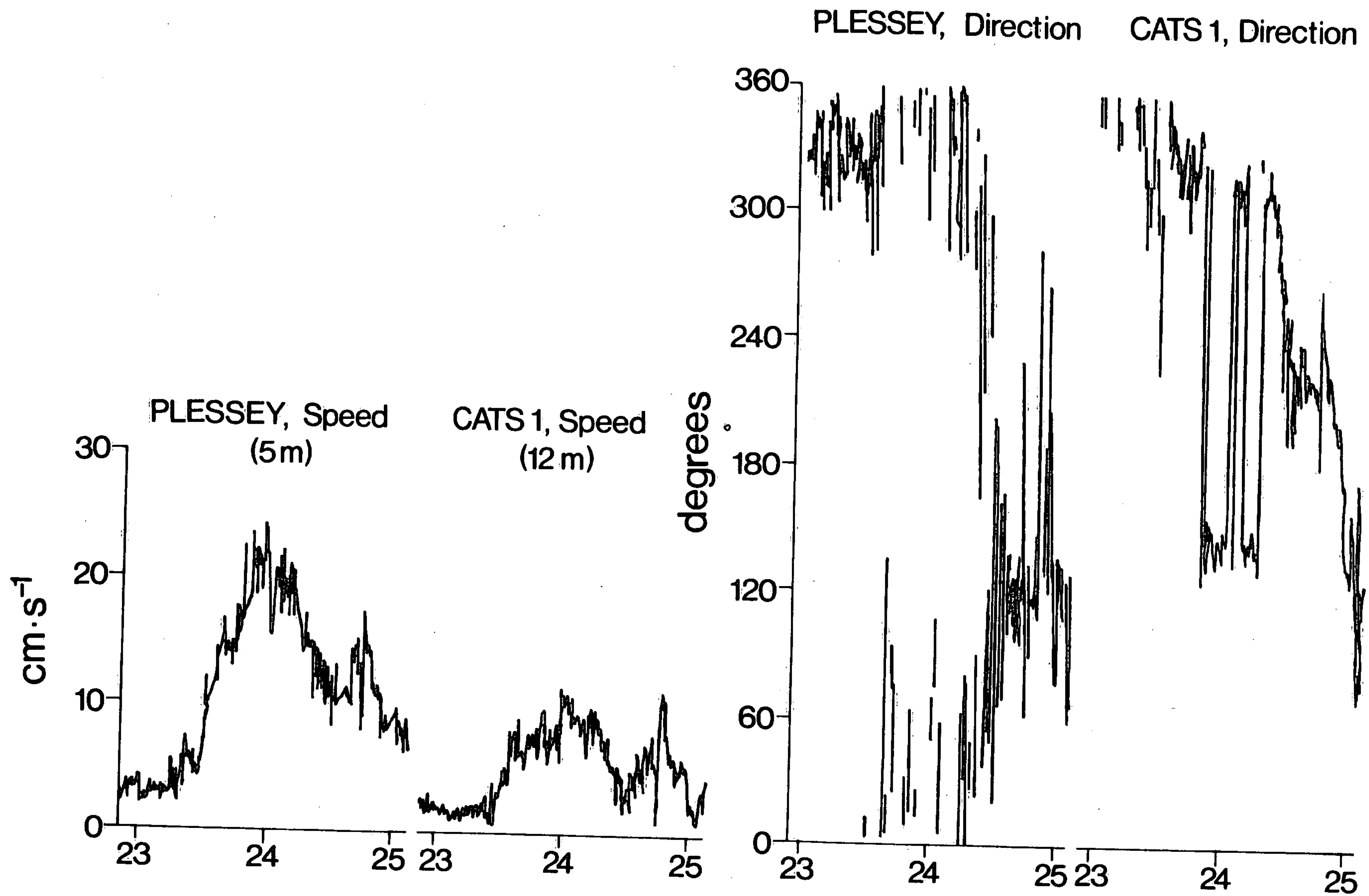


Figure 5·6·4 (a) FEB. 24, 1977 CATS 1 SENSING ANOMALY

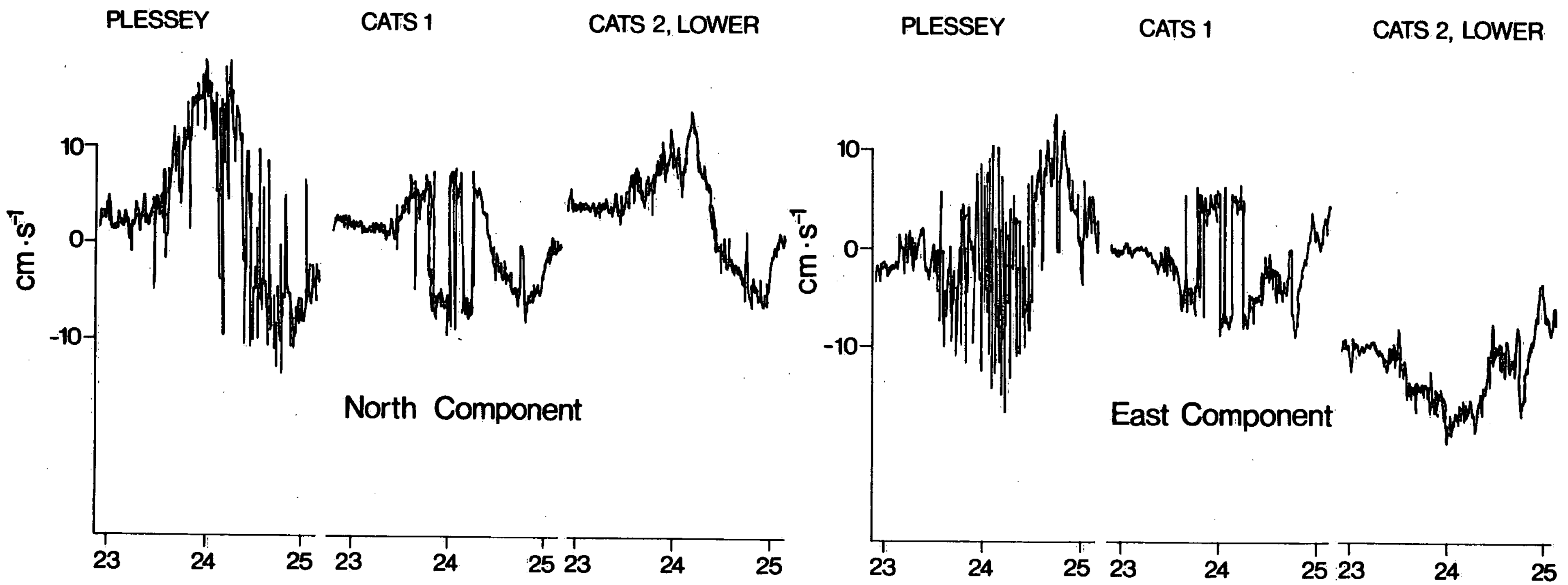


Figure 5·6·4 (b) FEB. 24, 1977 CATS 1 SENSING ANOMALY

Close scrutiny of the corrected data set shows an interesting anomaly on February 24, 1977. Fig. 5.6.4 shows the speed and direction time series extracted from the Plessey, CATS 2 and CATS 1. Also plotted are the CATS N and E component time series. This data shows the CATS 1 components to be switching signs (ie. rotating direction by 180 degrees). The speed is not affected, but the direction data shows the effect. It is difficult to postulate a hydrodynamic event with these characteristics and the spatial concentration necessary to elude the CATS 2 sensor and the Plessey current meter.

A more plausible argument is that the electronics in the CATS 1 electromagnetic current sensor, which determine the sensing sign, have an intermittent instability. Recall that the 180 degrees rotation previously applied to the CATS 1 data, was supported only by an empirical argument, in contradiction with the installation record.

6.0 SCIENTIFIC REQUIREMENTS AND INSTRUMENT CAPABILITIES

Scientists, with the benefit of experimental experience often define their measurement requirements in terms of what they believe they will obtain. The engineer is most often dubious of the prejudices which constrain the scientists' estimate of their requirement. To paraphrase a similar rhetorical question, "What do the scientists really want?" The engineer wants the scientist to define his end product objective (and its acceptable uncertainty), reflect that objective through his model (more uncertainty estimates) and estimate the acceptable measurement uncertainties consistent with this process for a variety of environmental / hydrodynamic conditions. In the engineer's ideal world he would use these constraints to select the instrumentation and configurations necessary to accomplish the objective. For the constraints he could not meet he can return to the scientist to get either an easement in the specification, or recommend altering the plan for the experiment.

Infrequently, studies proceed on this linear path. More often the constraints of time, resources and available technology precipitate a brief synergistic design phase where the constraints are recognized and a practicable solution selected. There have been many examples of the latter, not all of which are scientific successes. The costs of following this course are now coming to light as current measurement requirements move from the relative tranquility of general circulation as seen from conventional subsurface moored hydromechanical current meters toward the surface, bottom and nearshore boundaries. Here the dynamic characteristics of the flow field are nonlinearly mixed and sampled by conventional meters reducing confidence in the estimate of the mean flow. The attempts at engineering systems for these zones (VAPS - near surface; CATS, CATTS - near shore; Littoral Drift - surf zone) have had both successes and failures - particularly in the measurement of current.

The following questionnaire was distributed to scientists to glean an estimate of the direction in which the scientific requirement is perceived to lie. The responses represent only a first estimate of the requirements and should not be taken too rigidly. To organize this data I have plotted it in "McCullough space" (coined by me after J. McCullough - WHOI's discussion of current sensing). McCullough's analysis (App.II) is represented by Figures 6-1 and 6-2.

CURRENT MEASUREMENT REQUIREMENT QUESTIONNAIRE

- EULERIAN SYSTEMS

NAME: ____________ DATE: ________ STUDY DESCRIPTION: ________________

Depth of Measurement: ____________ <d< ________ metre

Reference frame: ___ bottom fixed structure
___ subsurface moor - float at ___ m
___ surface moor

Number of instruments and/or locations: ____________

Mean current speed dynamic range of interest: ________ <Vo< ________ $cm \cdot s^{-1}$

Data acquisition duration: ________ (hour, day, month)

Sample interval: ____________ (second, minute)

Largest orbital speed amplitude: ____________ $cm \cdot s^{-1}$; corresponding wave period: ______ second

DYNAMIC ACCURACY REQUIREMENT FOR MEAN CURRENT

CASE: Vo/aω -- i.e. mean speed / orbital component	ORBITAL COMPONENT ALIGNED WITH MEAN CURRENT		ORBITAL COMPONENT ORTHOGONAL TO MEAN CURRENT		COMMENT
	SPEED ACCURACY [$cm \cdot s^{-1}$ or %]	DIRECTION ACCURACY [°]	SPEED ACCURACY [$cm \cdot s^{-1}$ or %]	DIRECTION ACCURACY [°]	
>>1					
∿ 1					
<<1					

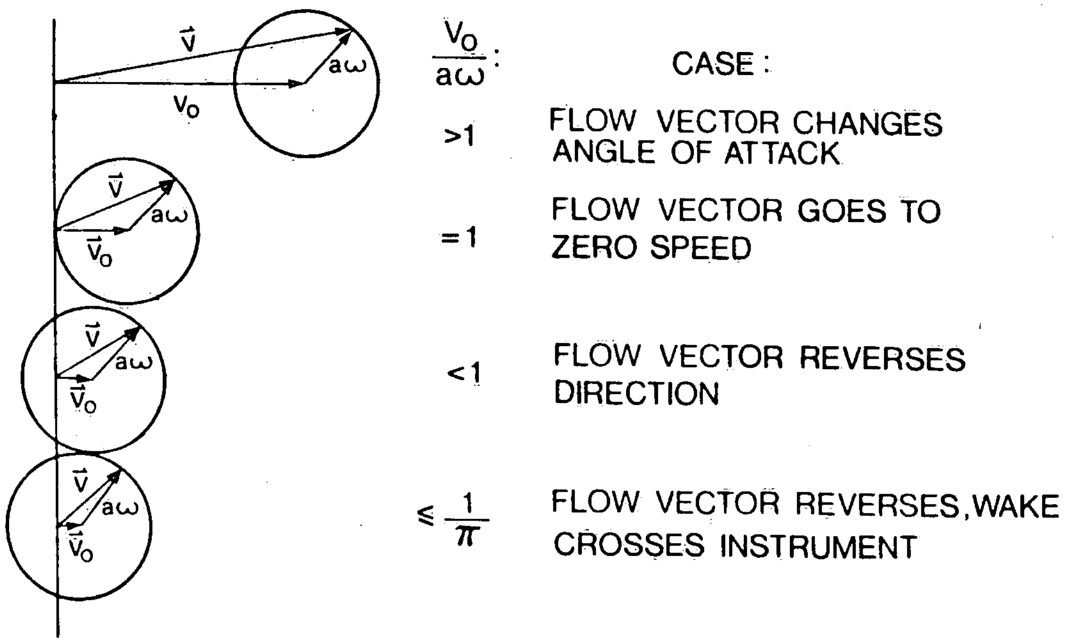
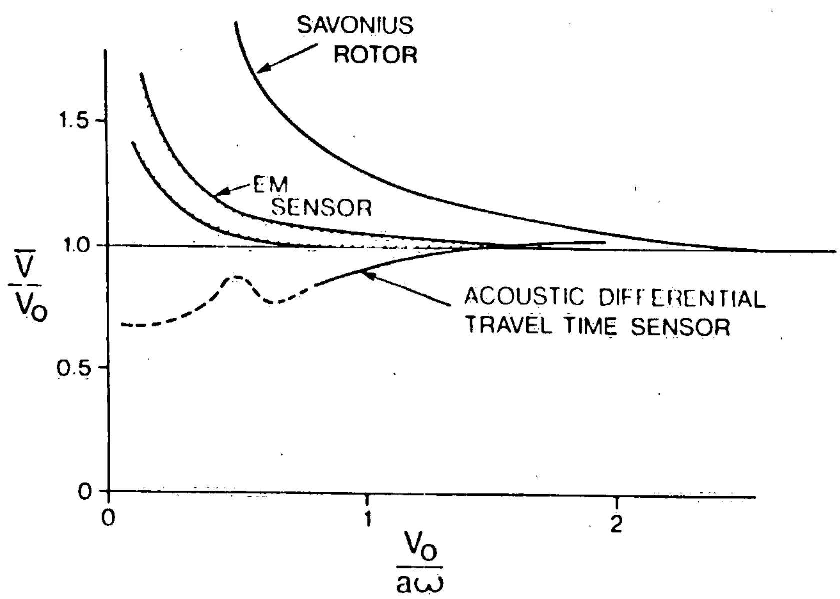


FIGURE 6-1 MEASUREMENT OF MEAN FLOW IN PRESENCE OF AN ORBITAL FLOW COMPONENT (After McCullough (WHOI), 1978)



INSTRUMENT RESPONSES TO ORBITAL MOTION

FIGURE 6-2

My M-space is a three dimensional space plotting certainty (accuracy or confidence if you like) in the estimate of the mean current versus mean velocity magnitude versus the ratio of the mean velocity to the orbital velocity amplitude. Figure 6-3 identifies this space with a hypothetical hydromechanical sensor of the propellor type represented. The plane where $\frac{Vo}{aw} \sim 1$ represents the limit of linear performance for sensors with thresholds, inertia, etc. The plane where this ratio $\sim \pi^{-1}$ represents the limit of linear performance for sensors which measure in their own boundary layer. Here the wave moves the sensor's wake back over the sensor as the mean velocity is too small to remove the wake generated by the orbital motion in one wave period. When working above this plane such sensors must have a wave spectrum dependent relaxed error specification. Alternatively, a remote sensing technology must be applied to be free of wake effects.

The survey results have been liberally represented in M-space-- the flat and/or warped planes are representations only. A special comment is necessary regarding the certainty axis. Invariably the replies showed a more stringent requirement for speed certainty than for direction. This was relaxed for the purposes of my M-space representation by the reasoning shown in Figure 6-4. If a $\pm 5^{\circ}$ direction error on the mean current is acceptable, then the uncertainty vector $\Delta\vec{V}$ is defined. If $\Delta\vec{V}$ is allowed to be evenly distributed in angle, then the inscribed circle of radius $|\Delta\vec{V}|$ is defined. This suggests a much larger, worst case speed uncertainty than is usually specified. In other words, the direction uncertainty is a dominating constraint - except at low speeds. The questionnaires have been mapped into M-space using these considerations. The example for the CATS requirement shown in Figure 6-4 illustrates the problem imposed by zero offset uncertainty at low speeds.

Figures 6-5 and 6-12 show the estimates of the M-space requirements. It is not my intent here to discuss the significance of every plane in each figure. By comparing the figures one can observe the difference in emphasis from one research study area to another. What is more to the point - one can plot the performance of different current measurement systems in M-space and compare these to the requirements (overlay) and deduce feasibility for the experiment.

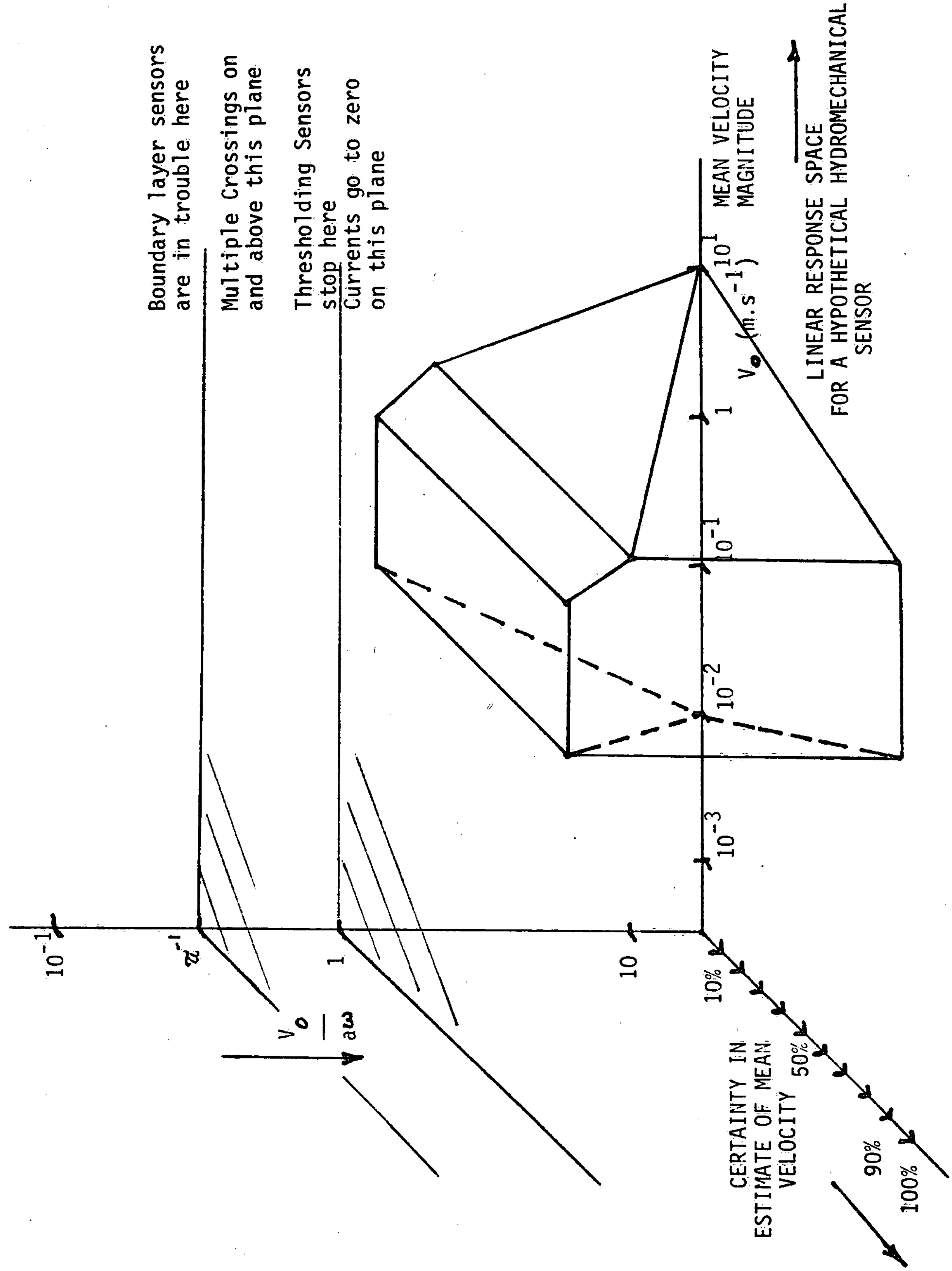
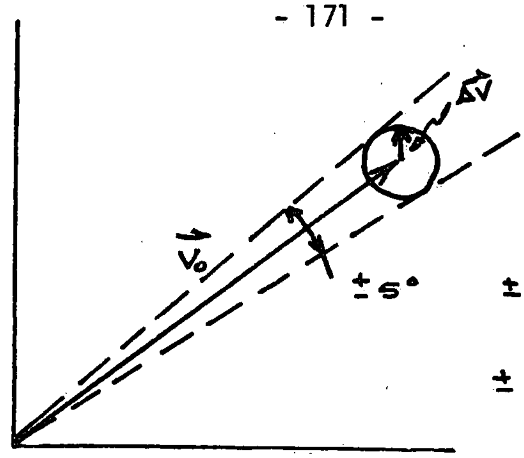

Boundary layer sensors are in trouble here
Multiple Crossings on and above this plane
Thresholding Sensors stop here
Currents go to zero on this plane
MEAN VELOCITY MAGNITUDE
V_o (m.s^{-1})
10^{1}
1
10^{-1}
10^{-2}
10^{-3}
LINEAR RESPONSE SPACE FOR A HYPOTHETICAL HYDROMECHANICAL SENSOR
10^{-1}
π^{-1}
1
10
$\frac{V_o}{a\omega}$
CERTAINTY IN ESTIMATE OF MEAN VELOCITY
10%
50%
90%
100%

Figure 6-3



WORST CASE

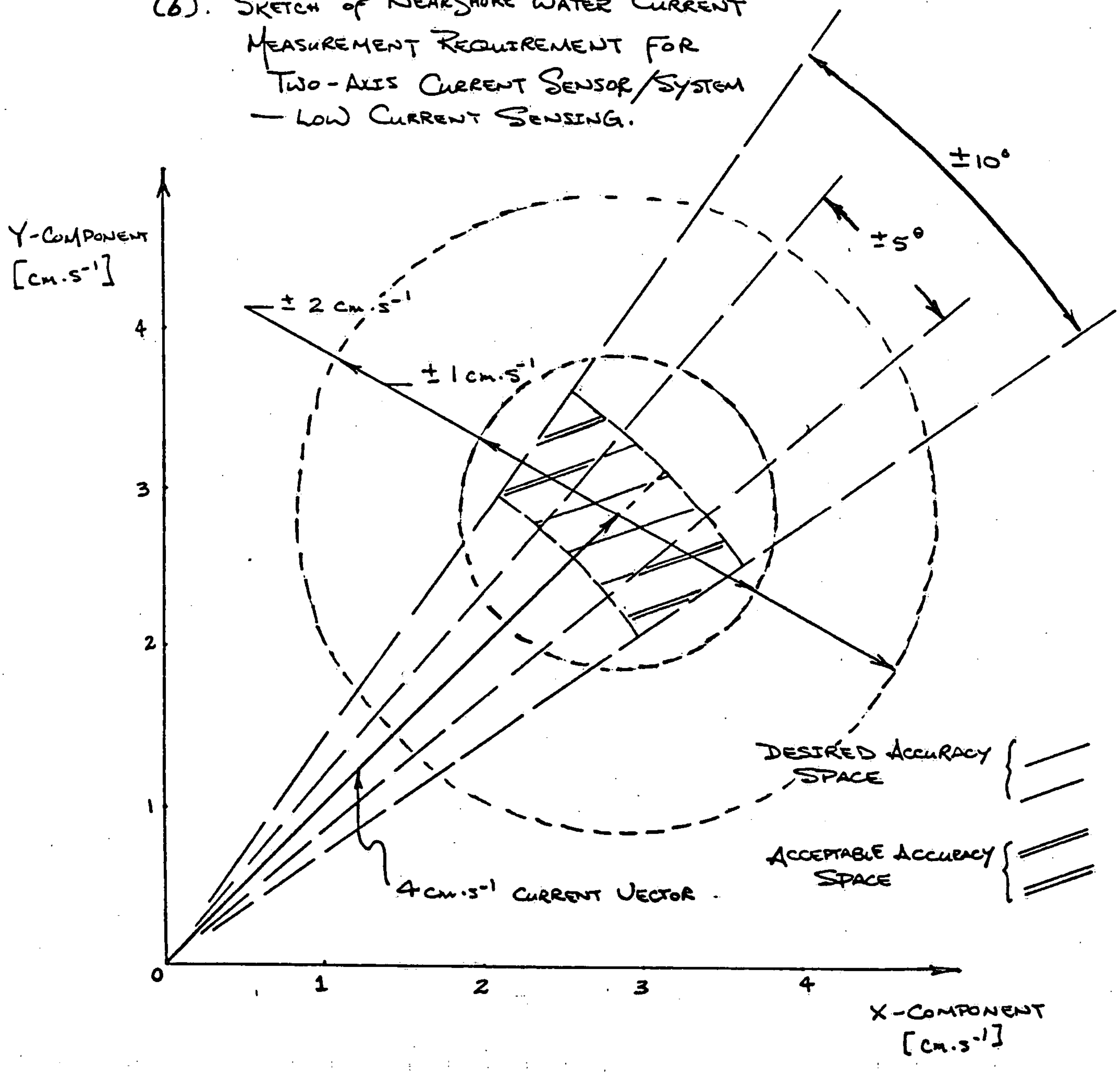
±5° : $\frac{\Delta V}{V_0} \sim \tan 5° \rightarrow \pm 8.75\%$

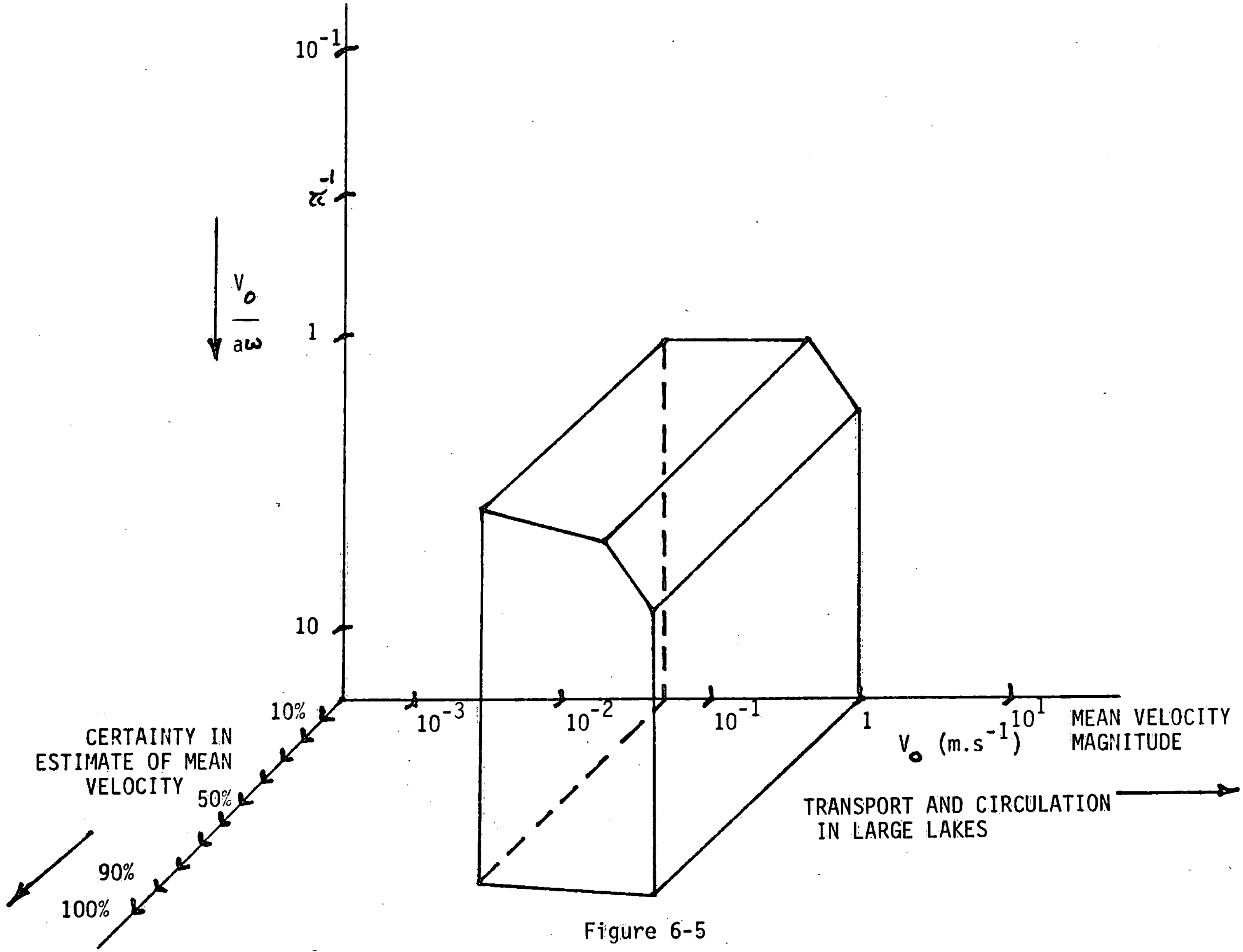
±10° : $\frac{\Delta V}{V_0} \sim \tan 10° \sim \pm 17.65\%$

TAKE ±5° AS ±5% TYPICALLY AND ±10° AS ±10% TYPICALLY.

FIGURE 6-4 (a) COUPLING OF SPEED AND DIRECTION UNCERTAINTIES.

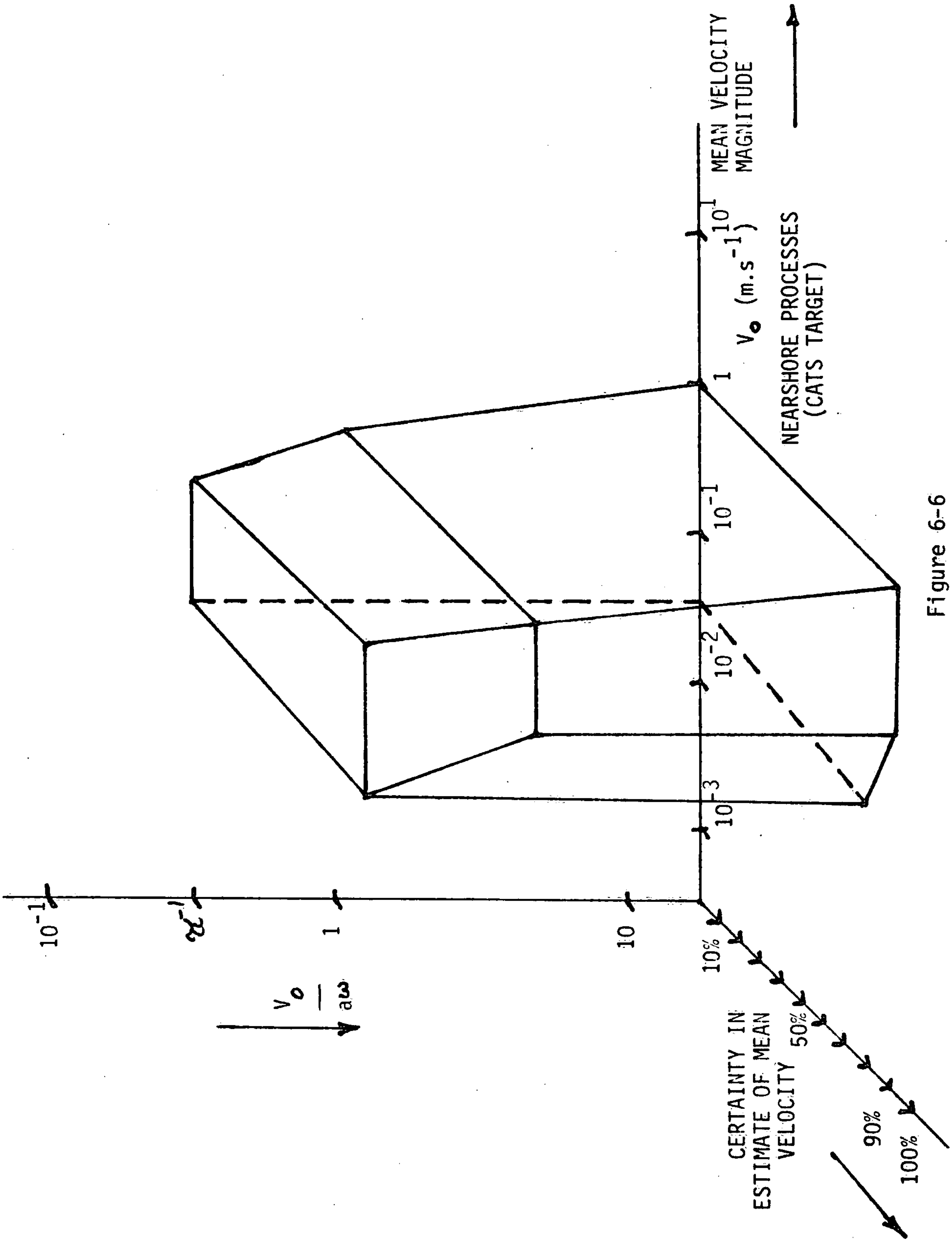
(b). SKETCH OF NEARSHORE WATER CURRENT MEASUREMENT REQUIREMENT FOR TWO-AXIS CURRENT SENSOR/SYSTEM — LOW CURRENT SENSING.





10⁻¹
1
10
V₀ / aω
10%
50%
90%
100%
CERTAINTY IN ESTIMATE OF MEAN VELOCITY
10⁻³
10⁻²
10⁻¹
1
10¹
V₀ (m.s⁻¹)
MEAN VELOCITY MAGNITUDE
TRANSPORT AND CIRCULATION IN LARGE LAKES

Figure 6-5



MEAN VELOCITY MAGNITUDE
V_o (m.s^{-1})
NEARSHORE PROCESSES (CATS TARGET)
10^{-3}
10^{-2}
10^{-1}
1
10^{1}
$\frac{V_o}{a\omega}$
10^{-1}
$\mathcal{R}^{-1}$
1
10
CERTAINTY IN ESTIMATE OF MEAN VELOCITY
10%
50%
90%
100%

Figure 6-6

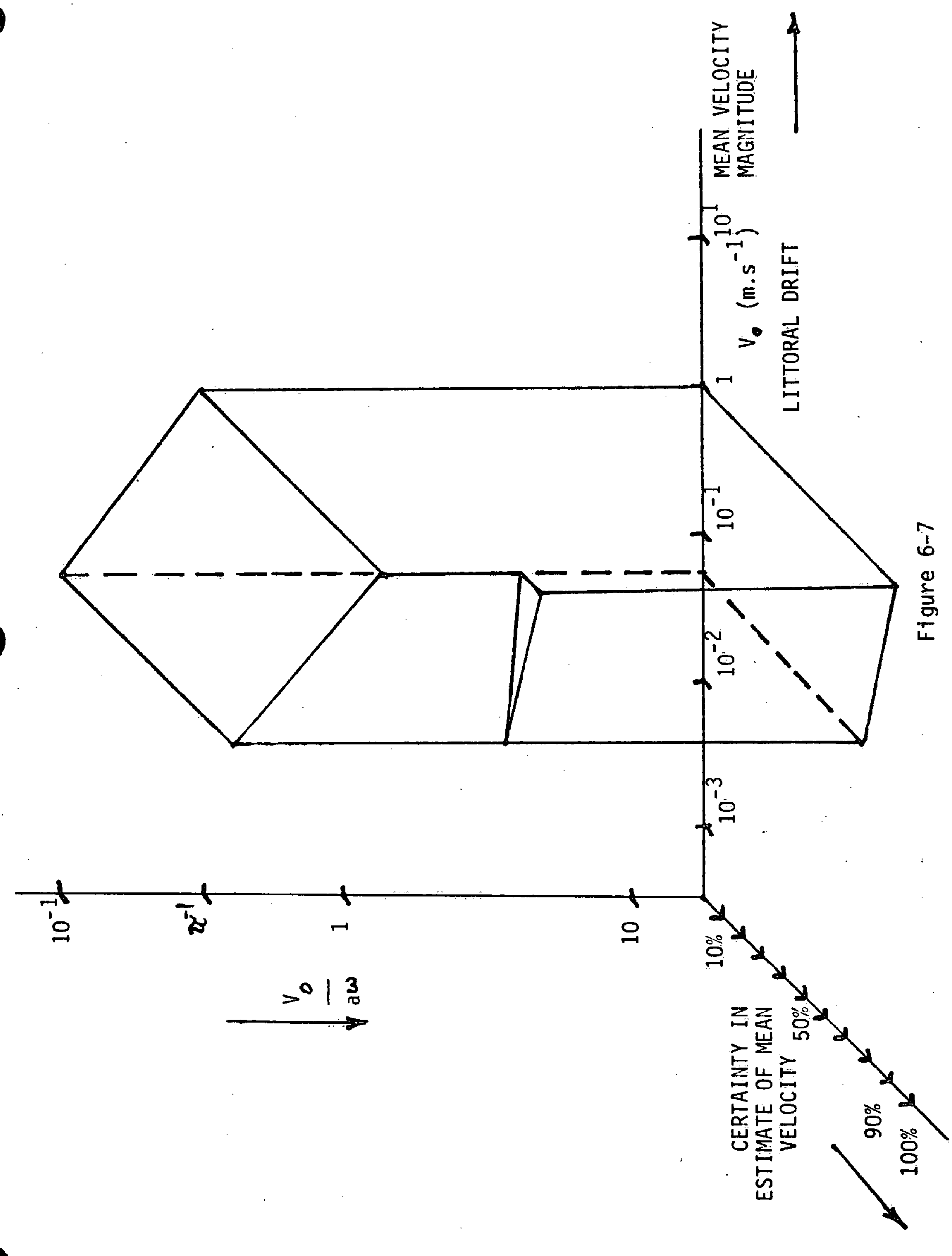
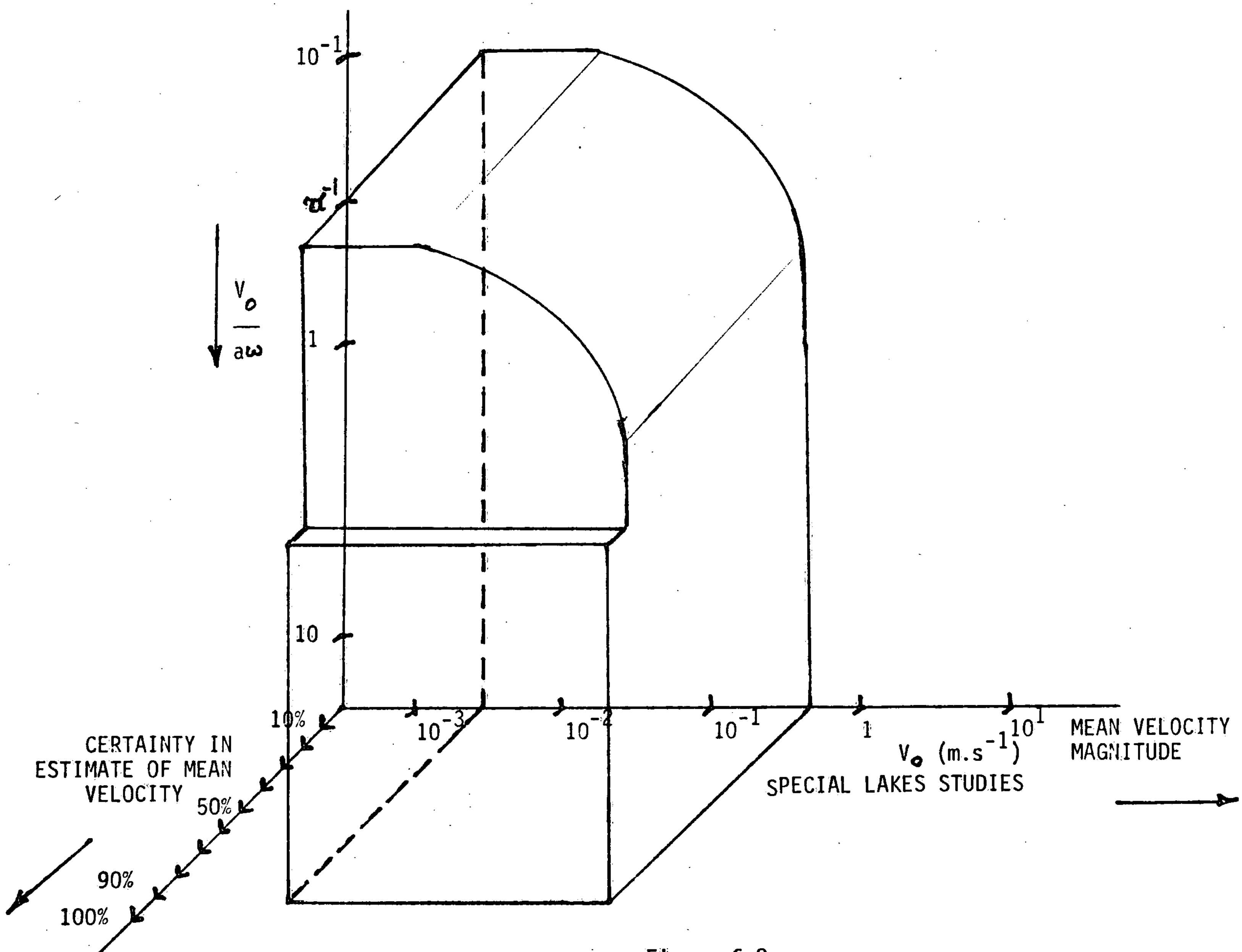

MEAN VELOCITY MAGNITUDE
LITTORAL DRIFT
V_o (m.s^{-1})
10^{-3}
10^{-2}
10^{-1}
1
10^{1}
$\frac{V_o}{a^3}$
10^{-1}
1
10
CERTAINTY IN ESTIMATE OF MEAN VELOCITY
10%
50%
90%
100%

Figure 6-7



10⁻¹
π⁻¹
1
10
V₀ / aω
10%
50%
90%
100%
CERTAINTY IN ESTIMATE OF MEAN VELOCITY
10⁻³
10⁻²
10⁻¹
1
10¹
V₀ (m.s⁻¹)
SPECIAL LAKES STUDIES
MEAN VELOCITY MAGNITUDE

Figure 6-8

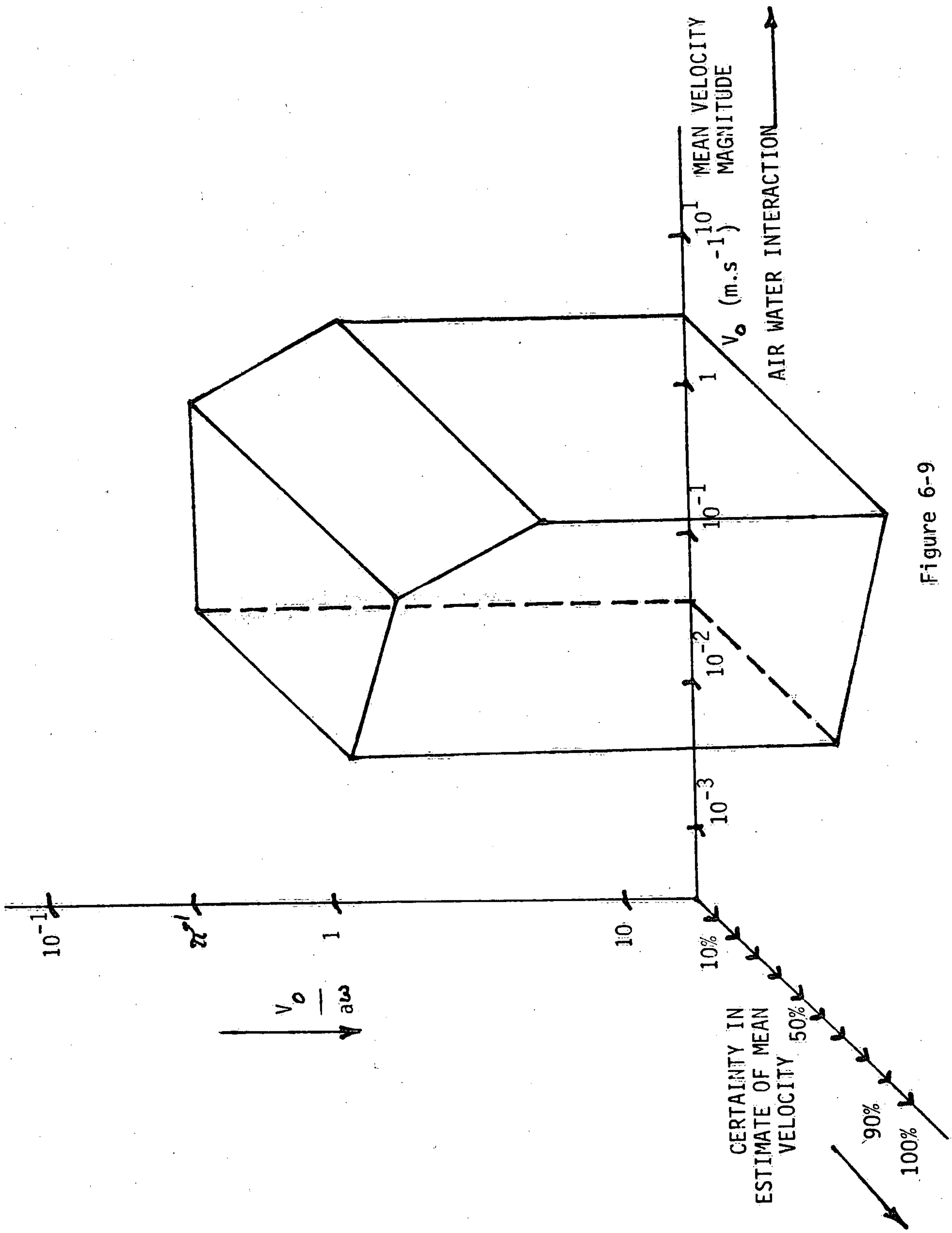

MEAN VELOCITY MAGNITUDE
AIR WATER INTERACTION
V_o (m.s^{-1})
10^{1}
1
10^{-1}
10^{-2}
10^{-3}
$\frac{V_o}{a\omega}$
10^{-1}
π^{-1}
1
10
CERTAINTY IN ESTIMATE OF MEAN VELOCITY
10%
50%
90%
100%

Figure 6-9

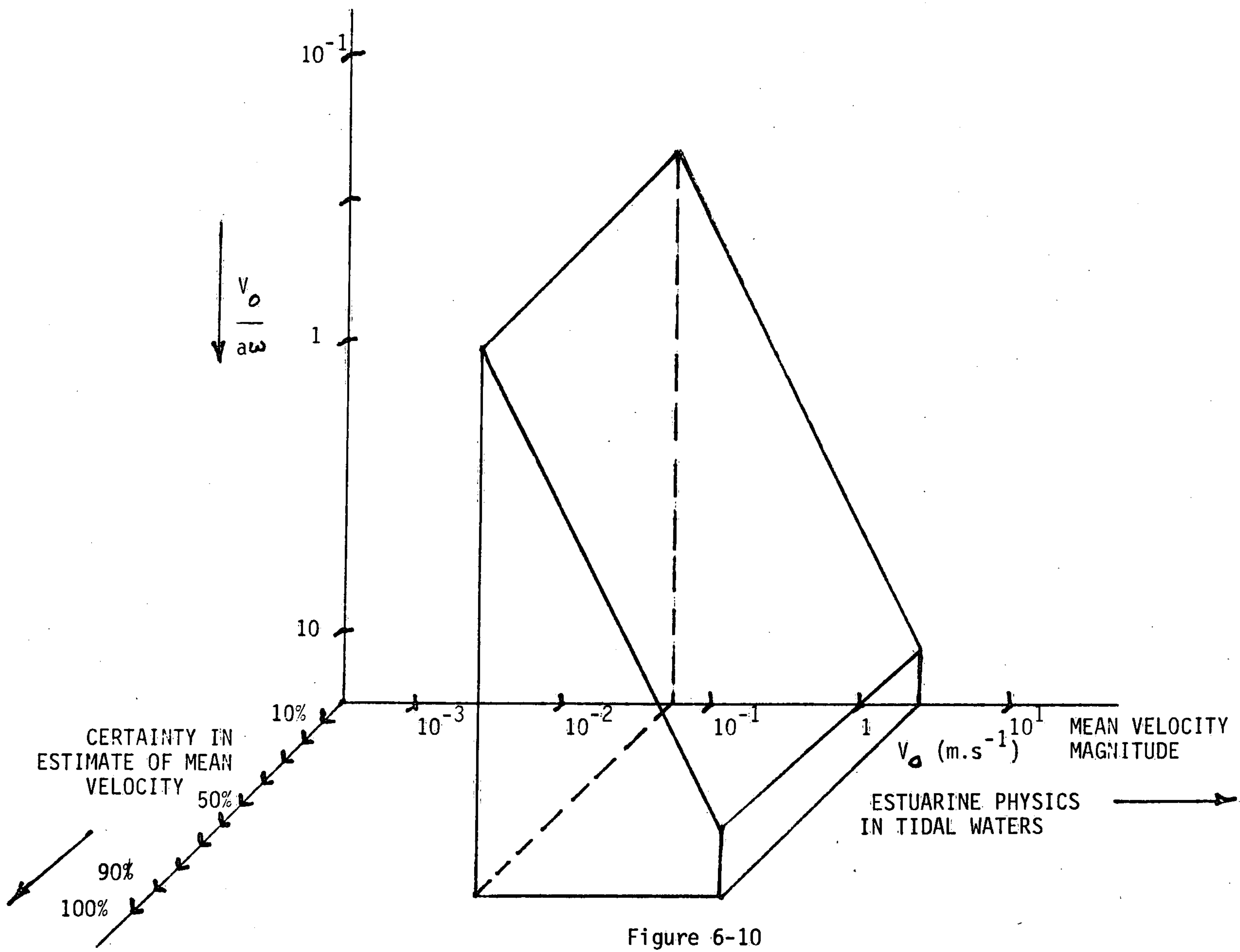

10^{-1}
$\frac{V_o}{a\omega}$
1
10
10%
CERTAINTY IN
ESTIMATE OF MEAN
VELOCITY
50%
90%
100%
10^{-3}
10^{-2}
10^{-1}
1
10^{1}
V_o (m.s^{-1})
MEAN VELOCITY
MAGNITUDE
ESTUARINE PHYSICS
IN TIDAL WATERS

Figure 6-10

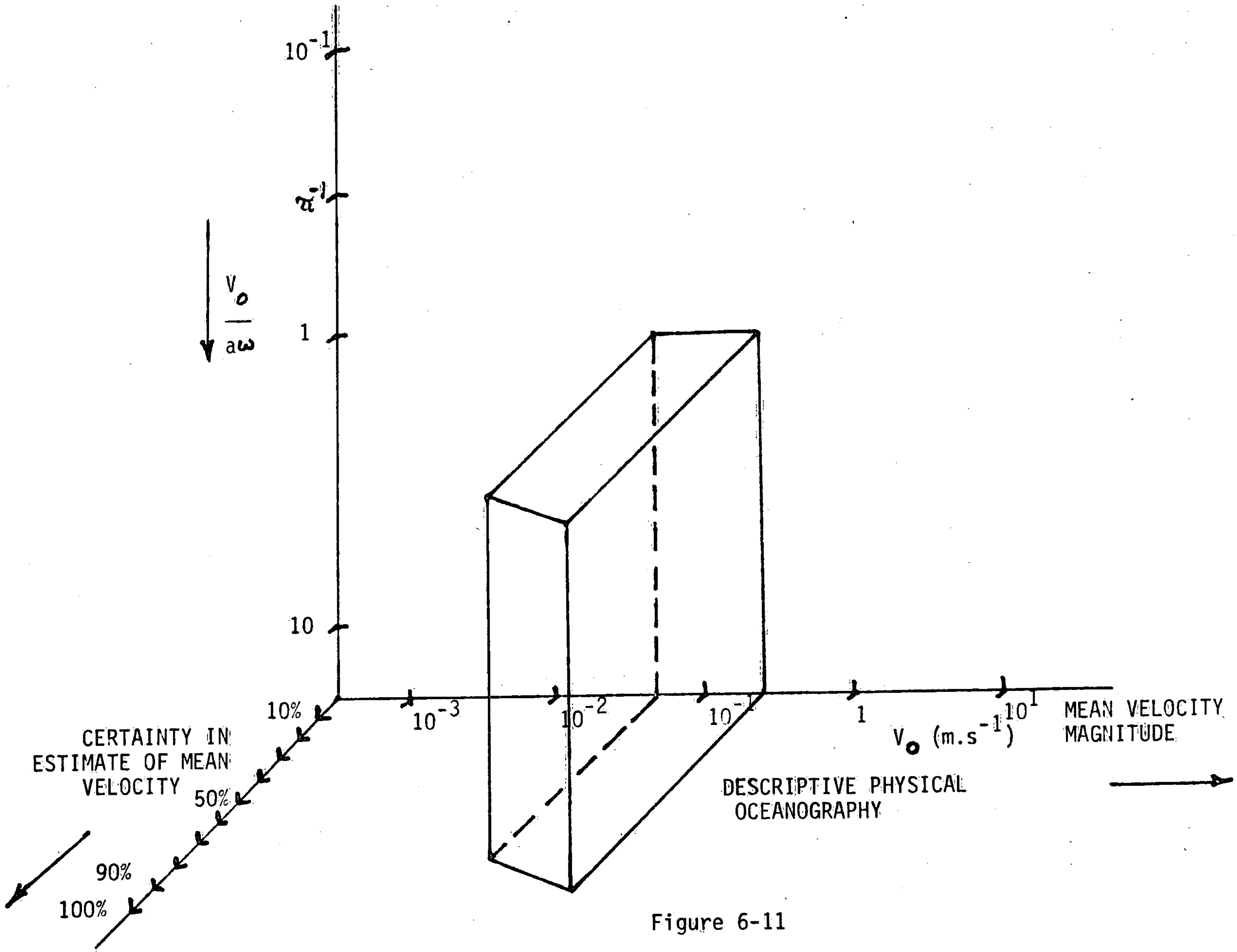

10^-1
π^-1
1
10
Vo / aω
10^-3
10^-2
10^-1
1
10^1
MEAN VELOCITY
MAGNITUDE
Vo (m.s^-1)
DESCRIPTIVE PHYSICAL
OCEANOGRAPHY
10%
50%
90%
100%
CERTAINTY IN
ESTIMATE OF MEAN
VELOCITY

Figure 6-11

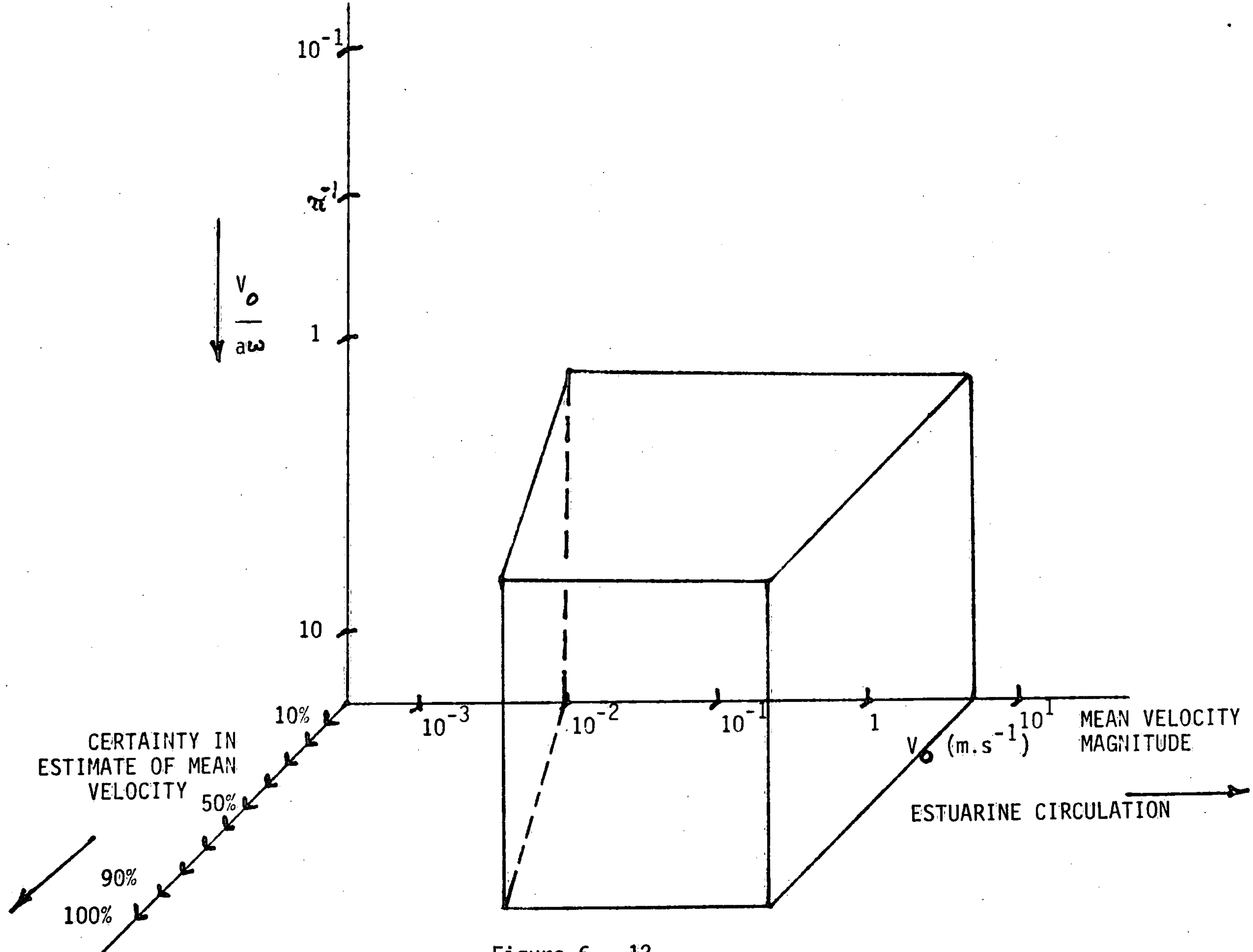

10^{-1}
π^{-1}
1
10
$\frac{V_o}{a\omega}$
10%
10^{-3}
10^{-2}
10^{-1}
1
10^{1}
MEAN VELOCITY MAGNITUDE
V_o (m.s^{-1})
ESTUARINE CIRCULATION
CERTAINTY IN ESTIMATE OF MEAN VELOCITY
50%
90%
100%

Figure 6 - 12

Figures 6-13 through 6-18 represent estimates of the performance of a variety of sensors - not all of which exist. Some simple observations can be made with a quick review of the figures.

Studies which require measurements above the $\frac{Vo}{aw} \sim \pi^{-1}$ plane must either accept relaxed uncertainty specifications or inspire the development of novel sensors.

- No sensor is believed to exist which will meet all the requirements (at any price).
- Stability, sensitivity and resolution at low speeds figure strongly in the requirements of lake boundary studies.
- Very little real data is presented in these figures for instrument performance - they are largely conjecture. As data becomes available from testing (such as that done by NOAA/ OEE / NOS) it should be cast into this representation to extend our understanding of the instruments.

The utility of this form of presentation can be illustrated by considering some example requirements. The CATS objectives for near shore measurement (Figures 6-4(b), 6-6) can be compared with the electromagnetic current sensor (Figure 6-14). It is clear that improved control over the zero offset uncertainty is necessary to meet the low speed objectives. More extensive testing is necessary to determine the feasibility of this. Fortunately, the zero offset can be measured in-situ by fitting a zero speed cap to the sensor. An alternative is to fit some higher performance sensor - such as an electro-acoustic type. Unfortunately, for sensors of this type measuring the zero offset in-situ is not as feasible as for the above.

Another example is the littoral drift study, Figure 6-7. It is an objective for this study to make measurements of the mean currents as well as possible under breaking waves. As suggested in section 4.3, the acoustic doppler sensor may be a candidate for this zone, along with the electromagnetic. By comparing Figures 6-7, 6-14, and 6-16, one can gain an appreciation of the technological problems involved in filling this requirement.

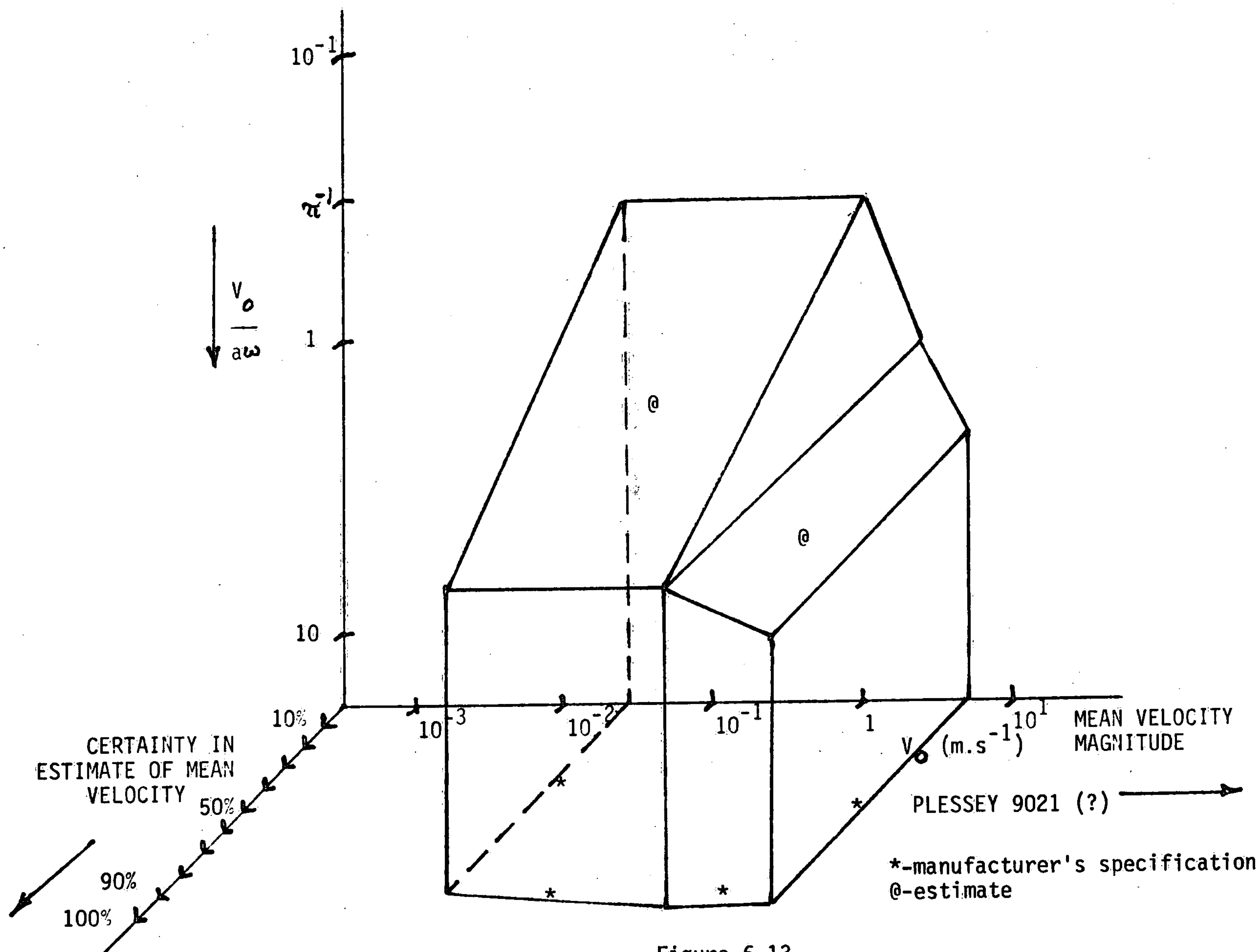
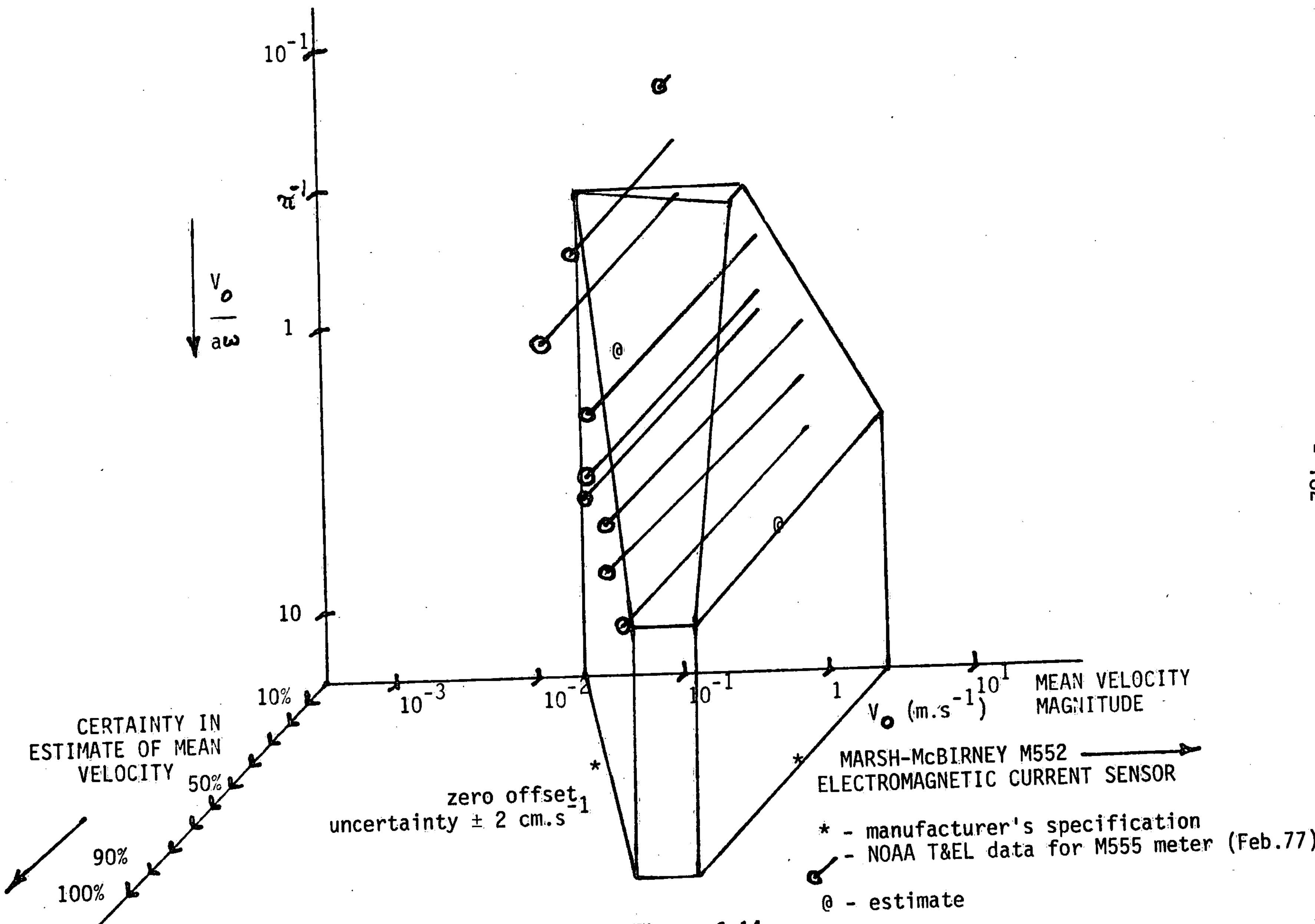
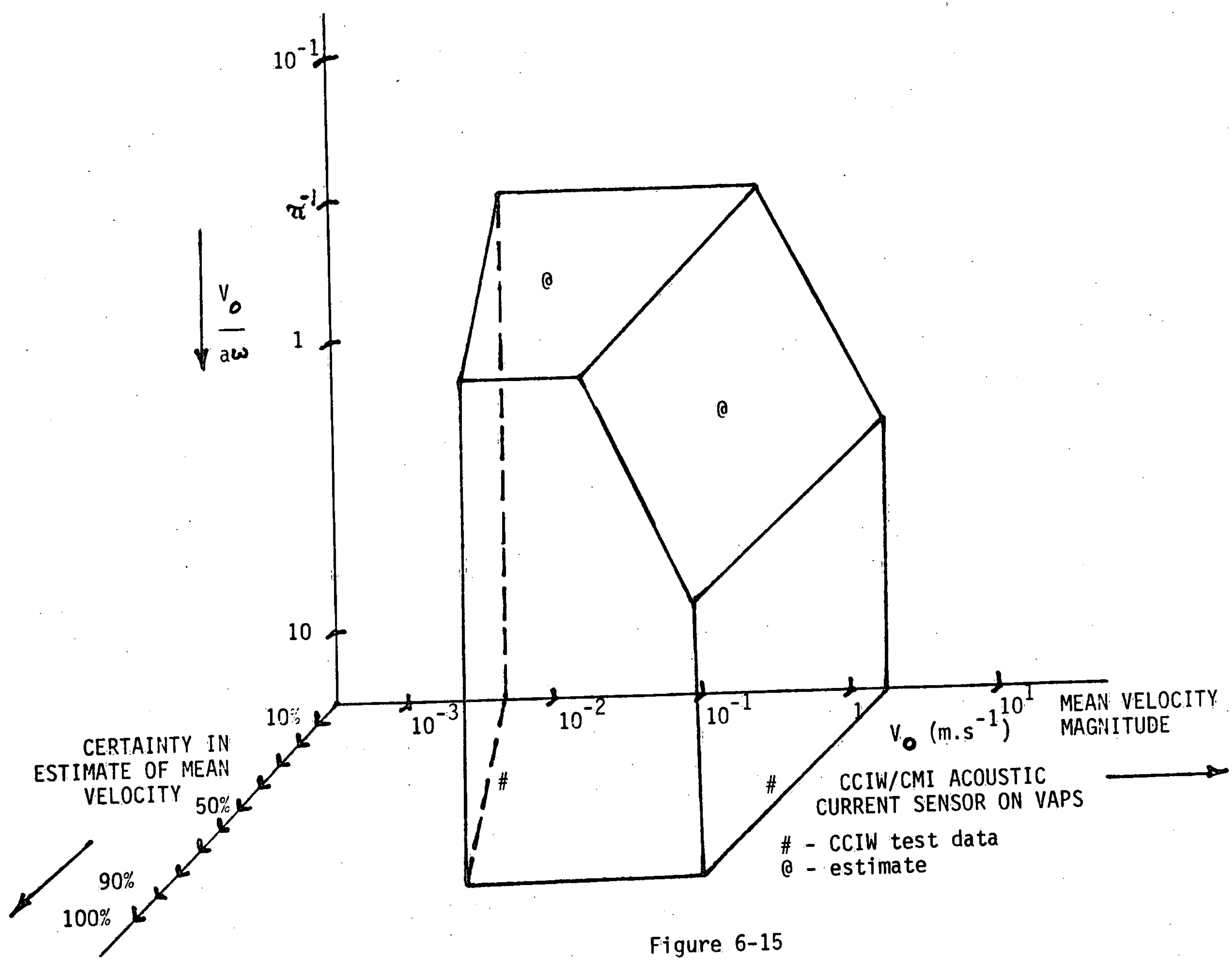

10^-1
π^-1
1
10
V_o / aω
10%
50%
90%
100%
CERTAINTY IN ESTIMATE OF MEAN VELOCITY
10^-3
10^-2
10^-1
1
10^1
V_o (m.s^-1)
MEAN VELOCITY MAGNITUDE
@
@
PLESSEY 9021 (?)
*-manufacturer's specification
@-estimate

Figure 6-13



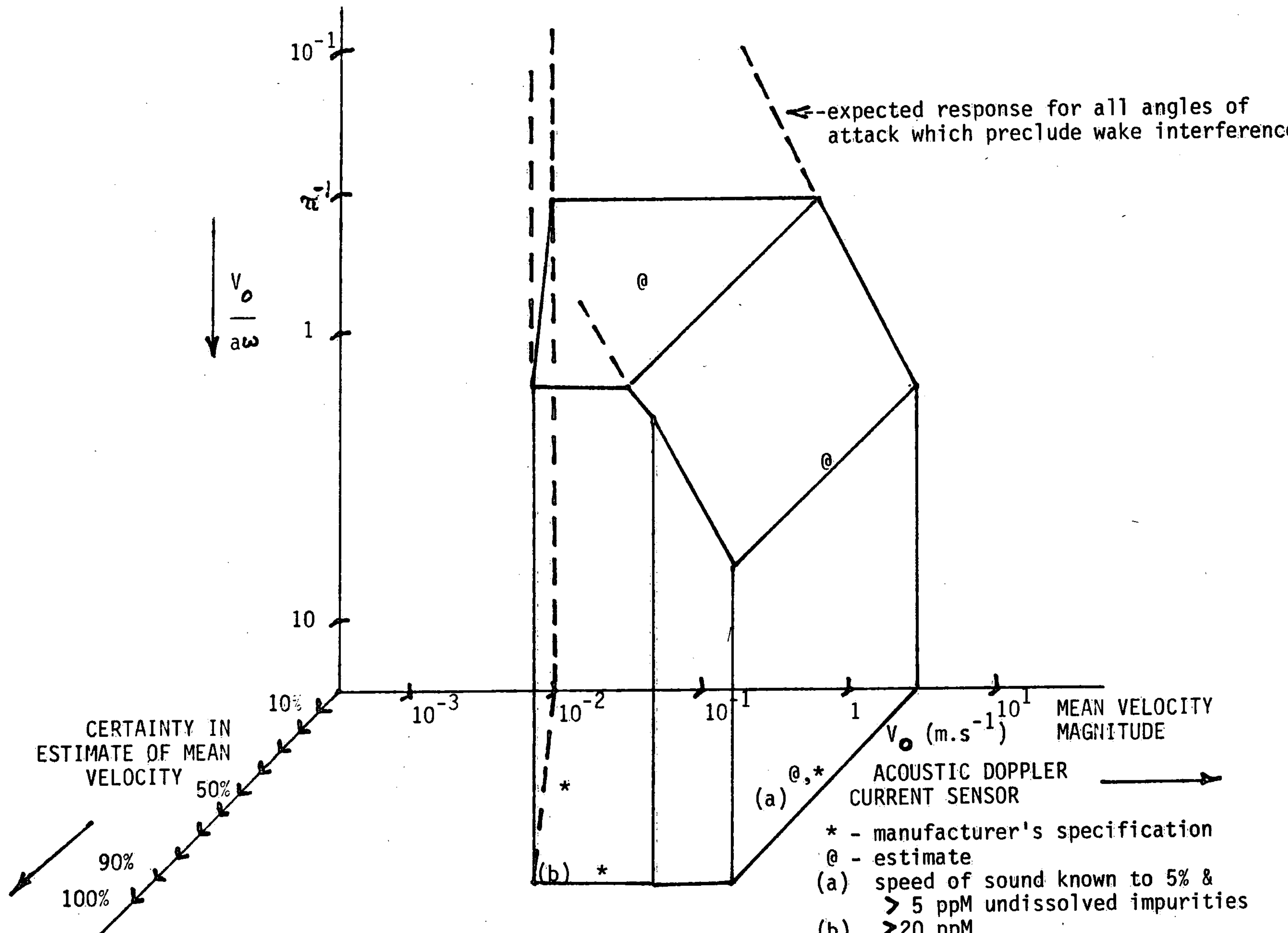
10^{-1}
π^{-1}
1
10
$\frac{V_o}{a\omega}$
10%
50%
90%
100%
CERTAINTY IN ESTIMATE OF MEAN VELOCITY
10^{-3}
10^{-2}
10^{-1}
1
10^{1}
MEAN VELOCITY MAGNITUDE
V_o (m.s^{-1})
zero offset uncertainty ± 2 cm.s^{-1}
MARSH-McBIRNEY M552 ELECTROMAGNETIC CURRENT SENSOR
* - manufacturer's specification
- NOAA T&EL data for M555 meter (Feb.77)
@ - estimate

Figure 6-14



10⁻¹
π⁻¹
1
10
V₀ / aω
10%
50%
90%
100%
CERTAINTY IN ESTIMATE OF MEAN VELOCITY
10⁻³
10⁻²
10⁻¹
1
10¹
V₀ (m.s⁻¹)
MEAN VELOCITY MAGNITUDE
@
@
#
#
CCIW/CMI ACOUSTIC CURRENT SENSOR ON VAPS
- CCIW test data
@ - estimate

Figure 6-15



←-expected response for all angles of attack which preclude wake interference
10^{-1}
π^{-1}
1
10
$\frac{V_o}{a\omega}$
@
@
10%
50%
90%
100%
CERTAINTY IN ESTIMATE OF MEAN VELOCITY
10^{-3}
10^{-2}
10^{-1}
1
10^{1}
V_o (m.s^{-1})
MEAN VELOCITY MAGNITUDE
(a) @,*
(b)
*
*
ACOUSTIC DOPPLER CURRENT SENSOR
* - manufacturer's specification
@ - estimate
(a) speed of sound known to 5% & > 5 ppM undissolved impurities
(b) >20 ppM

Figure 6-16

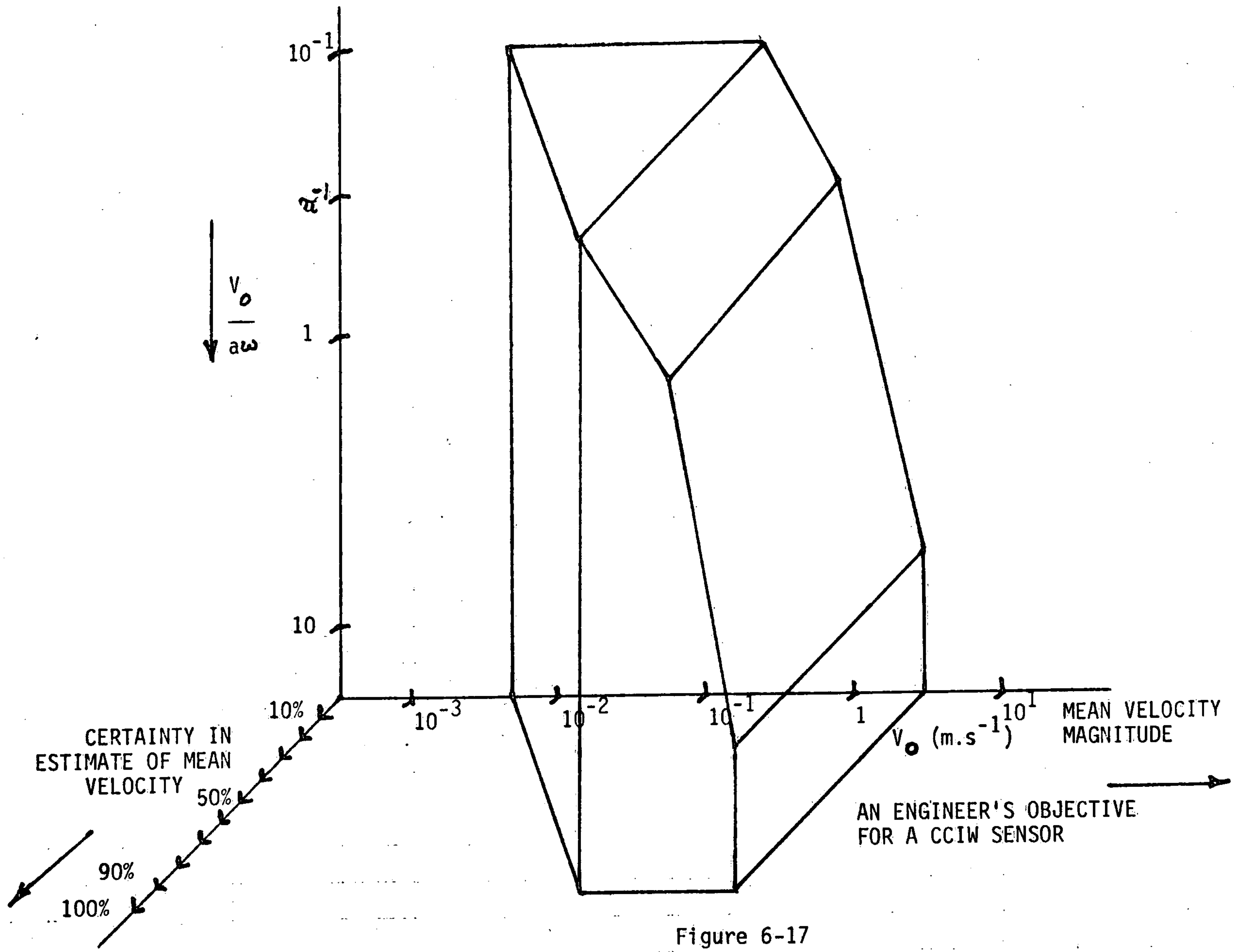
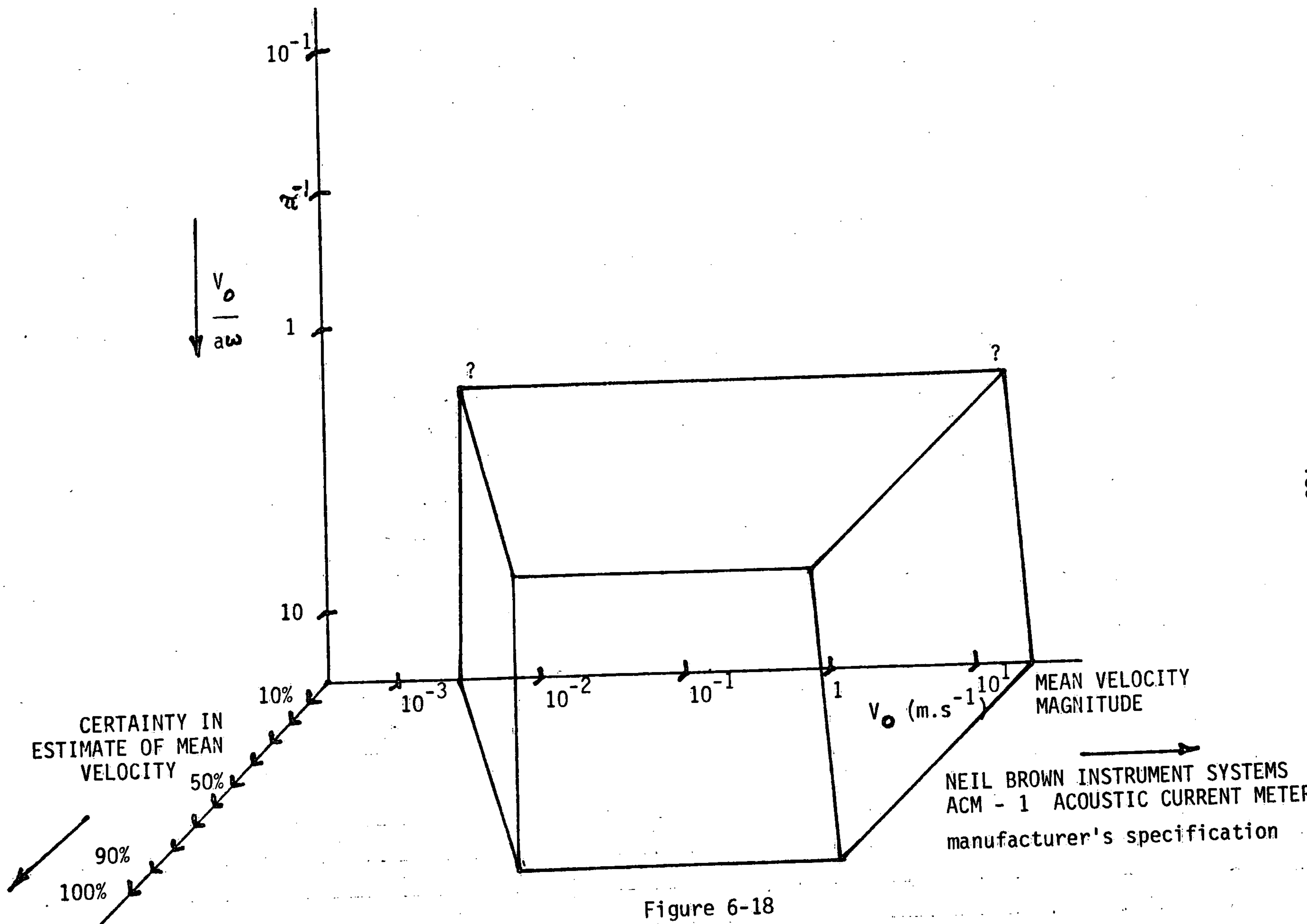

10^-1
a^-1
1
10
V_o / aω
10^-3
10^-2
10^-1
1
10^1
MEAN VELOCITY MAGNITUDE
V_o (m.s^-1)
CERTAINTY IN ESTIMATE OF MEAN VELOCITY
10%
50%
90%
100%
AN ENGINEER'S OBJECTIVE FOR A CCIW SENSOR

Figure 6-17



10^{-1}
π^{-1}
$\frac{V_o}{a\omega}$
1
10
?
?
10^{-3}
10^{-2}
10^{-1}
1
10^{1}
V_o (m.s^{-1})
MEAN VELOCITY
MAGNITUDE
10%
50%
90%
100%
CERTAINTY IN
ESTIMATE OF MEAN
VELOCITY
NEIL BROWN INSTRUMENT SYSTEMS
ACM - 1 ACOUSTIC CURRENT METER
manufacturer's specification

Figure 6-18

The transport and circulation in large lakes requirement, Figure 6-5, compares well to the Plessey estimate of performance, Figure 6-13. Here it is important to note that none of the behaviour above the bottom plane is supported with test measurements, although recent work by NOAA should improve on this conjecture.

January 1980 update: The Neil Brown ACM-1 current meter has been delivered and is awaiting testing. The performance illustrated by Figure 6-18 is supported by test data. Extension of the test data above the unity plane would be desireable for many potential applications. Field trials with other instruments may improve our estimates of their performance relative to the NBIS meter.

7.0 RECOMMENDATIONS FOR FUTURE CURRENT MEASUREMENT SYSTEM STUDIES AT CCIW.

7.1 Analysis and Testing of Dynamic Response of Hydromechanical Systems

Please note that the emphasis is on the current measurement systems. That is to say that analysis and testing, extending beyond the measurement instrument itself, is necessary to data quality assurance and data cost control. As an example, the tradeoff between deployment design, experiment siting and deployment costs should not be made without concern for data quality. It may be that the threshold conditions for deployment of one type of mooring over another may be modified following dynamic response analysis and testing to meet a necessary data quality standard. The tradeoff between data cost and data quality could be better evaluated with an analytical basis than with the accumulation of suspect field data. Herein lies the rationale for continuing the type of work described in this report.

It is recommended that the dynamic response characteristics of CCIW instruments be determined for the conditions of special interest. Further, it is recommended that the deployment configurations be modelled analytically, to determine the response characteristics for the field conditions anticipated. It is conceivable that the analysis may require supporting field measurements to bound certain effects. The analysis should be applied to predict performance under limiting application conditions to determine the effective margins of data quality expected.

7.2 Further Analysis of 1977 Field Experiment Data

The comparison of the Kinetic energy spectra for the Plessey MO-21 and CATS data in Section 5.0 provides an interesting observation. The low frequency energies are more than an order of magnitude lower for the CATS than the Plessey. This is a greater difference than would be expected for the depth difference between the two instruments. The Plessey transfer function defaults to 2.1 $cm.s^{-1}$ when the rotor stops. It is possible that suppressing this to 0 $cm.s^{-1}$ would alter the spectral characteristics due to the so-called "DC leakage". This question should be investigated to attempt to resolve our understanding of the discrepancy. This modification to the transfer function may well have implications for other studies which rely on Plessey current meter data where threshold flows are sufficiently common.

7.3 Test and Evaluation of New Sensor Types

With the limited resources available for test and evaluation, work on existing and new sensor types should be directed to those aspects of special concern to inland waters work, which would not normally be representative of other applications (e.g. low mean speeds, large orbital velocities). Every effort should be made to keep informed on other test results. It would be of particular value to have as a reference instrument a device which has been tested extensively and which is likely to be used in instrument comparison experiments. (Note: a Neil Brown Instrument Systems ACM-1 is ordered and expected in 1979.)

7.4 Requirement for Future Field Experiments

The developments of systems such as CATS and VAPS have demonstrated the benefit that measurement systems comparison experiments can bring to the system development cycle. Such experiments tend to receive late scrutiny in the multidisciplinary environment at CCIW, so that the realization of the implications of the data (and the study report) may be substantially delayed. This markedly reduces the effectiveness of the data for the system development team, in that the study development phase may be terminated without the benefit of the information collected.

Large scale comparisons, such as the 1977 CMC experiment, suffer principally from the delays common to co-operative ventures associated with reducing the data to a common format for processing and comparison. Smaller scale experiments (e.g. CATTS-1978) require less support, and are more readily completed. All such experiments would benefit from incorporating a reference instrument whose data reduction could be placed under the direction of the study team for expediency.

The requirement for and utility of small scale experiments is well-recognized. Other groups should be notified of such experiments, in order that they may plan a simultaneous experiment to benefit from the opportunity of obtaining a comparison data for the conditions encountered. The co-ordination of activities should remain with the original proponents to ensure that the effectiveness of the experiment is not hampered by unanticipated dilution of the operational resources.

The WAVES platform and data acquisition system provides an excellent site for such work as applicable in water of 12 m depth. The WAVES system would be more useful if it had one or more functioning two-axis current sensors available to support comparison work based at the platform. The data base obtained from such sensors would provide a good reference for the planning of experiments on the facility.

8.0 ACKNOWLEDGEMENTS

This study has benefitted from the efforts of a number of CCIW staff. Jim Bull (ARD) acted as study leader in FY76 and co-ordinated the team activities. Jim, Fausto Chiocchio, Paul Hamblin (ARD), Langley Muir (O&AS), Brian Taylor (SSD), Manual Pedrosa, Jim Diaz, Ralph Kuehnel, Technical Operations and Data Management Service staff all contributed to the field experiment and data reduction. Charles Der was Study Leader for the first half of FY'77. His contributions were in sensor testing, evaluation, and supplier liaison. John Valdmanis managed the Plessey MO-21 upgrading contract.

Most certainly CCIW management deserve thanks for recognizing the requirement for this work and for providing the opportunity to pursue it.

APPENDIX I

Trip Report Concerning Current Meter Technology

<u>NOTE</u>: This Appendix is <u>RESTRICTED</u> because certain company confidential information may be contained.

Access to a copy of this Appendix can be arranged through a written request to:

Head, Engineering Services Section
Scientific Support Division
867 Lakeshore Road, P.O. Box 5050
National Water Research Institute
Canada Centre for Inland Waters
Burlington, Ontario
L7R 4A6