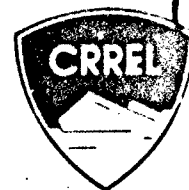
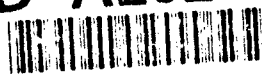


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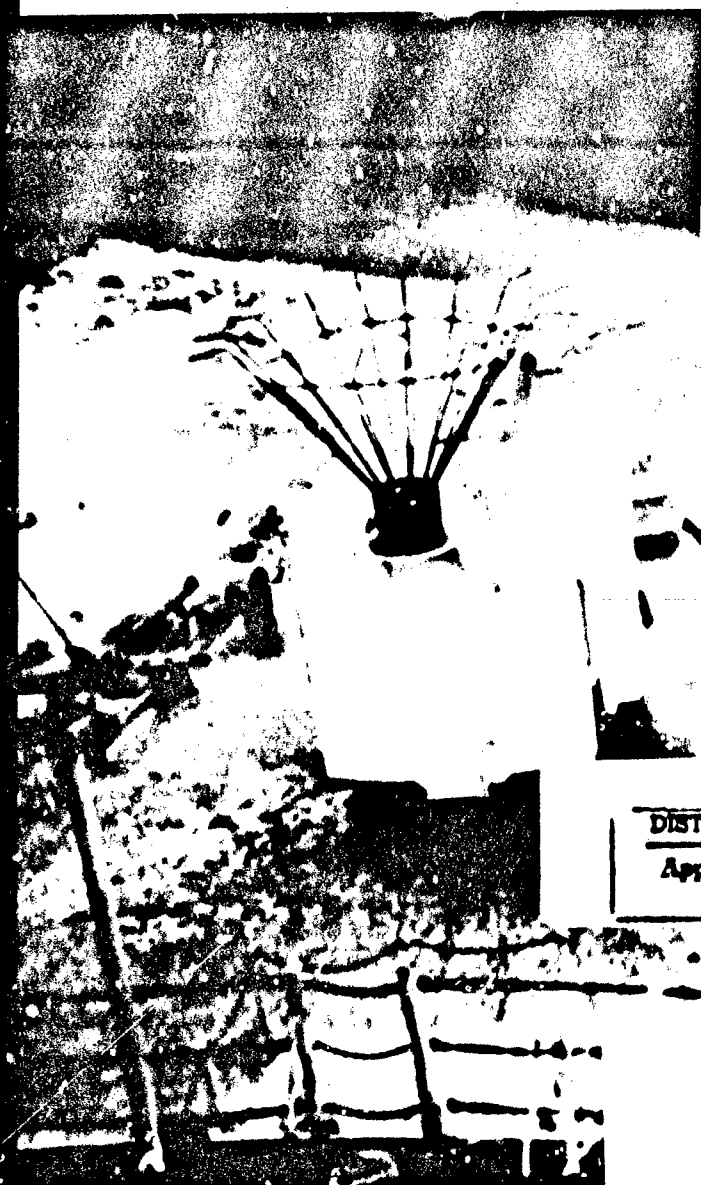
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Ship Superstructure Icing Data Collection and Instrument Performance on USCGC *Midgett* Research Cruise

Charles C. Ryerson and Paul D. Longo

December 1992



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Abstract

Spray generated by the collision of a ship's bow with waves freezes on decks, bulkheads and ship's components. It is most common on smaller vessels, where it has been known to cause sinking, typically by capsizing. Superstructure icing may also reduce the operating efficiency or mission performance of larger vessels. The ability to predict the environmental conditions under which icing may occur, the location of icing on a vessel under those conditions, and the rate at which ice will accrete may allow vessels to avoid hazardous conditions or operate in a manner so as to minimize the accretion of ice. This report describes how spray delivery and superstructure icing were measured during a research cruise on the U.S. Coast Guard Cutter *Midgett*, operating in the Gulf of Alaska and Bering Sea in February-March 1990, to support the validation and calibration of a numerically based icing prediction model being developed for the U.S. Navy. This research cruise represents the first such measurements on a vessel significantly larger than fishing trawlers, the basis for prior work. Development of the instrumentation, its placement on the *Midgett*, and ancillary equipment used to supplement the principal measurements are discussed. Data collection and problems encountered in the process are covered extensively. Finally, measurement error is discussed, with conclusions drawn concerning corrections to the data and their validity.

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Cover: Superstructure ice created from bow spray on the Coast Guard Cutter Midgett in the Bering Sea.

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, *Standard Practice for Use of the International System of Units (SI)*, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

CRREL Report 92-23



**US Army Corps
of Engineers**

Cold Regions Research &
Engineering Laboratory

Ship Superstructure Icing

Data Collection and Instrument Performance on USCGC *Midgett* Research Cruise

Charles C. Ryerson and Paul D. Longo

December 1992

Prepared for
U.S. NAVY DAVID W. TAYLOR NAVAL SHIP RESEARCH CENTER

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PREFACE

This report was prepared by Dr. Charles C. Ryerson, Research Physical Scientist, Snow and Ice Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory, and Lieutenant Commander Paul D. Longo, Civil Engineer Corps, U.S. Navy, CRREL Navy Liaison Officer. Funding for this research was provided by the Office of Naval Technology through the U.S. Navy David W. Taylor Naval Ship Research Center (DTRC), Bethesda, Maryland, with additional funding provided by CRREL.

Technical review was provided by Don Garfield, CRREL, and William L. Thomas, DTRC.

The following key members of the USCGC *Midgett* crew were particularly helpful during installation of equipment and during the research cruise: Captain Winslow, Commanding Officer; Commander Hill, Executive Officer; Lieutenant Commander Berry, Chief Engineer; Lieutenant Boyd, Operations Officer; Lieutenant Junior Grade Lingle, Assistant Engineer; Lieutenant Junior Grade Smithouser, Navigator; Chief Warrant Officer Parent, First Lieutenant; Ensign DiSanto, Student Engineer; Boatswains Mate Chief Petty Officer Lee, Deck Division Chief; Damage Control Chief Petty Officer Kelley, Damage Control Chief, Engineering Department; and Marine Sciences Technician Johnson.

William L. Thomas measured ship dynamics during bow spray events with accelerometers, and Bruce Pyle conducted research on ice prevention techniques and ice removal tools for DTRC. The CRREL measurement team (Kurt Knuth and Charles Ryerson) assisted in both DTRC projects, and were, at times, assisted by both of the above individuals. Equipment for the *Midgett* research cruise was designed and assembled by Dennis Lambert, Kurt Knuth, James Morse, Michael Walsh and Charles Ryerson at CRREL.

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Ship Superstructure Icing

Data Collection and Instrument Performance on USCGC *Midgett* Research Cruise

CHARLES C. RYERSON AND PAUL D. LONGO

INTRODUCTION

Superstructure icing occurs when spray, generated mainly from bow-wave collisions, freezes on decks, bulkheads and ship components. Most common to smaller vessels because of their low freeboard and greater motion in the sea, icing hinders deck activity, increases draft, decreases freeboard and raises center of gravity. The superstructure icing threat to larger ships is probably less serious because of their greater length and freeboard, which tend to reduce superstructure wetting. Nevertheless, even on large vessels, icing can reduce ship operating efficiency and combat readiness.

The ability to accurately and reliably forecast potential ice accretion rates may significantly reduce the icing hazard because ships could avoid areas where hazardous conditions are forecast or operate in a way that minimizes ice accretion. However, the complexity of the process makes modeling difficult. Empirical methods have dominated ice accretion forecast techniques. Using data collected primarily on fishing trawlers, because of their quantity and frequent operation in winter and polar waters, researchers have developed several models that are currently in use by the National Weather Service (Feit 1985) and the U.S. Navy (Mertins 1968).

Unfortunately, most empirically based models of fishing trawler icing do not thoroughly consider the physics of the processes they simulate. They simply relate, statistically or otherwise, the rate of icing to the magnitude of environmental conditions such as air temperature, sea state and wind speed (Mertins 1968, Wise and Comiskey 1980). As a result, such models cannot be numerically transferred to larger ships because the physical processes that change from one type of ship to another

cannot be properly transferred. This necessitates either empirical modeling of larger ships or numerical modeling of physical processes. Since ample superstructure icing data bases are not currently available for larger ships, the numerical approach is necessary for forecasting icing on these vessels. In addition, numerical models promote an understanding of all processes involved in freezing spray, and can be transferred more easily to many ship types.

The thermal processes involved in freezing spray on ship surfaces are generally understood. The process of cooling and freezing of falling droplets, aside from complications arising from sea water's salinity-depressed freezing point, has been modeled (Andreas 1989, Jessup 1985, Zarling 1988).

Water delivery processes, on the other hand, are not well understood for superstructure icing. The process of lofting water from the sea surface during a hull-wave collision is a poorly understood hydrodynamics problem that cannot be currently solved numerically, making empirical methods necessary. The quantity of water lofted by a spray jet and entrained by the wind as a cloud passing over the ship superstructure must be related to ship-, sea- and weather-dependent factors. As a result, even numerical modeling of superstructure icing requires empirical shipboard measurements for calibration and verification.

This report describes measurements of spray delivery and superstructure icing made by CRREL on board the U.S. Coast Guard Cutter *Midgett* in the Gulf of Alaska and the Bering Sea in support of a numerically based ship icing model being developed at the University of Alberta for the U.S. Navy (Zakrzewski 1987). Included in this report are discussions of the structure of the University of Alberta model, requiring the described measurement cruise,

instrumentation on the ship, data quantity and quality, data problems and data validity.

UNIVERSITY OF ALBERTA ADVANCED ICING MODEL

The University of Alberta advanced icing model is intended to compute ice accretion on ship superstructures caused by bow spray. The model, incomplete at this writing, is designed to compute ice load and thickness on some or all ship components, and is driven by environmental and ship conditions that can be changed as a voyage progresses. By computing ice thickness and mass on any or all ship superstructure components, the model is three-dimensional, unlike other models that compute ice load only for an index feature such as the forward mast or forward bulkhead. The model is also time dependent; ice load changes with location and time on the superstructure as weather, sea and ship dynamics change.

Unlike most previous models, which have been largely empirical, such as the model by Mertins (1968), the Alberta model is quasi-deterministic in structure. As in models by Kachurin and Stallabrass (Jessup 1985), Alberta attempts to numerically describe all thermal fluxes. However, elements that are not well understood physically and thus are difficult to deterministically model, such as spray cloud liquid water content, cloud height and spray frequency for a given hull configuration, are empirically derived.

Mass flux computation

Both mass flux to the ship, and heat flux away, are necessary for ice formation. Mass flux is more difficult to evaluate because few field measurements have been made, and there is not sufficient theoretical understanding of the water lofting process during bow-wave collisions to evaluate flux numerically. During infrequent spray events and extreme cold, mass flux will be the limiting factor for ice growth. During heavy spraying or warmer conditions, or both, thermal rather than mass flux will probably be the factor limiting ice growth rate (Ackley 1985, Itagaki 1990). However, since spray flux decreases with height above the ship and with distance aft of the bow, both mass- and thermal-flux-limiting conditions may be occurring on different portions of the ship concurrently (Ackley 1985, Zakrzewski 1987). Therefore, reliable estimates of both thermal and mass flux rates, and their effects on icing, are necessary in the development

of a three-dimensional model with time dependency.

Mass flux in the University of Alberta model depends entirely upon collision generated spray. Spin drift, spume and precipitated fresh water are not considered (Zakrzewski 1987). Though ship icing can be caused by snow, freezing rain, rime and hoar, the major contributor of ice mass to a ship superstructure is freezing spray (Makkonen 1984, Minsk 1984). Previous work at the University of Alberta has concentrated on modeling mass flux at only a few locations, such as the forward bulkhead and the foremast of Soviet and Canadian fishing trawlers. The advanced model evaluates flux using procedures similar to those developed for the trawlers, and from the *Midgett* measurements at more locations.

In trawler models, the spray flux is evaluated as a cloud of droplets originating in a jet of water rising above the bulwarks. Spray cloud motion is simulated as a multitude of droplets free-falling while entrained in the relative wind around the ship (Zakrzewski 1987). Vertical motion and air turbulence around the ship are assumed negligible. Ship speed and heading, relative wind speed and direction, relative wave speed and wave height, and droplet drag coefficients are all considered.

The Liquid Water Content (LWC) distribution of the vertical water jet is computed in Zakrzewski's (1987) trawler model by adapting experimental values measured by Kachurin on a Soviet trawler. LWC with height was related to trawler speed, heading relative to the waves and wave height. Since these trawler-based relationships may not be correct for a different or larger hull, the Alberta model relates LWC with height to ship speed and heading, and wave height. Droplet trajectories are projected from their point of origination in the jet to their impact locations on the superstructure using measurements made on the *Midgett* by CRREL.

Zakrzewski (1987) considered spray duration primarily to be a function of ship speed and heading and wind speed. Soviet measurements have provided sufficient information for deriving relationships between ship speed and heading, wind and spray on a trawler. Similar measurements must be made on larger ships because of differences in freeboard, length and response to the seaway.

Two versions of the Alberta advanced icing model are being created: pre-cruise and post-cruise models. The pre-cruise model uses ship geometry specific to the *Midgett* hull form and superstructure shape to compute spray and ice accretion. However, empirical algorithms for model spray genera-

tion are derived from Soviet measurements made aboard trawlers. Some algorithms were altered for ship size by the University.

The post-cruise model uses ship geometry specific to the *Midgett*, as in the pre-cruise model. Most empirical algorithms, especially with regard to water delivery, are to be altered or totally rederived from measurements made aboard the *Midgett*. Data from the *Midgett* research cruise will allow empirical algorithms to be derived for spray jet frequency, height, location, trajectory, duration and flux with specific sea and weather conditions.

For each of the models, major target areas of interest on the ship (forecastle area, forward gun mount, etc.) are divided into components. These are further divided into rectangular grid cells or portions of circular arcs. The Alberta model calculates the spray for one bow-wave collision from a jet of water that rises above the ship's bulwarks. It causes water to be distributed onto the ship superstructure by calculating trajectories from the jet to the centers of a network of grid cells making up the surfaces of the selected vessel components. The results of this one spray-generating event are considered to be representative of what happens over the forecast period and are then extrapolated for the entire forecast period, in which other environmental parameters are also held constant, to determine the quantity of spray delivered to the component. Spray fluxes to all portions of the ship are similarly computed.

Thermal flux computation

Heat balances are computed for spray droplets in flight and for ice growth on superstructure surfaces (Lozowski and Zakrzewski 1990). Spray droplet temperature at the point of impact with the ship superstructure is a function of sea water and air temperature, evaporation and convection, droplet size and droplet flight trajectory time. Evaporation is considered for its thermal effects, and also for its effects on droplet mass. Radiative exchanges are not evaluated by Lozowski and Zakrzewski (1990).

The heat balance of the icing surface considers the temperature of the impinging droplets, of the air and of the moving brine film from higher locations on the superstructure. Latent heat of freezing, sensible and evaporative heat fluxes, and radiative fluxes are also computed.

Ship superstructure components

Major external components of the *Midgett* were digitized by the University of Alberta researchers for calibrating the model to the ship. Many compo-

nent outlines are partially defined by equations. The ship is represented by several hundred cells upon which ice can form. These cells represent objects ranging in size from a part of a railing to a part of a deck. This is the segmented approach to computing ice load, versus the statistical method, both described by Jessup (1985). The entire Alberta model is organized around this explicit cell approach, including brine drainage, thermal fluxes and ice growth rates. The ice loads computed for each cell are then totaled and ice thickness and mass on components and targets computed.

Model calibration

Calibration of the University of Alberta advanced icing model is necessary for two reasons. First, the model should better represent the *Midgett* if variables from the ship are used in the model. Second, the sensitivity of the model and ship type to spray and ice generation will be ascertained. Little change in model response when replacing trawler-specific algorithms with cutter-specific algorithms would suggest that either the advanced icing model is not sensitive to ship type, or that ship type is not very important with regard to spray and ice accretion and that the model could be used for other vessel types without extensive modification of algorithms.

Calibration of the model for spray parameters involves replacing algorithms derived largely from Soviet fishing trawlers with algorithms generated from spray data and videotapes recorded aboard the *Midgett* by CRREL. This process will create the post-cruise model from the pre-cruise model. Algorithms will be generated from the *Midgett* cruise information by the University of Alberta for the following variables: spray flux at various locations, spray frequency, spray cloud duration, spray jet height and spray jet location along the bulwarks. Each spray variable will be functionally related to independent variables relative to weather and sea conditions, and ship-operating conditions.

Model verification

Differences between model prediction and measurements aboard the *Midgett* will be identified by running the model through weather, sea and ship-operating conditions identical to those that create ice as measured during the cruise. Differences will be identified between the model's predictions and measurements. These differences will be used to identify logical, deterministic reasons for model error. If there is no functional reason for disagreement, the university will use the *Midgett* ice measurements to generate "calibration factors" to be

applied to the model to make prediction more closely approach measured conditions.

Significance of measurements made aboard the USCGC *Midgett*

The spray and ice accretion measurements made aboard the *Midgett* are, to our knowledge, the first on a large ship. Ship dynamics, such as pitch and roll, and freeboard, are largely a function of ship size. Since larger ships generally do not pitch or roll as frequently nor with the magnitude of smaller ships, bow-spray generation should be less frequent. In addition, the generally higher freeboard on larger ships prevents some spray from reaching the decks or superstructure. Measurements made on the *Midgett* are significant for their uniqueness, in addition to their usefulness in calibrating and verifying the University of Alberta advanced icing model.

RESEARCH CRUISE OVERVIEW

The research cruise was made aboard the USCGC *Midgett*, a Hamilton-Class high endurance cutter constructed in 1972 (Fig. 1). Though not as large as

a typical Navy destroyer or cruiser, the *Midgett* served the purposes of this measurement project well. The cutter has a "warship" hull, similar to the Navy FFG-7 and Spruance hulls. It displaces 2980 tons (2703 metric tons), is 378 ft (115 m) long and is significantly different in size and shape from Soviet fishing trawlers. Propulsion is provided by two diesel engines, for speeds up to 18 kn (9.3 m/s), and two gas turbine engines, which take it to a maximum of 29 kn (14.9 m/s). The FFG-7 and Spruance destroyers are both powered by gas turbines, with performance envelopes similar to that of the *Midgett*.

The ship's mission was Maritime Law Enforcement and Search and Rescue on an Alaskan Patrol (ALPAT), which included the Gulf of Alaska, the Bering Sea and the Aleutian Islands. The patrol was a single ship mission, giving the Captain considerable flexibility that aided our research. In addition, the mission took the ship into potentially severe weather areas where icing could occur, and significant spray does occur (Thomas and Lee 1987, Ryerson et al. 1991). The cruise began 5 February at Alameda, California, and reached Kodiak, Alaska, by 16 February (Fig. 2). After leaving Kodiak, the *Midgett* entered the Bering Sea through Unimak Pass and remained there until the research team

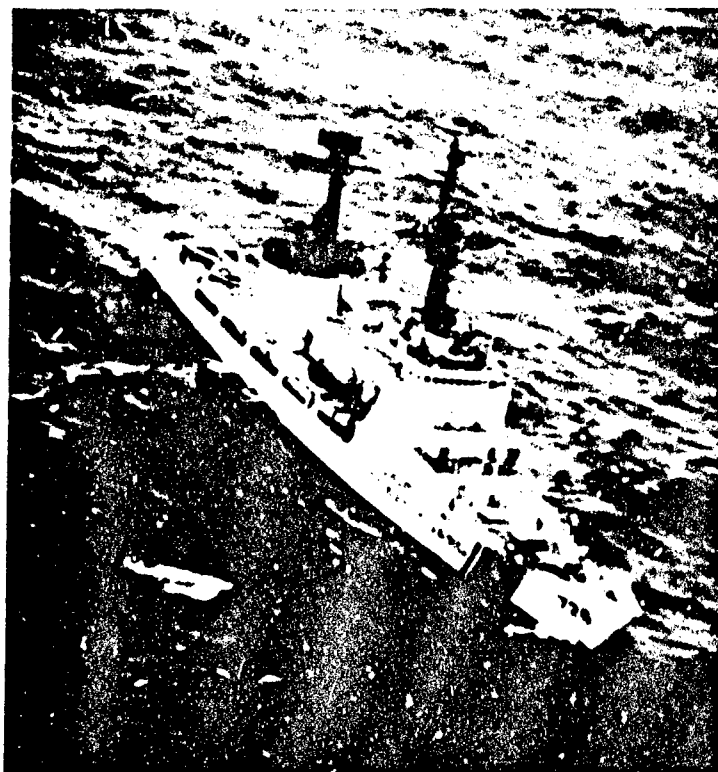


Figure 1. USCGC *Midgett* with CRREL instrumentation.

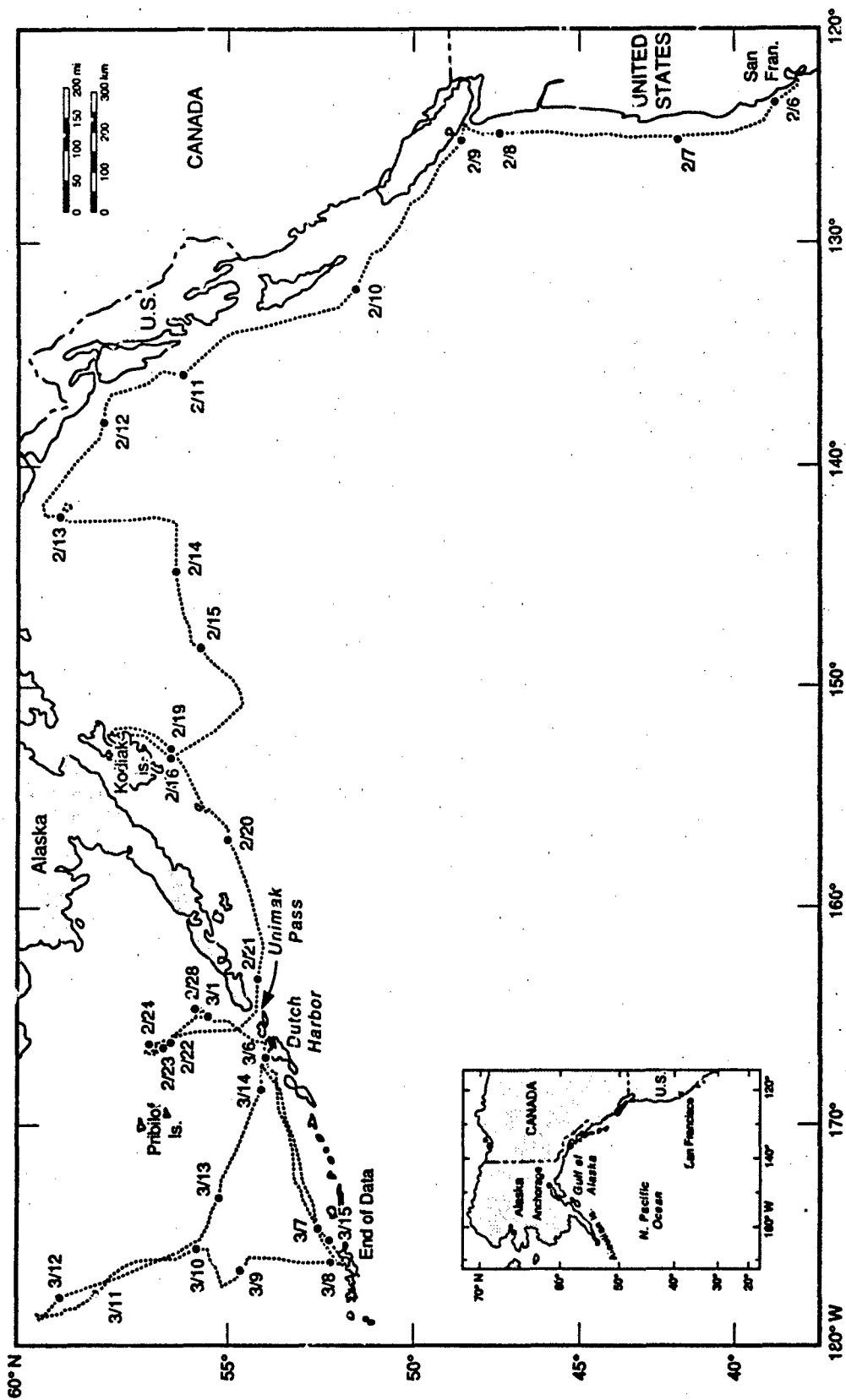


Figure 2. Track of Midgett during measurement research cruise.

disembarked at Adak, Alaska, on 13 March (Appendix A).

The *Midgett* was well-configured as a research platform. The measurement cruise was taken before the ship entered the FRAM (Fleet Rehabilitation and Modernization) program; therefore, the forecastle area was on the main deck, with stepped 01 and 02 level decks ahead of the bulkhead supporting the bridge. These three locations—forecastle, 01 level and 02 level—provided excellent places for mounting instruments at various heights above the water and at various distances aft of the bow.

Our mission was to measure spray flux and ice accretion on the *Midgett* at six locations, to record on videotape bow-spray events, to measure sea water temperature and salinity during icing conditions, and to obtain weather, sea and ship performance data throughout the cruise.

Concurrent research work was conducted aboard the *Midgett* by members of the David W. Taylor Naval Ship Research Center.

MEASUREMENT PARAMETERS

Parameters related to spray and to icing were measured during the cruise.

Spray parameters

Variables requiring measurement for spray cloud modeling in the Alberta model include (Lozowski and Zakrzewski 1988):

1. Ship course and speed.
2. Ship position (from which fetch is computed).
3. Relative or true wind speed and direction.
4. Spray flux measured at six locations.
5. Spray droplet diameters.
6. Frequency of spray cloud generation.
7. Duration of spray cloud residence.
8. Maximum height of spray cloud above ship.
9. Extent of wave impact area along bulwarks.

Specific instrument types and exposure conditions were suggested by the University of Alberta for most measurement parameters. Spray collector openings must be oriented horizontally (facing upward) if mounted on decks and representing the flux received by the deck, and must face the bow if representing the vertical surfaces of the superstructure. Collectors mounted on decks and measuring flux from the vertical must have openings about 1 m above the deck to protect them from intercepting green water. Collectors measuring horizontal spray flux against a bulkhead should ideally have openings less than 0.33 m from the bulkhead. The preferred locations for spray measurement equipment on a Spruance destroyer (the original ship of choice for the research cruise), as specified by the university, are indicated in Figure 3.

Units of measurement, ranges of expected values and acceptable error were specified by the University of Alberta in Table 1 (Lozowski and Zakrzewski 1988). Estimated accuracy of measurements taken aboard the *Midgett* are also noted. A maximum of

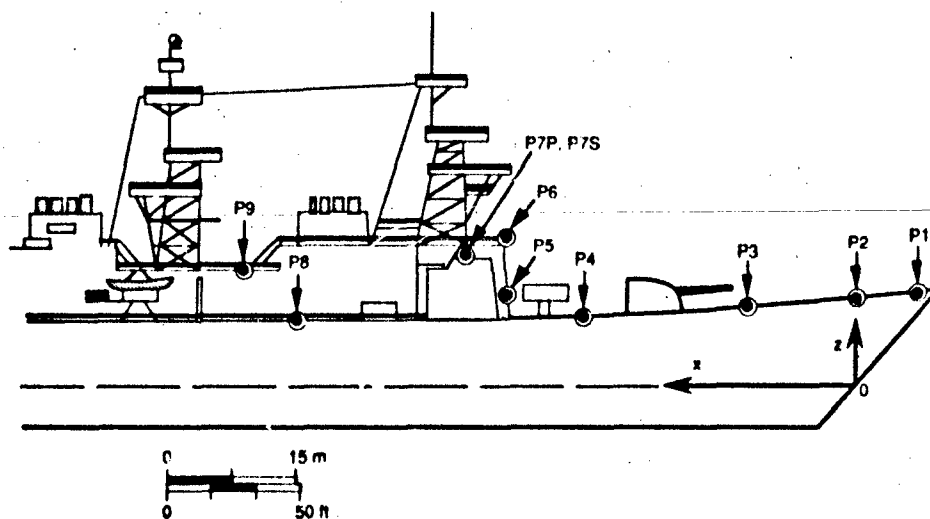


Figure 3. Locations preferred by the University of Alberta for spray and ice measurement equipment aboard a Spruance destroyer (after Lozowski and Zakrzewski 1988) (P7P = position seven, port side, for example).

Table 1. Range of expected values, and acceptable errors, for ship-board spray measurements (after Lozowski and Zakrzewski 1988) and estimated accuracy of measurements taken during the cruise.

Variable	Units	Requested measurements				Estimated accuracy of measurements		
		Required frequency	Range of values		Acceptable errors	Unit	Frequency	Estimated error
Ship position, latitude and longitude	degree minute	1/hr	—	—	± 5'	degree minute	1/30 min	± 2 min
Time	Julian day	—	—	—	± 1 min	minute	—	± 1 min
Relative wind speed	m/s or knots	130 min*	0-35 m/s	10-25 m/s	± 1 m/s (± 2 kn)	knots	1/hr††	± 3 kn
Relative wind direction	degrees	1/30 min*	-180 to 180	—	± 5°	degrees	1/hr†	± 5°
Ship course***	degrees	1/min	0-360	—	± 2°	degrees	1/30 min*	± 1°
Ship speed	knots or m/s	1/min	0-30 kn	10-20 kn	± 2 kn	knots	1/30 min*	± 1 kn
Spray flux	kg/m ² min	1/min	0-50	0-10	± 0.1 kg/m ² min	kg/m ² min	1/min	± 0.5 kg/m ² min**
Spray droplet diameter	millimeters	occasionally	0.1-10	0.1-10	± 0.1†	millimeters	1/0.03 s	± 0.05 mm

* And after any change of ship speed or course.

** Error was greater for horizontal collectors than for vertical collectors.

*** With respect to true North.

† A common sense rule should apply that any data are better than no data.

†† Computed from true wind direction/speed and ship course/speed.

15 sprays per minute could be expected, each with a duration of approximately 2 seconds. A maximum water mass flux of 50 to 100 kg/m² per minute was expected. The maximum number of measurement hours necessary was 50 to 100. Spray flux data should be acquired at least once each 10 seconds. Total acceptable spray flux measurement error was ±10%. The university indicated that 30 minutes of recorded spray parameters under a given set of weather, ship and sea conditions would be sufficient.

The university requested that video cameras with time stamps record the frequency and duration of spray clouds, and the frequency of bow-wave collisions. Cameras were to be located near the bridge, and preferably outside on bridge wings. Spray droplet size would be recorded and measured from "filter paper" that was to be exposed to spray clouds periodically.

Icing parameters

Variables requiring measurement for icing modeling in the Alberta model include (Lozowski and Zakrzewski 1988):

1. Ship course and speed.

2. Ship position (from which fetch is computed).
3. Relative or true wind speed and direction.
4. Air temperature.
5. Air pressure.
6. Relative humidity.
7. Sea surface temperature.
8. Sea water temperature.
9. Ice accretion density, salinity, liquid fraction and thickness.

In addition to units of measurement, ranges of expected value and acceptable error were specified by the university in Table 2 (Lozowski and Zakrzewski 1988). Estimated accuracy of measurements taken onboard the *Midgett* during the research cruise are also noted in Table 2. Suggested ice measurement instrument designs and ideal locations for these instruments were also provided (Fig. 3).

Preferred conditions for measurements

The University of Alberta specified the preferred range of environmental conditions, and the measurement time for each set of given conditions, for best calibration of the model (Lozowski and

Table 2. Range of expected values, and acceptable errors, for ship-board ice measurements (after Lozowski and Zakrzewski 1988) and estimated accuracy of measurements taken during the cruise.

Variable	Unit	Frequency	Requested measurements			Estimated accuracy of measurements		
			Range		Error acceptable	Unit	Frequency	Estimated accuracy
			Extreme	Moderate				
Air temperature	°C	1/30 min	-30 to 0	-10 to 0	0.5°	°F	1/hr	± 1°C
Air pressure	millibars	1/30 min or 1/hr	970-1040	960-1030	1 mb	in. Hg	1/hr	± 0.1
Relative humidity	percent	1 hr	30-100	70-95	2%	°F*	1/hr	± 1°F
SST	°C	1/hr	-1.8 to 10	-18 to 5	0.5°C (0.1°C is desired)	°C	1/hr	± 0.1°C
Seawater salinity	percent	1/hr	0-35	30-35	0.5%	°C	random**	± 1 ppt
Accretion density	kg/m ³	—	899-1000	790-920	—	kg/m ³	—†	± 5 kg/m ³
Accretion salinity	ppt	—	0-35	5-30	—	ppt	—†	± 0.02
Liquid fraction	percent	—	0-45	5-20	—	—	—	—
Ice thickness	meters	1/20 or 1/min	0-1 m	0-0.15	5-10%	meters	upon collection	± 1 mm

* Measured as wet bulb temperature.

** From engine intakes, reduced by 4°C (also, from bathythermograph and direct measurement by sampling occasionally).

† After shipment to CRREL.

Zakrzewski 1988). In addition, categories of expected spray rates and icing were suggested for each desired set of conditions.

CRREL EQUIPMENT DESIGN AND CONSTRUCTION

Design requirements

Design requirements for the spray and ice measurement instruments were established jointly by CRREL, the Navy and the University of Alberta early in the design stage. Several requirements were modified as design progressed and after a shakedown cruise with the prototype instrument in early 1989. The instruments were designed for the greatest reliability and accuracy with the least disruption of shipboard routine.

The Navy required that equipment installation should not alter ship structure. Welding to the ship would be allowed, but only in designated locations. Attachment could be either to steel or aluminum since most recently constructed ships have partially or totally aluminum superstructures and upper decks.

The equipment was to operate independently, except for mechanical attachments, for at least 2 weeks, without requiring data downloading or power recharging because of the period the ship could spend in heavy water. Power is not available

on decks, and high-voltage lines on weather decks are hazardous to personnel, especially if sharp instruments are used during ice removal details. No data transmission cables were to be run across decks because of hazards to personnel and the difficulty of penetrating bulkheads and decks.

The instrumentation had to operate in extreme cold, wind, spray and ice conditions. The minimum design temperature was -10°C, and the maximum design winds were 40 m/s. All hardware had to survive severe ship motions, as well as green water impacts (solid sheets of water over the bow or large waves over the decks from port or starboard). Design green water loadings were about 2900 kg/m², and survivable accelerations are 6 g's in any one direction.

The equipment could not be large, cumbersome or heavy, so as to cause a hazard to the deck crew, or impair ship operations. Tall, heavy instruments can impose high moment loading on thin decking (typically 1.0-cm-thick steel or aluminum). This might require doubling plates to be welded to the deck to increase its strength, and dock side crane services for equipment installation and removal. Tie-down cabling is also a hazard and its use was discouraged if it was to span deck areas traversed by personnel.

The instruments could not create electromagnetic interference for the ship, nor be affected by electromagnetic radiation from the ship. In addi-

tion, operational status lights on the instruments had to be dim and red, with no lights being preferred.

Early prototype design and testing

In the early stages of the project (summer and fall of 1988), two research cruises were planned by the Navy—one to measure spray and the second to measure ice accretion. With this consideration, a measurement system was designed to measure spray on the first cruise, and to be reconfigured for icing measurement on the second to reduce cost and simplify hardware construction.

Several methods were proposed to measure spray flux, all previously developed for measuring rainfall. These included tipping buckets, weighing buckets, tanks with floats, tanks with capacitive sensors and ultrasonic level detectors. The tipping bucket was rejected because of ship motion; the count would be in error and a tipping bucket could not measure ice accretion. Weighing buckets suffer acceleration effects and cannot measure ice. Buckets with a float and stilling well could measure water depth but not ice thickness. Buckets with a capacitive sensor and a stilling well can measure water level but not ice on a bulkhead or a deck.

Ultrasonic level detectors can measure water level in a bucket and measure the distance to a deck or bulkhead. They also are not affected by ship pitch, yaw and roll. An ultrasonic detector would allow the measurement instrumentation to be used for two cruises by changing the orientation of the sensor heads.

Any collection bucket needed to drain rapidly to prevent data loss during periods of high spray flux. Several types of drain valves were examined, including solenoid operated butterfly, ball, gate, foot and check valves, and air operated flapper and ball type valves. We chose a ball check valve that could be opened with a compressed-air operated solenoid and closed with a spring.

The first enclosure selected to hold all the proposed equipment and allow room to work on each subsystem without removing any of the other subsystems measured 1.8 m tall, 0.8 m wide and 0.6 m deep. This enclosure was too heavy, and potentially had too much moment for the deck, so a second was selected that would hold all necessary equipment but with much reduced free space. This enclosure was 0.9 m tall, 0.8 m wide and 0.5 m deep (Walsh et al. 1992).

Finally, the Navy decided to make both spray and ice measurements on the same cruise, thus

the equipment had to measure both variables without reconfiguring hardware. This required duplication of hardware and a more complex design.

The prototype spray measurement system (Fig. 4) collected spray through a 30-cm-diameter vinyl funnel that drained into a baffled Plexiglas tank. Water depth was measured with an ultrasonic transducer mounted in the tank top. A Campbell CR10 data logger recorded the water level and drained the tank when full. The tank drained through the ball check valve, operated by an air solenoid. A door atop the funnel closed when the tank drained, and when ice was being measured, to prevent the tank from filling more rapidly than it

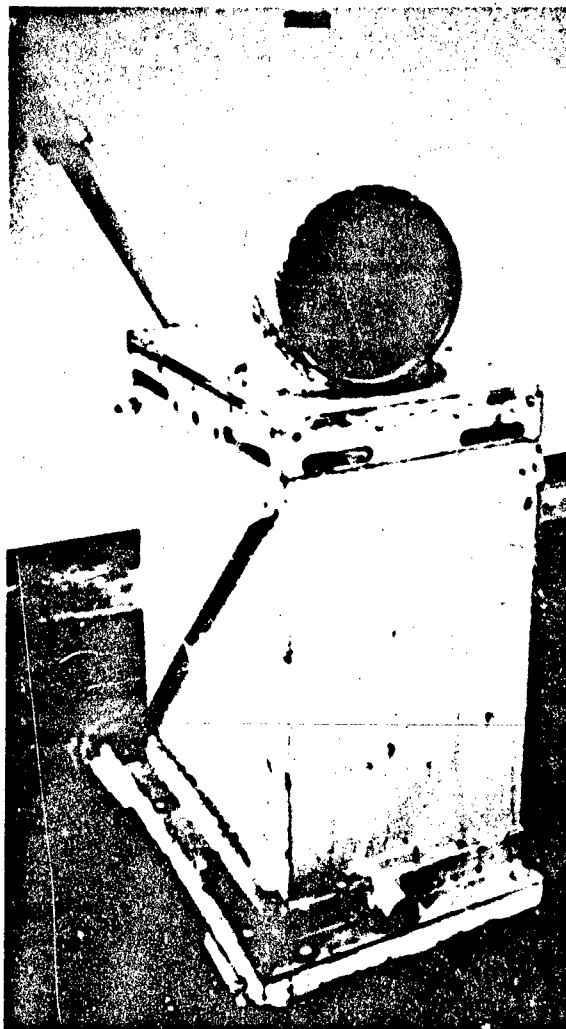


Figure 4. Prototype CRREL spray and ice measurement system aboard the Yorktown for shakedown tests.

drained. Spray was directed into the funnel from the horizontal with a 30-cm-diameter elbow mounted atop the funnel.

Ice thickness was measured with an ultrasonic transducer aimed at a bulkhead. The transducer device was installed to measure the decreasing distance to the bulkhead as ice accretes. Its design was effectively identical to the final design described later.

Prototype equipment tests: USS Yorktown

One prototype spray collector and ice accretion measurement system was tested aboard the USS Yorktown during the North Star exercises from 25 February–19 March 1989. The equipment was mounted to the main deck about 1 m ahead of the bridge superstructure, and starboard of the ship's center line (Fig. 4). Weather during the cruise was relatively mild and calm. Temperatures did not drop below freezing; thus, no ice accreted.*

Spray was not measured successfully during the USS Yorktown cruise. Spray entered the equipment box, but no spray was measured within the spray holding tank. No spray being measured may have been caused by a leaking holding tank, by malfunctioning transducers, or by spray simply not entering the holding tank. The latter could have happened because an automatic door atop the funnel may not have opened when necessary, or because of the design of the collection elbow–funnel connection. The 30-cm-diameter elbow was larger than the funnel opening, allowing water running down its sides to escape. In addition, a pressure bulb may have formed ahead of the elbow because of inadequate venting, preventing spray from entering the tank. The tank vent was oriented into the wind. The boundary layer from the vertical surface immediately behind the instrument may have adversely affected the collection process. Finally, a gap below the automatic door between the collection elbow and funnel may have allowed water to escape before it entered the funnel.

The USS Yorktown shakedown cruise was an important step. It identified several serious deficiencies requiring correction and indicated a need to redesign the equipment before the final research cruise. Safety considerations during spray events restricted deck access and precluded identifying specific causes of these deficiencies during the cruise.

* Personal communication with K. Knuth, CRREL, March 1989.

Final equipment design

Design concepts

The final spray and ice measurement system is a self-contained, integrated unit designed to operate independently and store data internally until queried, as required for the prototype design (Ryerson et al. 1991). The unit contains independent spray flux and ice thickness measurement sensors, a data logger control system, and pneumatic and electrical power supplies. All systems are contained within a rectangular steel box having collectors for intercepting spray from the horizontal or vertical, and an attached arm with ultrasonic distance transducers aimed at a deck or bulkhead for measuring ice thickness. The arm is required to extend the transducers beyond air streams affected by the large instrument enclosure. In addition, mounting points are provided for additional instrumentation, as required. Spray flux is measured as a changing depth of water in a holding tank that drains automatically when water accumulates to a predetermined level. Ice thickness is measured as a decrease in distance from a deck or bulkhead to the transducers.

Instrument design

Driving the mechanical design of the spray and ice measurement equipment was the need for a unit that could withstand environmental rigors yet be quickly installed and easily maintained. The equipment also needed to be convertible to monitor decks or bulkheads without modification. Thus, the design incorporates a rugged outer shell that mounts to any decking, with features allowing rapid conversion to fit the required monitoring situation.

The rectangular outer shell, a reinforced standard weatherproof electrical enclosure with mounting points for various measurement configurations, is identical to the prototype unit (Fig. 5). The shell is designed to face oncoming spray or green water with its narrow side forward, thus reducing the forces encountered. The exposed end is reinforced with angle iron and a sheet steel prow that also serves to mount and protect a commercial rain gauge. Provision is also made to mount an anemometer on the door of all units. A circular flange welded to the top of the shell allows attachment of spray collection accessories. On the leeward end of the shell is mounted the icing transducer arm.

A large (30-cm-diameter) funnel attached to the circular flange serves as a vertical spray collector (Fig. 6). Various sized apertures can be attached to

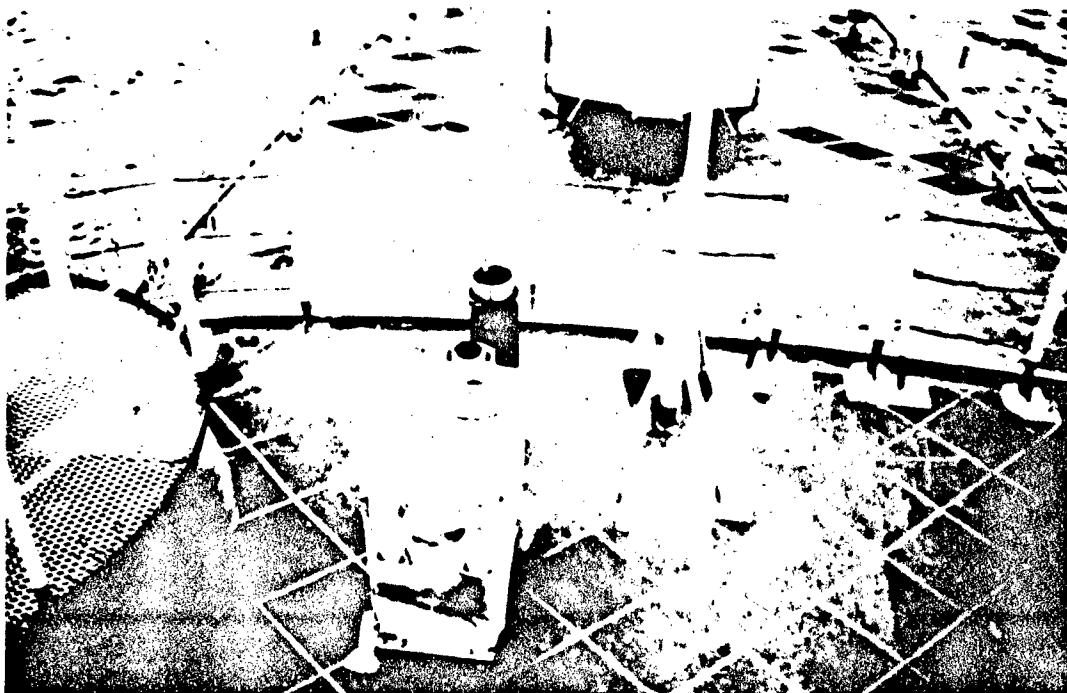


Figure 5. Final CRREL spray and ice measurement system aboard the Midgett (01 Level unit). Visible from foreground to background are the icing transducer arm, the CRREL spray funnel with aperture, the Young rain gauge and the NWS standard rain gauge.



Figure 6. CRREL funnel for intercepting deck spray from vertical (foreground) and Young rain gauge.

the flange around the funnel to restrict the area and thus the amount of spray collected, depending upon the expected amount of spray. The funnel drains spray water into a holding tank where its depth is measured. When full, the tank automatically drains onto the ship deck. A screen in the neck of the funnel excludes debris that could interfere with the operation of the holding tank drain valve. It also automatically prevents most water from entering the tank during freezing conditions when it is not desirable to measure spray flux. There is nothing in the unit to prevent spray from freezing because of the limited power availability. Therefore, droplets clinging to the fine screen wire by surface tension rapidly freeze in cold air, clogging the screen and inhibiting water entry.

A horizontal spray collector also mounts above the funnel to the circular welded flange (Fig. 7). This collector must remove spray droplets from the air stream while minimizing disturbance of the natural airflow. The design promotes the free flow of air through the collector, reducing any pressure bulb ahead of the inlet opening that would divert droplet-laden air around the collector.

The horizontal spray collector separates incoming air from the general air stream by diverting it around a convex baffle. The change in air direction around the baffle causes larger droplets to collect on its surface. The rim of the baffle causes these droplets to coalesce and fall to the funnel. The air and remaining smaller droplets then enter a chamber twice the cross-sectional area of the inlet opening and baffle annulus. This lowers the air stream velocity, promoting gravitational fall of droplets. In addition, the air stream encounters a screen that scavenges and coalesces droplets, causing them to fall into the funnel. A ring at the collector exit stops any spray collected on the inner walls from running out and redirects it to the funnel.

Water from the collection funnel flows into a 12-L-capacity PVC holding tank. The tank drain is operated by a pneumatic cylinder connected to a ball check valve in the bottom of the tank. An

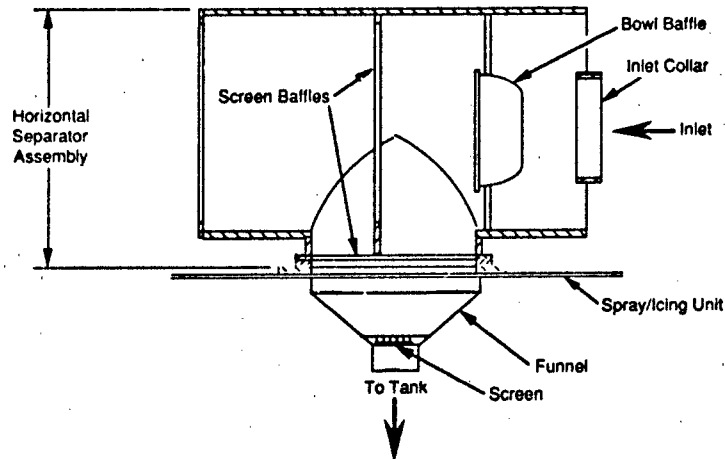


Figure 7. Collector mounted atop funnel for intercepting bulkhead spray from horizontal (from Walsh et al. 1992).

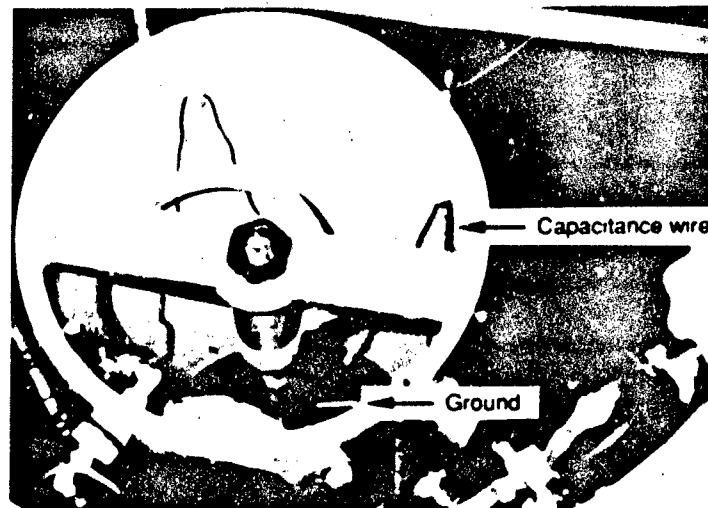


Figure 8. Teflon-coated capacitance wire on tank sides, with metal ground on tank bottom (funnel and tank top removed) (from Walsh et al. 1992).

overflow line is also provided in case the valve malfunctions.

Water depth is measured by a capacitance system, consisting of a Teflon-coated wire laced up and down inside the tank, with a metal rod lying on the bottom of the tank as a ground (Fig. 8). The wire laced around the perimeter of the tank helps reduce the effects of water movement from ship motion on measurement accuracy. The "plates" of the capacitor are the wire conductors, and the water is the ground. The wire insulation is the dielectric. As water rises in the tank, capacitance increases. This "capacitor" is part of an oscillator circuit with final output integrated to give a dc voltage proportional

the capacitance. This voltage is recorded and, when the water reaches a predetermined depth, the controller program opens the drain valve and empties the tank (Walsh et al. 1992).

When the temperature drops below freezing, the data logger disables the spray collection system and enables the ice measurement system. Ice thickness is measured by an ultrasonic range finder operating at 150 kHz, with output converted into a voltage and read by the data logger. The range finder consists of a pair of transmit and receive transducers mounted in a box on the 60-cm-long extension arm on the aft of the main collection unit.

The icing transducer arm allows freedom of positioning in two axes. Within a box at the end of the transducer arm is a pneumatic cylinder to control a shutter protecting the transducers from salt, spray and ice. The data logger opens the shutter automatically when an ice thickness reading is required (Walsh et al. 1992).

Control system

The controller for spray and ice measurement is a Campbell CR10 data logger with an external 716-k memory module and associated software. The software, a Campbell specific command set, was written to make spray or ice measurements, depending on the outside temperature (Walsh et al. 1992).

Spray is measured when air temperatures are above freezing, and ice thickness is measured when temperatures are below freezing. Set point temperatures were varied in the field, but were generally near -2.5°C for transition to the ice measurement mode from spray measurement and 0.5°C for transitions from ice to spray measurement (Walsh et al. 1992). The temperature sensor triggering the data logger ice or spray measurement modes is in the box at the end of the transducer arm.

In general, spray was not measured during icing because no deicing capability was possible in the unit with the limited power available. The freezing screen and opening of the tank drain valve (the latter controlled by the data logger) during these conditions prevented the tank from freezing solid with ice.

Equipment calibration

Mechanical system

The only calibrated mechanical component was the horizontal spray collector (Ryerson et al. 1991). Initial low-speed tests were done at 5.3 m/s to verify the optimum design. With a final design, higher speed calibration runs were conducted with

a prototype unit mounted in the bed of a pickup truck. Collection efficiencies varied from 100% at 1.4 m/s to about 75% at 19.4 m/s (Walsh et al. 1992, Fig. 19). In all tests, spray was injected as a fine mist consisting of approximately 0.5-mm-diameter droplets, a worst case analysis since the collection efficiency for small droplets is low and they tend to stay entrained in the air stream.

Spray measurement system

Each spray collection tank was individually calibrated by filling it with known quantities of fresh water at least three times. The resultant calibration factors of all units were then compared and found to be within 1.5% of each other, thus allowing the tanks to be interchanged. These measurements were done at room temperature. The tanks were not calibrated with salt water (Walsh et al. 1992).

Ice measurement system

The ultrasonic device used to measure ice accretion was tested in a CRREL coldroom at -7°C in a spray booth with saltwater spray. The resultant thickness agreed within 3% when measured repeatedly with a micrometer. The device operated reliably to -10°C if started at a higher temperature. However, when the units were cold soaked at -10°C and powered up, the electronics failed. Only one such test was made because of the cost of the electronics.

Video system design

Two identical video systems were placed on the *Midgett* for redundancy. Each consisted of a camera unit and a monitoring unit. The camera unit is a watertight aluminum cylinder containing a video camera, defroster and windshield wiper and washer. The camera unit mounts on a deck or bulkhead and is articulated to allow aiming of the camera, which must be done manually (Fig. 9).

The video system was cold-tested at -10°C for 10 days while the wash-wipe device ran automatically. No problems were encountered during the test. However, the washers failed immediately upon installation on the ship and the peristaltic pumps were replaced with automobile windshield washer pumps.

The monitoring unit contains a CRT monitor, a VHS video recorder with time stamp capability and controls for automatically operating the washer and wiper on the camera unit (Fig. 10). The monitoring unit was installed within the ship. The wipe and wash cycles can be controlled manually or operated at intervals automatically.

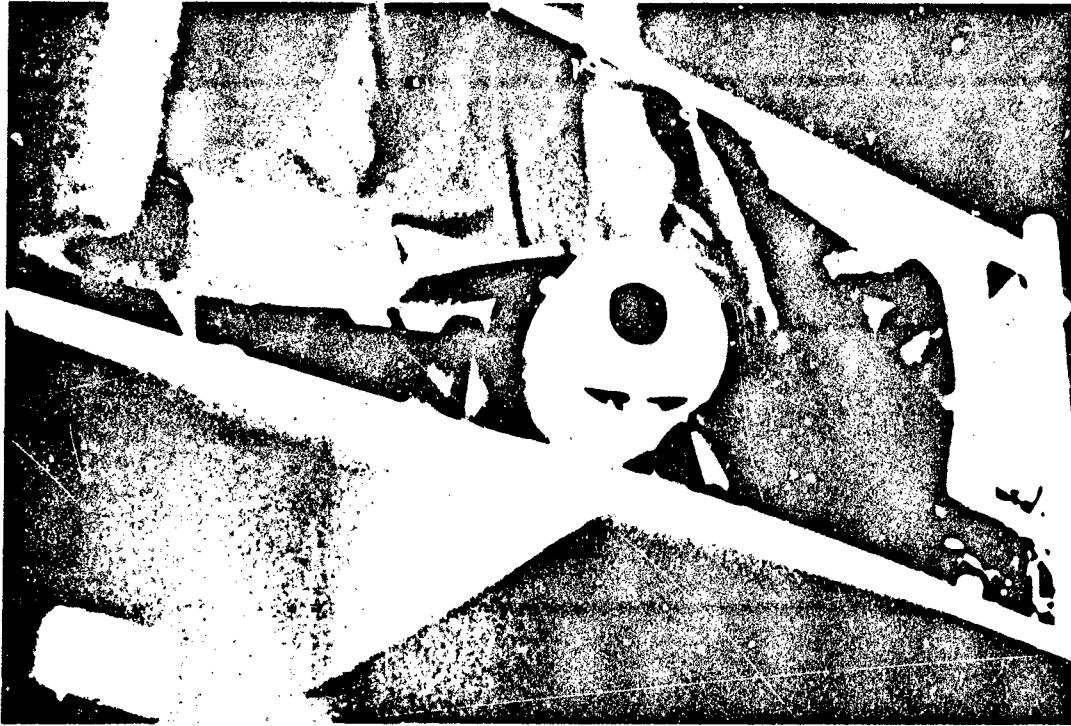


Figure 9. Video camera system mounted on the Midgett's flying bridge.

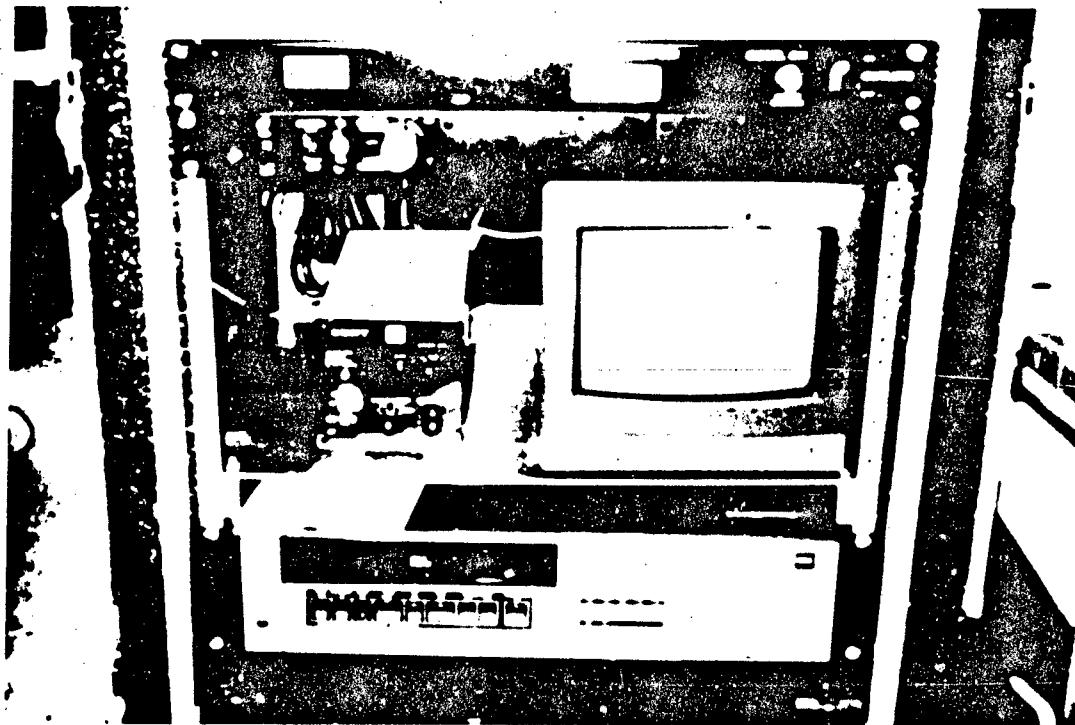


Figure 10. Video camera control center on the Midgett.

ANCILLARY EQUIPMENT

Several other instruments were used aboard the USCGC *Midgett* to provide additional data to verify the CRREL spray and ice measurement instruments, or to provide additional information for the University of Alberta.

Young rain gauges

Two Model 50202 automatic rain gauges manufactured by the R.M. Young Co. were installed on the spray instrument boxes (see Fig. 5). The Young gauges are self-siphoning and require power for capacitance depth measurement electronics and for a heater that keeps the tubing thawed in sub-freezing weather. The heaters were not used on the *Midgett* cruise. Similar designs are used at sea in data buoys (Holmes and Michelena 1983, Michelena and Holmes 1986).

Each rain gauge was mounted on the front of spray units to avoid turbulence effects created by the CRREL units. Horizontal collectors were not attached to the Young gauges; they intercepted vertical spray only. Therefore, they were mounted on CRREL units only intended to intercept vertical spray for direct comparisons.

National Weather Service precipitation gauges

Two Model 6310-A Standard Rain and Snow Gauges manufactured by Qualimetrics, Inc. were installed to check measurements made by the automated gauges (Fig. 11). These are non-recording, standard National Weather Service (NWS) gauges built to National Oceanographic and Atmospheric Administration (NOAA) specifications. Each gauge was mounted within a protective steel tube and intercepted spray from the vertical only. The gauges were mounted in front of the CRREL and Young units to avoid turbulence effects.

No data are presented in this report from these gauges. They required manual measurements, and personnel could not reach them with sufficient frequency during heavy weather to make useful measurements.

Young anemometer

A Young Wind Monitor Model 05103 was mounted on the side of a CRREL spray unit, and about 2 m above the deck (Fig. 12). The unit, measuring wind speed and direction, was originally developed for ocean data buoy use. Considerable data were lost because of salt water intrusion that

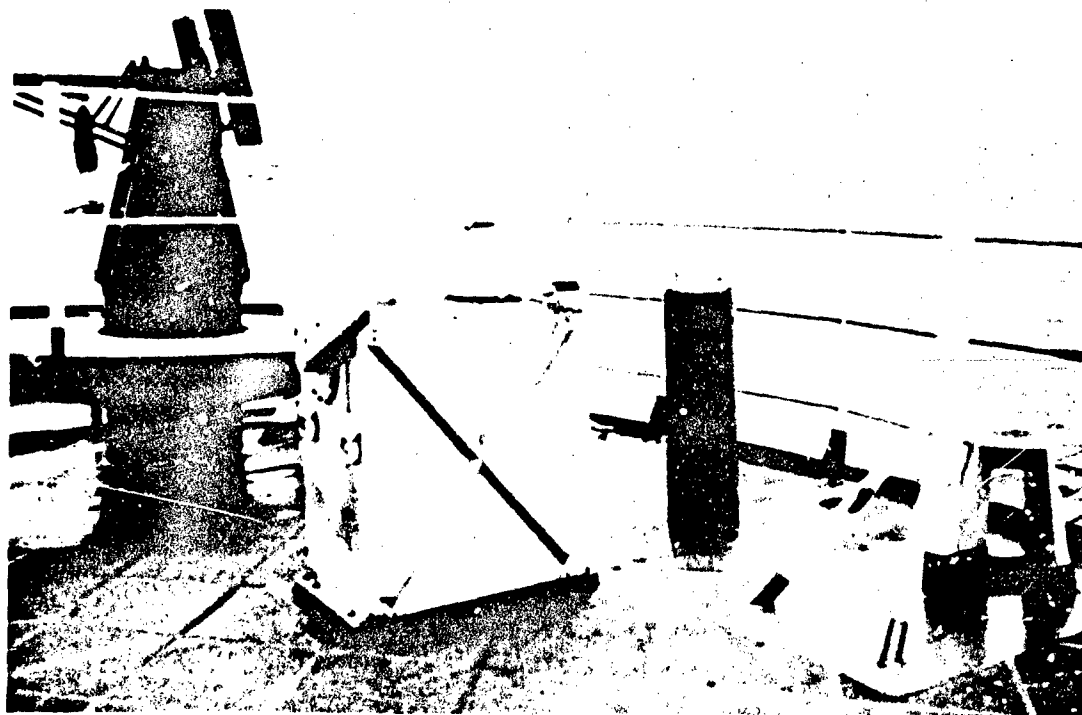


Figure 11. National Weather Service precipitation gauge mounted on the *Midgett*'s 01 level.

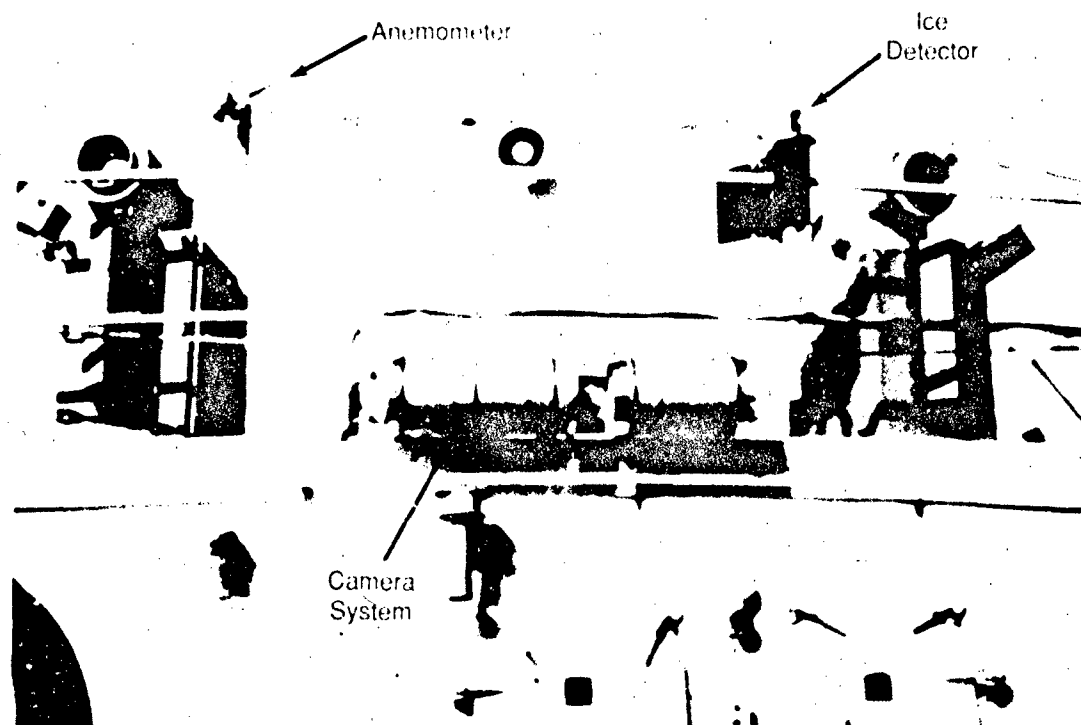


Figure 12. Universal flying particle camera, Rosemount ice detector and Young anemometer mounted on the *Midgett's* 02 level.

damaged electrical connections. In addition, the instrument was mounted within a transition zone between the free relative wind around the ship and the turbulent boundary layer that extended at times over 2 m ahead of the forward bulkhead. Data from this instrument are not discussed in this report.

Salinometer and digital thermometer

Sea water temperature and salinity were recorded manually with a portable digital thermometer and digital salinometer. The non-recording digital Quick thermocouple mini-thermometer had a resolution of 1°C.

Sea water salinity was measured with a Labcomp Instruments Model SCT Salinity, Conductivity, and Temperature Analyzer. The instrument had a resolution of 0.1 ppt from 0–99.9 ppt. However, the instrument had several shortcomings for our application. Response time was very slow (about 3–5 minutes) because of the probe design. In addition, though the instrument could read water temperatures to –5°C, salinity readings were not reliable until water was warmed to near room temperature.

Measurements of seawater temperature and salinity were made by dropping a 2-L stainless steel

bucket overboard and measuring temperature immediately on deck. The water was then warmed to room temperature, and salinity measured (several hours after the sample was taken). Seawater samples could not be taken in heavy weather because access to weather decks was secured, nor when ship speeds were greater than 10 kn (2.8 m/s) because the sampling bucket could not be retrieved safely.

Universal flying particle camera

Droplet sizes in the spray cloud enveloping the ship were recorded with a universal flying particle camera developed at CRREL (Itagaki and Ryerson 1990). Droplets were “frozen” in flight on videotape with a camera aimed at a high-speed strobe light. Droplets as small as 100 µm can be resolved and measured in the 1.4-cm³ sampling volume. All electronics were placed in watertight enclosures for mounting on the *Midgett* (Fig. 12).

University of Alberta ice penetration probe

The University of Alberta supplied two ice penetration probes for use on the *Midgett* (Lozowski and Zakrzewski 1988). The probes were designed to be inserted into ice on ship decks and bulkheads, ex-

tracting an ice core of known diameter. Each unit was nominally 50 cm long and 6 cm in diameter, fully assembled. Although they were tried several times, the probes could not successfully remove ice samples. The probes were replaced with standard putty knives.

Rosemount ice detector

An automatic aircraft ice detector, Rosemount Model 871FA, was mounted to the ship to measure ice accretion rates (Fig. 12). The Rosemount Model 871FA was designed for use on helicopters. The instrument measures only icing rate.

Ice is detected on a 0.6-cm-diameter by 2.54-cm-long probe that vibrates axially at 40 kHz. Ice accreting on the probe lowers the probe frequency until, after about a 200-Hz drop, the probe deices with a heater and the cycle begins anew. Typical ice thickness to accrete per deicing cycle is 0.5 mm $\pm$ 25%. Results for this instrument are not presented in this report.

VHS camcorder

A standard VHS camcorder was taken aboard the *Midgett* for recording conditions not visible from the two video cameras mounted on the Flying Bridge. The camera operated well in the cold, but was only protected from spray by a plastic bag device that was manufactured to protect the camera during shallow water diving. Operation of the camera inside the watertight bag was difficult. Some images were ruined because portions of the bag interfered with the camera lens, and sound quality was poor because the microphone rubbed against the plastic. A waterproof camcorder would have been more useful. The camcorder allowed us to record ice sampling procedures, spray generation along the ship sides and ice removal operations on the main deck.

EQUIPMENT INSTALLATION ON USCGC MIDGETT

From 21 January–6 February 1990, the sea spray measurement equipment was installed on the *Midgett* for deployment to Alaska. The *Midgett* presented an excellent platform to conduct the work because it offered decks at various levels to place instrumentation. The deck-mounted equipment consisted of six CRREL spray and ice measurement system boxes, two Young rain gauges, one Rosemount ice detector, an anemometer, two video cameras, the universal flying particle camera and two standard NWS rain gauges.

Spray collectors

CRREL spray measurement units were installed on the main deck, 01, 02 and flying bridge levels of the ship (Fig. 13). Each unit, weighing approximately 550 lb (250 kg), was placed by USCG Support Center Ship Repair Division personnel using a crane with 70-ft (21-m) boom. Units were lifted with hooks placed through the attached lifting eyes

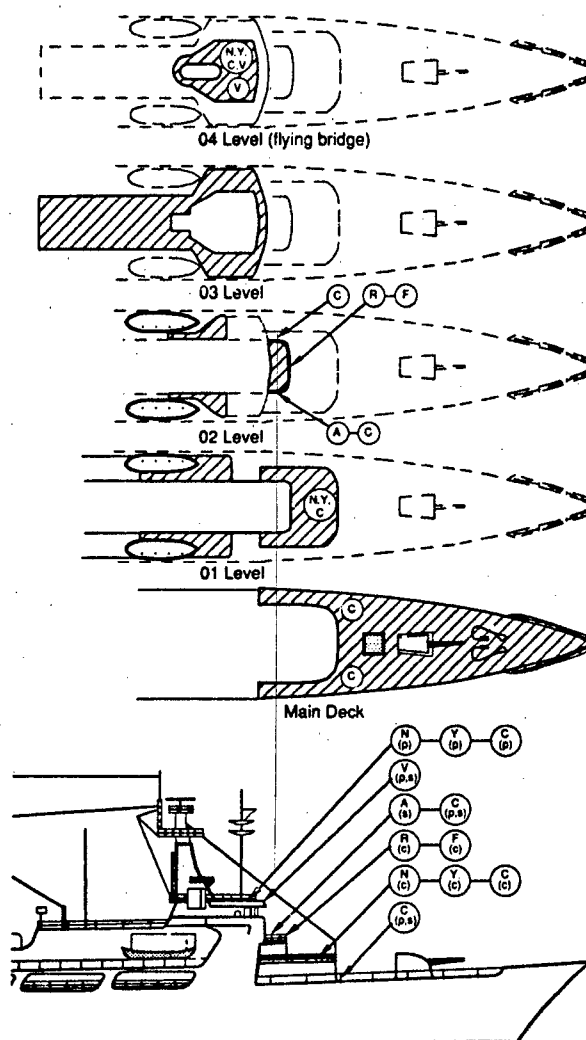


Figure 13. Locations of CRREL spray and ice measurement systems, video cameras, Young rain gauges, NWS precipitation gauges, Young anemometer, flying particle camera and Rosemount ice detector (N = National Weather Service rain gauge, Y = Young rain gauge, C = CRREL spray unit, R = Rosemount ice detector, A = Young anemometer, V = video camera, F = Flying particle camera system, p = port, s = starboard, c = center).

at their corners and positioned approximately at the desired locations. This operation required two men on the dock to attach the loads and two aboard the ship to remove the loads.

Two units were installed roughly symmetrically about the center line of the ship on the main deck (Fig. 13). Exact location was dictated by plates placed adjacent to the ladder from the main deck to the 01 level for a Navy-sponsored experiment concerning ice removal tools. The spray interceptors were installed for horizontal collection. The boxes, ultrasonic transducers and horizontal collectors were aligned to be approximately perpendicular to the bulkhead, which was curved at the point of placement. The units were attached to the deck with steel chairs provided by CRREL.

One collector box was installed on the 01 level (Fig. 11 and 13). Equipped with a Young rain gauge, it was placed off the center line (to port) to avoid shadowing by the antenna anchoring stanchion located at the deck center line. The stanchion extends at least 4.5 m into the air. The transducer was positioned to the starboard side of the unit to measure deck ice accretion at the center line. This level was also fitted with a NWS gauge in front of the collector box.

Two units were installed approximately symmetrically about the ship's center line on the 02 level (Fig. 12 and 13). The starboard unit had the Young anemometer installed. Both were aligned to allow the transducers a perpendicular look at the bulkhead, which was slightly curved at this location. Because of concern for the thinness of the aluminum deck (0.5 cm) at the 02 level, a 0.5-cm doubler plate was obtained from the ship and pieces cut for welding to the deck prior to welding on the spray unit chairs. Horizontal interceptors were installed on both units.

One unit was located on the port side of the flying bridge (Fig. 13). Placement location was limited by the lookout station, which took up most of the deck area. A canvas tarp, usually placed on the rails of the outboard wings, was not installed to minimize interference with the spray collection and video cameras' field of view. The transducer was oriented to measure deck ice accretion.

Video cameras

Two video cameras were mounted on the deck of the flying bridge (Fig. 9 and 13). Installation problems experienced with the video cameras supports the idea of developing self-contained equipment. Cables were attached to the railings and run to stuffing tubes on the port side of the bridge. The

cables were then run down into the bridge above the Captain's chair, across to the starboard side near the quartermasters' watch station and through cable raceways to the 02 level. From that point, interior raceways and cable trunks were not available. The cables were run down from the overhead, adjacent to a fire station at the athwartships passageway running adjacent to the Captain's cabin, then down the ladder well to the 01 level overhead, across the corresponding passageway on the 01 level and into the officers' conference room, which was being used by the researchers. Cables were tie-wrapped together and attached to perforations in the overhead panels where required. The 30-m cable originally attached to the cameras was barely adequate to reach the termination point in the conference room. Connectors were removed to facilitate passage of the cable through the stuffing tubes at the flying bridge, and then reconnected using spares brought along.

Universal flying particle camera

The universal flying particle camera was mounted on an aluminum channel held to the 02 level deck by four supports welded to, and extending over, the edge of the deck (see Fig. 12). Video and power cables and washer fluid tubing were tie-wrapped to the railings above the camera, and run to and through the air castle. The air castle was penetrated with a hole saw and the opening sealed with a PVC bushing set. From the air castle the cables were run to the athwartships passageway and a second set of penetrations with similar fittings was made under the ladder well to the 02 level for additional protection. The cabling was then carried from the overhead through the existing opening in the bulkhead separating the passageway and conference room.

Rosemount ice detector

The Rosemount ice detector was mounted on a port side stanchion at the 02 level. Cabling was run to the conference room in the same fashion as the universal flying particle camera, also on the same level.

National Weather Service precipitation gauges

The relatively fragile NWS standard precipitation gauges were mounted inside pieces of 0.3-m-diameter steel pipe approximately 1 m long. On the 01 level, the NWS rain gauge pipe was welded directly to the deck along its full circumference. On the flying bridge, small steel tabs cut from angle iron were welded to the base of the steel pipe and

held by screws to three aluminum pads welded to the deck. This mounting was considered adequate because it was not subject to extreme forces on the flying bridge.

Problems encountered

Cabling

There were problems with running cable from the exterior to the interior of the ship because vacant stuffing tubes were virtually nonexistent. The easiest way was to drill and place fittings through the air castle, and carry cabling inside through the tubes. Ship's personnel were reluctant to authorize permanent alterations, especially penetrations into living spaces or magazines forward of the air castle because of continual leakage problems those penetrations cause in heavy seas. The best solution appeared to be using the 01 level to penetrate the air castle between two weather decks where any water leakage will not cause problems.

Space

Adequate and appropriate berthing space was limited because extra junior officers were carried on board. Small research parties (1-2 people) are probably the most a ship can accommodate for an extended period of time (Coast Guard ships do carry women and gender should not limit the selection of personnel to ride the ship). Advance arrangements must be made with the ship's Executive Officer.

General cargo storage was also a problem. We solved this using knock-down boxes that could be rapidly reassembled using a power screwdriver on the deck or in a hold. Storage was available in the anchor windlass room and hawser storage locker-bosun's stores area for crates. One or two crates of accessible storage were necessary to keep available items that were frequently needed by the research party.

Attachments to the decks

Decks were thin. Welding requires a fire watch in any interior compartments below and behind the welding, as well as removing insulation, relocating cabling, etc., which may be damaged by it. Costs for civilian firms were high. Several types of welding were needed—aluminum, high yield steel, mild steel, etc.—that has to comply with Coast Guard specifications for work to maintain the ship's structural integrity. The unevenness of the deck area in some locations did not permit ready installation and direct welding of the spray unit chairs, which

require an even surface (Walsh et al. 1992, Fig. 9). The solution was to weld steel angle stock along the deck and then weld the chairs to the angles. Deck camber required that drain holes be drilled in the rear of each box to ensure rapid drainage of any water in the enclosure.

Survivability

DTRC computed deck wetness to assess the survivability of units on the main deck. Units near the bulkhead were likely to survive without damage. However, survivability concerns for one unit that we proposed be mounted forward of the hawsepipes caused it to be deleted. Videotapes taken during a previous passage from Alaska to the continental U.S. by the *Midgett* indicated that the hurricane bow "scooped" a significant amount of water and that any unit placed in this area would be exposed directly to "green water" impact and probably destroyed.

Gear removal

At northern port of call, gear removal is difficult. The size and weight of the units make removal necessary at a location where crane services are available. Removal must be accomplished in the short period (1-2 days) of a scheduled port visit while the crew is primarily dedicated to replenishing the ship and not available for assistance.

On the *Midgett*, it was necessary for the research team to terminate work several days before the final port call to disassemble and pack instrumentation prior to removal from the ship. The crew was reluctant to have the equipment aboard without personnel to maintain it. Where the gear is specialized, costly and not easily replaced, it is in the best interests of all concerned to remove it as soon as possible.

EQUIPMENT CONFIGURATION AND OPERATION

CRREL equipment configuration

The Coast Guard Cutter *Midgett* superstructure configuration was ideal for spray and ice measurement research. Decks were stepped at the 01 and 02 levels, with considerable deck space on each level for equipment placement, unlike Navy ships, which frequently have a single bulkhead several levels high from the main deck to the bridge. Our goal was to place equipment so as to get the greatest number and variety of locations for spray and ice thickness measurement, yet to place equipment in

- ① Horizontal Collector Unit
- ② Vertical Collector Unit
- ③ Young Rain Gauge
- ④ N W S Rain Gauge
- ⑤ Video Camera
- ⑥ Flying Particle Camera
- ⑦ Rosemount Ice Detector
- ⑧ Ultrasonic Transducer

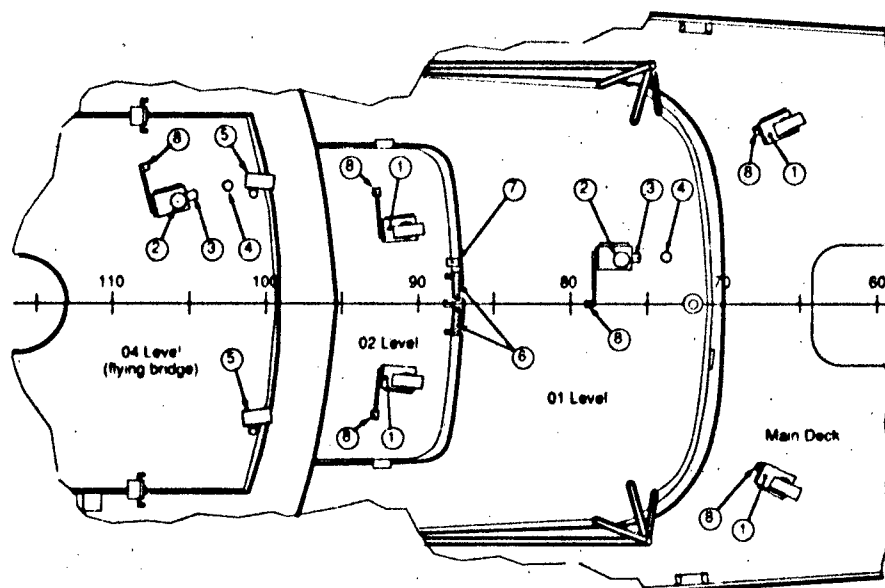


Figure 14. Scale plan view of instrument locations on the Midgett's deck. (Scale in center is distance in feet along the center line from the bow at the waterline.)

exposures sufficiently similar to allow comparisons from place to place. The equipment had to be in locations that would not hinder deck crew operations, and where welding and instrument weight and moments would not damage the ship structure. Lastly, the measurement locations had to satisfy the needs detailed by the University of Alberta researchers for calibration and verification of their advanced icing model (Lozowski and Zakrzewski 1988).

Spray and ice measurement equipment was placed at four levels on the *Midgett*: main deck, 01 level, 02 level and flying bridge (Fig. 13 and 14). The bridge wings were too small for spray equipment, causing a two-level gap between the 02 level and flying bridge locations. At the main deck and 02 level, equipment was also placed on the starboard and port sides as near as possible to the bulwarks for measures of spray flux and ice growth changes with regard to the ship side as well as with height.

Main deck units were placed approximately 1–2 m forward of the main bulkhead, and about 2 m inboard of the bulwarks (Fig. 13, 14 and 15). These locations were free of obstructions, did not seriously hinder deck operations and were somewhat protected from green water impacts because of their inboard location. Being 1–2 m forward of the main bulkhead allowed ice accretion without extensive shadowing of the bulkhead by the equipment. The main deck units also were not located farther forward because they would be sheltered

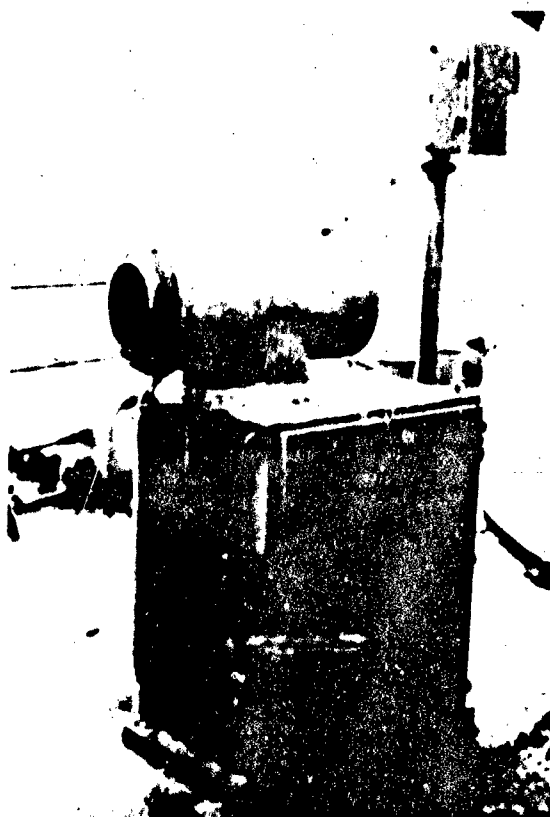


Figure 15. Main deck starboard spray and ice measurement unit.

by the 5-in. gun. They were not placed forward of the gun because of limited deck space, and the possibility of damaging green water impacts.

The main deck units were configured to measure spray striking the main bulkhead because of their proximity to it. Therefore, they were fitted with horizontal collectors. The ultrasonic transducers to measure ice thickness were aimed at the main bulkhead approximately 2 m above the deck surface. This bulkhead was curved, and this may have contributed to ice thickness measurement problems, as discussed later. No other equipment was collocated with the main deck units.

The 01 level spray and ice measurement unit was placed about 1–2 m aft of the forward portion of the deck, approximately 1 m port of the ship center line (Fig. 13, 14 and 5). The off-center location was necessary to avoid a mast carrying communications antennas. Locations near the bulkhead were shadowed by gun mounts and would have blocked a door providing access to a magazine. Because of its forward location and our need for measurement variety, the 01 level collector was configured to measure spray from the vertical, i.e., spray that impinges the deck surface. The ice measurement transducer was therefore aimed at the deck's nonskid surface on the ship center line (Fig. 5).

Equipment collocated with the CRREL 01 level spray and ice measurement hardware were a Young rain gauge mounted on the forward end of the CRREL unit, and a NWS precipitation gauge placed on the deck forward of the CRREL and Young units near the rail (Fig. 5). This equipment was intended to cross check measurement accuracy.

Equipment located on the 02 level was configured similarly to the main deck equipment, with horizontal collectors and ultrasonic transducers aimed at the bulkhead aft of the units (Fig. 12, 13 and 14). The units were located on the starboard and port sides, about 2 m from the ship center line. Collocated on the 02 level was a Young anemometer mounted to the starboard unit's door. Also at this location were the flying particle camera mounted to the 02 level deck and hanging over the front of the 01 level bulkhead (Fig. 12), and the Rosemount ice detector mounted to the rail port of the center line (Fig. 12).

The 02 level spray and ice measurement equipment was intended to match the main deck units, but two levels higher to observe the spray flux gradient. The anemometer, universal flying particle camera and Rosemount ice detector were located at the 02 level because of the relative ease of cable penetrations into the superstructure at this location, and to protect the equipment from damage by crew or green water. The 02 level deck was isolated, being accessible only by ladder from the 01 level. It was never used by crew and was immediately forward of the Captain's stateroom.

The flying bridge spray and ice measurement unit was given a vertical measuring configuration, identical to the 01 level unit (Fig. 12, 13 and 16). The ice measurement transducers were aimed at the nonskid deck surface. The entire unit was located several meters port of the ship center line to avoid interference with the flying bridge lookout position. Also, as on the 01 level, a Young rain gauge was mounted on the front of the CRREL unit, and a NWS precipitation gauge was located on the deck forward of this.

The video cameras for viewing bow spray were located on the forward edge of the flying bridge deck, overhanging a canopy over the top of the bridge windows immediately below. The cameras



Figure 16. Flying bridge spray and ice measurement unit.

were located on the extreme starboard and port sides of the flying bridge deck to provide different angles of view, and because they could not be located in the center of the flying bridge owing to interference by the watch station air deflector. The high location provided an encompassing view of most of the main deck, was relatively free of spray and was completely free of green water (on the February–March 1990 cruise). The location also allowed relatively easy maintenance of the equipment.

CRREL equipment operation

Spray and ice equipment operated automatically, but was programmed to record spray or ice at specific intervals and within specific temperature ranges. Spray tank water depth voltages were measured by the data loggers every second, and average voltages were stored in memory for each 12-second period. This measurement procedure remained unchanged throughout the research cruise.

Spray was measured whenever air temperature, as measured by a thermocouple in the transducer box, was higher than -1.5°C prior to 15 February, and higher than -2.5°C after 15 February. If air temperature dropped below these thresholds, the spray mode stopped and ice measurements began. When air temperature increased above 0.5°C prior to 15 February, or -0.5°C after 15 February, the units automatically switched back to the spray measurement mode after being in the ice measurement mode (Walsh et al. 1992). Spray was measured at the same frequency from the Young rain gauges, and in the same temperature range. Ice measurements were made every 15 to 30 minutes to conserve battery power and air tank pressure, and because ice growth rates would not be sufficiently rapid to warrant more frequent measurements.

Wind speed and direction were read from the Young anemometer initially every minute, and average speed, direction and gust were stored once per hour. After 15 February, wind speed, gust and direction were read and recorded every minute. Voltages from the Rosemount ice detector were read and recorded each 10 seconds. The NWS rain gauges were read very infrequently because weather decks were often closed.

The flying bridge video system was always powered to keep the cameras warm. The video recorders were operated whenever spray was expected or observed over the bulwarks. The camera affording

the best view, from starboard or port, was used, depending upon the circumstances. Two recorders were always used to produce a backup tape.

The universal flying particle camera was operated whenever spray was expected to reach the 02 level. Even though it could operate at night because of the strobe light, this was never done because we could not observe spray from the flying bridge video cameras.

Ship equipment: configuration and operation

Weather and sea conditions were measured primarily with ship-owned equipment, operated and maintained by the quartermasters.

Air temperature was measured with a mercurial thermometer located within a snail shelter attached to the inside of the starboard bridge wing to a white painted aluminum bulkhead below the rail. The shelter was about 0.3 m square with a natural wood finish.

Wet bulb temperature was initially measured from a thermometer within the air temperature shelter, with a sock over the bulb immersed in a cup of water. A sling psychrometer and Psychron on board were repaired at sea, and the quartermasters were taught how to use these instruments. However, wet bulb readings, and thus relative humidities, are suspect because the sling psychrometer and Psychron were frequently not allowed to cool to a stable temperature, especially in subfreezing temperatures.

Wind speed and direction were measured with an Aerovane anemometer located on the port yardarm on the forward mast. Relative wind was converted to true wind with a hand-held navigation calculator. During the cruise the wind direction display on the bridge failed. Quartermasters then looked at the sensor's direction on the yardarm and judged the azimuth angle by eye, or called the combat information center for a reading from the display for the Aerovane located on the starboard yardarm of the forward mast.

Air pressure was taken from a barograph located on the bridge. Wave and swell direction and height were estimated by eye using a Beaufort chart on the bridge for guidance. Night observations were frequently indicated as obscured because of darkness. Water temperatures were recorded from an engine coolant intake and were estimated by the quartermasters as 1 to 4°C too high, and were corrected by the quartermasters for this in the ship's logs.

SPRAY DATA COLLECTED

Spray flux voltage problems

Spray flux was measured during the entire research cruise, except for periods when data were being downloaded, equipment was being repaired or serviced, or temperatures had dropped below the threshold conditions that initiated ice measurement instead of spray measurement. Spray was initially recorded as a voltage from the capacitance system, and later converted, in a two-stage process, to spray flux.

Voltages indicating water depth in the collector tanks were measured each second by the data logger, and averaged over 12-second periods and stored in memory. Plots and discussions in this report are of 1-minute averages of the five 12-second averages per minute because the University of Alberta required 1-minute fluxes. Voltages are plotted in Greenwich Mean Time (GMT) in minutes starting from 0000 GMT 5 February 1990 (Fig. 17, Appendix B). Twelve full days of plots and portions of others are missing because of days in port, icing and instrument down time (Table 3).

The collectors were designed to intercept spray either from the vertical, as with the 01 level and flying bridge CRREL and Young units, or from the horizontal, as with the main deck and 02 level CRREL units. Accretion of spray causes the water level in each tank to rise, increasing voltage output from the capacitance system (Walsh et al. 1992). When operating properly, a full tank on a CRREL unit, just before draining automatically, should register 2100 mV, and 2400 mV for a Young gauge. The minimum voltage that either unit should indicate, when at the minimum readable volume of water, was 130 mV. Voltages occasionally fall outside of these ranges in the plots. Reasons for this are explained, if known.

Table 3. Full days of missing spray voltage plots.

5 February	— ship left port late in day, within San Francisco Bay the entire day.
11–12 February	— subfreezing temperatures
17–19 February	— docked at Kodiak, Alaska
23–24 February	— subfreezing temperatures
5 March	— docked at Dutch Harbor, Alaska
11–13 March	— subfreezing temperatures

A properly operating CRREL or Young gauge will show an increasing voltage over time as spray is intercepted and stored in the tank. For example, virtually no spray interception by any units shows on 6 February until minute 2400, when a small pulse of spray enters the main deck port and starboard CRREL units (Fig. B1a). A small pulse of spray also reaches the main deck and 02 level units at about minute 2880.

The main deck port and starboard units on 7 February also indicate how the voltages change over time as spray is intercepted (Fig. B2a). Both units show a gradual increase in voltage, with no decreases until drainage occurs. The main deck port unit drains at about minute 4320, with a decrease in voltage to about 140 mV when fully drained.

Problems with the units begin to appear on 7 February. Voltages in the 02 level starboard unit were somewhat erratic, and fluctuated at high frequency over a range of about 70 mV early in the day. On 8 February this fluctuation of voltage decreased in the 02 level starboard unit, but became apparent in the main deck port unit at a higher amplitude. This erratic behavior became more pronounced over time until fluctuation amplitudes became extreme on the main deck units on 10 February, and on the 02 level units by 14 February. These large fluctuations were a problem throughout the balance of the cruise.

Close inspection reveals patterns that suggest possible causes of the voltage fluctuation problem. Throughout the research cruise, the voltages fluctuated mainly in CRREL units measuring horizontal spray mounted on the main deck and 02 level. Few erratic fluctuations occurred in the CRREL units measuring vertical spray and in the Young gauges. Fluctuations in the Young gauges and vertical CRREL units on 21–26 February, 2 March and 14–15 March were probably caused by water freezing in the tanks, as freezing of water is a drying process.

The extreme low voltage of the CRREL 01 level unit from 13–21 February, essentially zero voltage, was probably caused by the tank being completely dry. When the unit drains completely, no voltage will register until water fills the valve piping and tank to the bottom of the capacitance system wiring.

In general, there were no serious fluctuations in tank voltage until tanks had cycled through at least one drainage cycle. The exception is the small, less

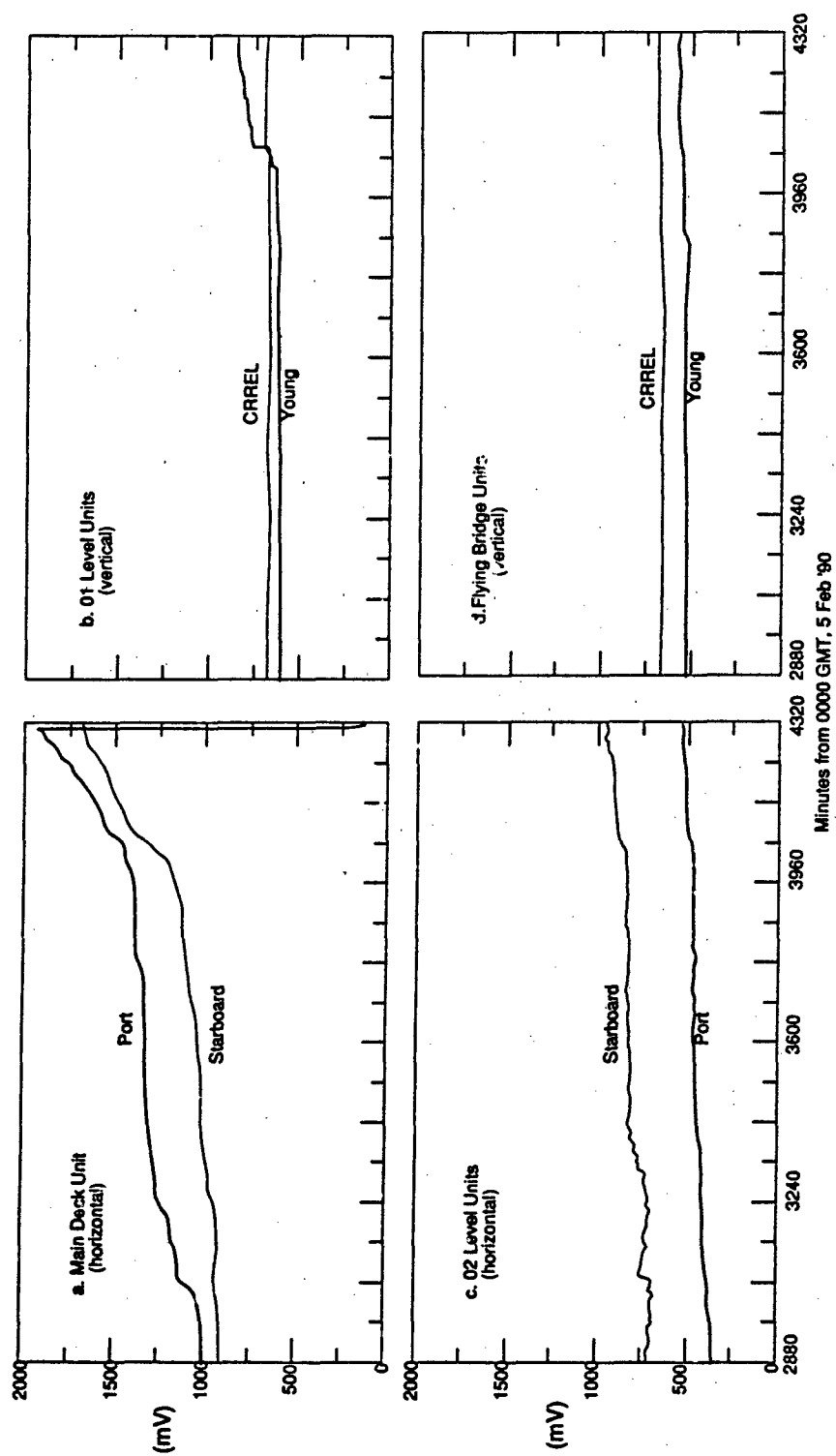


Figure 17. Spray collector tank voltages for each of the six CRREL and two Young collectors for 7 February 1990. See Appendix B for plots of the entire research cruise.

than 70-mV, fluctuations in the 02 level units on 7 and 10 February. The first seawater drained from the CRREL units at the times listed in Table 4.

Voltage fluctuations became more erratic and extreme as spray flux increased. An example of this occurs on 6 March, primarily after minute 42,660 on the main deck and 02 level CRREL units (Fig. B20). Voltages increase dramatically at about minute 42,840 on the main deck, 02 level and 01 level units, including the Young gauge on the 01 level. Some of the apparent erratic behavior of the main deck units may be attributable to the tanks draining automatically near minute 42,900. The starboard and port units both nearly reach the 2100-mV automatic drainage voltage at this time, and voltages do drop in both units, suggesting that they have drained. However, voltages do not decrease to the 140-mV dry tank voltage as they should. The port unit drops to about 1500 mV and the starboard unit to about 600 mV. This suggests that the tanks may not have drained completely, that spray entered more rapidly than drainage of the tank, or that there was another malfunction.

A similar incident is observed on 9 March (Fig. B23). At about minute 46,160, ship propulsion was switched from diesel to turbine, and speed increased to about 22 kn. This "high speed run," lasting about 90 minutes during three course changes from head seas and wind to nearly beam seas and wind, produced large and frequent spray

events, well-documented on videotape. As on 6 March, the main deck and 02 level horizontal units recorded flux erratically, whereas the 01 level units performed properly, with increasing voltages as spray entered the CRREL and Young gauges.

After approximately minute 46,220 on 9 March, no spray entered the collectors for the remainder of the day, at least during daylight hours, as indicated by the videotape record and suggested by the nearly steady voltages of the 01 level CRREL and Young gauges. However, the main deck and 02 level horizontal units all begin to dramatically drop in voltage after Julian minute 46,220. Though the initial voltage drops on both main deck and the starboard 02 level units could be attributed to automatic drainage cycles, drainage does not explain the rapid voltage drop in the port 02 level unit immediately after time 46,220, nor the unsteady decrease in voltage in all four units throughout the remainder of the day.

An explanation for erratic behavior of the horizontal collectors may be leakage in the drainage valves, allowing water to concurrently escape the tank as it was entering the top of the collector. Another might be RF interference by the ship's radar system with the data loggers or other electronics inside each collector unit.

Though each of these is a possible cause of problems, they are unlikely causes. Each of the six CRREL collectors is constructed exactly alike, except for the installation of the horizontal collectors on the main deck and 02 level units, the Young rain gauges on the 01 level and flying bridge units, and the anemometer installed on the 02 level starboard unit. It is unlikely that an electronic or mechanical defect would affect only the horizontal collector units. It is also unlikely that RF interference would affect only the horizontal units, especially since the flying bridge collector, a vertical unit, was much closer to RF sources than were the main deck units, which showed the greatest problems.

Since the only seriously affected units had horizontal collectors, the cause of their erratic behavior may be related to their interception of spray and wind from the horizontal. Because relative wind over the ship frequently ranged from 10 to 20 m/s, large volumes of air passed through the horizontal collectors. In addition, the large relative wind allowed the horizontal units to collect more spray than did the vertically oriented collectors on the 01 level and flying bridge. In fact, the units experiencing the most erratic behavior were the horizontal units on the main deck, which, by virtue of their position, collected the largest volume of spray.

Table 4. First drainage times of spray units.

The first seawater drained from the CRREL units at the following times:

Main deck starboard—1145 GMT 9 February (auto)*

Main deck port—2345 GMT 7 February (auto)

01 Level—about 0505 GMT 11 February (manual)

02 Level starboard—2340 GMT 13 February (auto)

02 level port—about 0505 GMT 11 February (manual)

Flying bridge—24 February (manual)

The first seawater drained from the Young units at the following times:

01 Level—after about 1800 16 February (auto)

Flying bridge—2010 28 February (auto)

*Auto refers to automatic drainage initiated by the data logger after registering a full tank. Manual refers to manual drainage of the tank, using the air-operated valve system, when data were downloaded.

Possible causes of fluctuating spray tank voltages

Main deck and 02 level tank voltages were compared to two environmental parameters measured aboard the *Midgett* using plots and inferential statistics—relative wind speed across the bow and air temperature. Relative wind speed was selected because it is frequently greatest when spray flux is greatest, and the horizontal units were oriented into the relative wind and received considerable ventilation. The vertical units received little ventilation, except perhaps that attributable to the Bernoulli effect when air passed over the collector boxes. Temperature was compared to voltage because it could systematically affect operation of the electronics and other parts of the units' hardware, though all units, horizontal and vertical, should be affected in the same manner by temperature changes.

The plots suggest that relative wind speed is randomly related to voltage fluctuation (Appendix C). On 6 February, main deck tank voltages increased slowly late in the day, indicating spray interception, and 02 level voltages were constant, indicating no spray interception. Correlations with relative wind speed (after minute 1980) vary from highly negative for the main deck units to positive on the 02 level (Table 5). Tank voltages on 7 February increased slowly but steadily on the main deck and 02 level, and correlations are all moderately to highly negative (Fig. 18). Correlations are mixed on 9 February, with high positive correlations between the 02 level units and relative wind speed, and moderate positive and negative correlations with the main deck tanks.

Though correlation coefficients are generally low, the 10 February graph suggests a positive relationship between wind speed and voltage change on the main deck after minute 8200 (Table 5 and Fig. C5). Graphic and statistical correlations between voltage and wind speed are strong for all four units on 13 February. However, despite large volumes of intercepted spray on 14 February, correlations between wind and tank voltage are weak or highly negative. No correlations were computed for 21 February because many of the voltage fluctuations are a result of water freezing in

the tanks late in the day. From 15 February through 14 March, with two exceptions, correlations are weakly positive or negative. Correlations between the 02 level tanks and relative wind speed are moderate to high on 7 March, and correlations are moderately positive on 9 March for all four units, where wind speed decreases throughout the day as voltage falls.

Similar patterns of days stand out in the correlations between air temperature and tank voltage, though many are reversed in sign from the wind speed correlations (Table 6). For example, temperature correlations are generally negative and opposite in sign to wind speed on 7 February, yet most correlations are high and positive for both temperature and wind speed with 02 level tank voltage on 9 and 10 February. Temperature correlations are again highly negative on 14 and 25 February, but weakly positive on 28 February. The same confused situation holds for March, with high correla-

Table 5. Correlations of spray tank voltage with relative wind speed.

	Main deck		02 Level	
	Starboard	Port	Starboard	Port
6 Feb	-0.83	-0.77	0.22	0.64
7 Feb	-0.77	-0.49	-0.72	-0.66
8 Feb	-0.45	-0.44	0.56	0.51
9 Feb				
<M 6470	-0.42	<M 6970	0.68	0.71
>M 6480	0.57			
10 Feb	0.14	-0.29	0.58	0.57
13 Feb	0.78	0.65	0.66	0.67
14 Feb	0.15	<M 13960	0.12	-0.19
		>M 13960		
15 Feb	0.26	-0.34	-0.16	-0.34
16 Feb				
<M 16850	0.51	-0.65	-0.04	-0.18
22 Feb	0.02	-0.30	0.06	-0.08
25 Feb	0.49	-0.05	0.72	0.17
28 Feb	-0.20	-0.26	-0.20	-0.08
1 Mar	0.42	0.37	0.44	0.35
3 Mar	0.34	0.13	0.32	0.39
4 Mar	-0.38	0.17	-0.24	0.22
6 Mar				
<M 42870	-0.15	<M 42870	-0.17	0.15
>M 42910	0.40	<M 42910		
7 March				
<M 43970	0.30	0.15	0.77	0.62
>M 43980	0.84			
8 Mar				
44820<M>45529		-0.18		
45545<M>46079		-0.37		
44640<M>46080	0.15		0.17	0.54
9 Mar	0.61	0.69	0.59	0.66
14 Mar	0.45	0.24	0.02	0.69

* Range of minutes correlated on indicated date for r to immediate right.

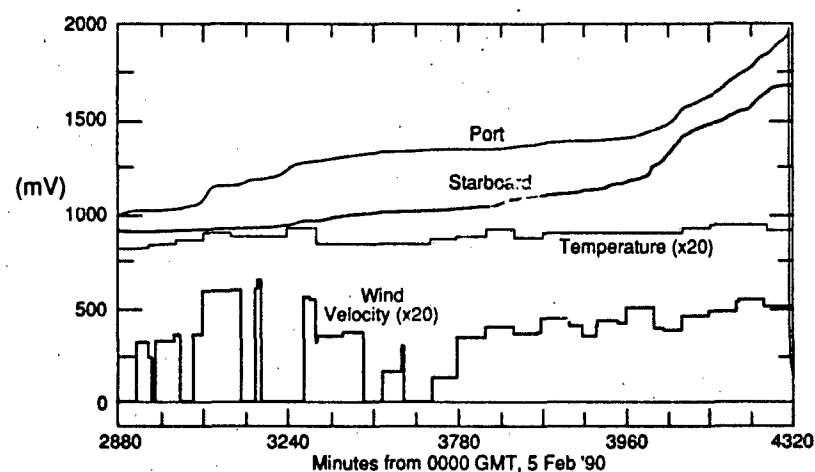


Figure 18. Sprny collector tank voltages, relative wind speeds and air temperature for the CRREL horizontal collectors on the main deck for 7 February 1990. See Appendix C for plots of the entire research cruise.

Table 6. Correlations of spray tank voltage with air temperature.

	Main deck		02 Level	
	Starboard	Port	Starboard	Port
6 Feb	-0.33	-0.15	0.12	0.39
7 Feb	0.71	0.70	0.67	0.68
8 Feb	-0.27	-0.28	0.64	0.72
9 Feb				
<M*6470	0.81	<M 6970 0.68	0.82	0.80
>M 6480	-0.51			
10 Feb	-0.05	-0.63	0.36	0.78
13 Feb	0.88	0.92	0.67	0.94
14 Feb	-0.32	<M 13960 -0.91	-0.56	-0.32
		>M 13960 0.53		
15 Feb	0.59	-0.23	-0.23	-0.29
16 Feb				
<M 16850	0.38	<M 16850 -0.30	<M 16850 -0.24	<M 16850 -0.29
22 Feb	0.38	0.54	-0.09	0.54
25 Feb	-0.43	-0.53	-0.53	-0.48
28 Feb	0.64	0.54	0.50	0.40
1 Mar	0.01	0.41	0.07	0.12
3 Mar	-0.27	-0.36	-0.71	-0.41
4 Mar	0.40	-0.39	-0.10	-0.22
6 Mar				
<M 42870	0.23	<M 42870 0.10	0.63	0.61
>M 42910	0.94	<M 42910 0.90		
7 Mar				
<M 43970	0.46	-0.66	-0.31	-0.32
>M 43980	0.05			
8 Mar				
44820<M>45529	-0.50			
45545<M>46079	0.20			
44640<M>46080				
	-0.01		-0.25	-0.12
9 Mar	0.57	0.41	0.55	0.58
14 Mar	0.82	0.72	-0.31	0.54

* Range of minutes correlated on indicated date for r to immediate right.

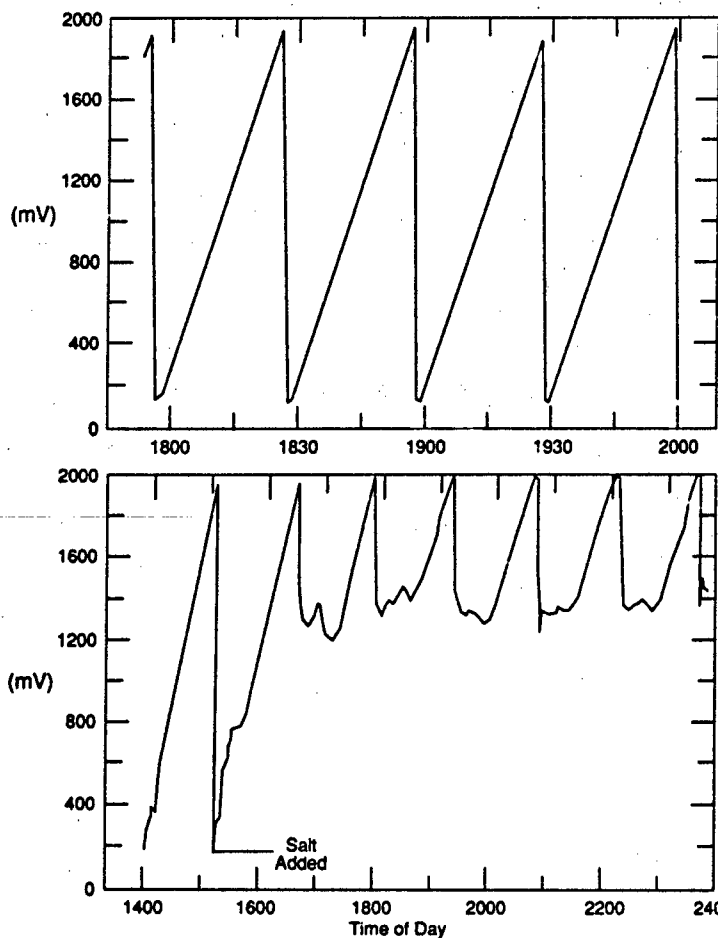
tions fluctuating in sign for the 02 level units on 3 and 6 March. As with relative wind speed, all temperature and tank voltage correlations are moderately positive on 9 March.

There appear to be no consistent and few strong relationships between relative wind speed or air temperature and tank voltage. Though individual days appear to have strong relationships, such as 9 March, there is no sufficiently strong overall pattern to suggest that either wind speed or air temperature was individually the cause of the measurement problems observed.

We have hypothesized that the primary cause for the spray data noise was that salt water rather than fresh water was being measured. The tanks exhibited only a minor noise problem prior to being filled with sea water and drained the first time. The noise appeared and became quite severe after salt water had once covered the capacitance system wires. This is evident for the main deck port tank from 7-8 February, the main deck starboard tank

from 9-10 February, and the 02 level starboard tank from 13-14 February. Residual salt water evaporating from the capacitance system wires after a tank drains may leave a film of either moist salt crystals or highly saline water. This solution may remain at least partially intact in the humid, cold environment of the tanks above the tank water surface. The solution's high salinity has a low vapor pressure, slowing the evaporation rate and preventing its complete evaporation. In addition, motion of the ship will cause wires to be periodically wetted, though not constantly immersed. Periodic wetting and slow evaporation may allow a conducting saline film to be maintained on the wires or imbedded in the wires, or both. Fluctuation in the "wetness" of the wires from splashing and humidity changes may have caused the noise problems observed.

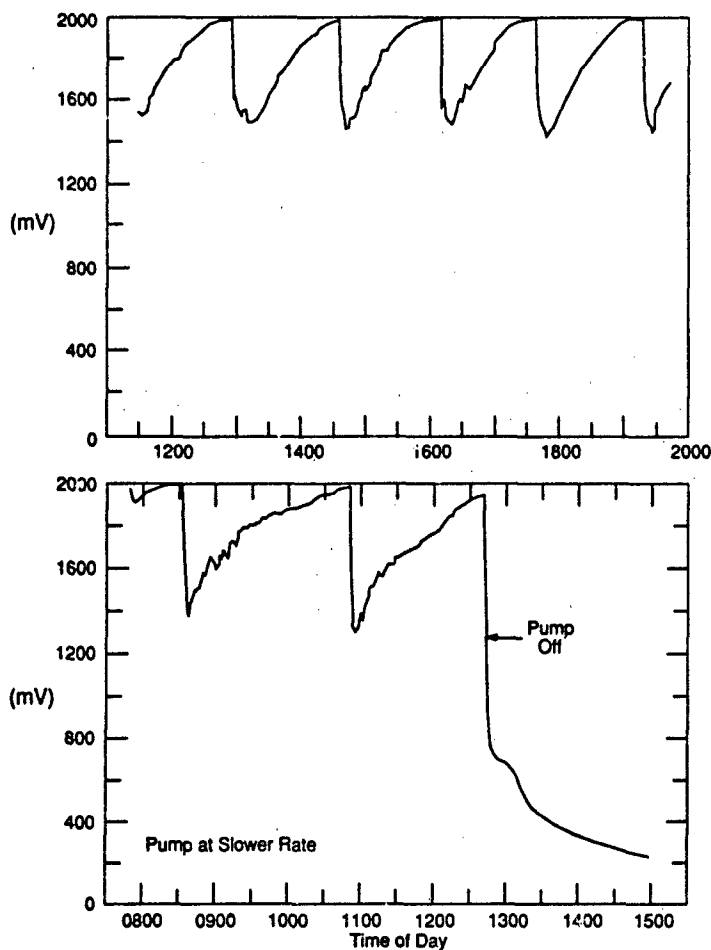
The potential for problems created by salt water on the capacitance wires is demonstrated by a post-cruise experiment conducted at CRREL to try to



a. Fresh water.

b. Salt water.

Figure 19. Test results for Teflon wire capacitance system in both fresh and salt water starting with dry, salt-free tank and wires.



a. After one day.

b. After one day with drainage and no filling after 1300 hours.

Figure 20. Test results for Teflon wire capacitance system in only salt water.

find the cause of the noise (Knuth 1991). A spray collector holding tank was constructed from the original spray tank schematics, because the collectors used on the *Midgett* were not available. An automatic pneumatic drain valve was installed that was identical to the originals, and a pump was used to slowly fill the tank. A data logger controlled the test. Two tests were conducted with three types of wire installed in the capacitance system and with fresh and salt water.

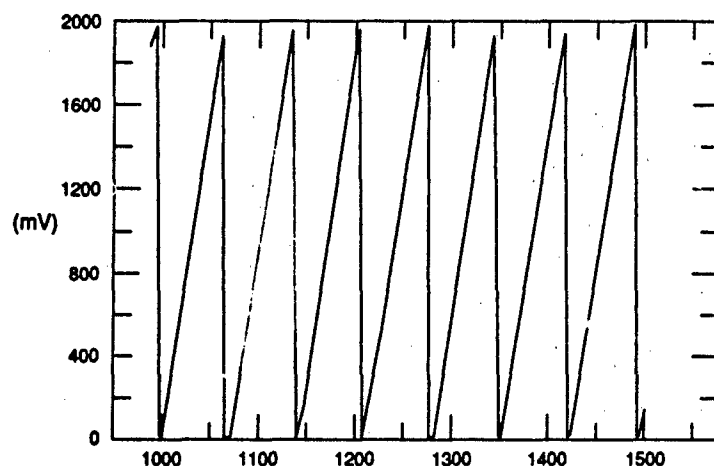
The first wire tested was Teflon insulated, identical to the wire installed in the *Midgett* spray units. Fresh water produced consistent full-scale voltage changes between empty and full tank conditions (Fig. 19a). However, salt water produced voltage fluctuations similar to those observed from the *Midgett* horizontal units (Fig. 19b). Full-tank readings were full scale, but voltages did not decrease below 1200 mV after salt water was drained. Continued cycling for over 24 hours produced even more severe "noise" problems (Fig. 20a). Decreasing

the tank filling rate produced ragged voltage increases similar to those observed on 14 February 1990, for example (Fig. B7). When the tank stopped filling and drained, voltage dropped slowly and approached an asymptotic curve (Fig. 20b).

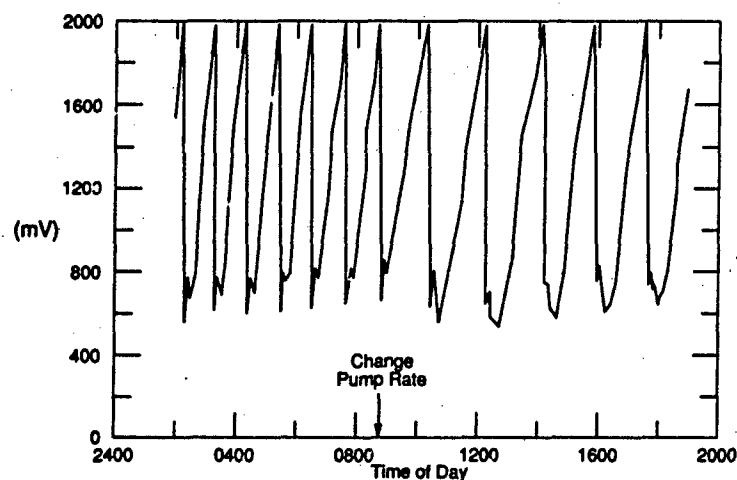
PVC-coated wire performed similarly to Teflon wire in fresh water and salt water (Fig. 21). Polyethylene-coated wire, tested third, caused such dramatic changes in system capacitance that it was not usable with the data logger. Manual readings in salt and fresh water were similar to those demonstrated by Teflon and PVC, however.

Though salt water could have been the primary cause of noise, noise was strongly enhanced in the horizontal collectors, and subdued in the vertical collectors and Young gauges. Since salt water should cause each unit to respond similarly, a noise-enhancing factor would have to be present to produce the strong effects observed in the horizontal units.

The horizontal units filled and drained more frequently because more water appeared to be



a. Fresh water.



b. Salt water.

Figure 21. Test results for PVC wire capacitance system in both fresh and salt water.

intercepted from the horizontal, rather than the vertical, owing to the high relative winds. Air may have passed through the horizontal collectors with sufficient speed to cause splashing in the tank water attributable to either Bernoulli effects or air being forced down the funnel neck; more rapid air exchange within the horizontal unit tanks because of scooping action by the horizontal collectors may have caused rapid changes in humidity and rapid alternate wetting and drying of the wires. Wetting could have increased conductivity on the outside of the wires' insulation sufficiently to mimic higher water levels than actually were in the tank, and thus causing higher voltages.

Conversion of tank voltages to spray flux

The CRREL and Young spray collection units are both capacitance systems. As the depth of water stored in the units' tanks increases, voltage in-

creases. Change in voltage over a time interval, therefore, allows the water flux over that interval to be computed. Thus, the slopes of the voltage curve, and not the absolute voltage values, provide the rate of spray flux (Appendix B).

Tank voltage was recorded and stored every 12 seconds by the data loggers, and mean voltages were computed for each minute. One-minute fluxes were then computed from the changes in mean tank voltage from one minute to the next to satisfy the need for 1-minute resolution fluxes.

The plots of spray tank voltages indicated that noise was generally not a serious problem with either the CRREL or Young vertical collectors (Appendix B). However, data could not be used from the entire cruise even from these collectors (Table 3 and Fig. 22). Periods were not analyzed when data were not recorded, such as during freezing periods, data downloading and equipment maintenance. Data were also ignored if the units switched

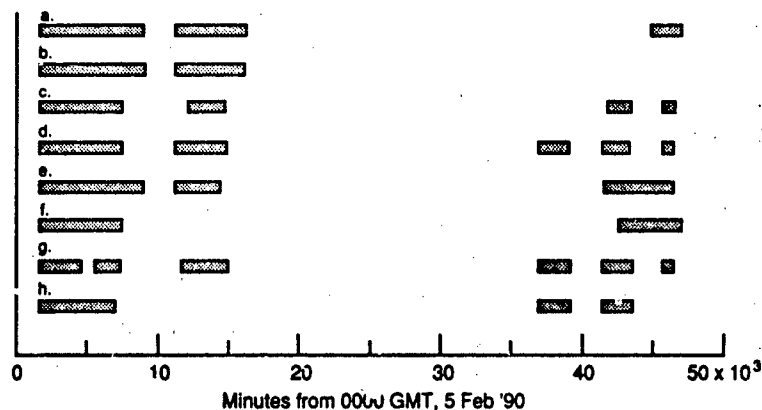


Figure 22. Periods of usable spray data, including directly measured and polynomial smoothed data (a = Young vertical unit on flying bridge, b = CRREL vertical unit on flying bridge, c = CRREL horizontal unit on 02 level port side, d = CRREL horizontal unit on 02 level starboard side, e = Young vertical unit on 01 level, f = CRREL vertical unit on 01 level, g = CRREL horizontal unit on main deck port side, h = CRREL horizontal unit on main deck starboard side).

from ice to spray measurement before any ice that may have formed in the tanks could have thawed. The lengths of these latter periods were based on judgment during analysis after the cruise. Finally, data were not used if the water level was too low for proper water depth recording. This was indicated by voltages that were lower than the minimum possible wet tank reading.

The horizontal collectors presented a more difficult problem. Factors reducing the amount of valid vertical collector data were also acting to reduce the amount of acceptable horizontal data (Fig. 22). In addition, at the outset the problem of data noise appeared to invalidate most of the horizontal unit data. However, several strategies were developed to salvage as much noisy data as possible without seriously degrading the quality of the final product.

The horizontal collectors showed little data noise prior to the first drainage of the holding tank. Those first drainage episodes provide in some cases several days of data prior to the beginning of serious noise (Table 4). Unfortunately, the ranges of ship and environmental conditions during these first few days were narrow, making poor material for generating algorithms useful to the University of Alberta model.

The primary strategy chosen to salvage the noisy data was to isolate periods when spray was thought to be accumulating in the horizontal collector tanks, as evidenced by the general shape of the horizontal collector voltage plots. These periods were then

compared to the 01 level CRREL and Young vertical collectors for flux in those units. For example, on 6 March (Fig. B20), voltages noisily increased throughout the day in the main deck and 02 level horizontal units. The 01 level CRREL and Young units also recorded clear voltage increases with plots of roughly the same shape throughout the day. This suggests that, underlying the noise, the general shapes of the plots, and slopes of the plots, are probably near correct. A similar example is 14 February, with main deck, 01 level and 02 level voltages increasing similarly (Fig. B7). CRREL 01 level voltages do not register because tank water levels were too low. In addition, the main deck starboard unit is not considered because it was apparently malfunctioning—voltages climbed to over 2700 mV and the tank had still not drained automatically.

The second strategy was to view videotapes of periods of spray to provide additional evidence of whether trends in the noisy data were totally noise, or were noise superimposed upon valid increases in tank voltages. We subjectively rated each tape spray segment viewed as representing light, moderate or heavy spray rates, and these were compared to the voltage slopes. Potential spray events after nightfall were removed from consideration because they could not be verified as actual spray events, or simply as artifacts of the noise.

Suspected spray periods with unusual voltage fluctuations caused by incipient freezing, or thaw-

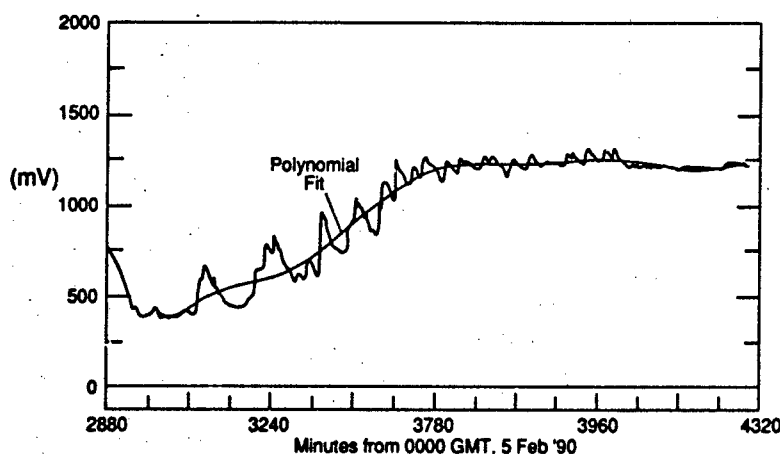


Figure 23. Polynomial fit for noisy spray tank voltages from the 02 level starboard horizontal collector, 14 February 1990. See Appendix D for fits for other periods in the research cruise.

ing of tank water, or unknown reasons, were removed from consideration. An example is the apparent spray events on 21 February (Fig. B11). Voltages increased dramatically on all units of the main deck, 01 level and 02 level after minute 23,580, yet voltages were very irregular—occasionally fluctuating full scale over periods of only a few minutes. This period was not considered for data retrieval because of the extreme noise, and because a freezing event began during this time, prior to automatic switching of the equipment from spray to ice measuring mode. The extreme voltage fluctuations may have been an artifact of saline water films freezing differentially on the capacitance system wires.

Finally, periods were avoided when instruments were suspected of malfunctioning. For example, the main deck starboard unit was suspected of malfunctioning from minute 6440 to its repair at minute 37,440. As indicated above, the high tank voltage without a drainage cycle on 14 February is evidence of this malfunction.

We converted noisy periods of horizontal unit tank voltages to usable data by smoothing the noise away and preserving trends with polynomial curve fits. Holding tank voltages were plotted by minute, as in Figure 23 and Appendix D, and the periods of noisy data selected for retrieval were fit with curves created from polynomial functions using a commercial plotting program, Grapher (Golden Software, Inc. 1988). Grapher will produce polynomial fits through the tenth degree, with a display of the polynomial curve superimposed over the original

data, and tables of fit statistics and orthogonal factors.

Polynomial functions were fit to 20 segments of noisy horizontal unit data (Appendix D). These fits represent 292.3 hours of record of occasionally coinciding times for more than one collector. We chose the degree of polynomial fit using two criteria: the percent of residuals fit to the line and appearance. Appearance was the dominant criterion, though it is subjective, because the purpose of the polynomial curve was to remove the effects of noise. A high percentage of residual fit also suggests that some noise may be included in the curve—the higher the percentage of residuals about the mean explained, the more noise that could be represented in the polynomial curve. Therefore, appearance, though not scientifically rigorous, dominated the fitting process.

Polynomial fits to the noisy data vary in complexity. The 9 February main deck port curve extending from minute 5800 to 6960 is a tenth degree polynomial (Fig. D1). Though nearly all of the residuals about the mean are explained with only a second degree fit, the trend of the voltage slope is better represented by the tenth degree polynomial.

The 14 February main deck port fit is split into two pieces because of an apparent automatic drainage of the unit at about minute 13,900 (Fig. D5). The fit before the drainage event is a seventh degree polynomial, and the portion after drainage is a second degree fit. This second portion only explains 44% of the residuals about the mean, but the curve represents the trend of the voltages, and thus

slope, well. The slope is the most important characteristic of these plots, for the slope describes the rate of water delivery to the spray collector. The absolute value of the spray unit voltages are unimportant outside of the slope that they create.

Periods of spray flux represented by polynomial fits were chosen for a full range of spray conditions, from light to heavy, to better typify all spray conditions experienced during the cruise. For example, the 3 March main deck starboard curve (Fig. D8) represents a low flux, whereas the 9 March main deck port curve represents a large flux (Fig. D15).

In the 20 polynomial fits, our goal was to remove as much noise from the data as possible, and still represent voltage in-

creases with an equation from which minute-to-minute voltages could be extracted. There was difficulty in the extraction process, because high degree polynomial equations become unstable with very small and very large coefficients and frequently generate wildly in-correct answers. To minimize this problem, the GRAPHER program provides orthogonal factors and recursion factors for each fit line, and a subroutine in FORTRAN for generating values from these factors (Golden Software Inc. 1988). These orthogonal and recursive factors were used to extract voltages in a CRREL written FORTRAN program, ORTHFLUX. FOR, within subroutine ORTHPOLY (Appendix E).

Program ORTHFLUX.FOR

Program ORTHFLUX.FOR converts tank voltages to spray flux for the CRREL and Young collectors (Fig. 24, Appendix E). The program removes periods of unacceptable measured tank voltages,

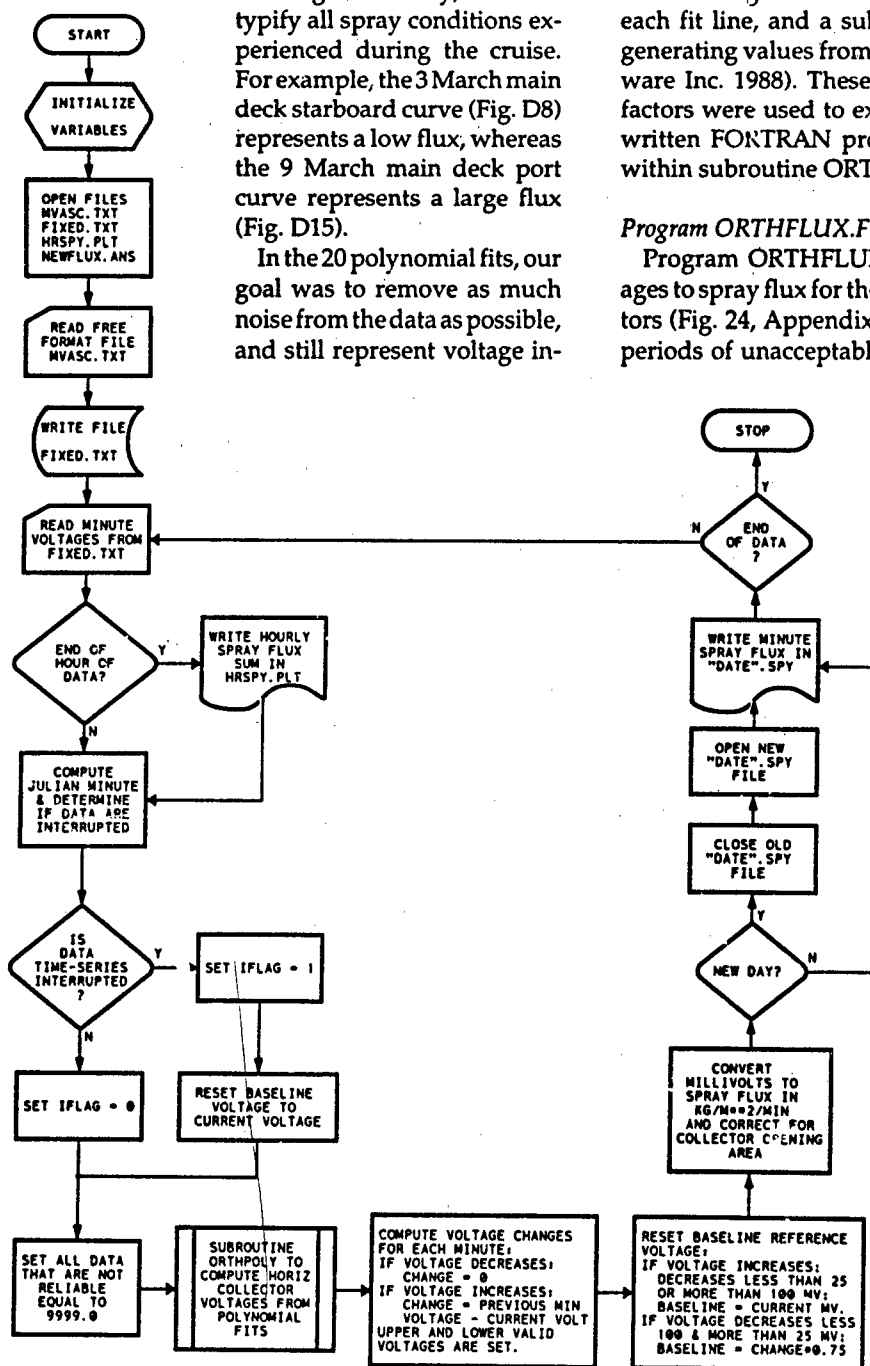


Figure 24. Flow chart of FORTRAN program ORTHFLUX.FOR for converting CRREL and Young spray tank voltages to spray flux. See Appendix E for program code.

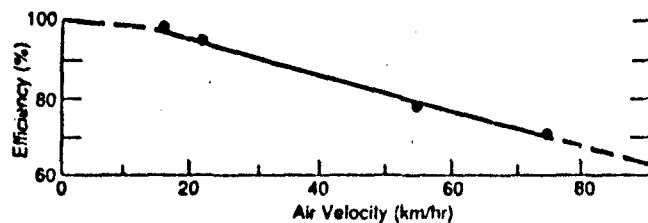


Figure 25. Efficiency curve for horizontal collector droplet interception (from Walsh et al. 1992).

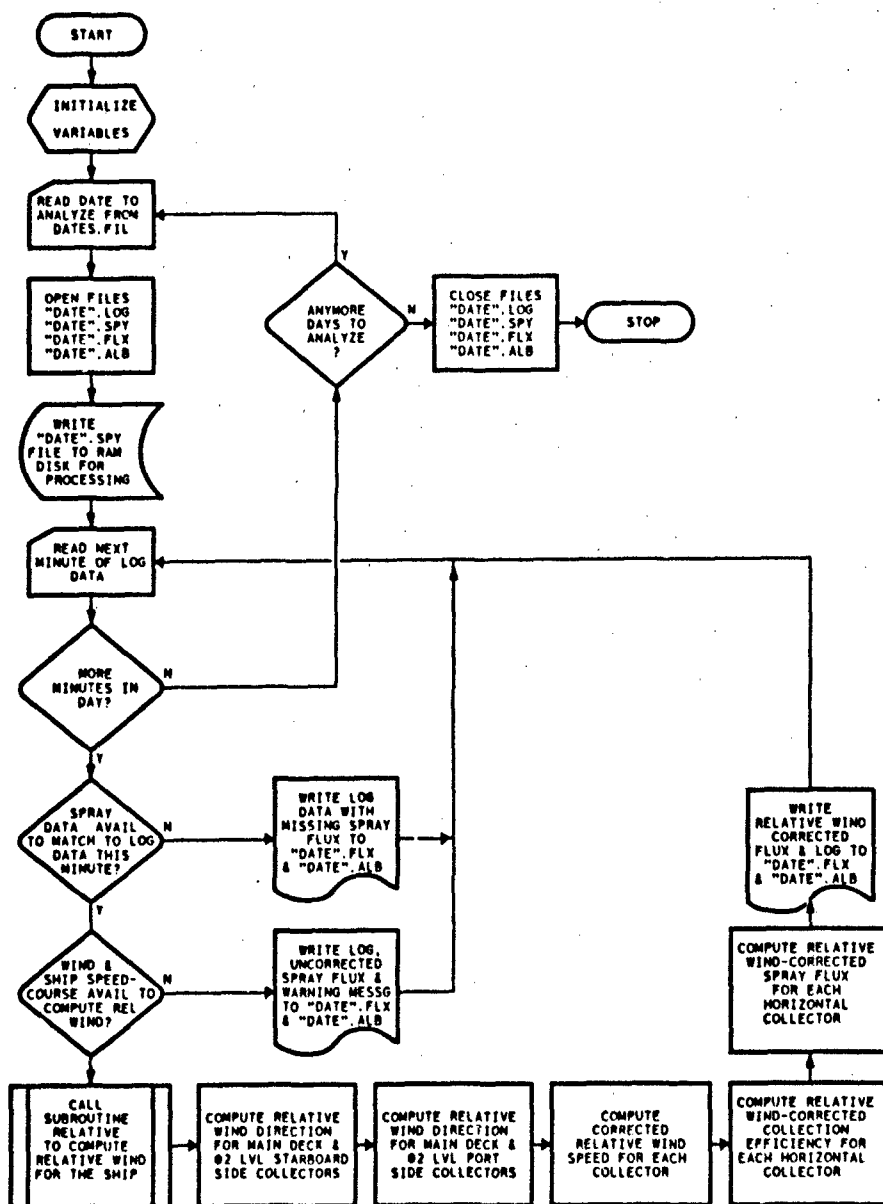


Figure 26. Flow chart of FORTRAN program WINDY.FOR for merging spray flux with ship logs, and for correcting horizontal collector spray flux for relative wind speed. See Appendix F for program code.

substitutes polynomial curve fits for noisy data where applicable, and converts minute-to-minute changes in tank voltage to spray flux for each unit. The spray fluxes are later corrected for wind-created changes in collection efficiency of the horizontal collectors in program WINDY.FOR.

Program WINDY.FOR

Spray fluxes computed in ORTHFLUX.FOR were not corrected for the collection efficiency of the horizontal collectors. As wind speed increases, the collection efficiency of the horizontal units de-

creases (Fig. 25) (Walsh et al. 1992). The collection efficiency of the CRREL and Young vertical units was not measured nor computed. FORTRAN program WINDY.FOR corrects spray flux for the horizontal units' collection efficiency, and also merges the ship logs with spray fluxes for a complete minute-to-minute data record (Fig. 26 and 27, Appendix F).

QUALITY OF SPRAY FLUX MEASUREMENTS

One purpose of this report is to verify the quality and reliability of spray measurements made aboard the USCGC *Midgett*. This is a difficult task because there is no instrument that can be used as a standard to measure the spray with absolute accuracy (Olbruck 1981). Since no such standard instrument is available, we used various methods to indicate as reliably as possible the quality of measurements aboard the *Midgett*.

Research on the difficulty of measuring precipitation aboard ships at sea has been reviewed by the World Meteorological Organization (WMO 1962, Olbruck 1981). Though these reports address problems measuring precipitation, they are similar to spray measurement difficulties. Turbulence created by air flow over the ship and over the gauge itself are the greatest sources of precipitation measurement error, though little is known about the patterns of air flow around a ship, and especially their effect on rain gauge measurement error. Studies on ocean station weather ships suggest that rain gauges should be located as high as possible to avoid the effects of ship-created turbulence (WMO 1962). In general, though, winds of greater than 15 to 20 m/s can reduce precipitation catch by as much as 50%. Greater winds are frequently experienced higher above the water, though these winds are less likely to be turbulent.

Gauge design also affects the air flow and can reduce, or even occasionally enhance, catch. In general, small gauges are more effective than large

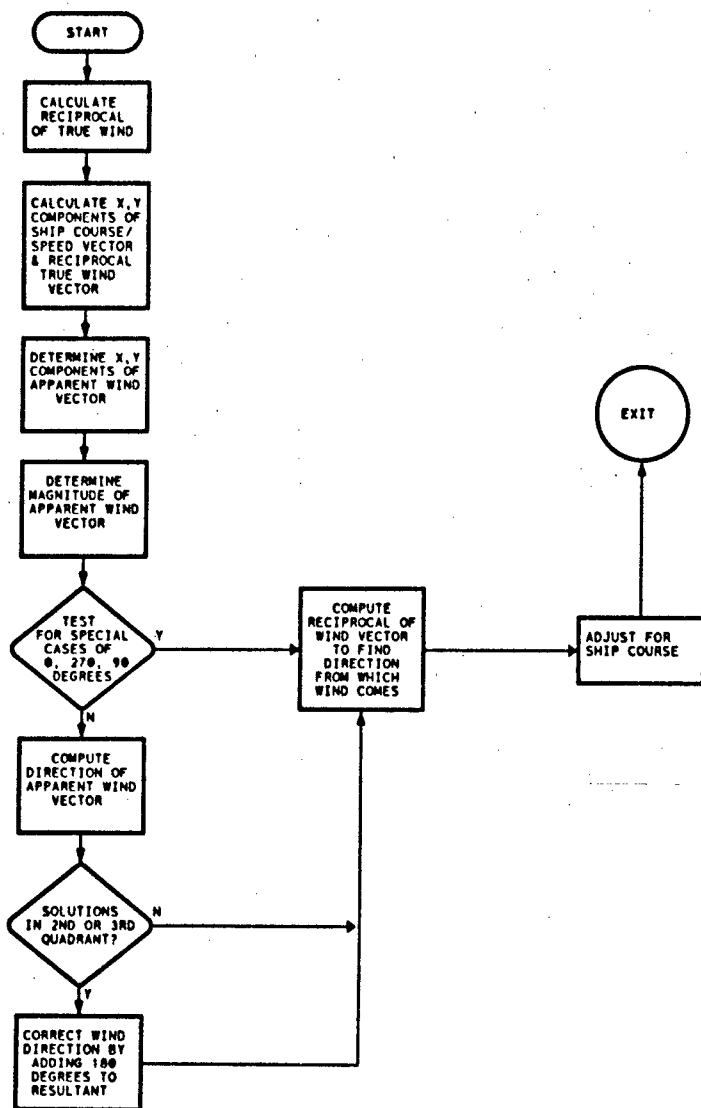


Figure 27. Flow chart of subroutine RELATIVE for computing relative wind speed and direction (from program WINDY.FOR).

gauges because they perturb air flow less (Olbruck 1981). Gimbal mounts, ship motion and wind screens have little effect, except in unusual circumstances, in improving gauge performance. The effects of ship motion and wind are greatest with light rainfall of small droplets (WMO 1962). On weather ships, WMO (1962) recommended that gauges be placed at least 16 m above the water to avoid sea spray.

Because of unit size and configuration, we had little choice in placement of gauges aboard the *Midgett*. The University of Alberta specified locations to suit their modeling needs (Lozowski and Zakrzewski 1988), and the size and weight of the equipment dictated placement on a substantial deck surface. It was not necessarily desirable to avoid the effects of turbulence, which, from visual observations aboard the ship, were great because they affect spray delivery to the ship superstructure. As a result, the collectors aboard the *Midgett* were in the worst possible locations for unbiased measurement of falling precipitation, but their placement for sea spray measurement was good. Yet, their size may have had a significant effect upon catch amount because of instrument-induced air turbulence. Undoubtedly, smaller gauges would have perturbed air flow less.

Several types of instruments were placed aboard the *Midgett* to measure spray, enabling cross-comparisons to be made. If each type of instrument making simultaneous measurements measured similarly, there is a probability, though not a certainty, that the measurements made may be reasonably accurate. However, this is best accomplished with instruments of significantly different design to assure that, even though the same phenomenon is being measured by each, the factors affecting the performance of each are different. Unfortunately, the design of each instrument placed on the *Midgett* was similar, being open-topped catchers receiving spray from the vertical.

Three types of spray measurement equipment were installed on the *Midgett* for the February-March 1990 research cruise: the CRREL collectors, precipitation gauges manufactured by the R. M. Young Company (Model 50202) (Young 1989) and rain and snow gauges manufactured by WeatherMeasure Weathertronics (Model 6310-A) (WeatherMeasure 1988). R. M. Young Model 5202 precipitation gauges were collocated on the *Midgett* with CRREL vertical instruments on the 01 level and on the flying bridge. Each Young gauge was mounted to the front of a CRREL unit and wired to the data logger controlling the CRREL unit. The

Young gauges were mounted on the bow-end of the units to reduce the effects of turbulence created by the large CRREL boxes. Each was protected by a sheet metal shroud to prevent damage, since the gauges are made of light plastic. Their small diameter, 14 cm near the collector opening, would have reduced turbulence effects on their catch. However, their mounting to the large CRREL units may have negated this feature. Ideally, they should have been attached to a nearby rail, within a protective tube, to reduce gauge-induced turbulence effects on catch.

The Young gauges use a capacitance system similar in concept and circuitry to the CRREL design. The gauges contain no moving parts and they self-siphon when filled. A variance of this Young design has been used for years on data buoys operated by the National Data Buoy center (Holmes and Case 1981, Holmes and Michelena 1983, Michelena and Holmes 1986).

There were a number of concerns about the Young gauges prior the cruise. Their lightweight plastic construction might not survive the rigors of ship-board use. The self-draining, siphoning feature may operate irregularly because of the ship's motion and the large expected volumes of spray could overwhelm the Young unit with its small-volume capacitance measuring system, small-diameter tubing and possible slow drainage rate. The apparent light construction was addressed with the addition of metal shrouds to protect each unit. In no manner were the units isolated from large volumes of spray or ship motion except to the extent that they were placed with CRREL units on upper levels where large volumes of spray were unlikely.

The third type of gauge placed aboard the *Midgett* for comparison was two rain and snow gauges manufactured by WeatherMeasure Weathertronics (Fig. 11). These gauges were an improved version of the standard 8-in. (20-cm) rain gauge built to meet NWS standards, and represent a "standard" gauge. The gauge is a nonrecording type with a measuring dip stick for manual readings. These gauges were also collocated with the vertical CRREL and Young units on the 01 level and flying bridge. Unfortunately, because readings had to be taken manually, insufficient data were taken for comparison with the CRREL and Young units because heavy weather too often closed the weather decks.

Spray flux measurement comparisons

The CRREL and Young gauges are compared using time series plots of flux measurements from both instruments at the 01 level and flying bridge

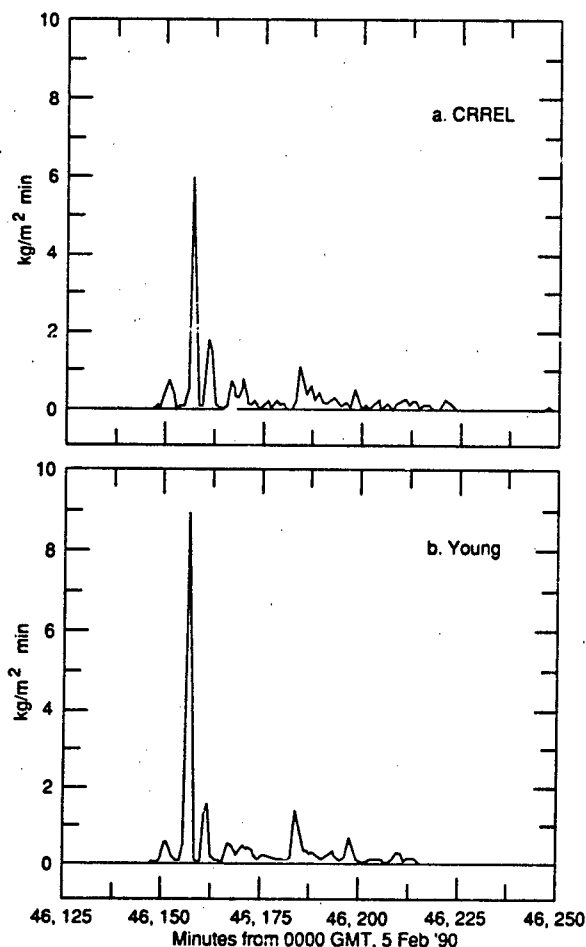


Figure 28. Spray flux measured by 01 level collectors during 9 March 1990 high speed run; data unsmoothed.

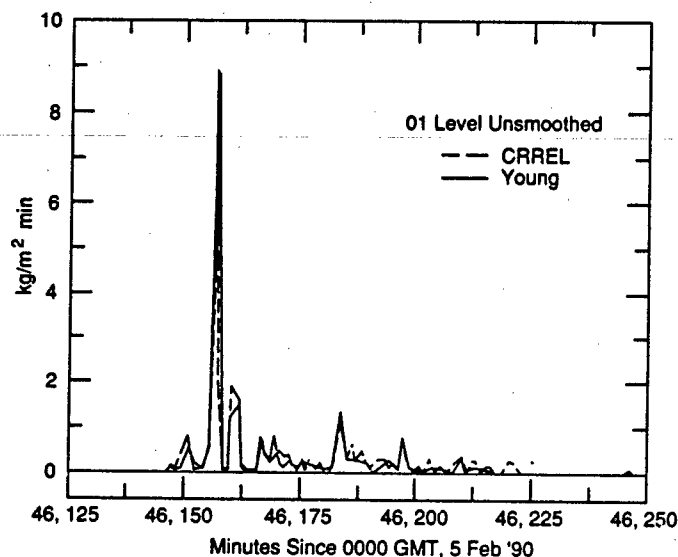


Figure 29. Comparison of the spray flux measurements by CRREL and Young 01 level collectors during 9 March 1990 high speed run.

for selected segments of the research cruise, and for the entire cruise. Statistical comparisons of the CRREL and Young collectors at the 01 level and flying bridge are also made for the entire cruise.

Plots of three short periods are used to compare the CRREL and Young units at the 01 level. Flux measurements from minutes 46,125 to 46,250, 125 minutes on 9 March, show that a peak of 6 to 9 kg/m² per minute of spray entered the gauges at about minute 46,157 (Fig. 28). Fluxes are generally less than 1 kg/m² per minute the remainder of the time. These plots illustrate flux received at the units during a high speed run of 22 kn for about 90 minutes, and represent one of the most severe spraying periods recorded during the entire research cruise. These are near maximum fluxes experienced by each gauge at the 01 level. "Unsmoothed" in the plot label refers to the use of measured voltages, and not voltages reconstructed with polynomial fits.

Figure 29 illustrates the plots from both gauges overlaid. Except for the 33 to 50% error in gauge comparisons for minute 46,157, all other minutes of data agree within approximately 20%. This is remarkably good agreement considering turbulence, the differences in size of the two collectors and the potential for noise.

The second example represents a longer period, about 500 minutes, between minutes 42,700 and 43,200 on 6 March 1990 (Fig. 30). Considerably less flux was recorded during this period, with peaks of less than 0.5 kg/m² per minute.

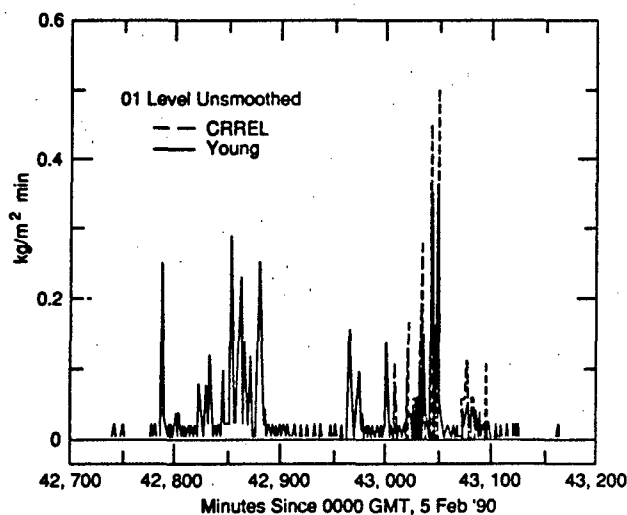


Figure 30. Comparison of the spray flux measurements by CRREL and Young 01 level collectors on 6 March 1990.

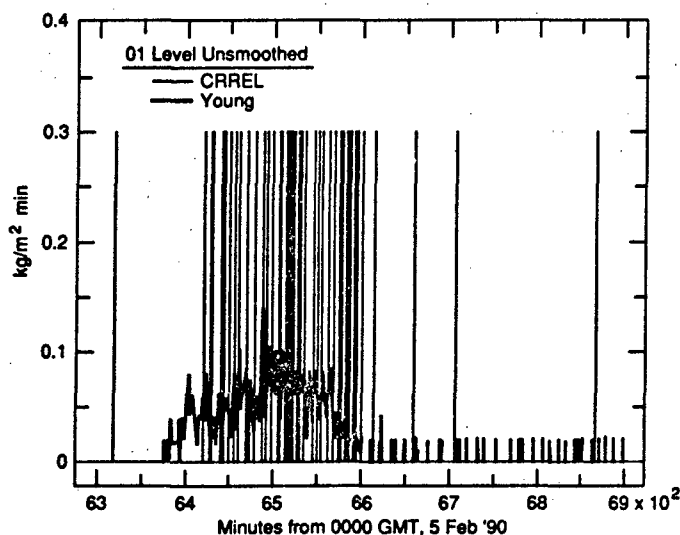


Figure 31. Comparison of the spray flux measurements by CRREL and Young 01 level collectors on 9 February 1990.

The plot suggests considerable disagreement between the two units prior to minute 43,000, with maximum fluxes of 0.3 kg/m^2 per minute recorded by the Young unit, and no flux measured by the CRREL unit. After minute 43,000, disagreements are not severe, with peak flux measurements near minute 43,050 being within 0.15 kg/m^2 per minute of one another. The plot suggests that these fluxes are near a lower threshold of measurement capability for the CRREL units, implying that they may be somewhat insensitive to smaller fluxes.

The third example, recorded between minutes 6300 and 6900 on 9 February, again illustrates very low fluxes, of less than 0.3 kg/m^2 per minute (Fig. 31). CRREL unit fluxes appear to be all identical in magnitude at 0.3 kg/m^2 per minute, whereas the

Young gauge records considerably smaller fluxes more frequently. Close observation of the CRREL fluxes suggests that they step at 0.1 - to 0.15-kg/m^2 per minute increments to a peak of 0.3 kg/m^2 per minute. Though the actual volume of flux received may be similar over the period if the curves were integrated, the plot suggests that, as in the 6 March example, the Young gauge is more sensitive to low fluxes and is perhaps more accurate.

Plots of hourly mean fluxes from the 01 level and flying bridge CRREL and Young units for the entire cruise demonstrate further how their measurements agree. Comparisons cannot be made for every hour of the cruise because of missing data, illustrated by the heavy line on the plots (Fig. 32). Relative magnitudes of hourly flux sums are in

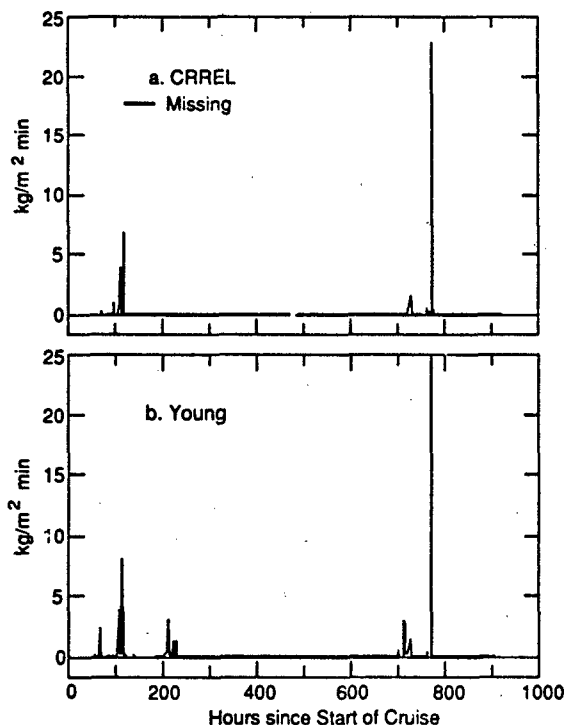


Figure 32. Hourly summaries of 01 level spray flux measurements through entire research cruise.

good agreement where data were coincidentally measured on each unit at the 01 level. For example, between hours 100 to 125, two spray peaks were recorded on each unit. The CRREL unit measured the larger peak as approximately 8 kg/m^2 per hour, and the Young gauge recorded it as about 7 kg/m^2 per hour. Both units recorded the smaller peak as about 4 kg/m^2 per hour. Agreement is also good between the units for the peak at about hour 770. There is considerable disagreement near hours 70 and 725, however, where the CRREL unit is lower by about 90 and 60% respectively.

On the flying bridge, as on the 01 level, several peaks are recorded between hours 100 and 125, with the largest again on the CRREL unit at about 3.5 kg/m^2 per hour, and the smaller on the Young unit at about 2.75 kg/m^2 per hour (Fig. 33). The CRREL unit also recorded larger peaks immediately prior to and after the 3.5-kg/m^2 per hour event. Both units are essentially in agreement on the magnitude of the hour 70 event, but in substantial disagreement on the peaks at hours 140 and 200. At hour 140 the Young unit recorded a flux of about 0.25 kg/m^2 per hour, whereas the CRREL unit recorded no flux. On the other hand, the CRREL unit recorded about 0.9 kg/m^2 per hour near hour

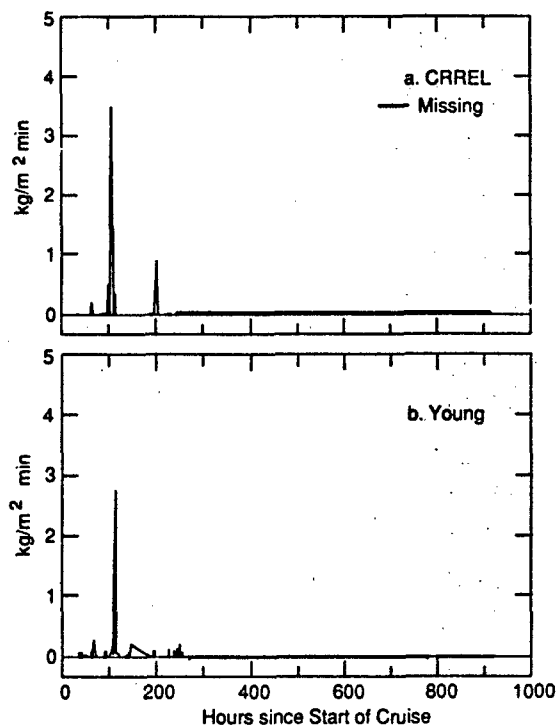


Figure 33. Hourly summaries of CRREL flying bridge spray flux measurements through entire research cruise.

200, and the Young unit recorded no flux. In general, there appears to be little consistent evidence to indicate whether the Young or CRREL units are more accurate or reliable for hourly summaries. Both units apparently "miss" spray events, and each records higher or lower fluxes than the other randomly.

Statistical methods used to compare the CRREL and Young units at the 01 level and flying bridge are nonparametric because the spray flux distributions are highly skewed for all units. Spearman Rank Correlations were used to test how well the units varied together, and Wilcoxon's Matched-Pairs Signed-Ranks Test was used to determine if measurements from the CRREL and Young collectors were sufficiently similar that they can be assumed to be identical. Missing values were not used in calculations of the statistics.

Correlation coefficients between the CRREL and Young units are moderate, at 0.55 for the 01 level and 0.70 for the flying bridge, but they are highly significant, with probabilities of rejection of the relationships at 0.0001 (Table 7). This suggests that the CRREL and Young units observe fluctuations in spray amount only generally similarly. The Wilcoxon Matched-Pairs Signed-Ranks Test was

Table 7. Hourly flux comparisons for CRREL and Young units—01 level and flying bridge.

	01 Level	Flying bridge
Spearman rank correlation*		
ρ	0.55	0.70
N hours	136.0	188.0
Probability	0.0001	0.0001
Wilcoxon Matched-Pairs Signed-Ranks Test*		
Z corrected for ties	-1.55	-0.396
Probability	0.1211	0.692

* Computed with StatView on Macintosh

made with the null hypothesis that there is no difference between the magnitude of flux measured each hour by the Young and CRREL collectors on the 01 level and flying bridge. The probabilities, 0.1211 and 0.692 for the 01 level and flying bridge, respectively, are cause to accept the null hypothesis because the rejection region is smaller than a probability of 0.01. That is, the probability that the flux measured by the CRREL and Young units is different is less than one chance in one hundred.

The plots and statistics suggest that the vertical CRREL and Young units on the 01 level and flying bridge compare well, and that their performance can be considered essentially the same. This does not mean that either type of instrument measured spray accurately, only that they measured spray flux similarly.

Another indication of whether the spray units were operating properly is to examine hourly plots for the entire cruise for all eight units—CRREL and Young (Fig. 34). Examination of the plots indicates that port units on the main deck and 02 level generally received considerably more spray than did starboard units. Inspection of main deck and 02 level starboard and port pairs of plots indicates that the patterns of peak and low flux events are essentially similar and have an expected generally lower magnitude on the 02 level.

Fluxes measured at the 01 level are considerably smaller than those measured at the 02 level. This may not appear logical at first inspection. However, the 02 level collectors were horizontal, while the 01 level collectors were vertical. The horizontal collectors probably intercepted considerably more spray than the vertical collectors because of the generally high relative wind speed over the ship. Relative winds across the bow were frequently 10 to 20 m/s. The "typical" raindrop falls at about 6

m/s. If the typical sea spray drop behaves similarly to raindrops, then more spray should have been intercepted by the horizontal collectors because of the high relative winds. This suggests that, on the average, horizontal collectors may have received 1.7 to 3.3 times more spray flux than the vertical collectors.

The gradient between the 01 level and flying bridge vertical units is also as expected, with flux decreasing considerably at the flying bridge. Inspection of all plots indicates that the timing of spray peaks, and the position of relative high and low magnitudes, are all similar, suggesting that the collectors are probably indicating relative amounts of flux with location well, even though absolute values cannot be certified as correct. The greatest unknown is the accuracy of the horizontal collectors, against which there is nothing to compare the fluxes they measured.

The preponderance of evidence suggests that, in general, the CRREL and Young vertical spray units were operating similarly. Despite the serious noise problems in the horizontal units, measurements appear to be acceptable if smoothed by polynomial functions to remove noise. The arguments presented, however, do not indicate that the absolute values of spray measured are correct. Since there is no absolutely "correct" instrument to compare to, only the careful application of scientific logic and method can suggest whether values are even close to the amount of spray actually lofted aboard the *Midgett*.

Consequences of smoothing flux data

The intent of recording spray unit tank voltage each minute was to enable individual spray events to be extracted from the data if they occurred more than 1 minute apart. Ideally, the spray videotapes and spray data could be synchronized. Noise in the spray data acquisition systems has prevented this from being done reliably. In addition, curves generated from polynomial functions were used on the horizontal units to salvage data that otherwise were too noisy to use. The polynomial functions, in their ability to smooth out noise, also smooth out minute-to-minute fluctuations in flux data representing individual spray events. Two examples follow.

On 9 February spray events occurred between minutes 6300 and 6900 (hours 105 through 115). Noise in the main deck port unit during these events required that a tenth degree polynomial equation be fit to the tank voltage curve. Spray was

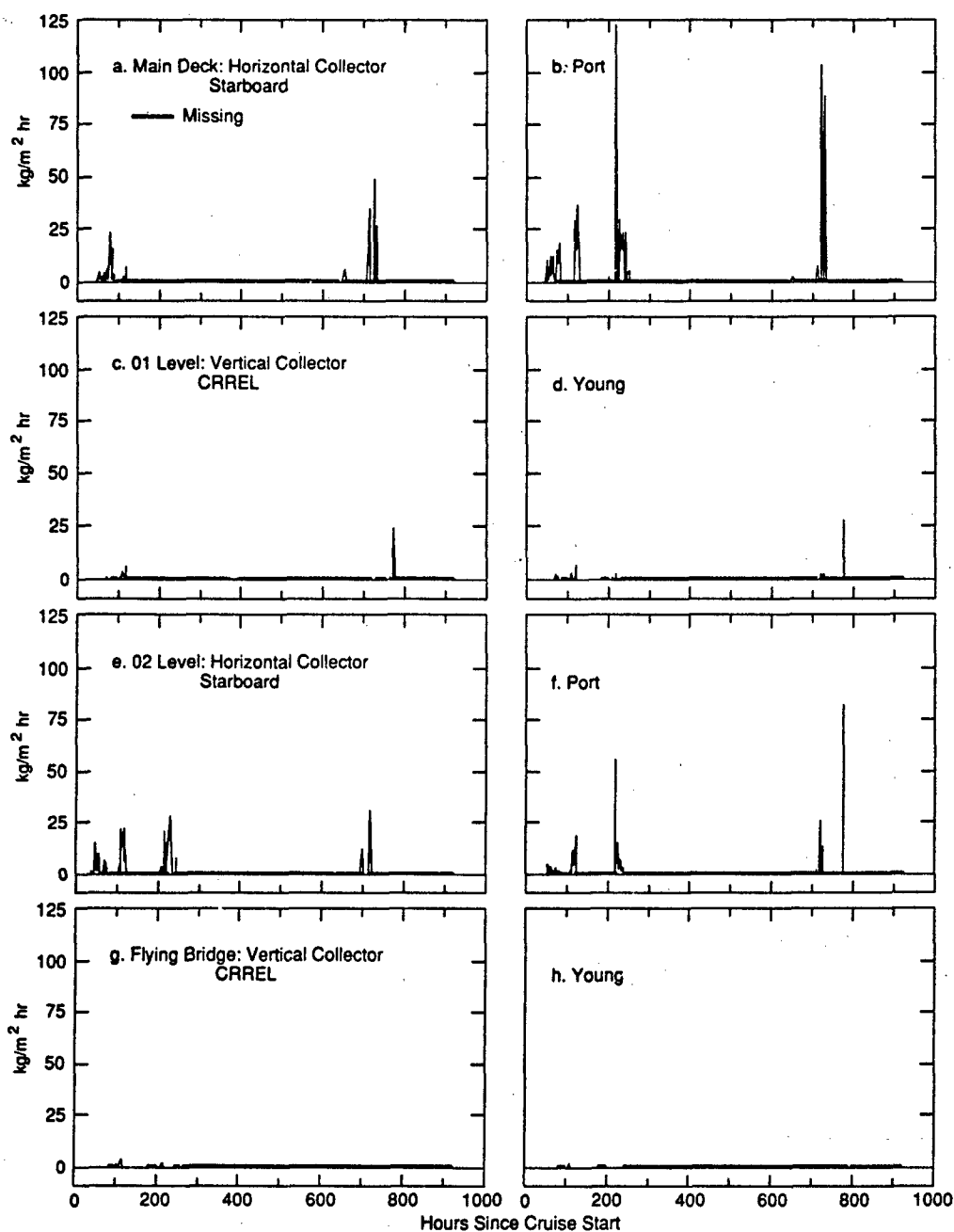


Figure 34. Hourly summaries of spray flux measurements through entire research cruise for all collectors.

being recorded at this time without serious noise problems in the 02 level starboard unit. A comparison of the shape of minute interval flux curves obtained during this period on the main deck port and 02 level starboard appears in Figure 35. The plot demonstrates that individual spray events show clearly in the 02 level record, whereas poly-

nomial smoothing of the main deck data produces an undulating curve that masks individual spray events. As a result, such smoothing not only masks the timing of spray events, but it also masks their magnitudes throughout the spraying period, making the absolute range of minute-to-minute fluxes unavailable.

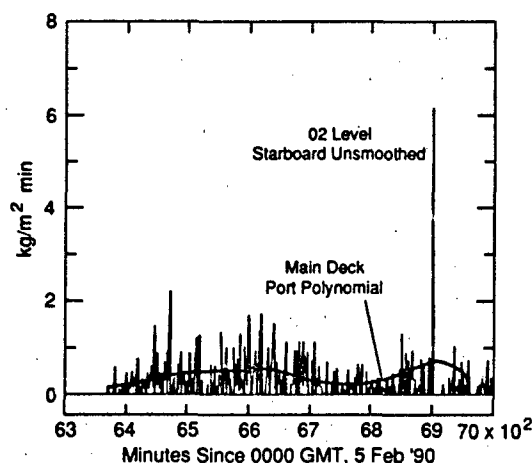


Figure 35. Comparison of minute fluxes on 9 February for the smoothed data from the CRREL main deck port unit and the unsmoothed data from the CRREL 02 level starboard unit.

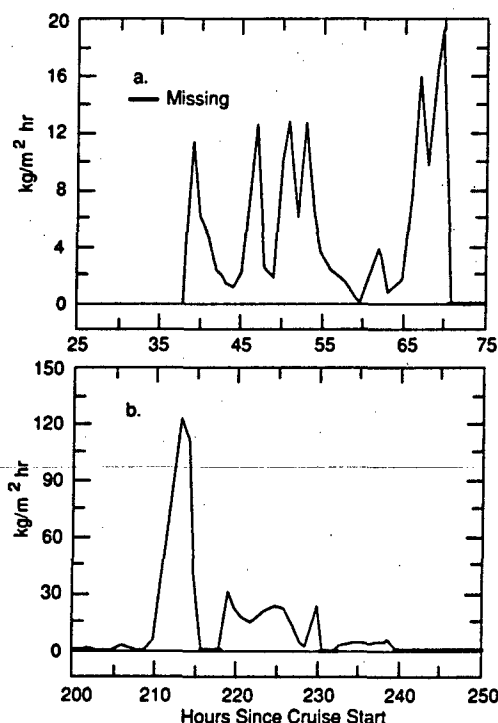


Figure 36. Hourly summaries of fluxes from the CRREL main deck port unit (a—unsmoothed data from 7 February; b—smoothed data from 14 February).

The differences between smoothed and unsmoothed minute fluxes are not as evident when summarized hourly. Figure 36a shows main deck port flux summarized hourly from minute fluxes that were not smoothed. Figure 36b shows main deck port flux summarized hourly from minute fluxes that were smoothed. The differences are not as dramatic as for minute summaries. Only minute interval flux measurements appear seriously compromised by smoothing because individual spray events are lost.

ICE DATA COLLECTED

There were several subfreezing periods during the Midgett research cruise. Only two produced sea spray ice on the ship superstructure. These events occurred from 22–25 February and from 10–14 March. Ice thickness was measured both automatically with the CRREL ultrasonic equipment by echolocation, and manually by removing samples from bulkheads and decks.

The CRREL instruments measured ice on vertical surfaces on the main deck and 02 level, and on horizontal surfaces on the 01 level and flying bridge. As with the capacitance-based horizontal snow measurements, data noise plagued the ultrasonic-based ice thickness measurement systems.

The ultrasonic systems measured ice thickness as a function of distance from the deck or bulkhead monitored. Decreasing distance represented increasing ice thickness, for the bulkhead or deck will "appear" closer as ice thickness increases. Though in this conceptual view the system operated much as a simple range-finder, refinement of the circuitry increased the resolution but somewhat complicated the process of converting the voltages output to the data loggers (Walsh et al. 1992). The equipment initially measured ice thickness at intervals of 15 minutes. The measurement interval was increased to 30 minutes late in the cruise to conserve battery and pneumatic power.

Plots of the February and March icing events illustrate the noise problems in the data. The plots were generated from ice thicknesses computed by post-processing of the voltages from the data loggers. Because of noise, thicknesses appeared in the data as negative as well as positive. Zero ice thickness on the plots was found by averaging all ice thicknesses measured during freezing events prior to 22 February. None of these early freezing events produced ice and, as a result, the mean ice thickness computed during these periods should have

been zero. If the thickness computed during these ice-free freezing periods was positive on a given unit, it was a bias that was subtracted from the later ice measurements. If the ice thickness from the ice-free freezing period was negative on a given unit, this value was added to the later ice thickness measurements. This was done for all six measurement locations, and negative values were changed to zero for plotting.

Though some noise was removed before plotting, sufficient noise remained to judge the data insufficiently reliable to verify the University of

Alberta model. However, the data can be compared to manual measurements for accuracy, and icing measured at several locations should yield similar patterns of growth and decay despite their different locations. To aid these analyses, polynomial fits were used to smooth the data where possible.

Icing on the main deck starboard bulkhead reached a maximum thickness of about 1.5 cm near minute 29,400 after fluctuating around 0.2 cm for several days, though with a small 0.3-cm peak near minute 26,500 (Fig. 37a). Similar patterns, though

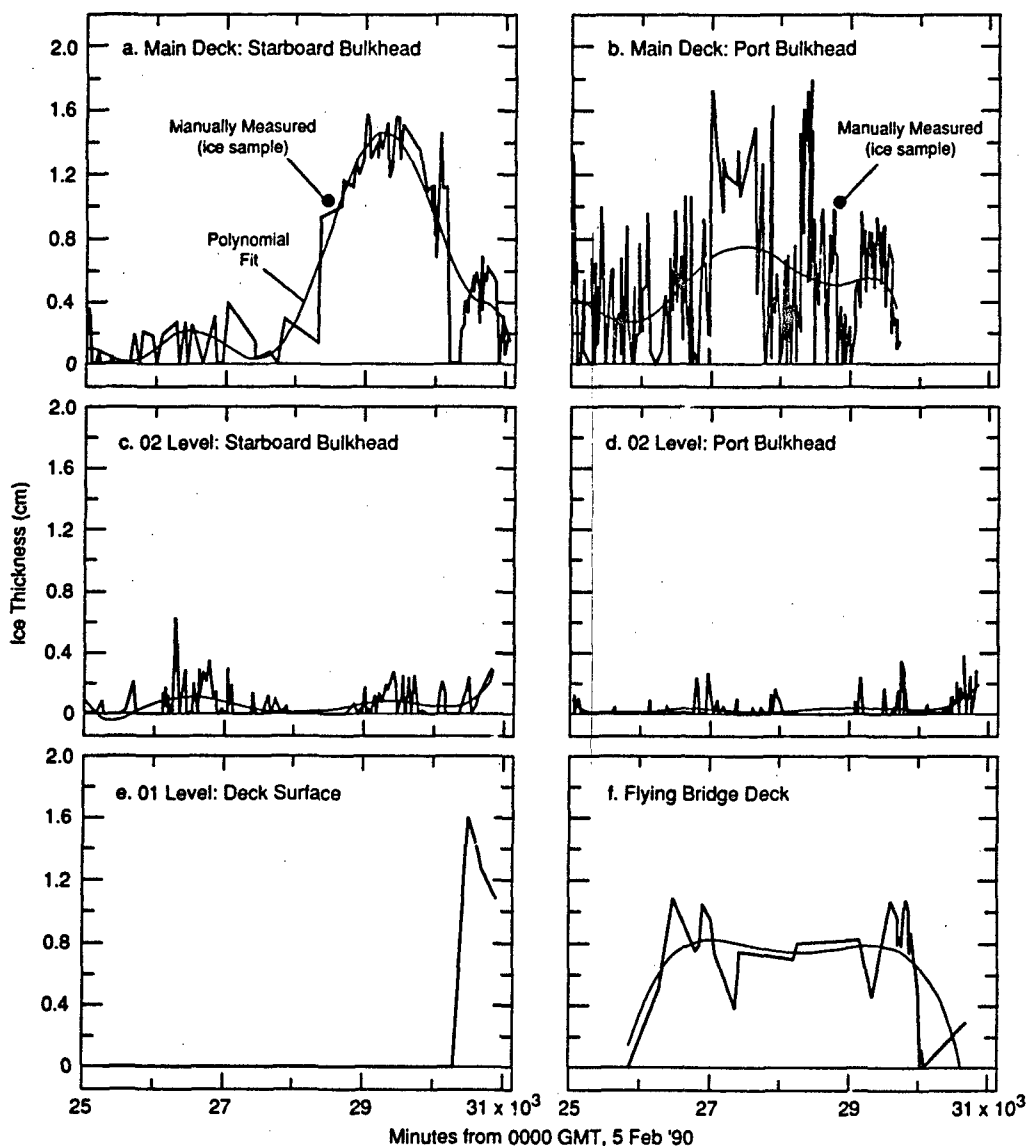


Figure 37. Ice thicknesses measured by CRREL units, 22-25 February.

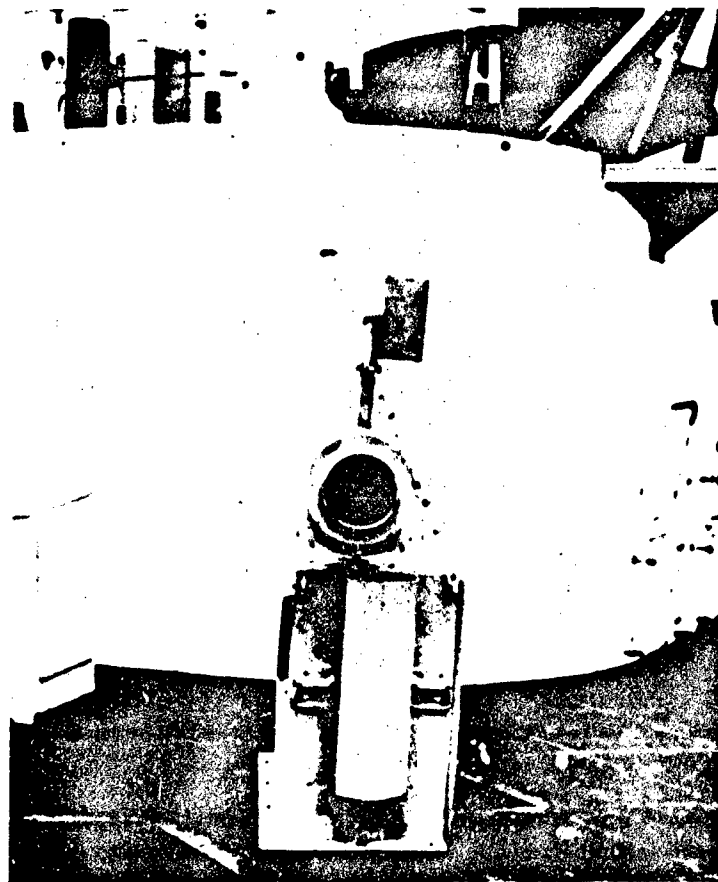


Figure 38. Location of ice thickness measurements by main deck port CRREL unit on curved bulkhead.

with small thicknesses, are observed on the 02 level starboard and port sides, with minor peaks near minutes 26,500 and 29,400 (Fig. 37c and d).

The main deck port, 01 level and flying bridge patterns do not compare as well to the main deck starboard and 02 level patterns (Fig. 37e-f). There is no obvious explanation for the differing main deck starboard and port patterns, except that main deck icing surfaces faced considerably different directions because they were located on curved structures (Fig. 38).

The 10-14 March icing event shows good agreement in pattern among the starboard and port main deck and 02 level units (Fig. 39a-d). Ice thicknesses peak near minutes 51,200, 52,500 and 53,600 at all four locations, and additionally at 48,600 and 49,400 at three of the locations. As in the February icing event, there is little correspondence in pattern between the 01 level and flying bridge locations, and between them and the main deck and 02 level locations (Fig. 39e and f).

The similar patterns illustrated by the main deck and 02 level units suggest that those four instruments were observing ice similarly, though with considerable noise. Differences between the bulkhead and deck icing patterns may be a result of true differences in temporal icing patterns attributable to differences in orientation and thermal properties. It may also be ascribable in part to the types of surfaces to which the ultrasonic range finders were echolocating.

There were many potential causes of noise in the automatically measured ice thickness data. Normal ship vibration and shocks from bow-wave impacts could have caused some vibration of the transducer arm. Shaking of the transducer mount by wind could have caused some of the noise. Though unlikely, reading of ice thickness at the same moment that spray is in flight between the sensor and the bulkhead could cause echoing from the droplets, and noise. In addition, multiple returns, or echoes, of the transducer pulses from the

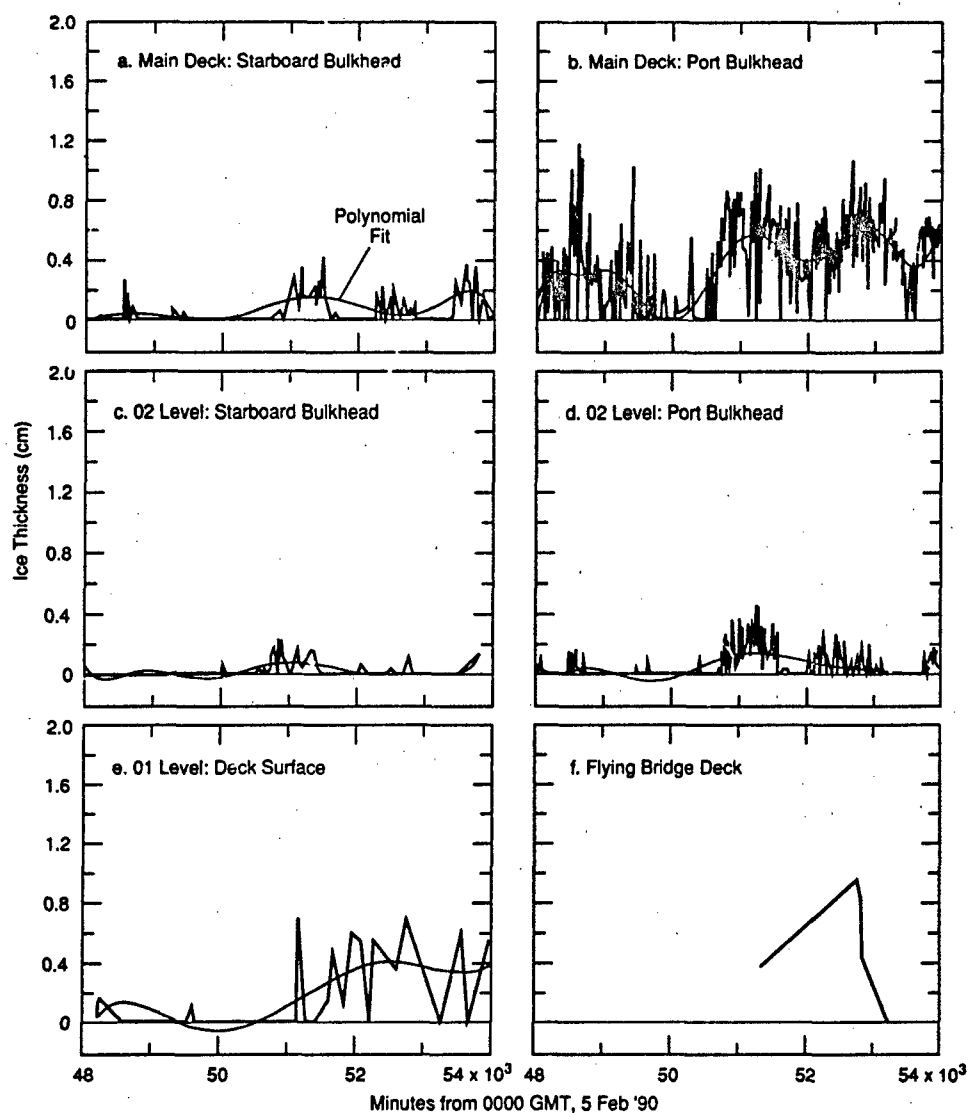


Figure 39. Ice thicknesses measured by CRREL units, 10-14 March.

bulkheads or decks may have caused some of the noise. As with any electronic device, electromagnetic interference, such as from ship radar or radio, could have contributed to the noise. All distances were corrected for the change in the speed of sound with air temperature.

Another potential cause of noise was the types of surfaces observed. The main deck units were aimed at a smooth, convexly curved bulkhead surface of about 1.6 m radius. The curvature of the bulkhead, coupled with an approximately 1-m² reflecting area because of beam spread, could have produced some noise. Vibration of the arm in addition could have made the situation worse. The 01 level and

flying bridge transducers were aimed at the decks, covered with nonskid. The rough relief of nonskid (about 5 mm), could have caused echo noise. If nonskid were a significant source of noise, and if sufficient ice had formed to completely cover the nonskid, the noise should have disappeared.

A further possible cause of noise was in the design of the ultrasonic ranging system circuitry. The data loggers were constructed to record the voltage from the ranging system at regular intervals of 15 to 30 minutes. The ultrasonic transducers were designed to operate independently of the data loggers—to "ping" the ice surface at regular intervals—and to hold the distance-indicating volt-

age until the next ping. If the data logger read the current output of the transducer system during a ping rather than between them when complete distances could be read, only a portion of a ping would be recorded, resulting in an incorrect distance being retrieved. We manually removed all such obvious occurrences from the ice thickness data prior to plotting, but less obvious cases that may have been missed by us could be a source of some of the noise.

One last problem the CRREL ice measurement system experienced was the automatic air temperature reading by the data logger. Air temperature was read from a thermocouple mounted on the data logger inside of the main instrument cabinet, and from a thermocouple mounted in the ultrasonic transducer housing located at the end of the transducer arm. The temperatures frequently did not agree with each other or with the ship's log. The temperature recorded from the arm was used to place the equipment into the ice or spray measurement modes. Error in temperature readings may have caused the equipment to enter spray or ice modes too early or too late. No serious problems have been encountered with either spray or ice data because of this, however. The cause of the disagreement is unknown, though a warning was

issued by CRREL technicians after the *Midgett* cruise that thermocouples attached to Campbell CR10 data loggers were providing incorrect temperatures.

Ice thickness was also manually measured. Despite requirements by the University of Alberta that samples be taken during icing, this was largely impossible because dangerous conditions kept the weather decks closed. Samples were taken, however, when the ship stopped or slowed for small boat operations or helicopter launches.

Two ice penetration probes, or sampling tools, were supplied by the University of Alberta and taken aboard the *Midgett* (Fig. 40) (Lozowski and Zakrzewski 1988).

The University of Alberta sampler was difficult to use and did not provide useful samples. The sampler was initially used on 24 February. Despite carefully following the university's instructions, we could not obtain samples of superstructure ice. The ice was of recent origin, the last accretions having been deposited either on 23 February, or the evening of 23–24 February, and it was very firm in its resistance to penetration, but not as hard as fresh water ice. The probe was pushed by hand, driven in a slide-hammer fashion with the extractor driver, and the end of the probe was driven with the

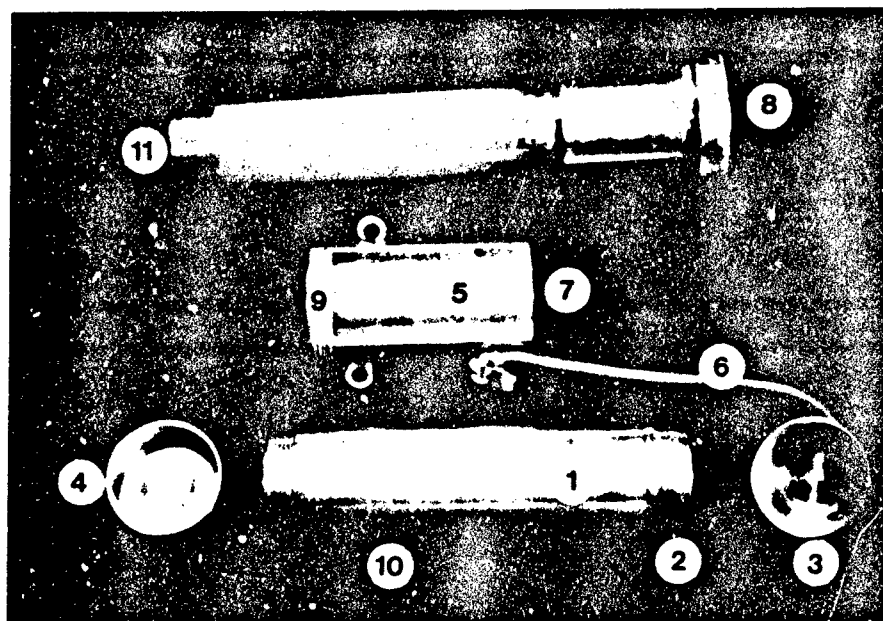


Figure 40. General view of the University of Alberta ice penetration probe (1 = extractor, 2 = knife, 3 and 4 = caps, 5 = extractor driver, 6 = cable, 7 = driver's front edge, 8 = hammer, 9 = screw at rear of driver, 10 = slots, 11 = handle-piston) (from Lozowski and Zakrzewski 1988).

hammer that was part of the tool. The probe entered the 3-cm-thick ice reluctantly, and samples removed were broken into pieces approximately 1 cm and smaller across. The broken samples did not serve the needs of the project because ice thickness and density could not be obtained from them.

The University of Alberta sampler design appears to have failed because inadequate clearance was provided by the cutting edge for the following sampling tube to penetrate the ice. The knife edge of the sampler tried to push ice aside unsuccessfully. Therefore, the sampling tube could not penetrate the ice without great resistance. Large threads cut on the outside of the sampling tube for the protective end caps further hampered penetration. In addition, the knife edge of the sampler was dulled when it struck the ship superstructure. A saw-toothed cutter with the same thickness as the attached barrel may have effectively cut through the ice and provided clearance for the barrel without crushing the sample.

A standard, stiff-blade putty knife, obtained from the ship store, served excellently as an alternate ice sampling tool. With the blade rotated 90° rather than parallel to the ice surface, and tilted 45°, a shallow groove was cut into the ice by the edge of the blade. Several additional passes were usually required to cut through the thicknesses (1–5 cm) accreted on the *Midgett*. Once a groove was cut to the superstructure surface around the portion of ice to be removed, the knife blade was forced under the ice edge, and the entire sample slab lifted. Samples occasionally fractured or broke if they were too large and firmly attached to the superstructure. However, slabs of ice up to 15 cm per side were removed without damage using these techniques. Ice integrity was preserved and the ice surface undamaged.

Ice sample location, thickness and temperature were noted. The sample thickness and location were measured on the ship deck with a retractable carpenter's rule. The temperature was measured with the digital Quick thermocouple mini-thermometer. The thermometer had a resolution of 1°C, though the probe frequently could not be fully inserted into the firm ice and the readings may reflect in part the air temperature.

Approximately 23 ice samples were removed from the *Midgett* and returned to CRREL. Upon removal from the superstructure, samples were placed into marked plastic freezer bags, sealed and stored for the remainder of the cruise in the *Midgett's* main food locker at a temperature of about -18°C. The ice was packed in dry ice and returned to

CRREL by air freight after the *Midgett* returned to Alameda, California. At CRREL, sample thickness, density and salinity were measured, and photographs were made of the ice structure in unpolarized and polarized light.

Table 8. Spray tape log.

Tape no.	Date	Time (GM.)
1	5 Feb	2248-1537
2	6 Feb	1537-1737
3	6 Feb	1737-1940
4	6 Feb	1946-2146
5	6-7 Feb	2213-0025
6	7 Feb	0030-0230
7	7 Feb	1540-1930
8	7 Feb	1940-2140
9	7-8 Feb	2210-0010
10	8 Feb	0020-
11	9 Feb	1626-1826
12	9 Feb	1855-2055
13	9 Feb	2100-2300
14	9 Feb	2316-
15	10 Feb	1615-1815
16	10 Feb	1820-2025
17	10 Feb	2040-2250
18	10-11 Feb	2250-0050
19	11 Feb	1720-1920
20	11 Feb	1930-2130
21	11-12 Feb	2240-0040
22	12 Feb	1830-2030
23	12 Feb	2040-2240
24	13 Feb	1740-1940
25	13 Feb	2025-2225
26	13-14 Feb	2242-0120
27	14 Feb	1700-1930
28	14 Feb	1935-2130
29	14 Feb	2140-2348
30	14-15 Feb	2348-0150
31	15 Feb	1738-1942
32	15 Feb	1946-2155
33	20 Feb	1734-1940
34	20 Feb	1949-2145
35	20 Feb	2145-2350
36	21 Feb	0000-0200
37	21 Feb	1918-2125
38	21 Feb	2125-
39	22 Feb	2235-
40	23 Feb	0315-
41	23 Feb	1805-
42	3 Mar	1835-
43	6 Mar	0230-
44	6 Mar	0440-
45	6 Mar	1740-
46	6 Mar	1946-
47	6 Mar	2145-
48	7 Mar	0000-
49	9 Mar (high spd run)	0100-
50	11 Mar	2120-
51	12 Mar	2300-
52	13 Mar	0200-
53	13 Mar	0500

VIDEO IMAGES OF BOW SPRAY

Video images of bow spray were made for the entire cruise during daylight hours, primarily when bow spray was being lofted on the bulwarks. Taping of bow-wave interaction during no-spray conditions would have been useful for establishing spray thresholds. This was not done to conserve the supply of tapes for spraying conditions.

Two cameras, for redundancy and for a slight difference in perspective, were mounted on the flying bridge deck and aimed at the bow. The starboard camera viewed the main deck from the bow to near the forward bulkhead, whereas the port camera was aimed a few degrees higher to view the main deck forward of the main hatch to the horizon. Since neither camera failed, cameras were switched electronically to provide the best view of the spray conditions. All recording was done at the fastest recorder speed to produce the highest quality images. The videotapes were

stamped with GMT date and time for each second in a corner of each frame (Fig. 41).

Camera housings were water-tight and equipped with internal heaters, window heaters, washers and wipers. The window and internal heaters were absolutely necessary for reliable operation. Occasionally, however, the viewing window fogged when sunlight entered and heated the housing. Also, the cameras had difficulty restarting in cold weather if turned off. More powerful window and internal heaters would provide better operation, especially in very cold weather (temperatures never dropped below -14°C during the *Midgett* cruise). Windshield wipers were used frequently, often automatically timed. The windshield washer was seldom used.

Approximately 100 hours of spray recordings were made during the *Midgett* cruise (Table 8). All recordings are of high quality, except when the ship sailed into direct sunlight, which tended to wash out images. All images are usable for measur-

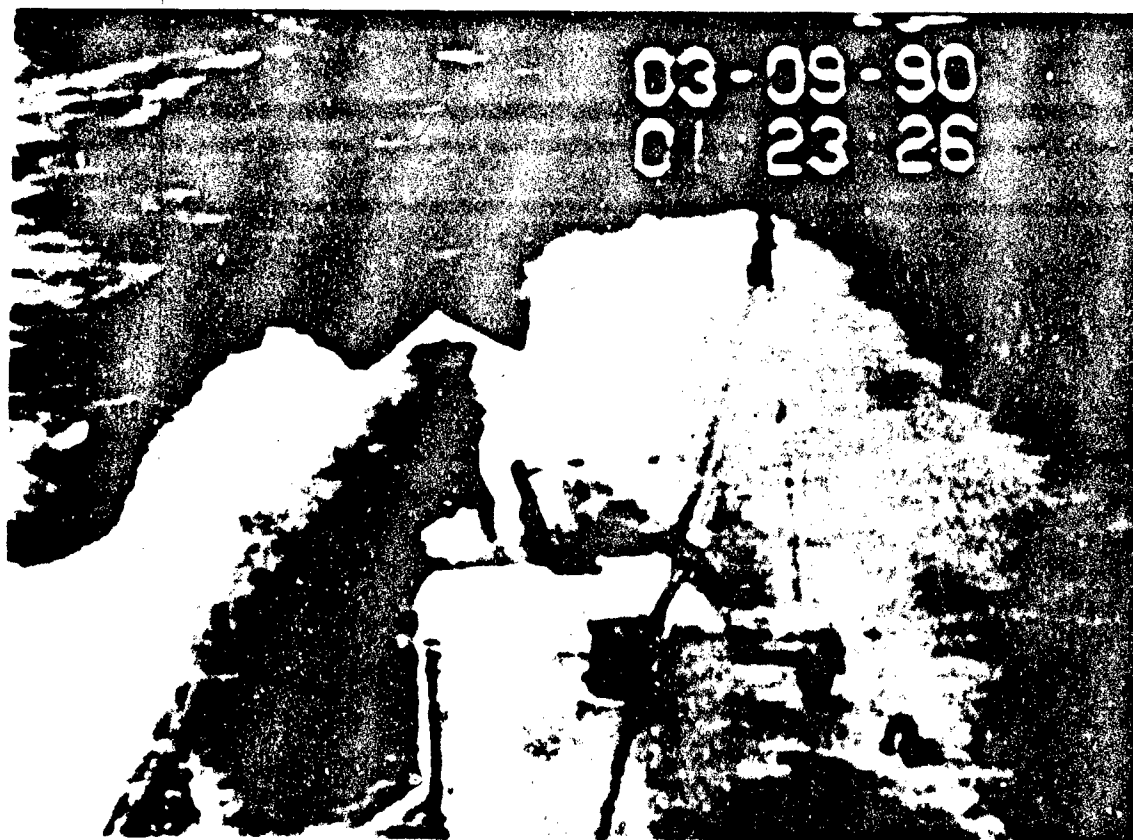


Figure 41. Video frame of USCGC *Midgett*'s bow during spray event from flying bridge video camera.

ing spray frequency and spray location, and most are usable for measuring spray height. Some of the highest spray clouds were observed during the high-speed run on 9 March. At this time the highest spray clouds frequently disappeared over the top of the camera and thus were not recorded well. Minor problems occurred during the high-speed run when high g-forces (greater than 1 g) reduced tape-to-recorder-head contact. Though images were not lost because of this problem, image quality was reduced for periods of several seconds. Special provisions were not made to facilitate acquisition of data from the tapes except for the time-stamp fixed on each frame by the recorder.

SPRAY DROPLET SIZE SPECTRA MEASUREMENTS

Spray droplet size was measured with the universal flying particle camera, a stroboscopic video

system, on the *Midgett* (Itagaki 1966, 1990, Itagaki and Ryerson 1990). The University of Alberta had provided a manually operated device to intercept spray drops based upon stain patterns created by dried drops on filter paper (Lozowski and Zakrzewski 1988). Though the manual system may have provided usable data, it required personnel to function on weather decks during dangerous conditions. In addition, a representative spectral profile could not be obtained with the University of Alberta device because overwetting would cause droplet stains to overlap. We used the stroboscopic camera instead.

Approximately 38 hours of drop spectra videotapes were made (Table 9). All tapes had date-time stamps in GMT. There are about 2 hours of actual spraying on the 38 hours of tape because when spraying began, we did not know if clouds would reach the 02 level where the camera was located.

The resolution of the tapes is high (Fig. 42). Drops can be viewed each 0.033 second during a spray

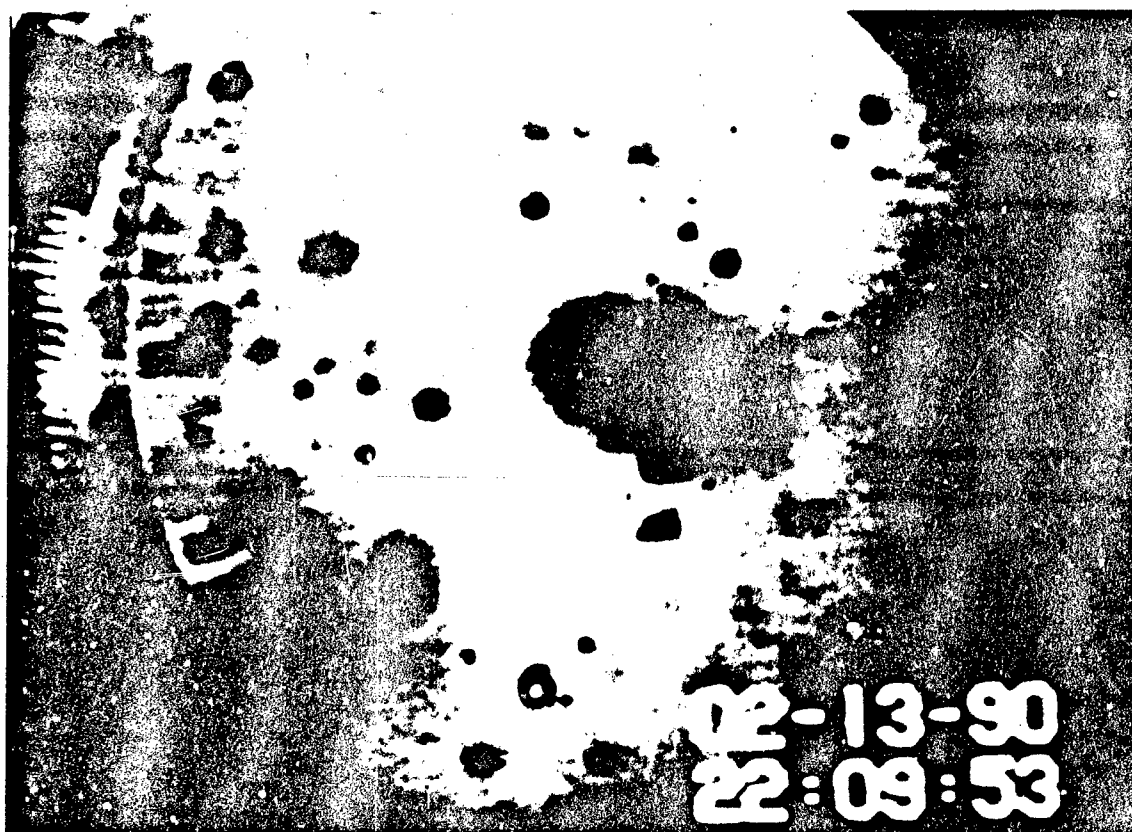


Figure 42. Video frame of spray cloud droplets from flying particle camera.

event (one view for each frame, 1/30 second). Drop sizes are resolvable to a minimum diameter of 0.1 mm. Measurement accuracy is about $\pm 3 \mu\text{m}$. Typical natural cloud droplets are about 0.02 mm in diameter, and typical raindrops are larger than 0.2 mm in diameter.

Though digital image processing can be used to extract the spray droplet diameter, only manual

methods have been used. One difficulty is deciding which droplets to measure in a video frame. Only droplets in focus, within the depth-of-field of the close-focus video camera, can be accurately measured and counted for making volume flux calculations (Fig. 42). This problem has not been completely resolved for automated measurements, and makes manual measurements difficult.

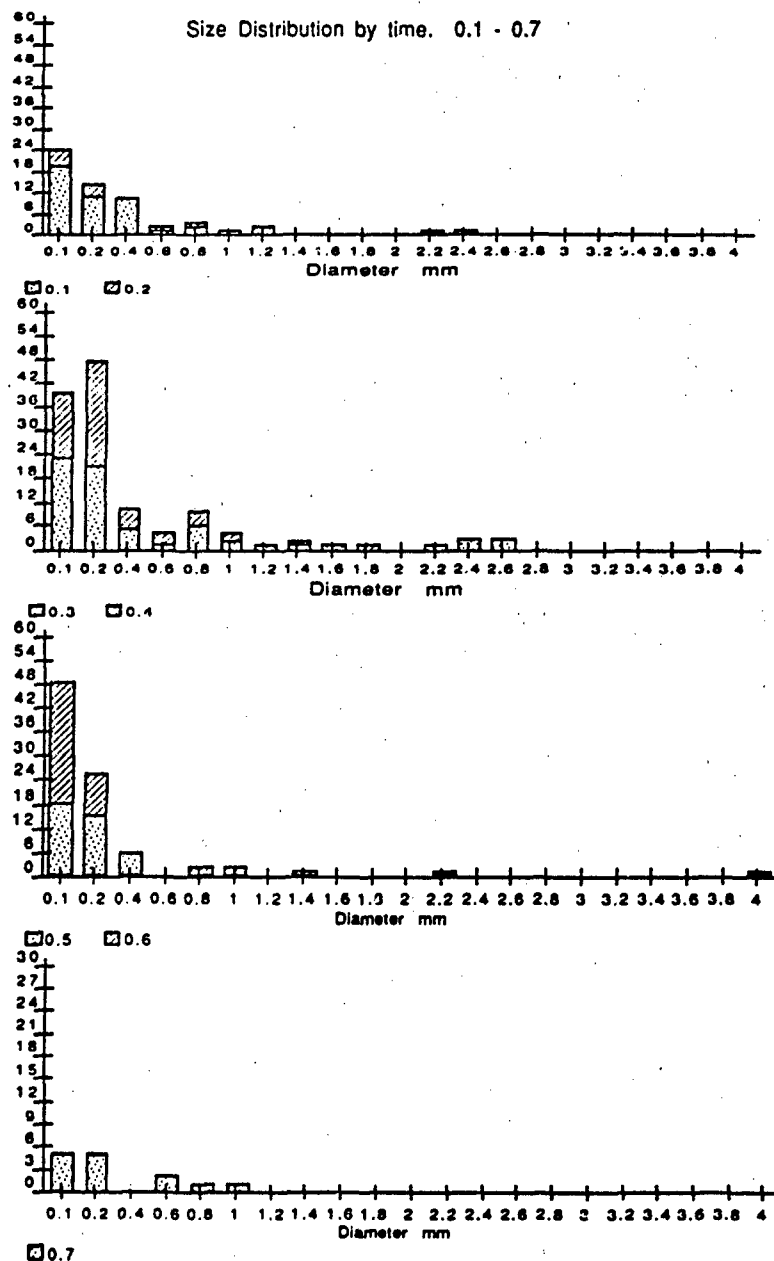


Figure 43. Range of droplet sizes observed during one spray event on 9 March 1990 during the high speed run (from Itagaki and Ryerson 1990).

Table 9. Universal flying particle camera tapes.

Tape no.	Date	Times (GMT)
1	7 Feb	1856-2139
2	7-9 Feb	2210-1941
3	11-13 Feb	0000-2148
4	13-14 Feb	2200-2244
5	14-15 Feb	2250-0054
6	15 Feb	1917-1952
7	20 Feb	1739-1940
8	20 Feb	1945-2045
9	20-21 Feb	2345-0145
10	21 Feb	1919-2123
11	23 Feb	0320-0459
11A	23 Feb	1805-2009
12	5 Mar	2250-0056
13	6 Mar	0230-0430
14	6 Mar	0440-0645
15	6 Mar	1740-1940
16	6 Mar	2013-2150
17	6 Mar	2150-2354
18	6-7 Mar	2356-0200
19	9 Mar	0100-0300

Preliminary analysis of one spray cloud indicates the range of drop sizes observable over time within a spray cloud (Itagaki and Ryerson 1990) (Fig. 43). With this system it is clear that the spectrum of droplet sizes with time within a spray cloud can be resolved. Most important for modeling, the mass flux per drop diameter range can be determined.

SEAWATER TEMPERATURE AND SALINITY MEASUREMENTS

Seawater temperature and salinity were acquired manually and from shipboard measurements at engine coolant intakes and occasional bathythermograph recordings. Sea water temperature obtained from the engine coolant intakes was recorded every hour by the quartermasters in the Weather Observation Log. Bathythermograph recordings were made 12 times, and CRREL personnel observed water temperature and salinity 14 times during the cruise.

Water temperatures and salinities were needed only for icing conditions. Water temperature and salinity have no effect upon spray generation, but have a potentially large effect upon superstructure ice formation (Zakrzewski 1987, Jessup 1985). The hourly readings of water temperature from engine coolant intakes in the weather log were claimed by the quartermasters to be too high by about 2.8°C. Bathythermograph readings were made at times of ship need, and did not correspond to research needs. Water temperature and salinity were mea-

sured by CRREL personnel when icing was expected, and when safety allowed such measurements during daylight hours, at low ship speeds and with accessible weather decks.

Readings made by CRREL personnel are judged accurate. Water temperature was sampled immediately after the retrieval bucket was placed on deck. The mean interval between water retrieval and temperature measurement was less than 3 minutes. The digital thermometer probe was deeply immersed in the water volume, about 1 L, and did not touch the container sides. Salinity was measured hours after the water sample was taken because the LabComp salinometer was most accurate near room temperature. Salinity readings were accurate to ± 1 ppt.*

DISCUSSION

The USCGC *Midgett* research cruise was a valuable experience because of the unique data acquired, despite the problems encountered while doing such work at sea. We made measurements during the cruise that were never made before, to our knowledge, and none had ever been systematically made on a ship this large. Spray has also not been recorded as continuously on video to acquire spray frequency, location along the bulwarks and height as aboard the *Midgett*. To our knowledge, drop spectra have not been measured aboard a ship before with automated equipment. Though spot measurements have been made, data collected aboard the *Midgett* will allow drop spectra to be determined in a variety of spray conditions through individual spray clouds.

Though ice thickness measurements have been made many times before on smaller ships, and occasionally on ships as large as the *Midgett*, measurements of ice quality are uncommon. Zakrzewski** has measured ice salinity, density and sponginess on small research trawlers, and Tabata et al. (1968) and Golubev (1972) have measured ice structure on fishing vessels. Measurements made aboard *Midgett* are a useful contribution to scientific understanding of superstructure ice characteristics.

Serious problems were encountered in the measurement of spray flux and ice thickness aboard the

*Personal communication with LabComp Instruments, 1990.

**Personal communication with N.P. Zakrzewski, University of Alberta, 1989.

Midgett. Horizontal spray collectors and ice thickness measurement devices produced noisy data. Water temperature and salinity could only be measured intermittently. The anemometer failed because of salt water intrusion into its electrical connections. Many instrument design and data acquisition lessons were learned, though solutions are still not available for several of the problems encountered.

The overall goal of the research cruise was to measure phenomena useful to understanding the process of ship icing, to measure data useful for calibrating and verifying the University of Alberta advanced icing model, and to measure data truly representative of the environment experienced. Some of the first two goals were accomplished. It is still not clear whether the last goal was accomplished. True accomplishment of the last goal would require a separate research cruise dedicated only to that end, with many experimental, specially designed and constructed instruments. It is doubtful whether any measured data are truly representative of their environment.

There were a considerable number of successes on the *Midgett* cruise. Most of the spray instrumentation operated continuously throughout the cruise. Data downloading and battery and air tank recharging were easily accomplished. Video images of bow spray were virtually all excellent, with no serious equipment failures. The droplet spectrum camera system worked flawlessly, except for a window wiper that occasionally slipped. Water temperature and salinity measurements produced useful data, though too infrequently. A large number of ice samples was obtained and successfully returned and analyzed at CRREL without loss. Finally, the research project did not appear to hinder operations aboard the *Midgett*, and appeared to draw no complaints from officers or crew. The entire ship's company was helpful and cooperative throughout the research cruise.

The *Midgett* research cruise demonstrated to CRREL, and perhaps to the Navy, the problems of conducting this type of research aboard a ship. Though many anticipated problems were dealt with successfully, this report shows that many remain to be solved.

FUTURE RESEARCH SUGGESTIONS

Equipment developed by CRREL to monitor spray flux and ice accretion on the USCGC *Midgett*

demonstrated sufficiently serious problems for us to recommend against its use again without alteration. The true cause of noise in the data from the horizontal spray units should be further investigated and discovered, or a completely different approach tried. The horizontal units could be tested in a vertical spray accretion mode (without the horizontal collectors) aboard a ship to determine if the problem is in some manner created by the horizontal collector, or if the problem is the capacitance system, with noise accentuated by the larger volumes of spray intercepted by the horizontal collector system. Since the Young collectors operated without apparent problems in the vertical accretion mode, they could be fitted with small horizontal collectors to determine if they are stable, even though they are capacitance systems. Other approaches could be tested to determine water depth, such as floats.

The rain gauge approach could be abandoned, and totally different technologies tested. Particulate volume counters, such as the Aerometrics (1987) Laser Doppler Velocimeter and Particle Analyzer, could be used to measure spray flux and drop spectra. This unit is sufficiently small to minimally disrupt natural air flow, and can detect small flux changes.

Ice thickness may be measured in other ways as well. Rosemount ice detectors may be useful for measuring ice accretion rate, rather than total thickness. Other devices, such as the Campbell ultrasonic snow depth measurement system, may operate successfully even though the technology was similar to CRREL's. Other approaches could perhaps be based upon laser range-finding technology.

Future projects should rely more heavily upon connections to the ship for power supply and data transmission. Stand-alone units, such as CRREL's, have the obvious advantages of not requiring penetration of ship bulkheads and decks for cables, and the concomitant reduction in hazards created by cables on decks. The disadvantages of self-contained systems are several, however. Self-contained power supplies, such as batteries and air tanks, are heavy and bulky, stressing decks with high weight and moments. In addition, self-contained systems are more costly to design and construct because of the greater complexity and need for complete automation. Systems drawing power from the ship can be small, light, relatively simple in design and heated. This reduces impact on the ship, maintains equipment at uniform temperatures, allows heating of things that might normally freeze, and in some ways increases flexibility in

design and location of instruments. In addition, real-time monitoring of data acquisition can alert researchers to instrument problems for possible corrections before too many data are lost.

Meteorological measurements, and sea water temperature and salinity measurements should, if possible, be automated. Sea water measurements can be made in all weather conditions at all times with an automated system. Weather measurements can be made with less error because researchers have direct control over equipment quality and exposure, and are not subject to the variable skill levels of quartermasters.

CONCLUSIONS

In general, much of the data collected on the USCGC *Midgett*, such as the video records of spray cloud characteristics, most weather data and the manual ice thickness measurements, are useful and accurate. The automated vertical spray measurements from both the CRREL and Young instruments contained little noise and were generally usable as measured without need for smoothing. The horizontal spray measurements had considerable noise problems, however, and had to be smoothed or selectively discarded to obtain useful information. The automated ice thickness measurements were not reliable and had to be discarded.

The cruise served the purposes of the overall project well, despite the instrument problems. Sufficient data were obtained to allow the University of Alberta to calibrate the advanced icing model to the U.S. Coast Guard Cutter *Midgett*. Lessons were learned by both CRREL and the Navy about conducting research at sea and designing instrumentation for extreme environmental conditions. The failures and successes of this field program provide valuable lessons and examples of how to properly conduct similar research at sea in the future.

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APPENDIX A: BRIEF LOG OF FEBRUARY-MARCH 1990
MIDGETT RESEARCH CRUISE ACTIVITIES

6 February—rolling sea, some spray on deck—perhaps to the 01 level. Recorded spray on video.

8 February—Indian Island, Washington. Downloaded data loggers. 1 cm water in NWS rain gauges. Spray collector boxes beginning to rust.

9 February—much spray on forecastle, but none aft of gun mount. NWS rain gauge 3.6 cm at the 01 level. Flying bridge 1.6 cm rain.

10 February—off south Alaska coast. No spray because moving slowly. Calm seas.

12 February—high speed run on turbines—29 kn—calm winds and seas about 1 m. No spray.

13 February—rolling seas—1.2–1.5 m. SW winds. 4°C. Spurious results on 02 level gauges. Checked consistency of units for measuring known volume. Later in day 5–6 kn into 3–4.6 m head sea. Much spray—some hitting bridge windows. Starboard camera wiper not working on automatic mode.

14 February—strong gale—wind streaks on waves, 45-kn winds. 7.6-m waves. NWS gauge 1.8 cm on 01 level. Flying bridge, no spray in gauge.

16 February—docked at Kodiak—NWS gauge at 01 level, 6 mm water. Problems with starboard main deck unit—cycles erratically and dumped air. Flying bridge—no water in NWS gauge. Tested ability of each unit to measure known volume.

19 February—leave Kodiak—low seas, NE winds—headed into storm north of warm front—headed to Unimak Pass. Removed 01 level gauge aperture.

20 February—experimented with ship course and speeds to determine spray thresholds. Sailing at 255° with seas at 240°. Sailed at 10–12 kn. Changed course 15° intervals. Reduced speed to 8 kn to see spray reduction. Spray threshold at these seas, speeds and headings about 8–9 kn; 3.6 cm of spray fall in 01 level NWS gauge by 1623. Wiper fails on universal flying particle camera. Measure trace in flying bridge NWS gauge.

21 February—Ship stopped in Bering Sea for boardings.

22 February—air temperature -11°C, wind 24 kn, very raw conditions. Problems on ship due to cold—pipes—davit circuit breaker—small boat engine. Starboard spray unit erratic. Port unit not working because air valve not opened. Instruments in ice mode—0.6 cm ice on forecastle. About 160 km north of Unimak Pass and about 160 km south of ice edge. Seas very calm and in high pressure. Much sea smoke yesterday and today. Heaviest smoke in ship wakes. Hoarfrost reported on fantail rails. Temperature dropped to -14°C at night. Water temperature 1.5°C. Salinity 33.4 ppt. Rode helicopter over the ice edge. Fishing trawler heavily icing at high speed with much spray. Some rime ice occurring on *Midgett*. Steam fog runs in strips over ocean—perhaps due to upwelling. Cutter beginning to cold soak. Heat first turned on today. Some spray ice on fantail and helicopter deck on 21 and 22 February.

23 February—12 km south of ice edge, 25–30-kn winds. Spray hitting 01 level bulkhead during night of 22–23 February. Water temperature 0.8°C. Helicopter blades have 0.5 cm ice, port side of helicopter has 0.3 cm ice. Helicopter deck has some ice. Ice measurements made on deck—and samples taken. Deck forward of 5-in. gun ice is about 2.6 cm thick, ice temperature -9.3°C; deck in front of bulkhead ice thickness 2.6 cm, temperature -6.6°C; front face of bulkhead ice thickness 1.1 cm, temperature about -8°C. Water temperature -0.3°C. Ice harder on vertical DTRC panels, perhaps because they are colder. Alberta ice sampler did not work well, crushes and damages ice samples. Putty knife produces better intact slab samples. Sea chest temperature under 5-in. gun 1.5°C. Bucket water temperature 2.1°C. Sea chest temperature lower—2 m deep.

25 February—sea water salinity 33.5 ppt from bucket over side, sea chest 33.4 ppt. Main deck spray units problems—starboard unit readings fluctuate, port unit frozen—did not drain—air not turned on at Kodiak. 90% of ice on deck spray ice, rest snow. Spin drift maybe 20% of ice total. Sides of hull had thin skin of ice. Side decks and fantail spindrift, and spray from natural waves oversteepened by bow wave, causing breaking. Wind carries it to ship. 0.6 to 1.2 cm rime on parts of ship—especially lines. Much sea smoke—probable cause of rime.

26 February—put flying bridge tank in starboard box. Boardings and helicopter operations all day—calm. Seas pick up and air warms in afternoon.

28 February—rewired flying bridge tank. Ice thickness measurements on flying bridge fluctuate heavily—may be due to EMI, nonskid roughness, or changes in air temperature. No spray.

3 March—water temperature at Dutch Harbor 2.7°C. Went out 50 miles and made spray on forecastle and along side decks and perhaps fantail. Headed back to Dutch Harbor.

4 March—at Dutch Harbor yet. Salinity at Dutch Harbor 32.6 ppt. 2.7°C water temperature.

5 March—Dutch Harbor area, but ready to leave for Adak. Photographed snow on decks and helicopter. No spray ice on ship, only snow. Spray generated by bow wave along sides of ship.

6 March—headed to Adak—15–16 kn. Making much spray. Varied course all day to observe effects on spraying. Performance as expected. Beam to head seas. Varied headings 60°. Seas diminished through day because of dying seas and in lee of islands frequently.

8 March—leaving Adak to doughnut hole. 1.2-m waves, 2.4-m swells, 20–25-kn winds from northwest. Ship heeling to starboard. Taking little spray. Instability aloft and frequent heavy snow squalls. Little spray hitting ship on lee, but more on windward, as expected. Deck wetted on sides each 10 minutes or so. Almost constant light spray—spin drift? 01 Level NWS gauge after Dutch Harbor, 4.3 cm water. Flying bridge NWS gauge, trace of water. Some may be due to snow. 1500–1700 Captain allowed use of turbines. Ran at about 20–22 kn on three different courses—excellent spraying. Seas

3.4 m, winds on port beam 25 kn. Spraying quite dramatic—many wettings of bridge area.

10 March—very cold—7-kn speed—2-m seas. No spraying.

11 March—seawater temperature 1.8°C, 0.6 cm ice on forecastle behind gun and forward of main hatch—nonskid just covered. Some snow collecting on weather decks—only thin skin. Air temperature -5°C. 3.5-kn ship speed. Water temperature decreases to 1.7°C. Salinity 34.4 ppt. Much steam fog, about 30 miles from ice edge. Icing beginning on decks. Almost 1.2 cm of ice on side weather decks. Air temperature drops to about -13°C. Rime ice forming on life lines and helicopter tie downs. Wind about 15 kn. Water temperature down to 1.6°C. Salinity 34.5 ppt. Water temperature decreasing to 1.3°C. Ice increasing on forecastle—1.2 cm forward of gun, ice increasing aft of gun. Evening—following seas and wind. Moving at 15 kn. Air temperature in low teens. Light snowfall incorporated into ice.

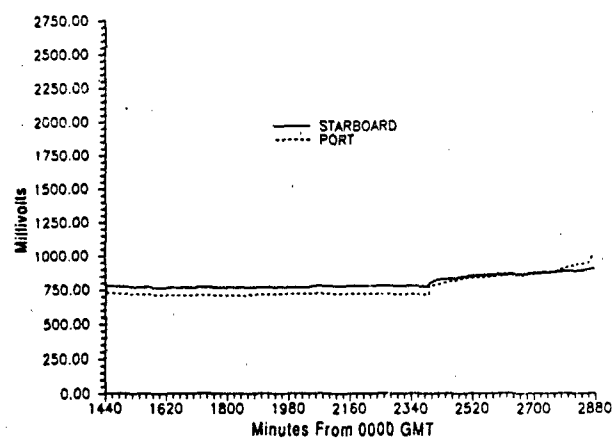
12 March—water temperature 1.9°C. Sampling ice from forecastle, gun and rail during active icing. Headed to Dutch Harbor to drop helicopter. Heavy seas—perhaps 5-m swells, ship speed about 16 kn, much spray, air temperature -2°C, water temperature about 2.3°C, salinity 33.9 ppt, windy.

13 March—0.6 to 1.2 cm ice on helicopter. Heavier icing on port side of ship. Water temperature 3.2°C. Measured wind speeds with hand-held anemometer near horizontal spray units to correlate with anemometers on mast. 01 Level NWS gauge has 0.9 cm of slush. Wind speeds 25–30 kn. No water in flying bridge rain gauge.

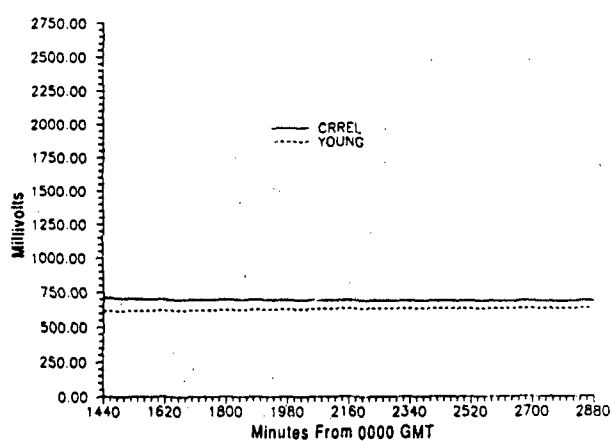
15 March—docked in Adak mid-morning.

APPENDIX B: SPRAY COLLECTOR TANK VOLTAGES FOR SIX CRREL AND TWO YOUNG COLLECTORS DURING THE MIDGETT RESEARCH CRUISE

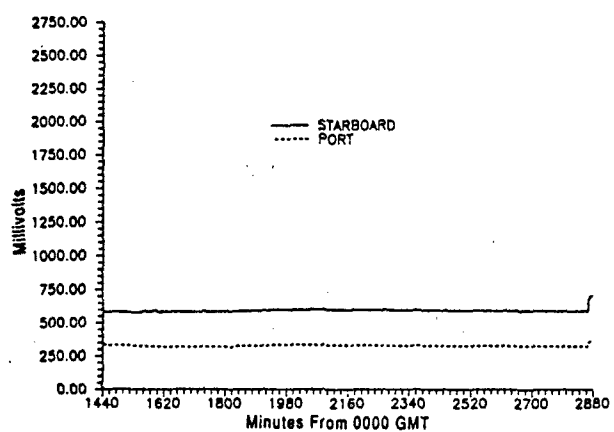
All plots begin at 0000 hours.



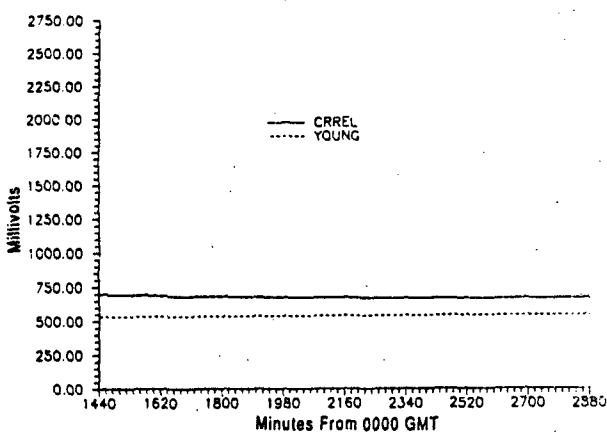
a. Main deck units, horizontal.



b. 01 Level units, vertical.

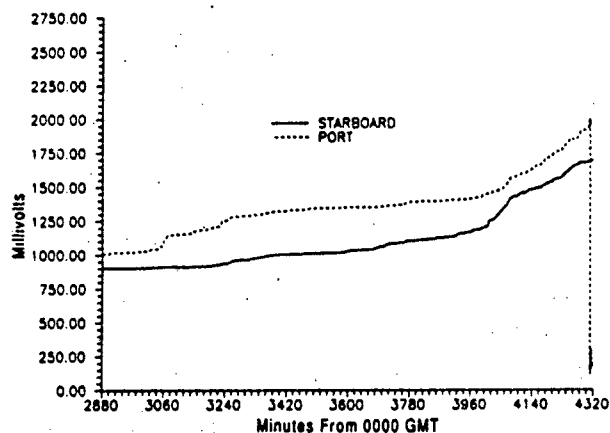


c. 02 Level units, horizontal.

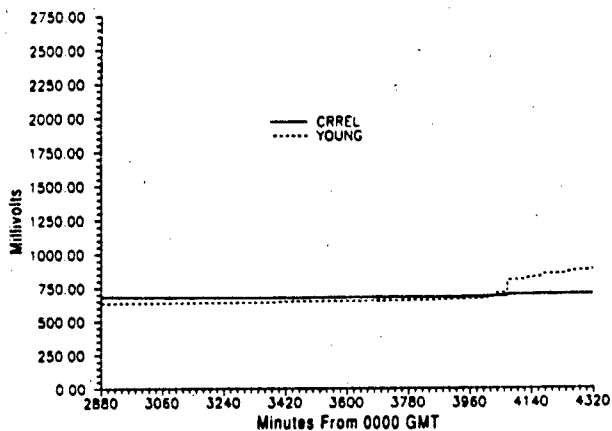


d. Flying bridge units, vertical.

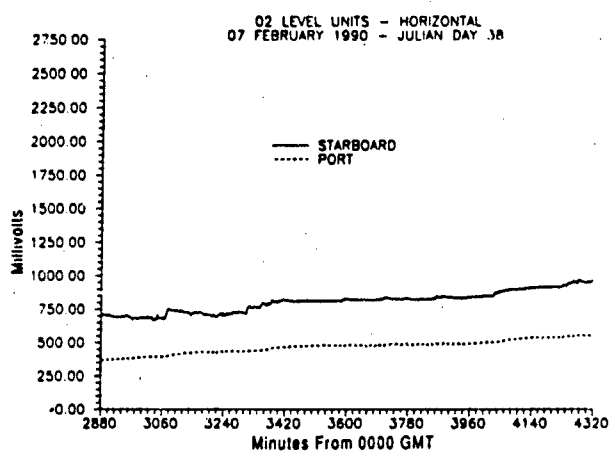
Figure B1. 6 February 1990.



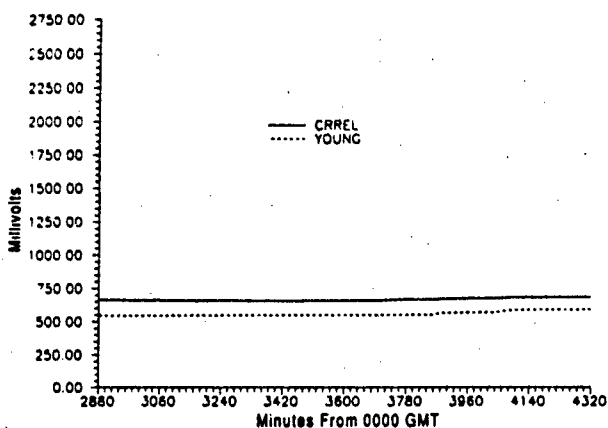
a. Main deck units, horizontal.



b. 01 Level units, vertical.

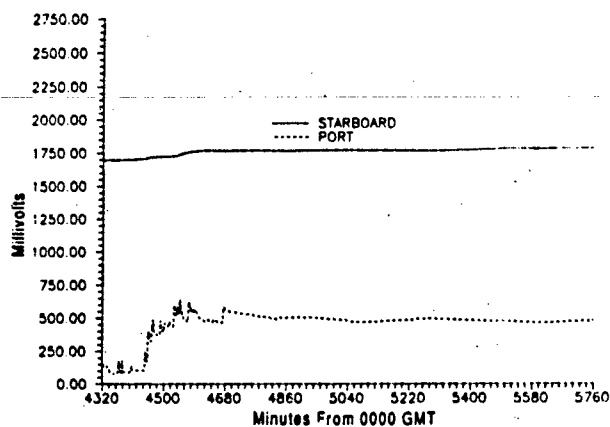


c. 02 Level units, horizontal.

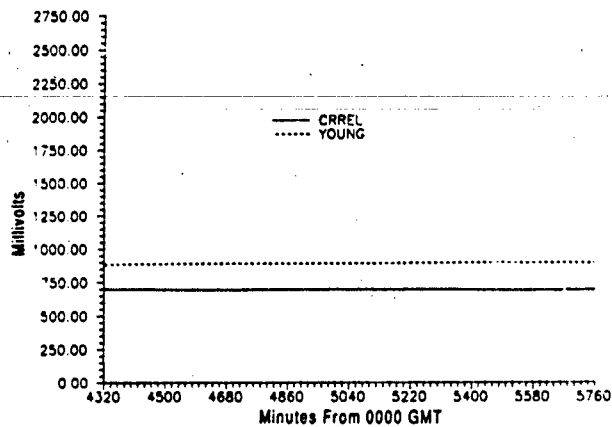


d. Flying bridge units, vertical.

Figure B2. 7 February 1990.

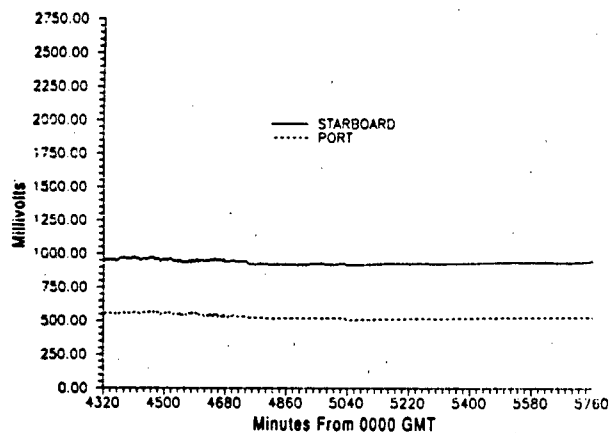


a. Main deck units, horizontal.

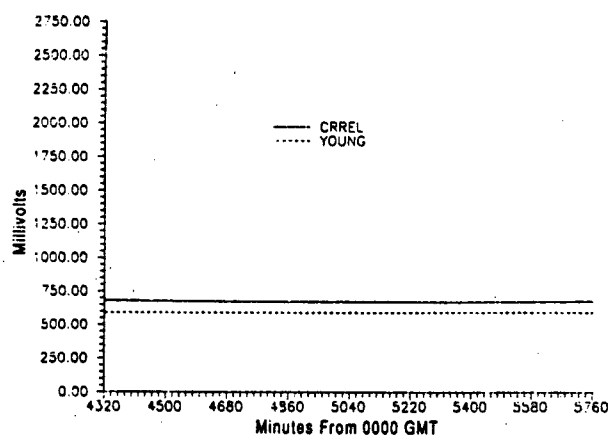


b. 01 Level units, vertical.

Figure B3. 8 February 1990.

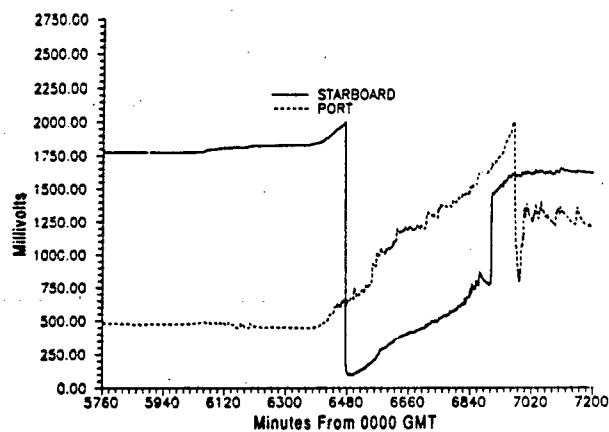


c. 02 Level units, horizontal.

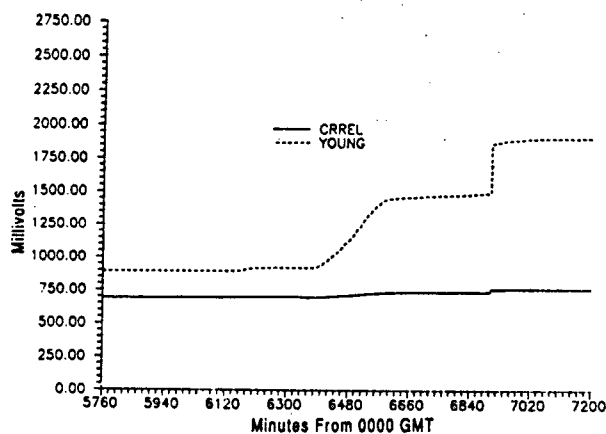


d. Flying bridge units, vertical.

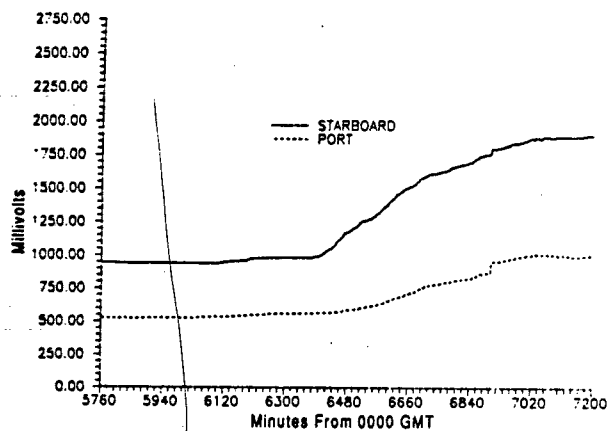
Figure B3 (cont'd). 8 February 1990.



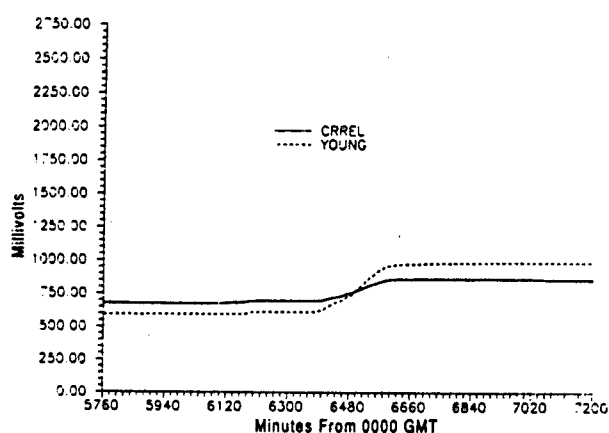
a. Main deck units, horizontal.



b. 01 Level units, vertical.

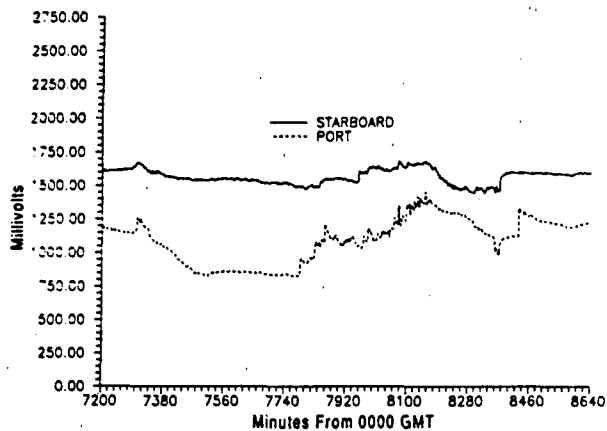


c. 02 Level units, horizontal.

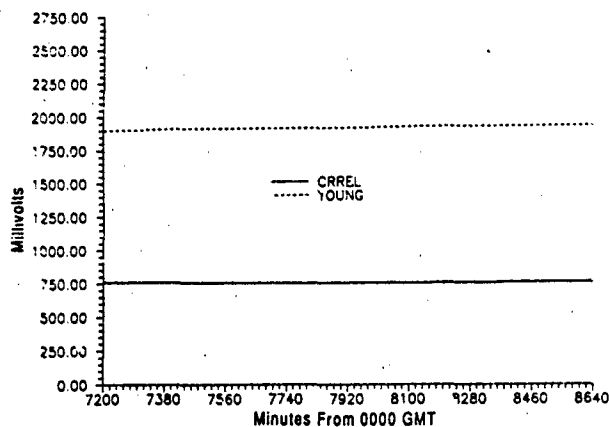


d. Flying bridge units, vertical.

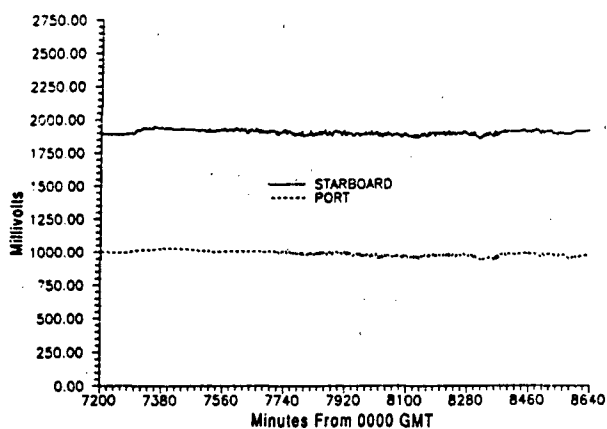
Figure B4. 9 February 1990.



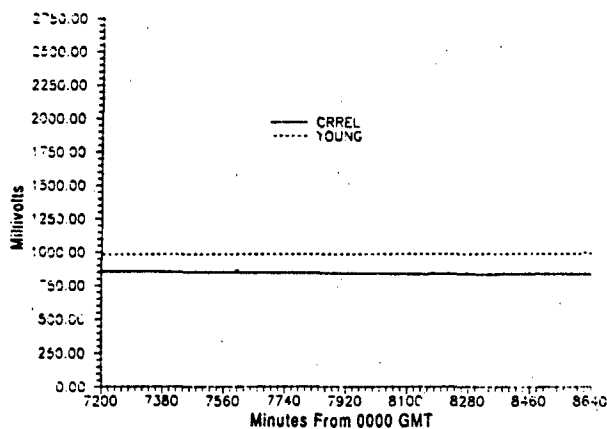
a. Main deck units, horizontal.



b. 01 Level units, vertical.

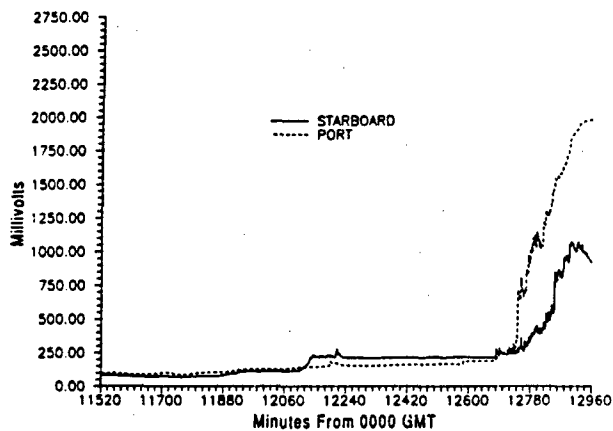


c. 02 Level units, horizontal.

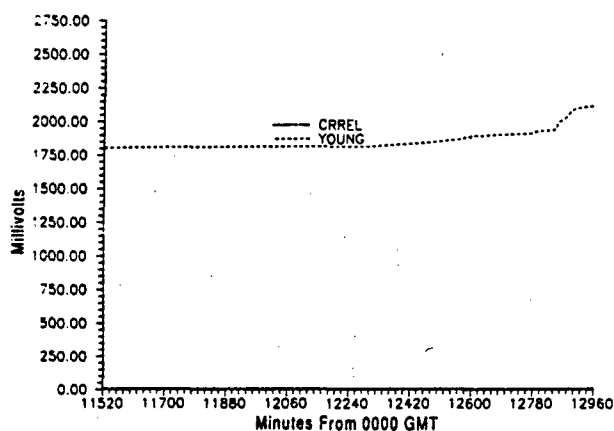


d. Flying bridge units, vertical.

Figure B5. 10 February 1990.

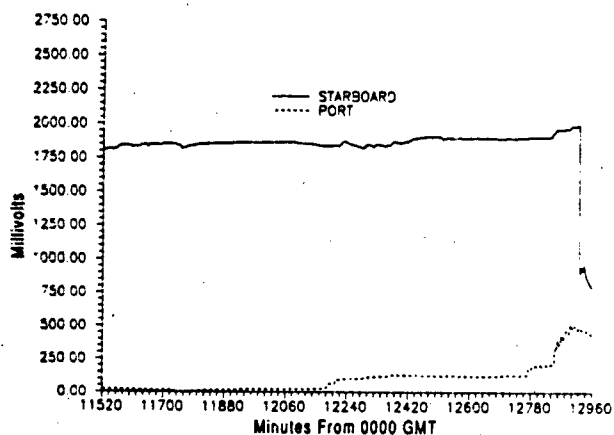


a. Main deck units, horizontal.

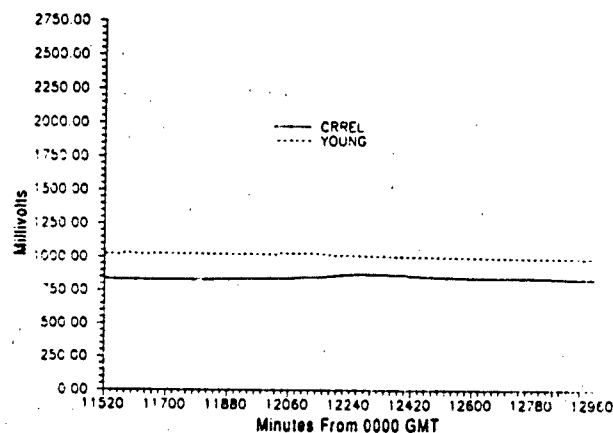


b. 01 Level units, vertical.

Figure B6. 13 February 1990.

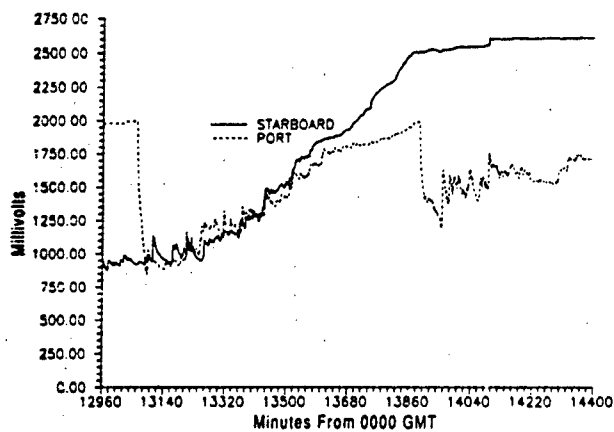


c. 02 Level units, horizontal.

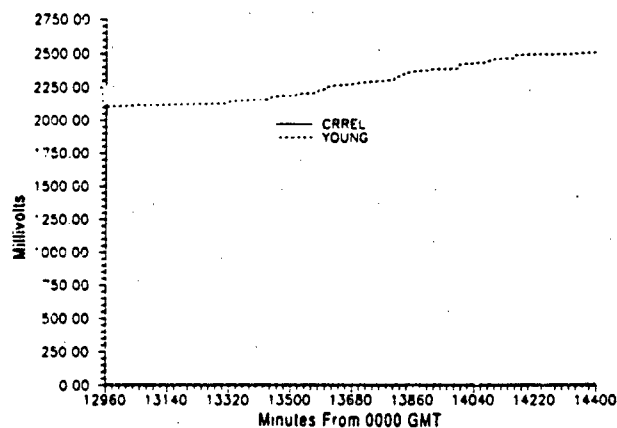


d. Flying bridge units, vertical.

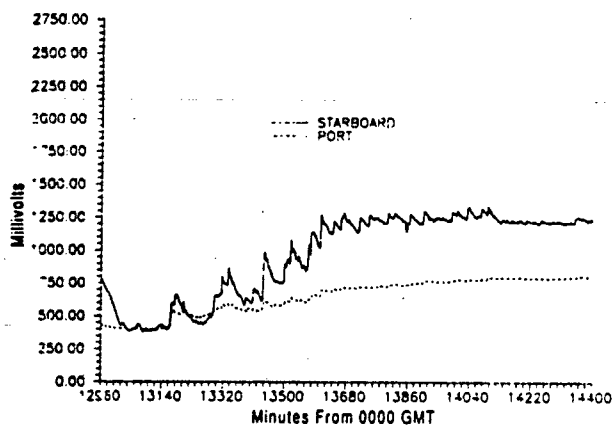
Figure B6 (cont'd). 13 February 1990.



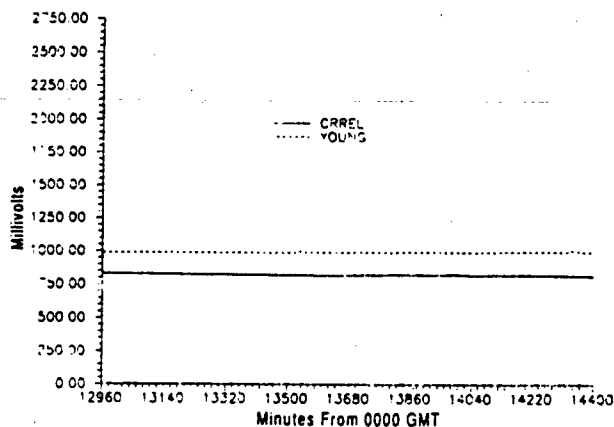
a. Main deck units, horizontal.



b. 01 Level units, vertical.

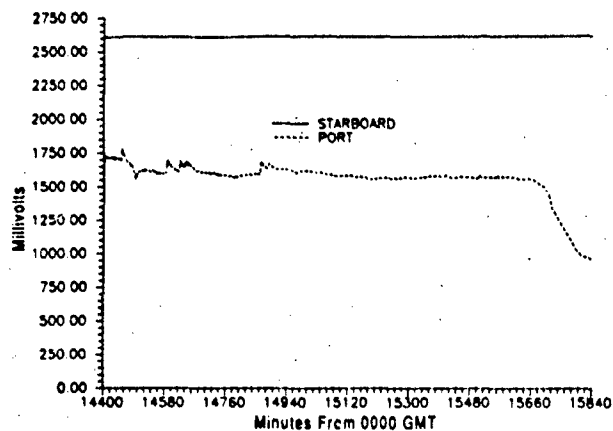


c. 02 Level units, horizontal.

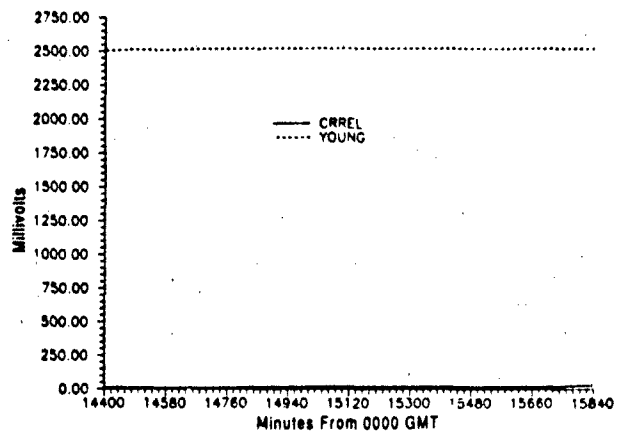


d. Flying bridge units, vertical.

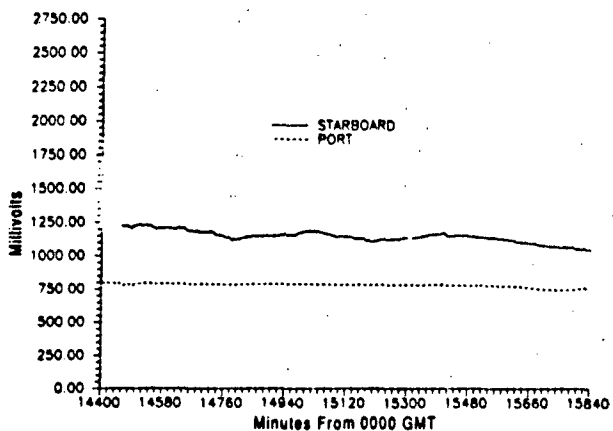
Figure B7. 14 February 1990.



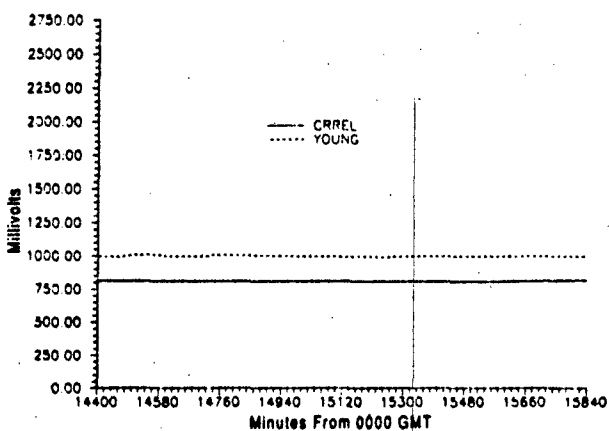
a. Main deck units, horizontal.



b. 01 Level units, vertical.

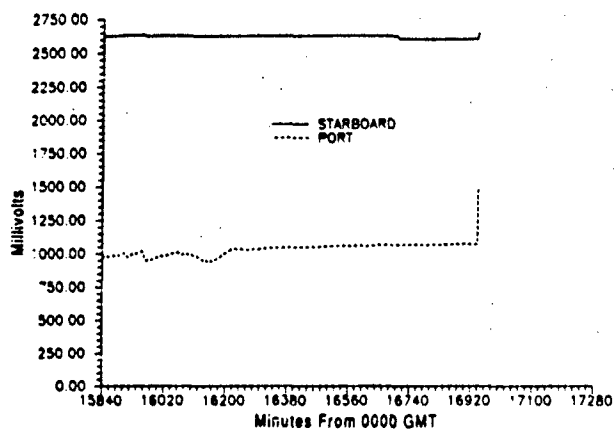


c. 02 Level units, horizontal.

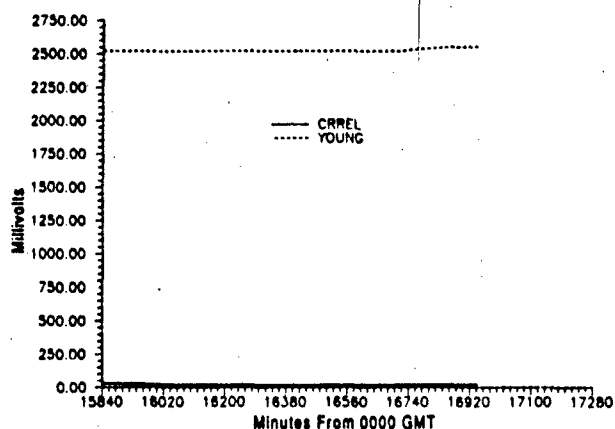


d. Flying bridge units, vertical.

Figure B8. 15 February 1990.

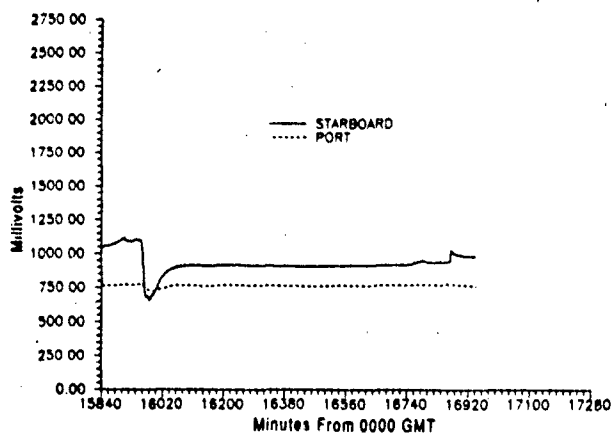


a. Main deck units, horizontal.

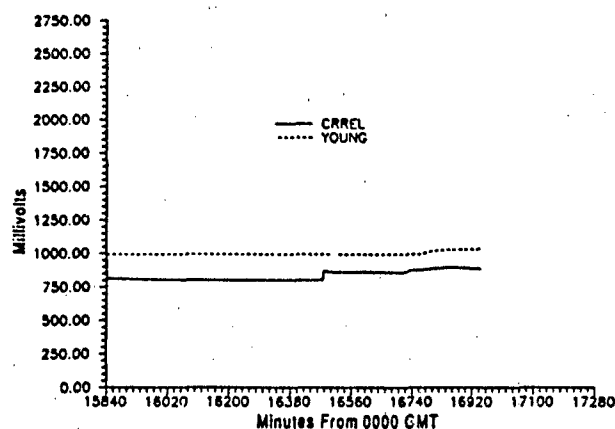


b. 01 Level units, vertical.

Figure B9. 16 February 1990.

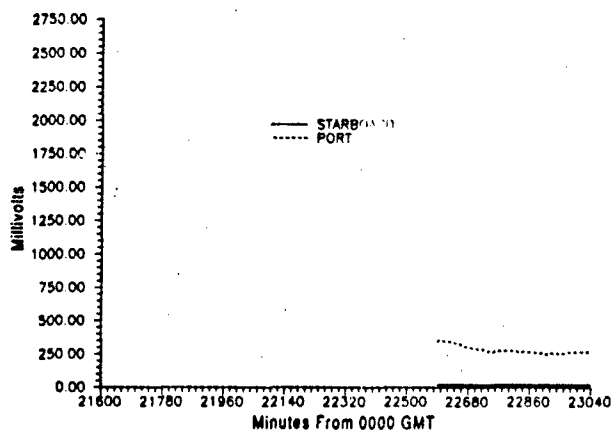


c. 02 Level units, horizontal.

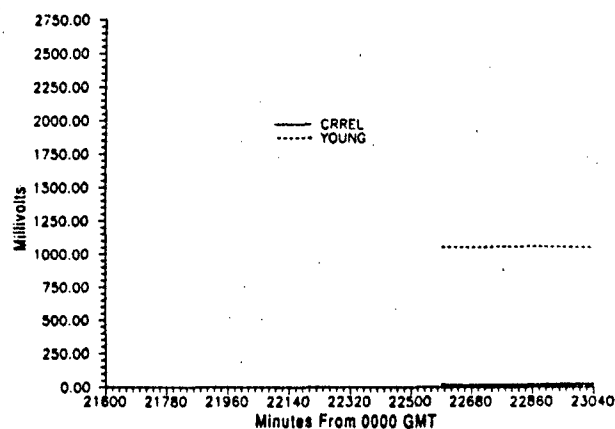


d. Flying bridge units, vertical.

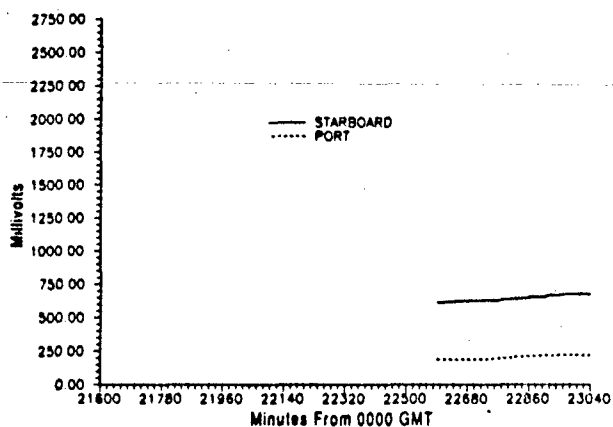
Figure B9 (cont'd). 16 February 1990.



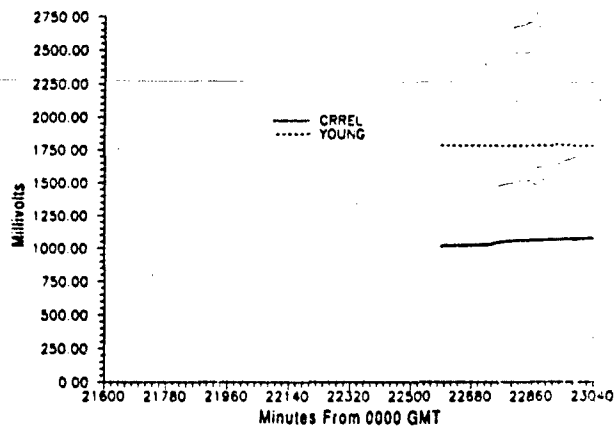
a. Main deck units, horizontal.



b. 01 Level units, vertical.

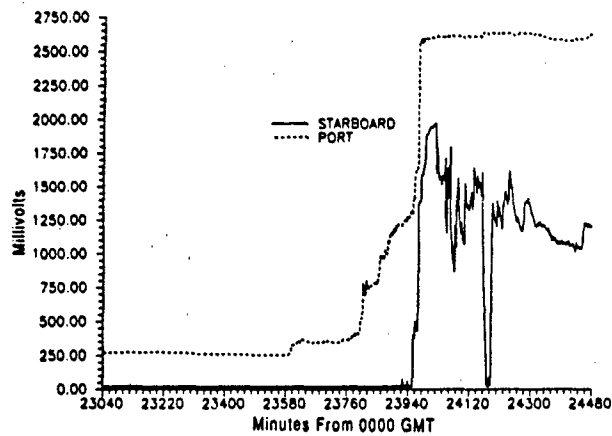


c. 02 Level units, horizontal.

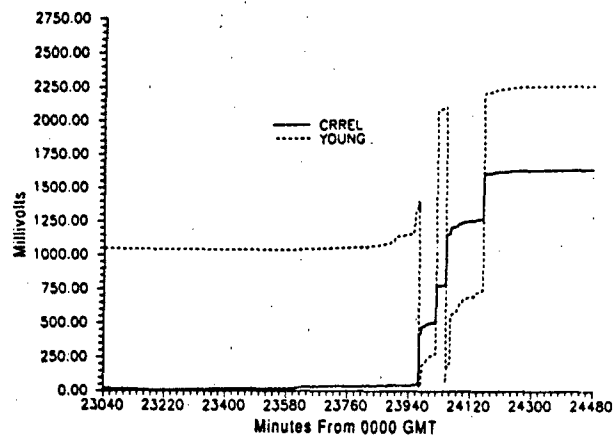


d. Flying bridge units, vertical.

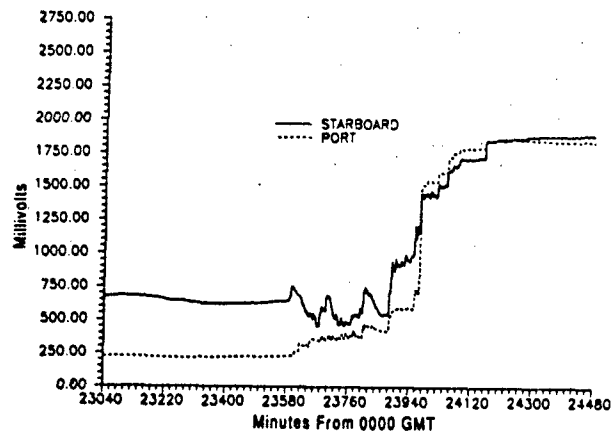
Figure B10. 20 February 1990.



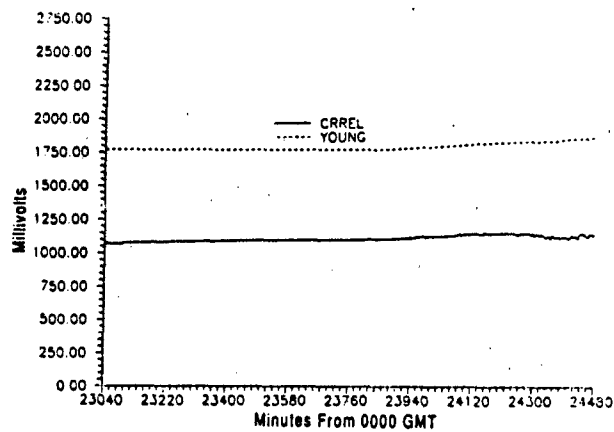
a. Main deck units, horizontal.



b. 01 Level units, vertical.

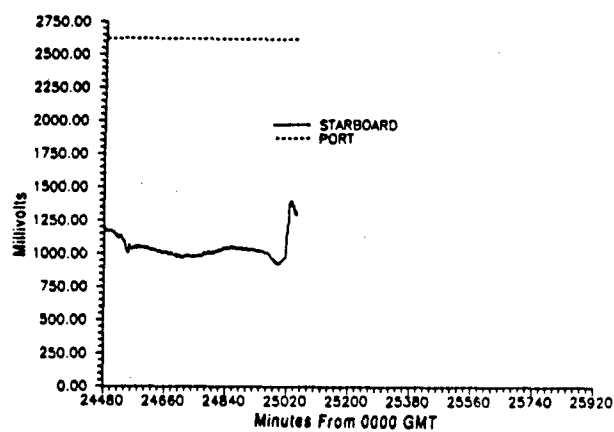


c. 02 Level units, horizontal.

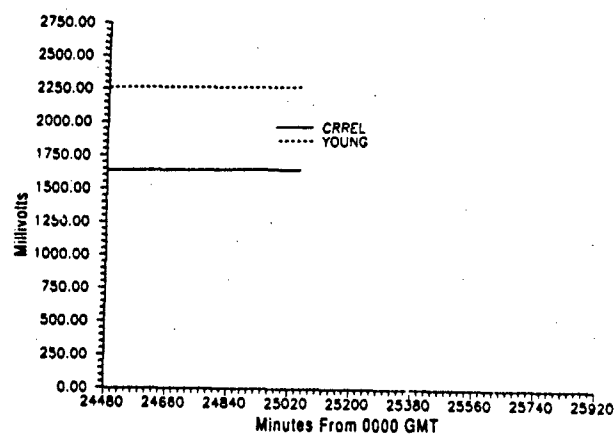


d. Flying bridge units, vertical.

Figure B11. 21 February 1990.

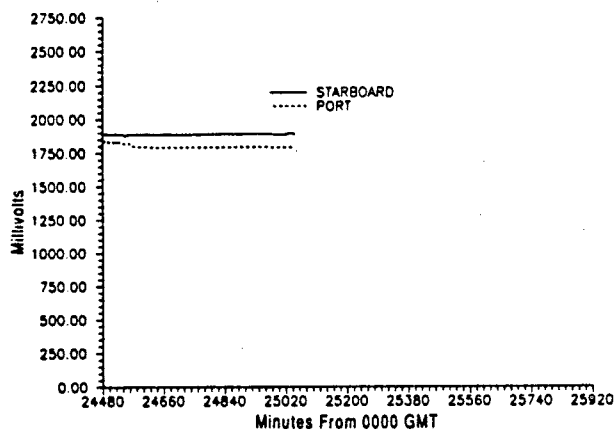


a. Main deck units, horizontal.

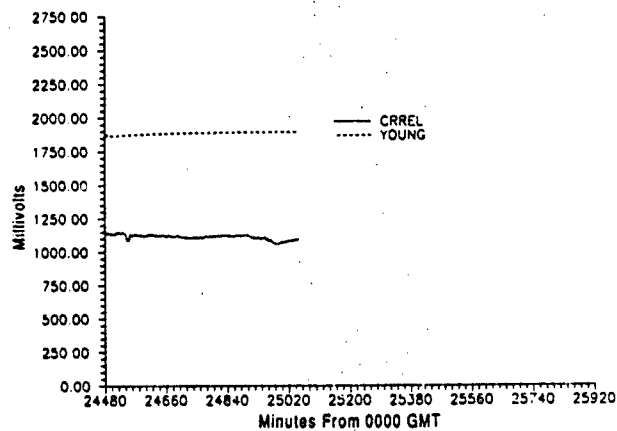


b. 01 Level units, vertical.

Figure B12. 22 February 1990.

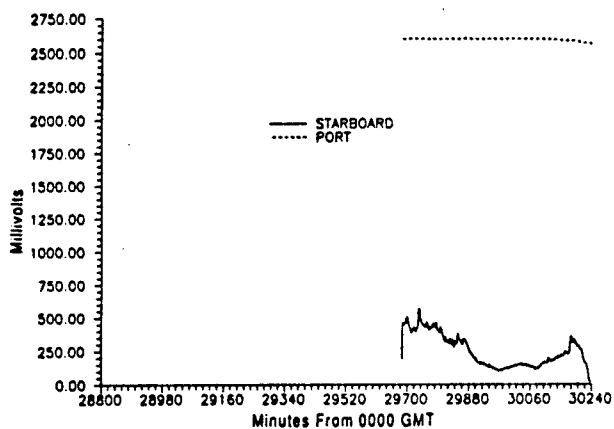


c. 02 Level units, horizontal.

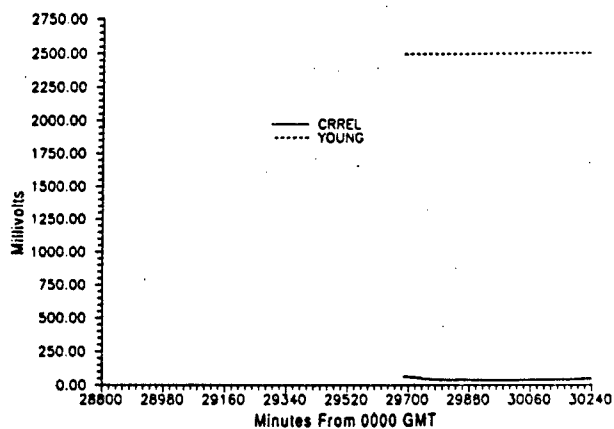


d. Flying bridge units, vertical.

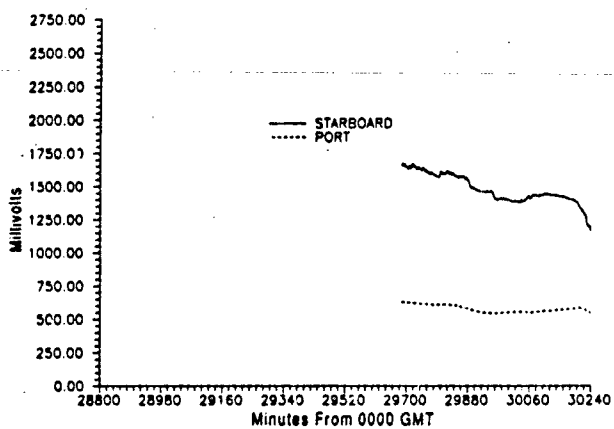
Figure B12 (cont'd). 22 February 1990.



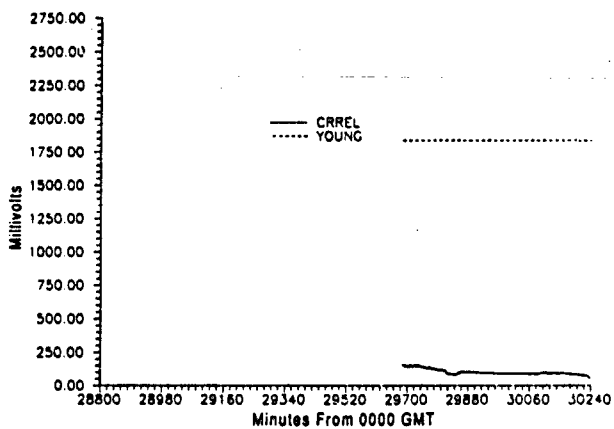
a. Main deck units, horizontal.



b. 01 Level units, vertical.

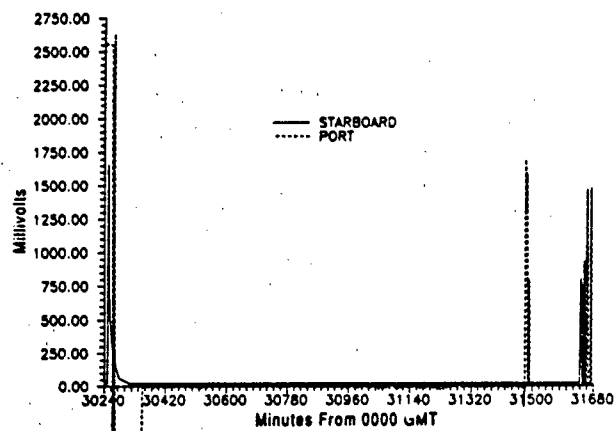


c. 02 Level units, horizontal.

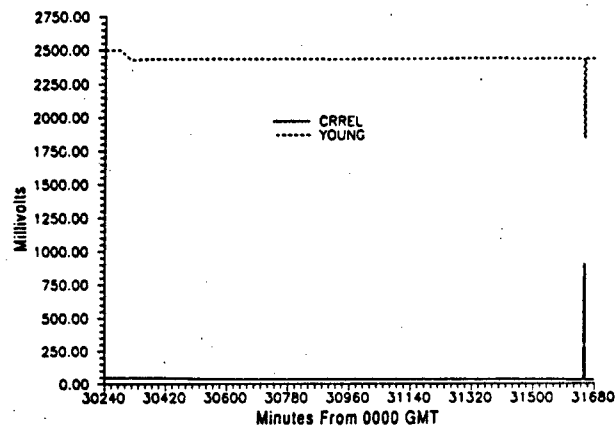


d. Flying bridge units, vertical.

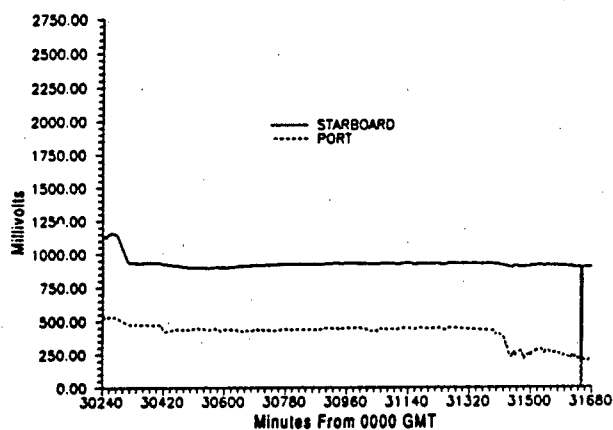
Figure B13. 25 February 1990.



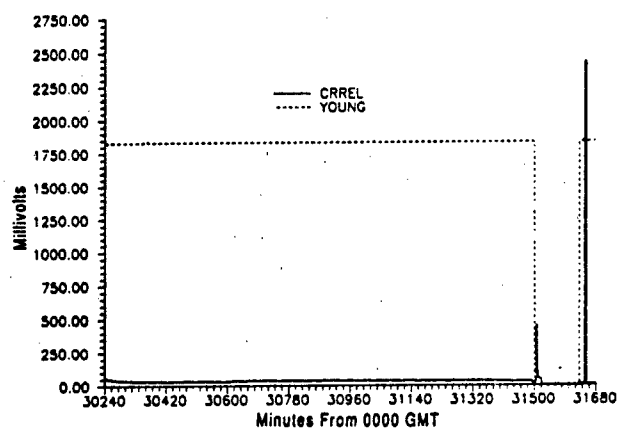
a. Main deck units, horizontal.



b. 01 Level units, vertical.

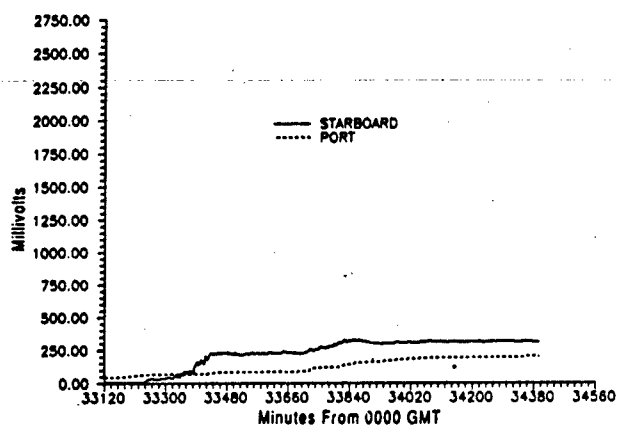


c. 02 Level units, horizontal.

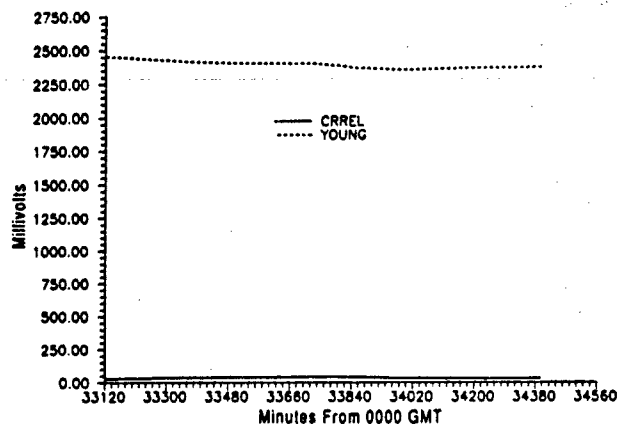


d. Flying bridge units, vertical.

Figure B14. 26 February 1990.

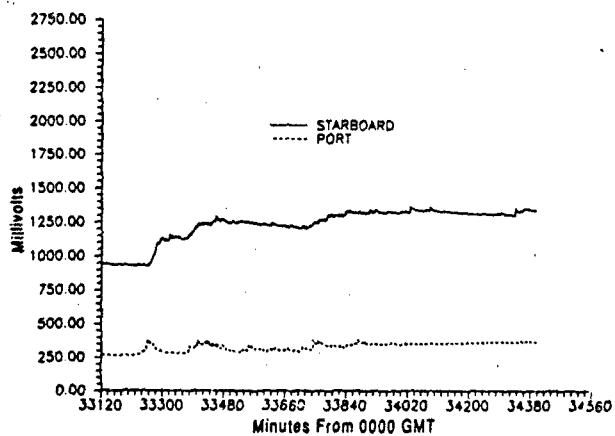


a. Main deck units, horizontal.

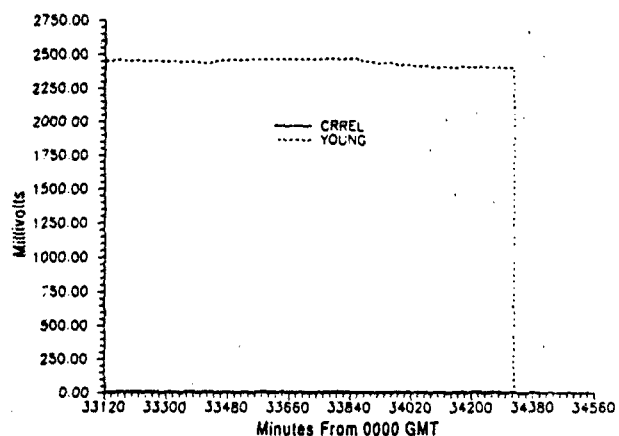


b. 01 Level units, vertical.

Figure B15. 28 February 1990.

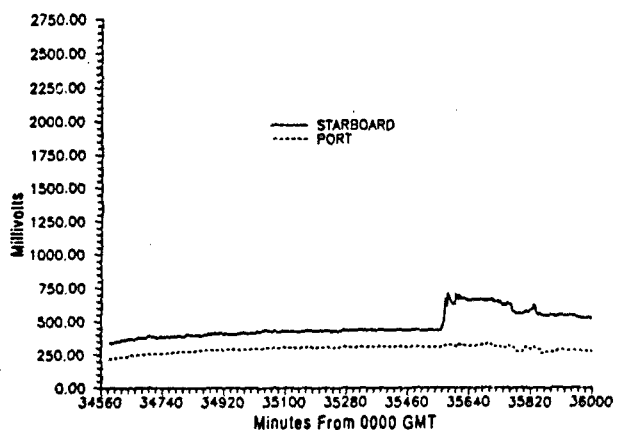


c. 02 Level units, horizontal.

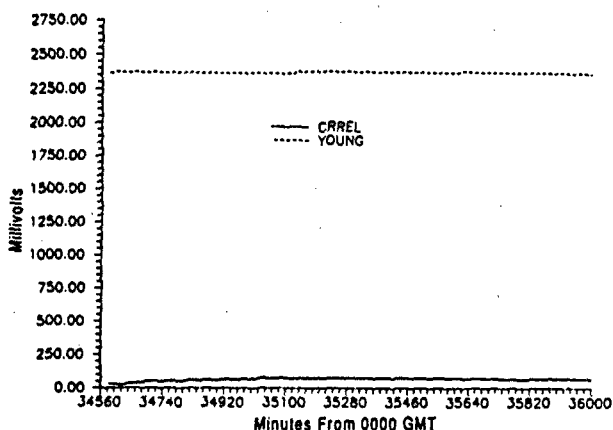


d. Flying bridge units, vertical.

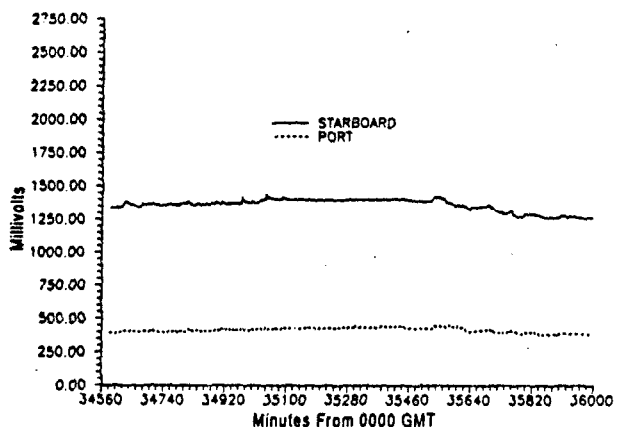
Figure B15 (cont'd). 28 February 1990.



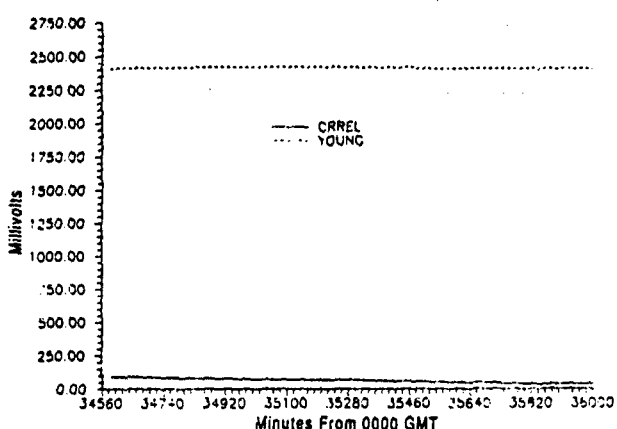
a. Main deck units, horizontal.



b. 01 Level units, vertical.

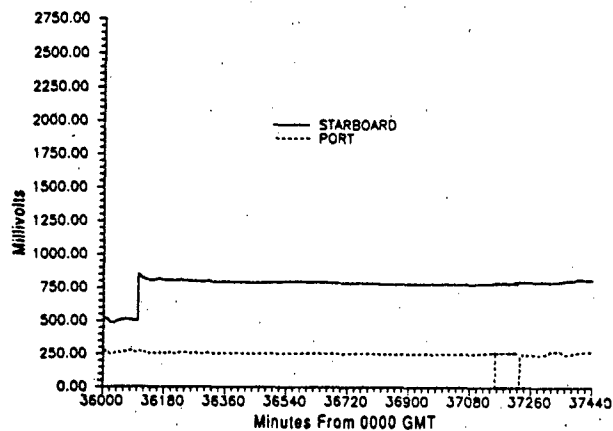


c. 02 Level units, horizontal.

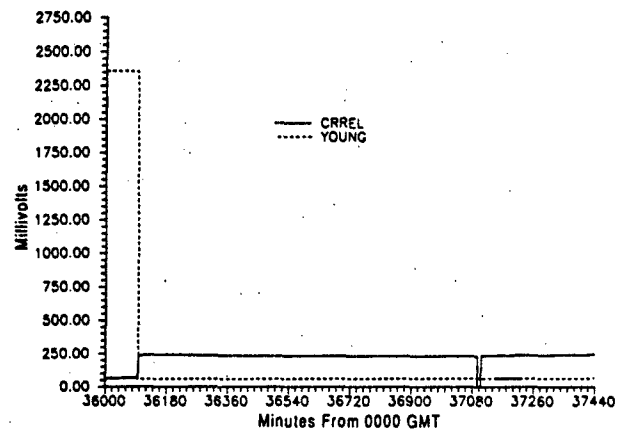


d. Flying bridge units, vertical.

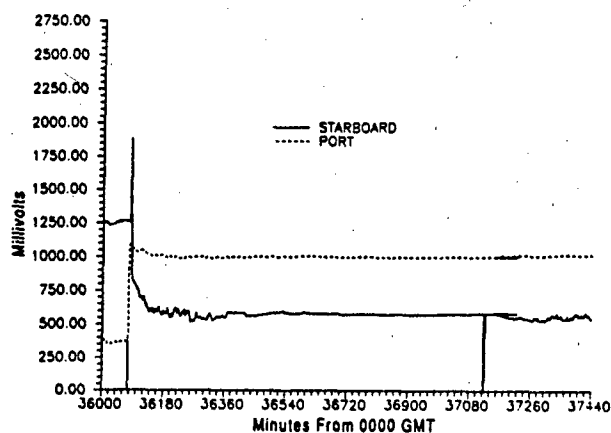
Figure B16. 1 March 1990.



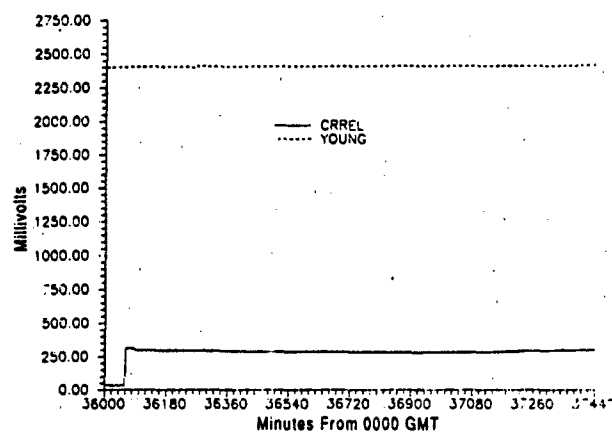
a. Main deck units, horizontal.



b. 01 Level units, vertical.

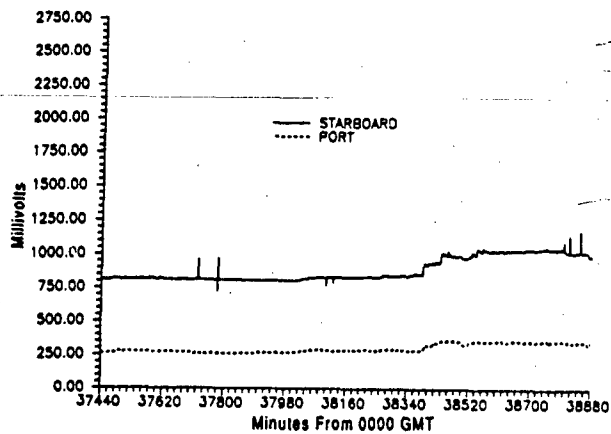


c. 02 Level units, horizontal.

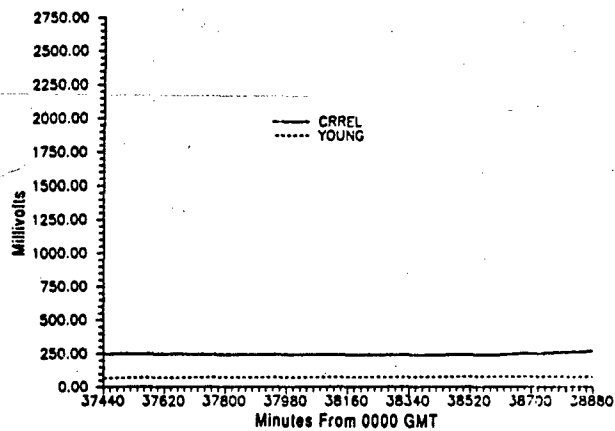


d. Flying bridge units, vertical.

Figure B17. 2 March 1990.

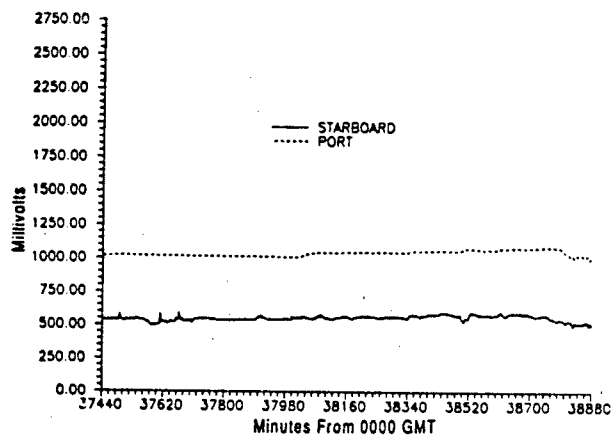


a. Main deck units, horizontal.

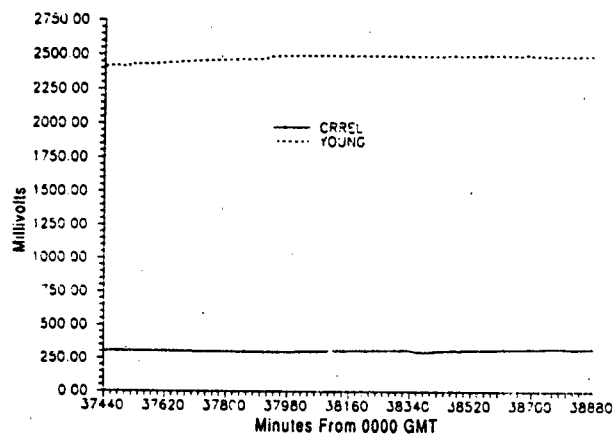


b. 01 Level units, vertical.

Figure B18. 3 March 1990.

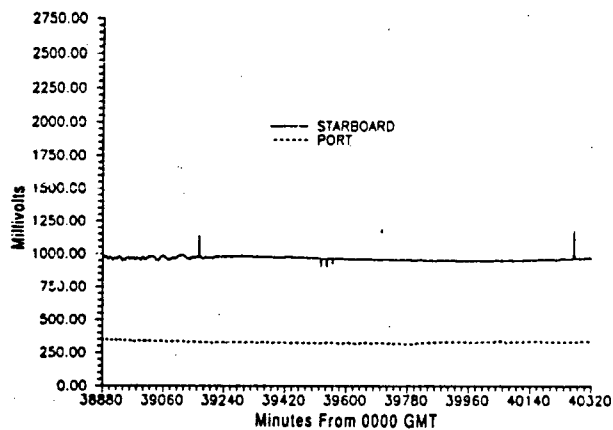


c. 02 Level units, horizontal.

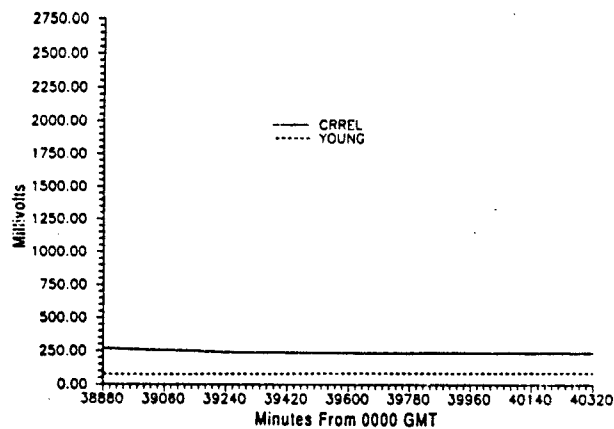


d. Flying bridge units, vertical.

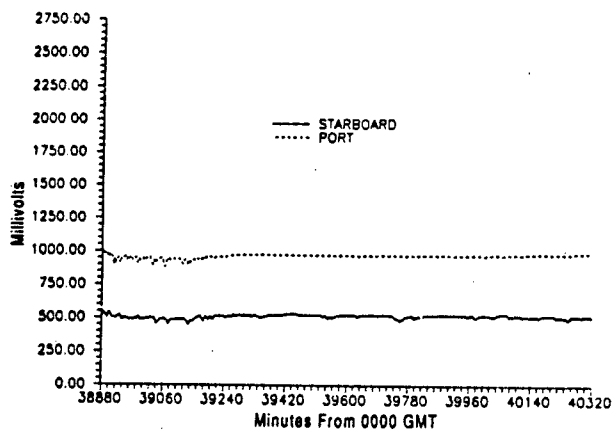
Figure B18 (cont'd). 3 March 1990.



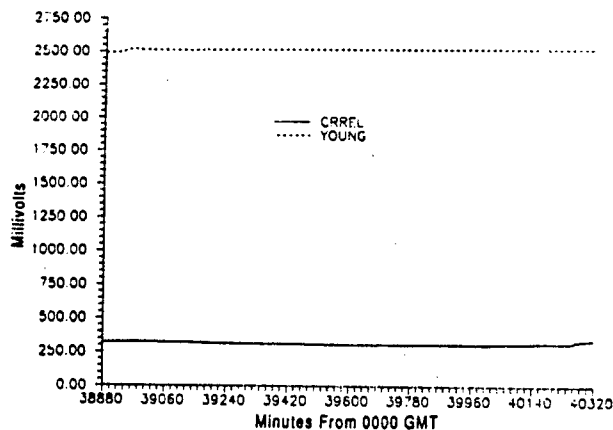
a. Main deck units, horizontal.



b. 01 Level units, vertical.

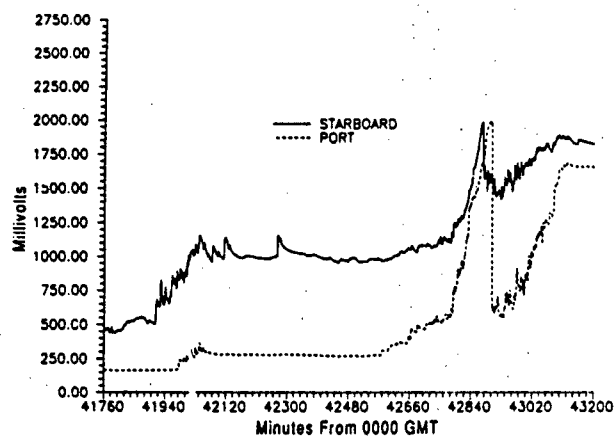


c. 02 Level units, horizontal.

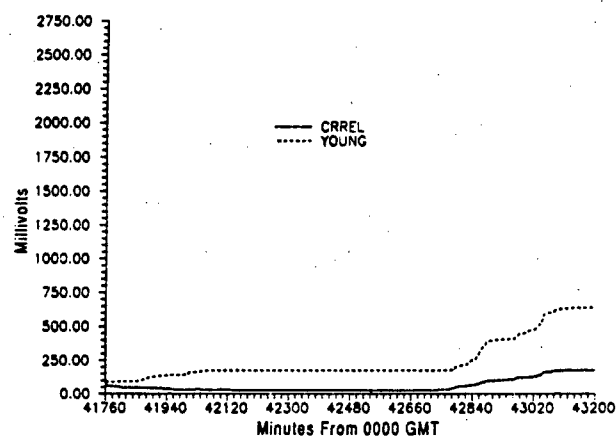


d. Flying bridge units, vertical.

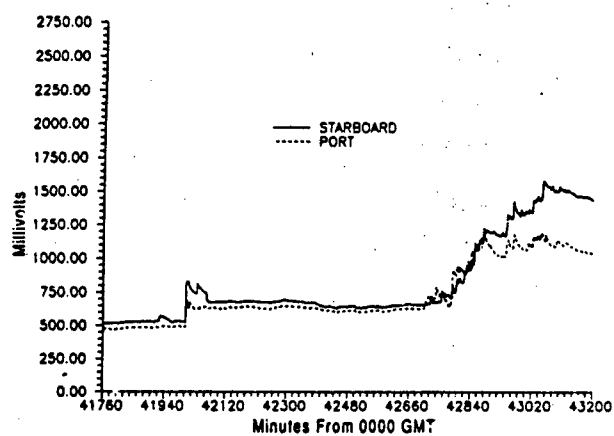
Figure B19. 4 March 1990.



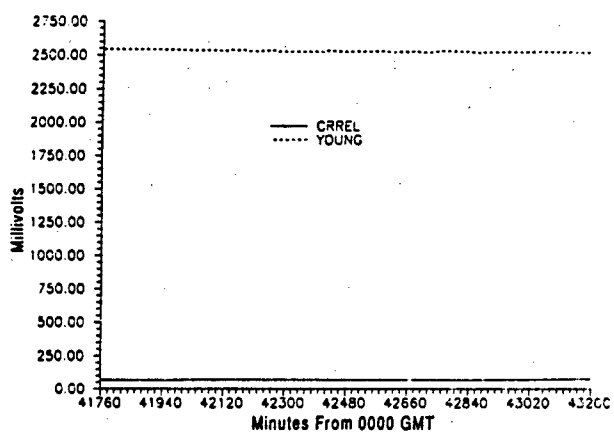
a. Main deck units, horizontal.



b. 01 Level units, vertical.

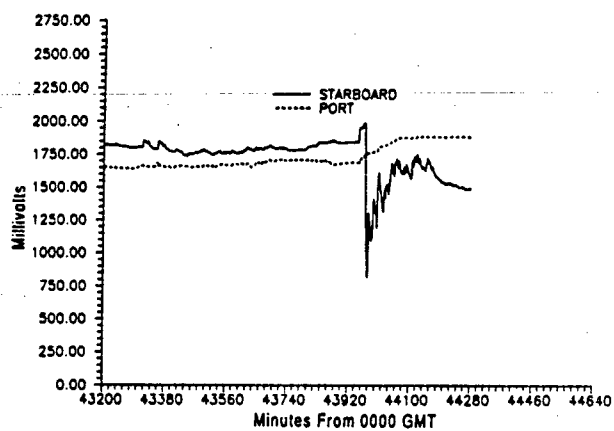


c. 02 Level units, horizontal.

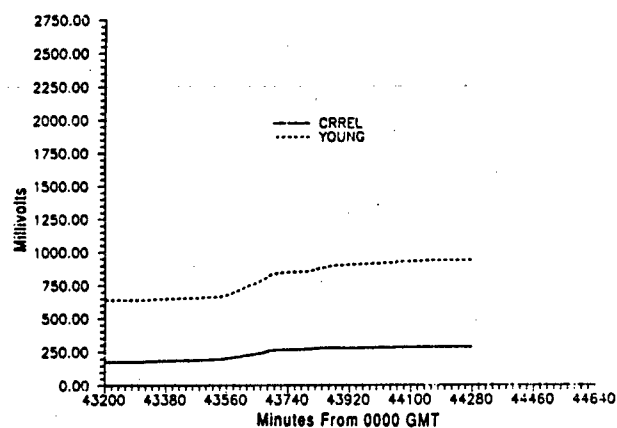


d. Flying bridge units, vertical.

Figure B20. 6 March 1990.

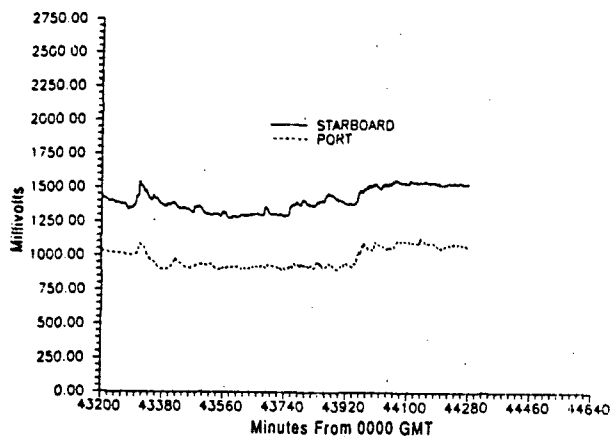


a. Main deck units, horizontal.

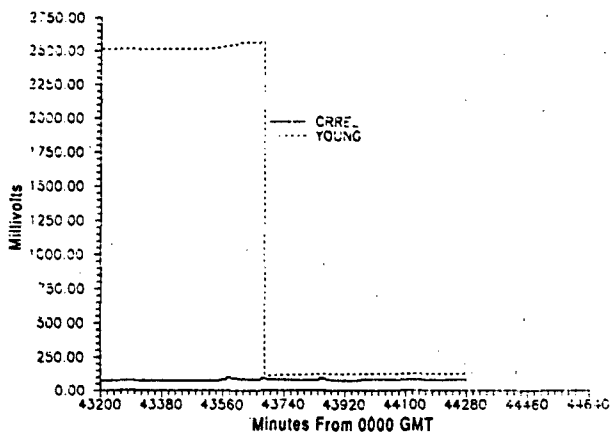


b. 01 Level units, vertical.

Figure B21. 7 March 1990.

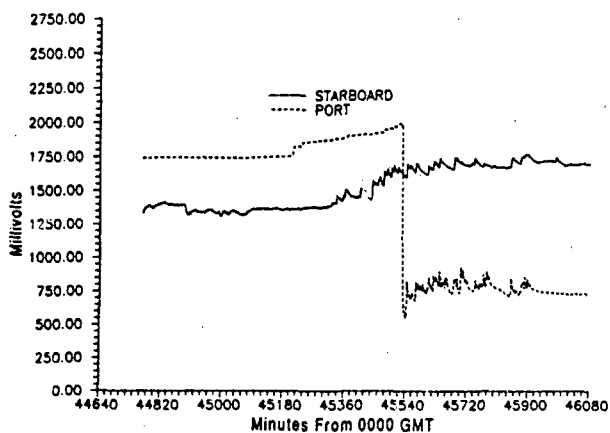


c. 02 Level units, horizontal.

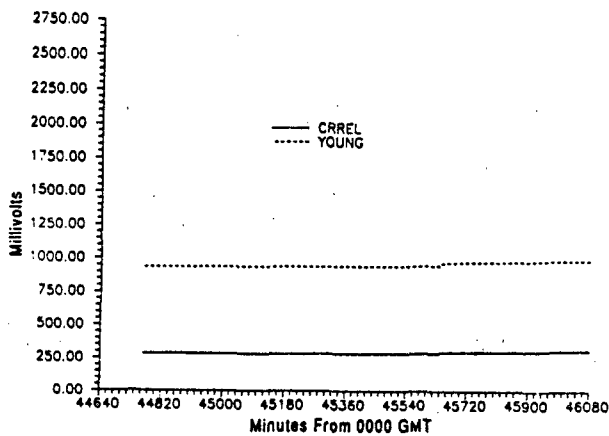


d. Flying bridge units, vertical.

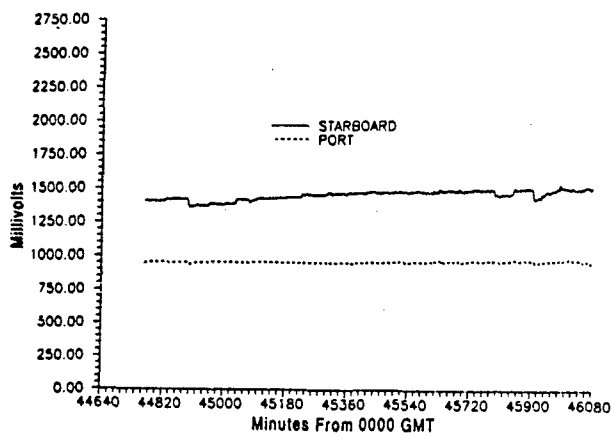
Figure B21 (cont'd). 7 March 1990.



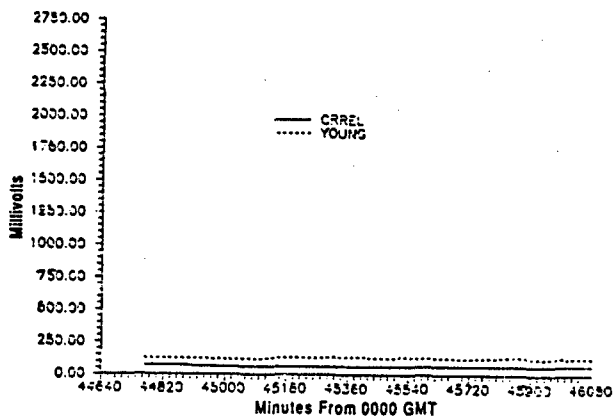
a. Main deck units, horizontal.



b. 01 Level units, vertical.

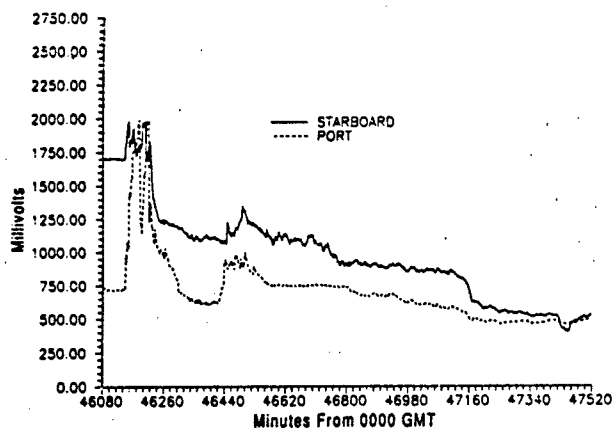


c. 02 Level units, horizontal.

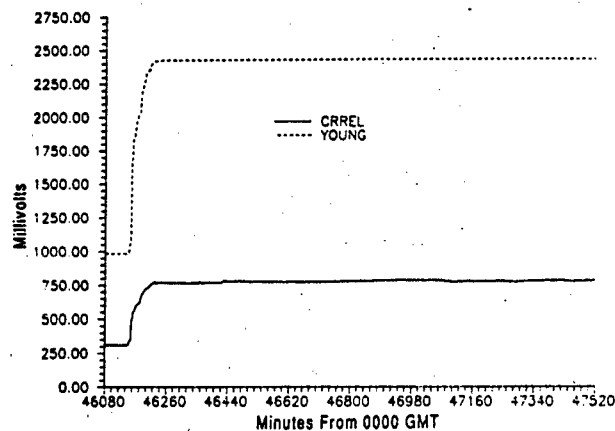


d. Flying bridge units, vertical.

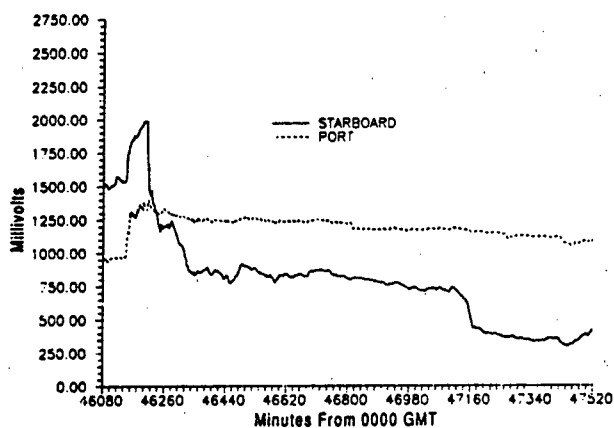
Figure B22. 8 March 1990.



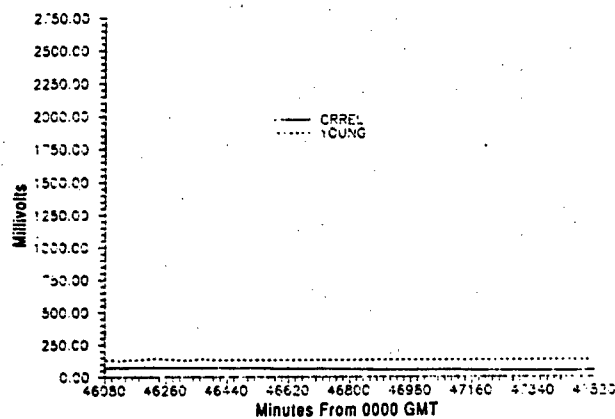
a. Main deck units, horizontal.



b. 01 Level units, vertical.

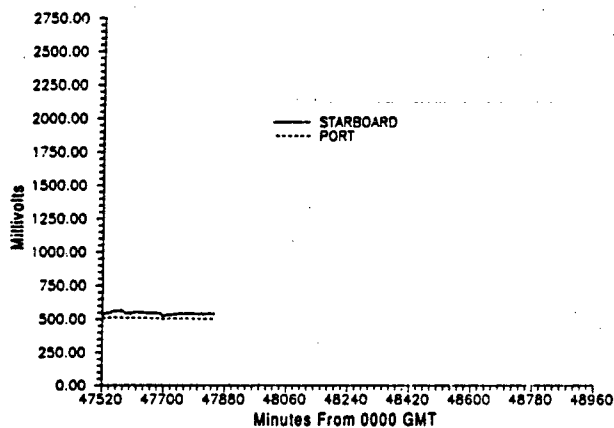


c. 02 Level units, horizontal.

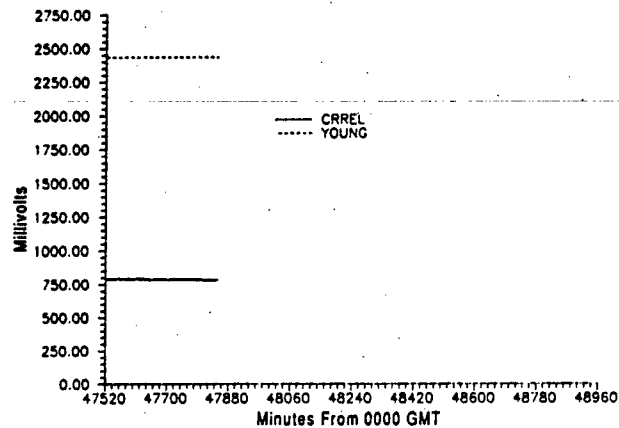


d. Flying bridge units, vertical.

Figure B23. 9 March 1990.

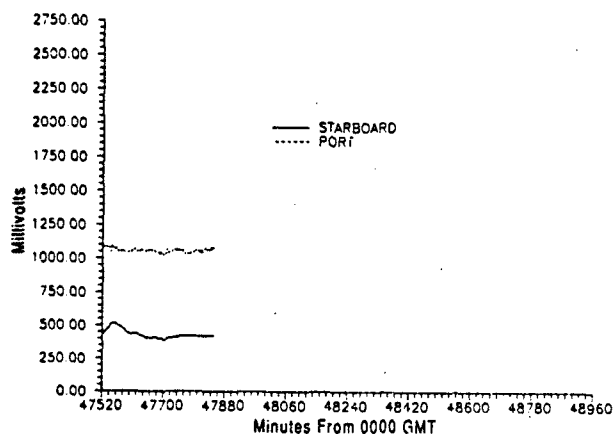


a. Main deck units, horizontal.

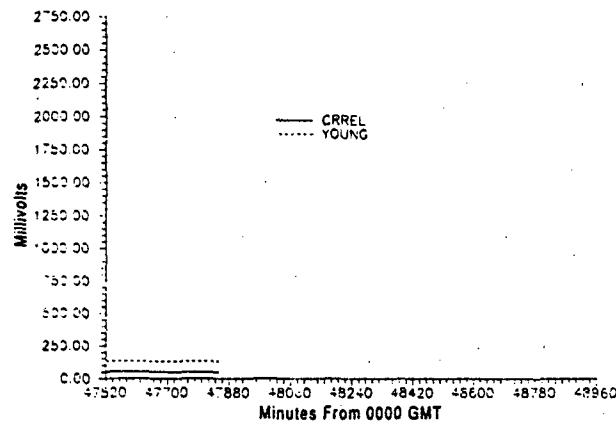


b. 01 Level units, vertical.

Figure B24. 10 March 1990.

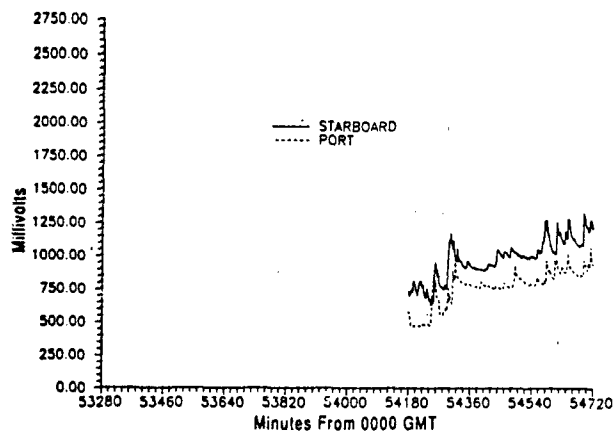


c. 02 Level units, horizontal.

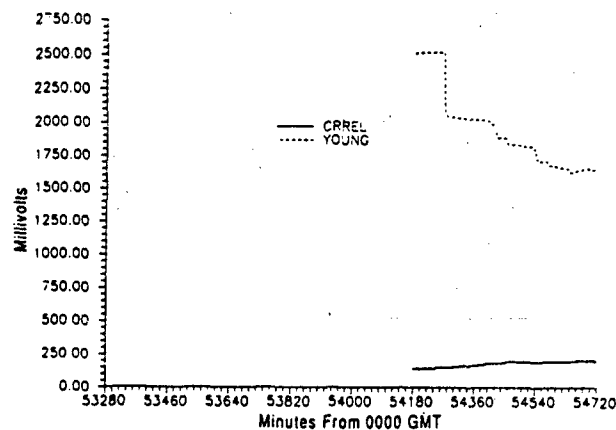


d. Flying bridge units, vertical.

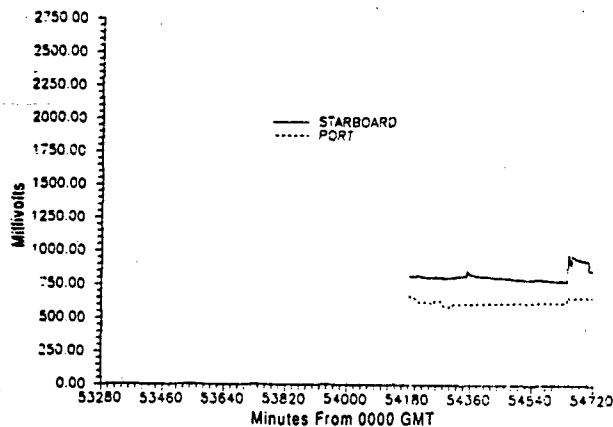
Figure B24 (cont'd). 10 March 1990.



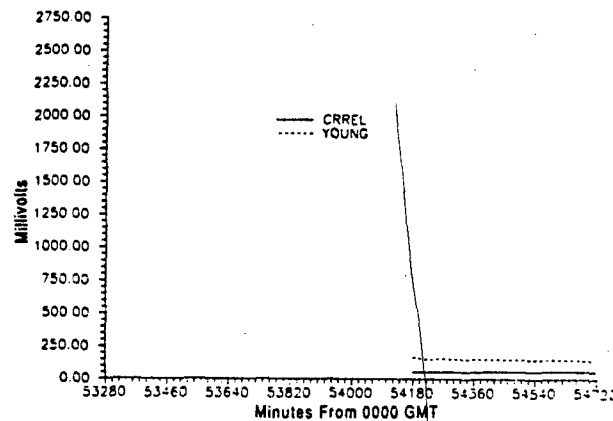
a. Main deck units, horizontal.



b. 01 Level units, vertical.

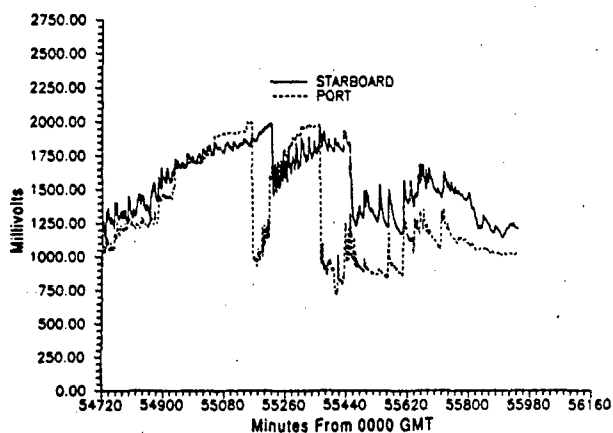


c. 02 Level units, horizontal.

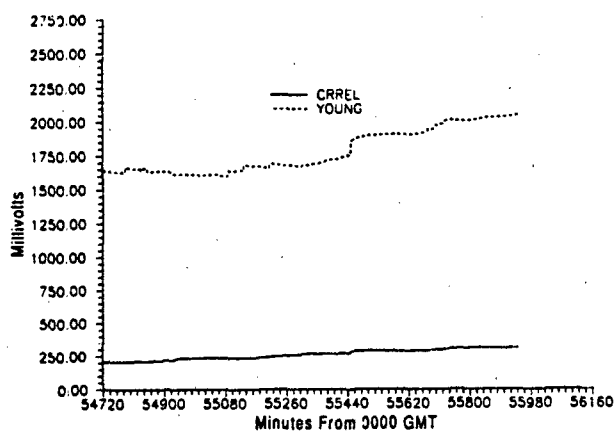


d. Flying bridge units, vertical.

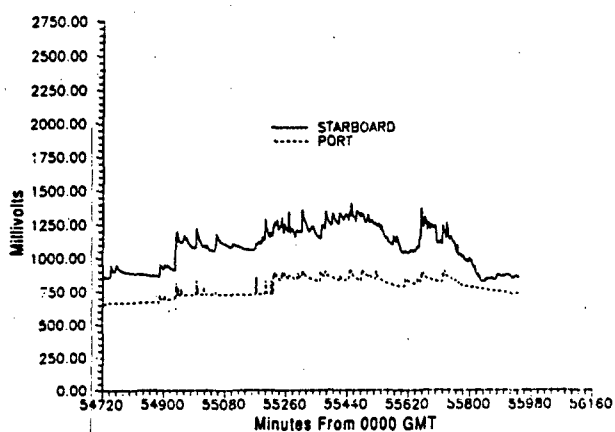
Figure B25. 14 March 1990.



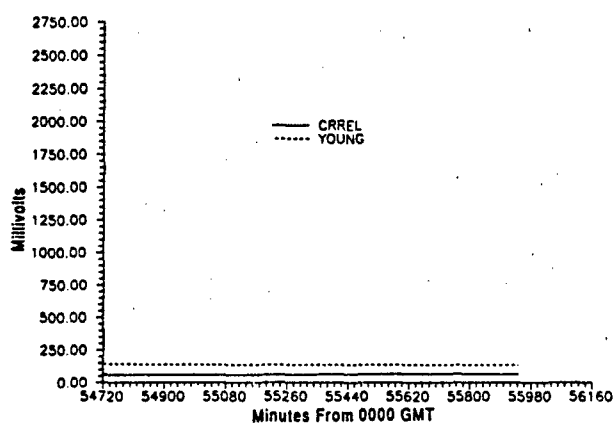
a. Main deck units, horizontal.



b. 01 Level units, vertical.



c. 02 Level units, horizontal.

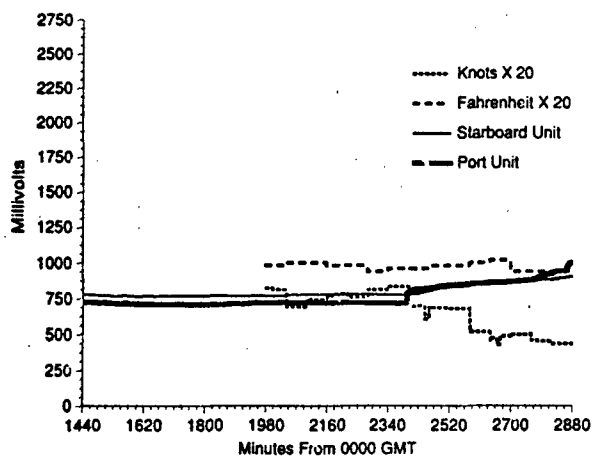


d. Flying bridge units, vertical.

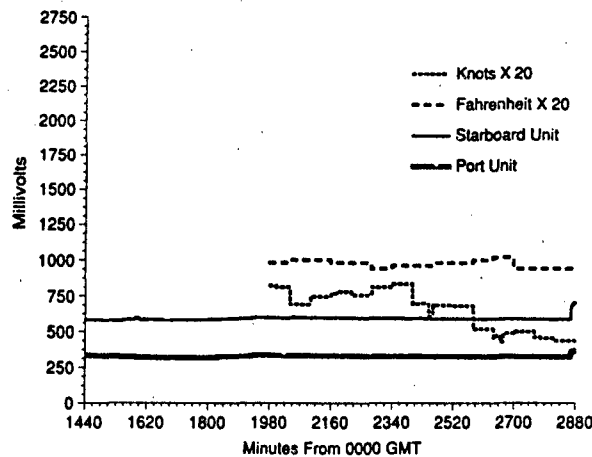
Figure B26. 15 March 1990.

**APPENDIX C: SPRAY COLLECTOR TANK VOLTAGES,
RELATIVE WIND SPEEDS AND AIR TEMPERATURE FOR THE FOUR CRREL
HORIZONTAL COLLECTORS FOR THE MIDGETT RESEARCH CRUISE**

All plots begin at 0000 hours.

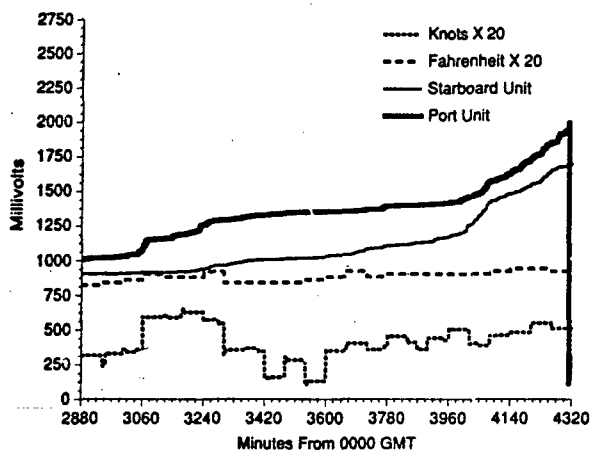


a. Main deck units, horizontal.

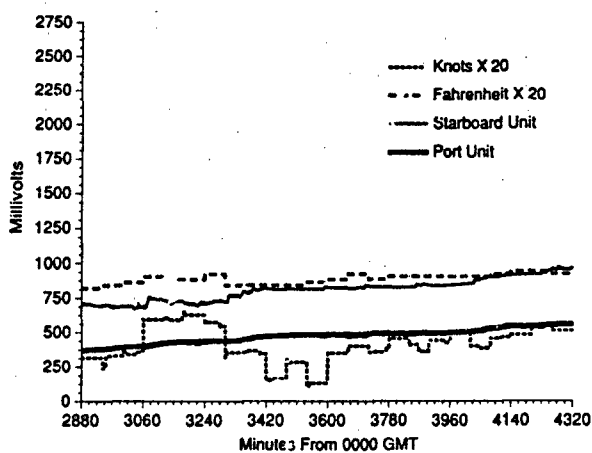


b. 02 Level units, horizontal.

Figure C1. 6 February 1990.

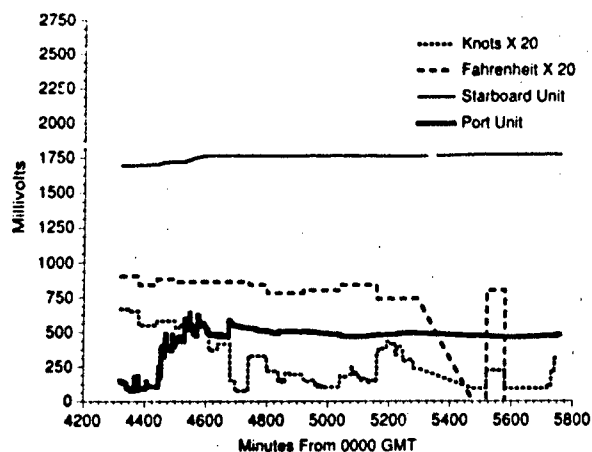


a. Main deck units, horizontal.

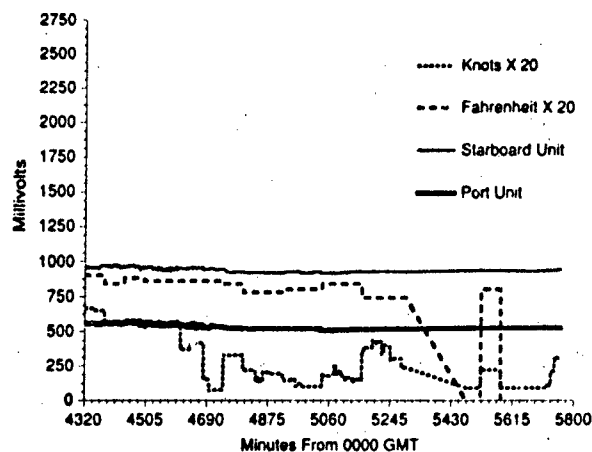


b. 02 Level units, horizontal.

Figure C2. 7 February 1990.

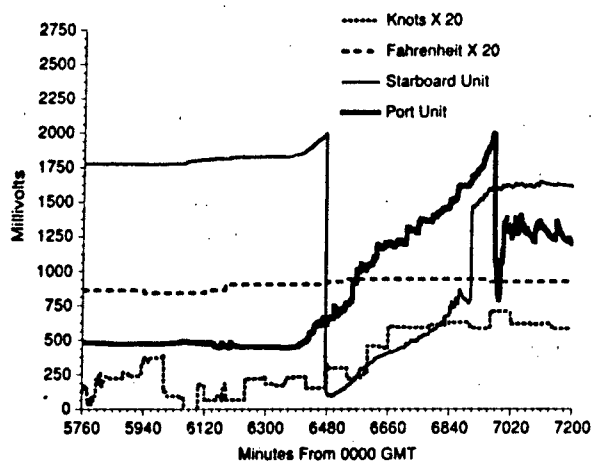


a. Main deck units, horizontal.

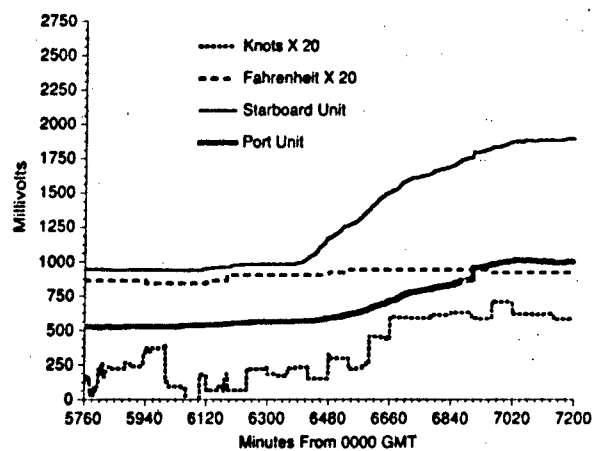


b. 02 Level units, horizontal.

Figure C3. 8 February 1990.

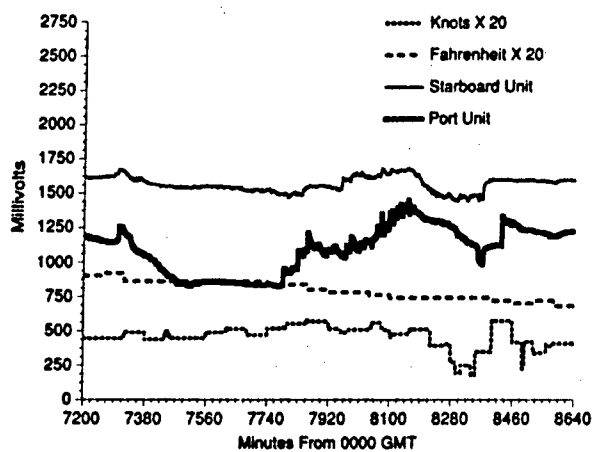


a. Main deck units, horizontal.

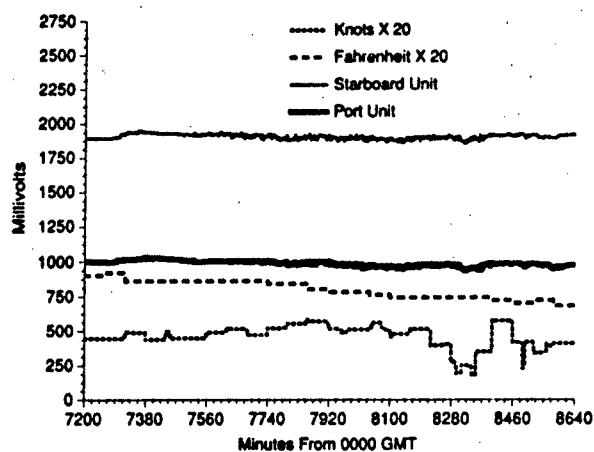


b. 02 Level units, horizontal.

Figure C4. 9 February 1990.

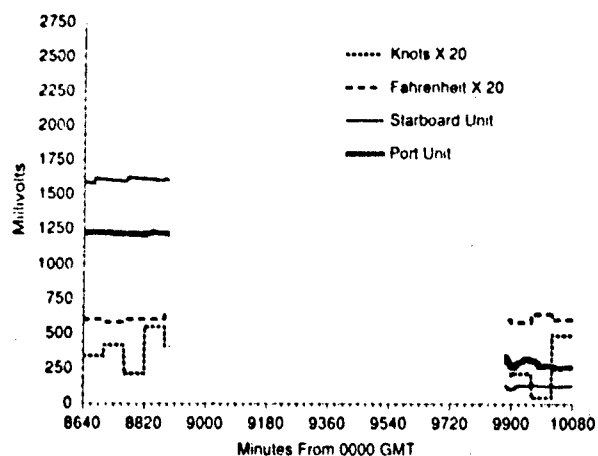


a. Main deck units, horizontal.

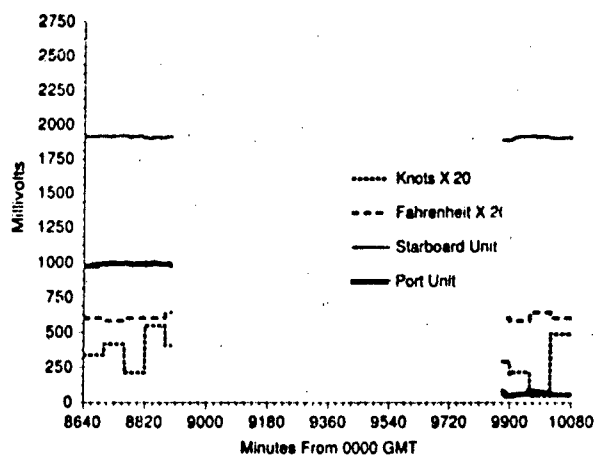


b. 02 Level units, horizontal.

Figure C5. 10 February 1990.

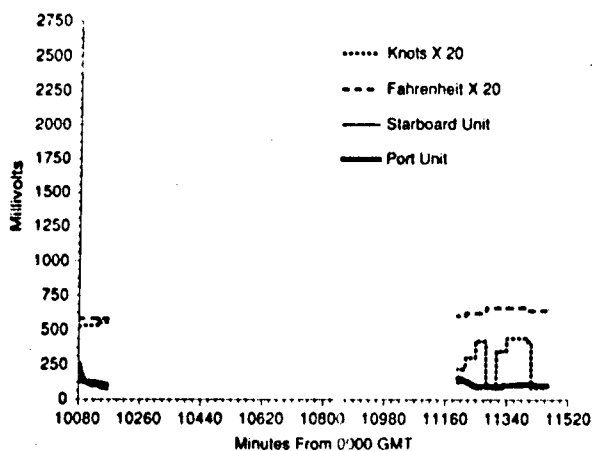


a. Main deck units, horizontal.

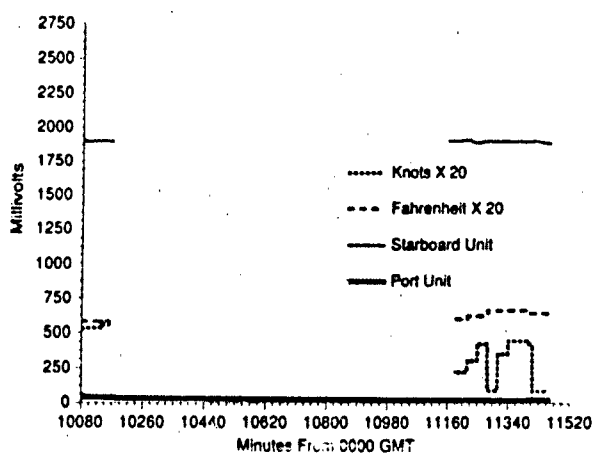


b. 02 Level units, horizontal.

Figure C6. 11 February 1990.

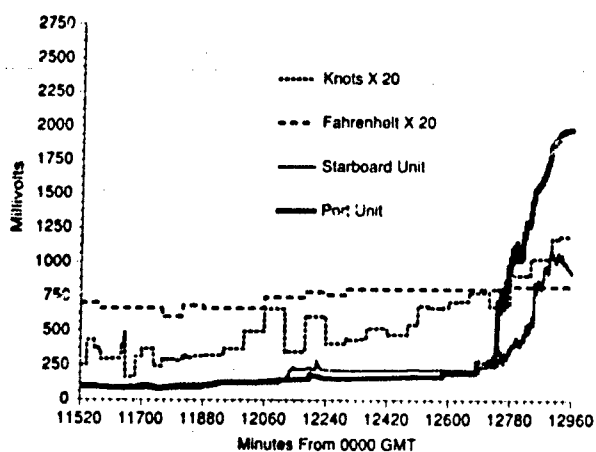


a. Main deck units, horizontal.

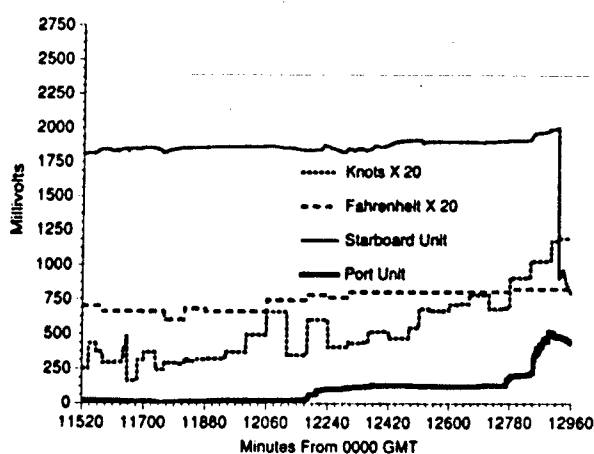


b. 02 Level units, horizontal.

Figure C7. 12 February 1990.

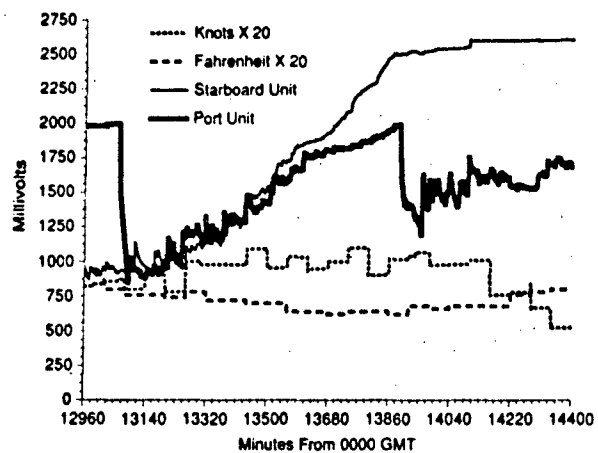


a. Main deck units, horizontal.

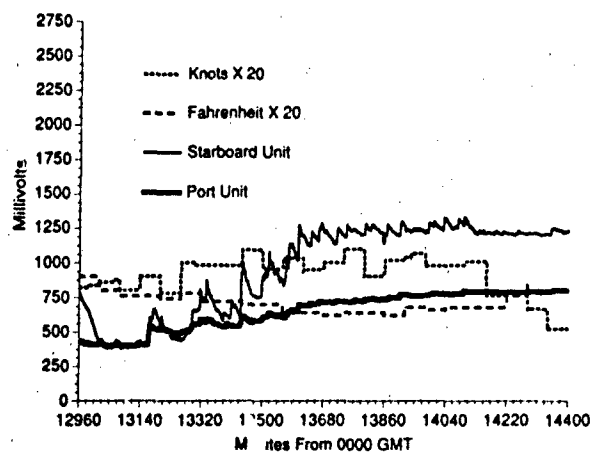


b. 02 Level units, horizontal.

Figure C8. 13 February 1990.

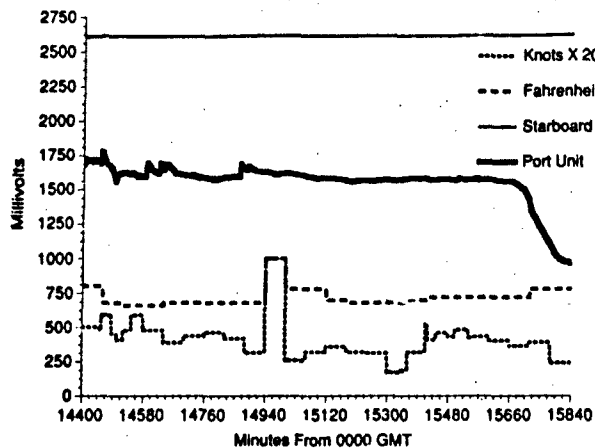


a. Main deck units, horizontal.

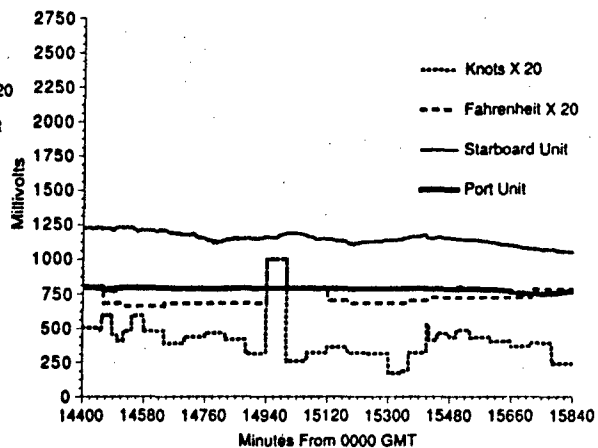


b. 02 Level units, horizontal.

Figure C9. 14 February 1990.

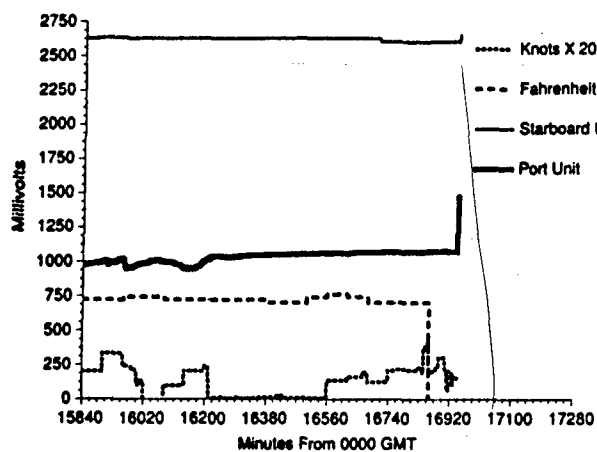


a. Main deck units, horizontal.

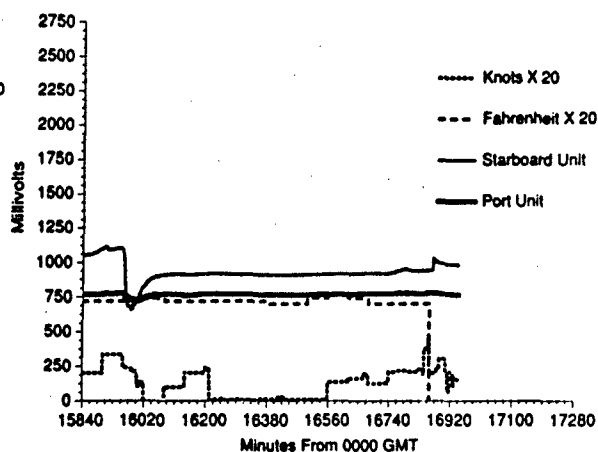


b. 02 Level units, horizontal.

Figure C10. 15 February 1990.

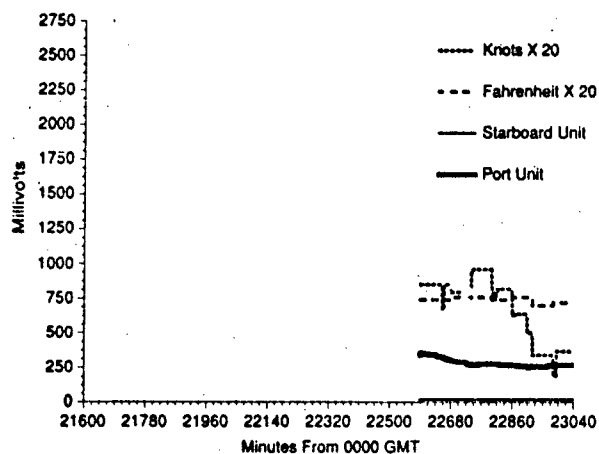


a. Main deck units, horizontal.

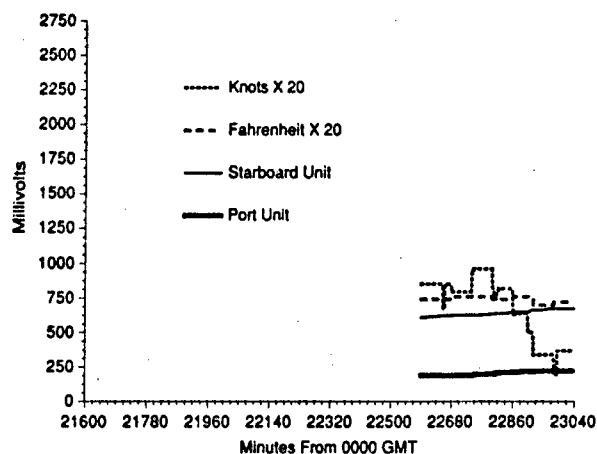


b. 02 Level units, horizontal.

Figure C11. 16 February 1990.

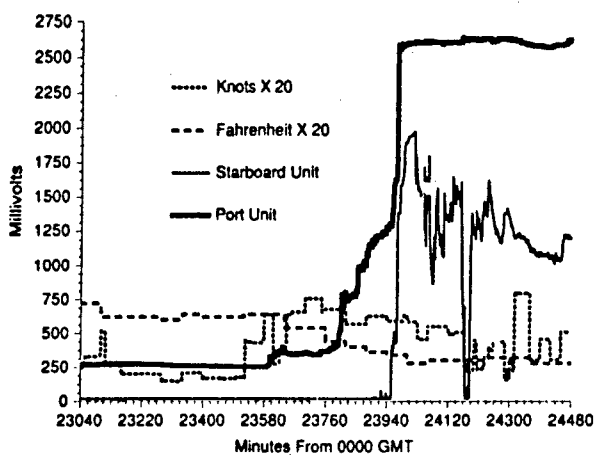


a. Main deck units, horizontal.

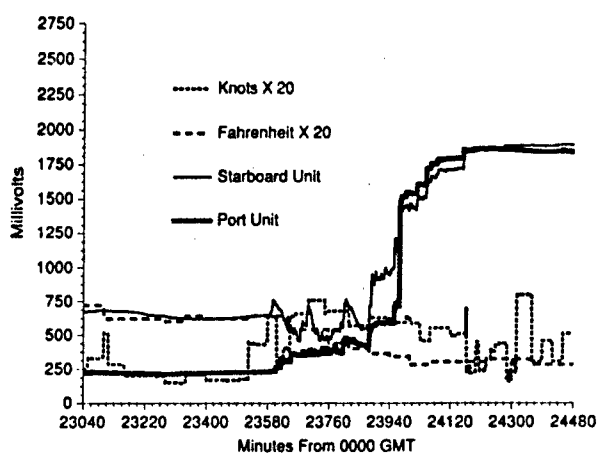


b. 02 Level units, horizontal.

Figure C12. 20 February 1990.

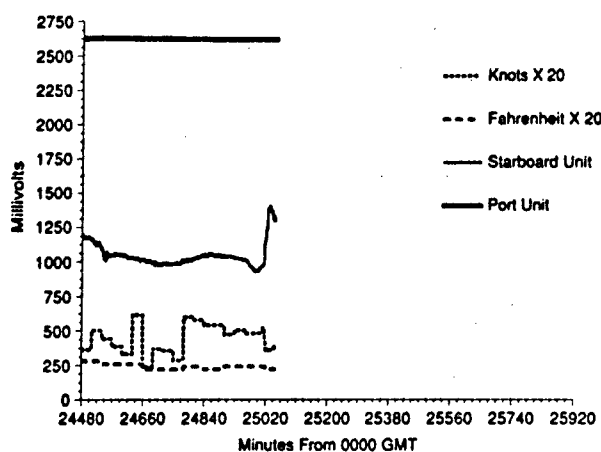


a. Main deck units, horizontal.

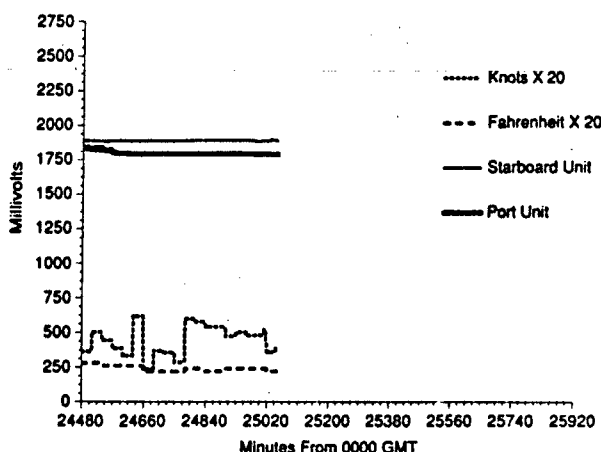


b. 02 Level units, horizontal.

Figure C13. 21 February 1990.

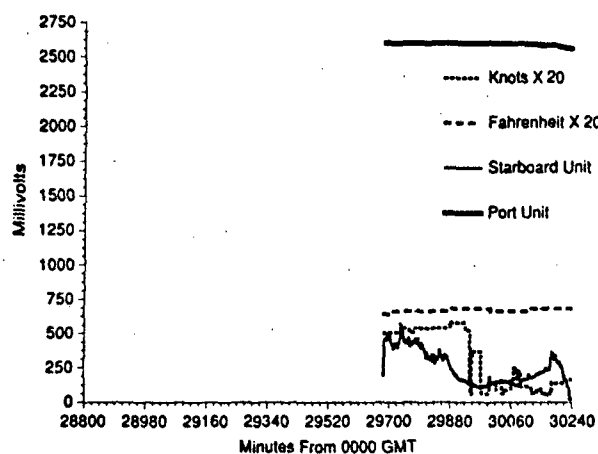


a. Main deck units, horizontal.

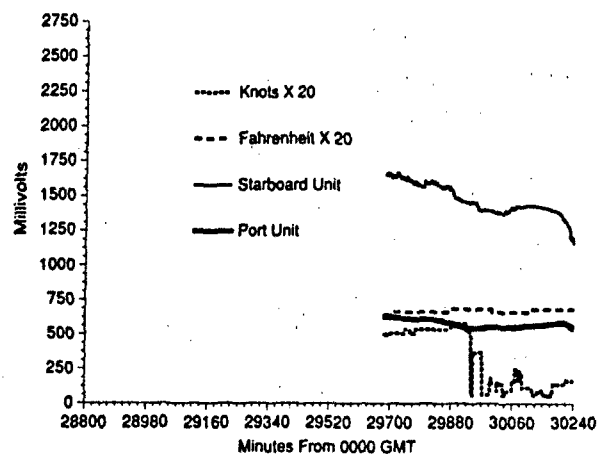


b. 02 Level units, horizontal.

Figure C14. 22 February 1990.

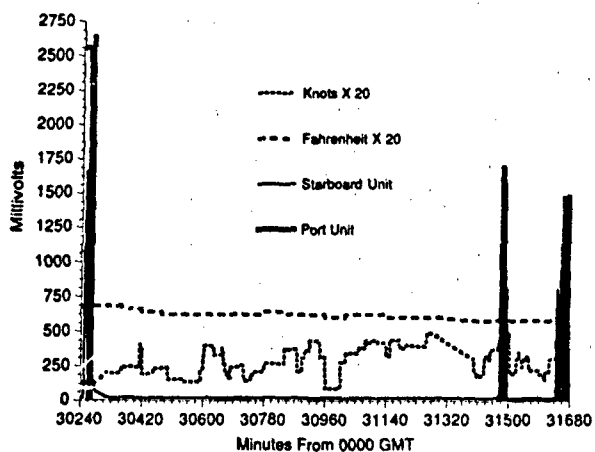


a. Main deck units, horizontal.

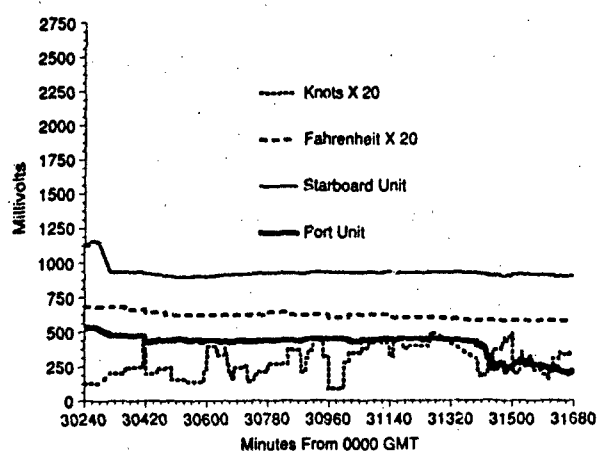


b. 02 Level units, horizontal.

Figure C15. 25 February 1990.

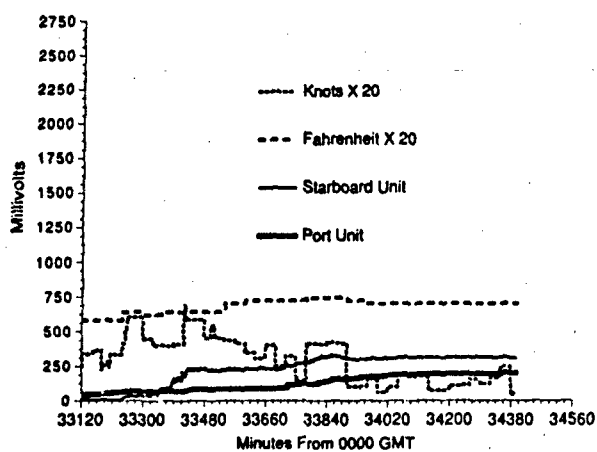


a. Main deck units, horizontal.

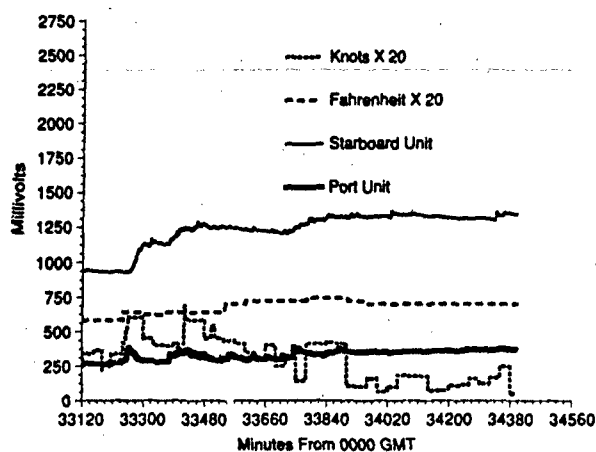


b. 02 Level units, horizontal.

Figure C16. 26 February 1990.

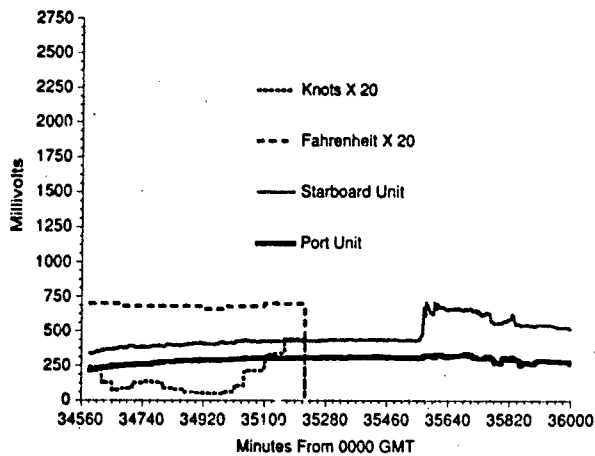


a. Main deck units, horizontal.

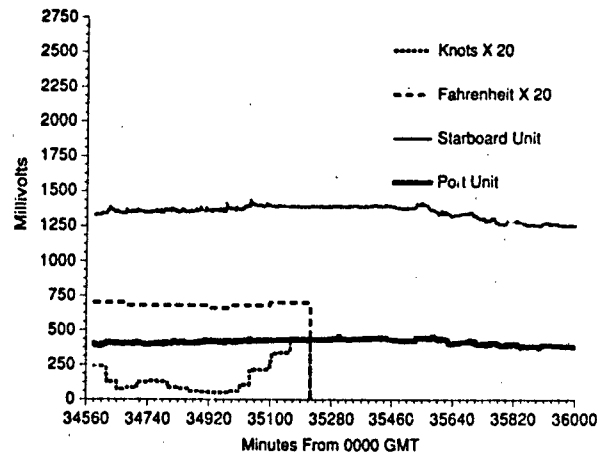


b. 02 Level units, horizontal.

Figure C17. 28 February 1990.

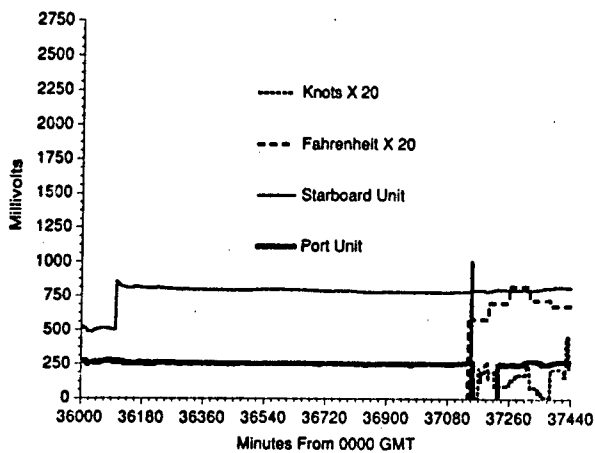


a. Main deck units, horizontal.

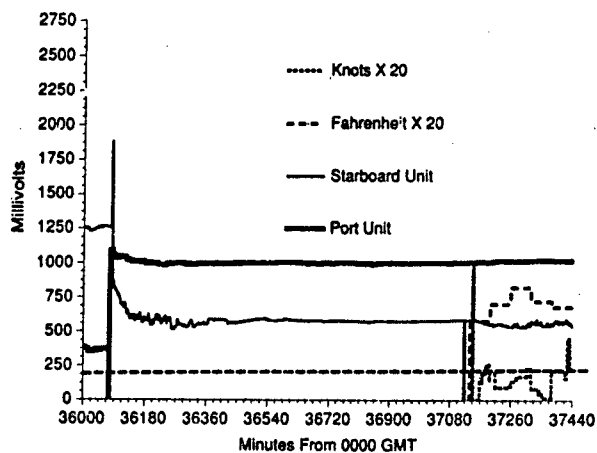


b. 02 Level units, horizontal.

Figure C18. 1 March 1990.

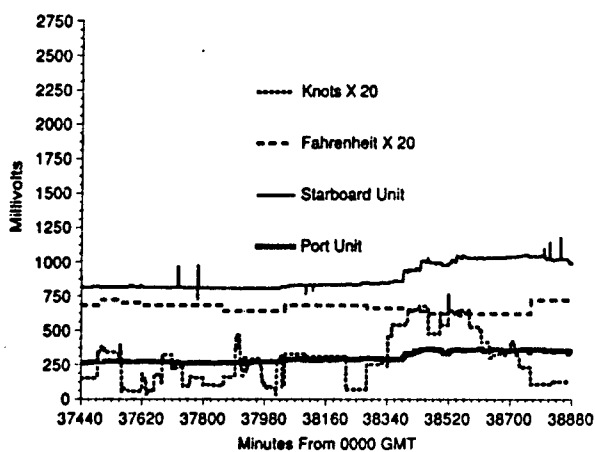


a. Main deck units, horizontal.

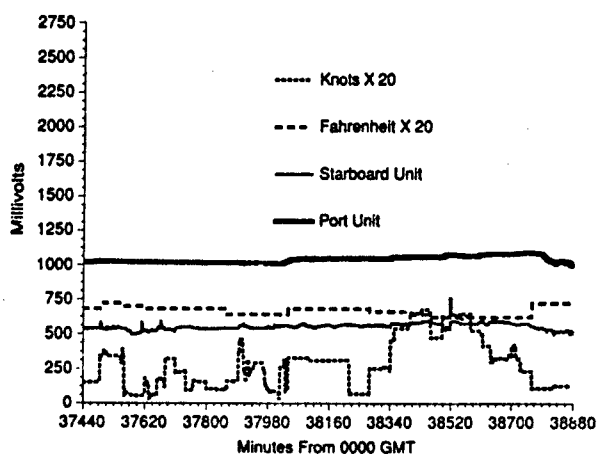


b. 02 Level units, horizontal.

Figure C19. 2 March 1990.

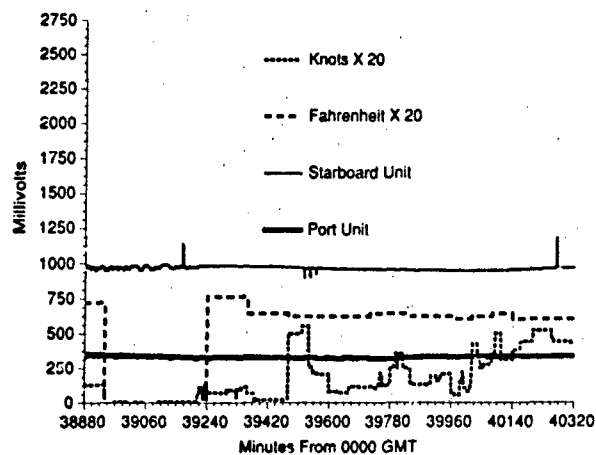


a. Main deck units, horizontal.

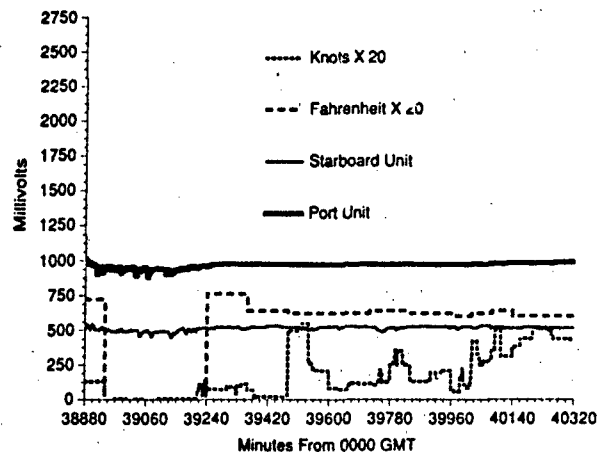


b. 02 Level units, horizontal.

Figure C20. 3 March 1990.

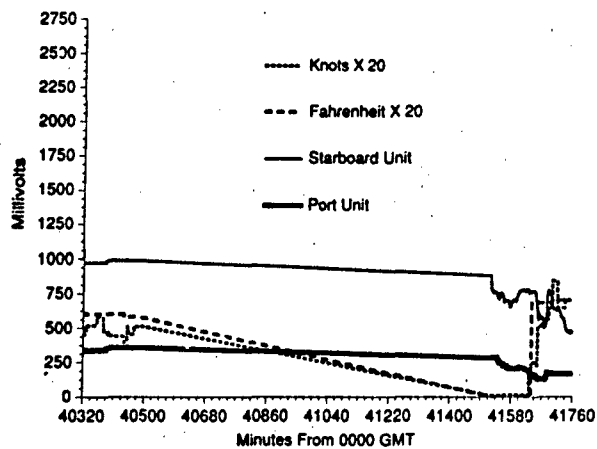


a. Main deck units, horizontal.

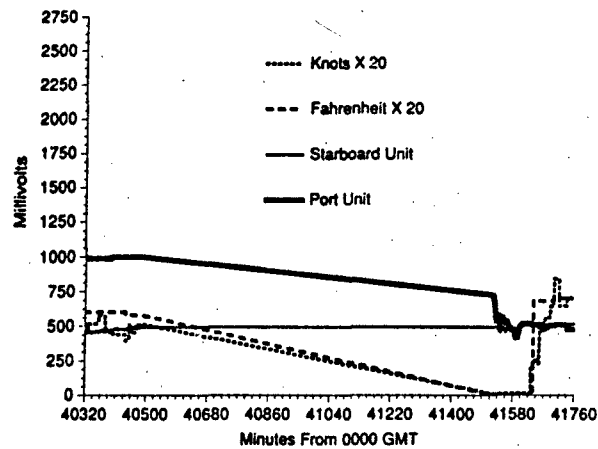


b. 02 Level units, horizontal.

Figure C21. 4 March 1990.

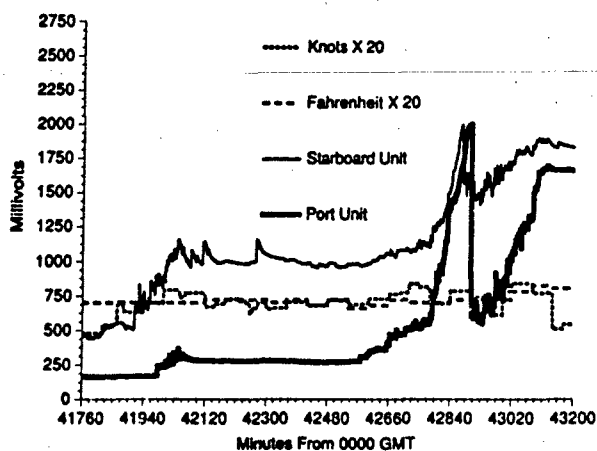


a. Main deck units, horizontal.

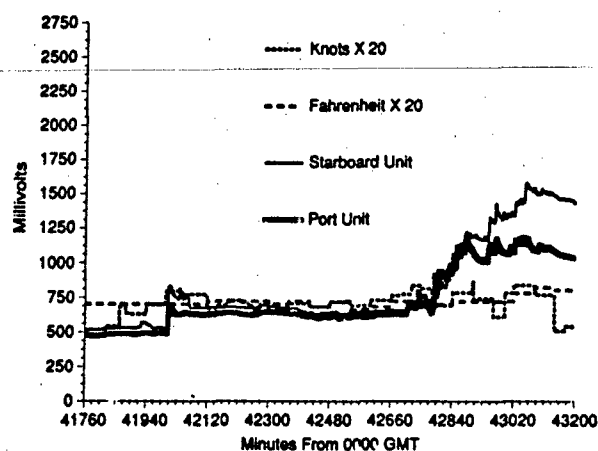


b. 02 Level units, horizontal.

Figure C22. 5 March 1990.

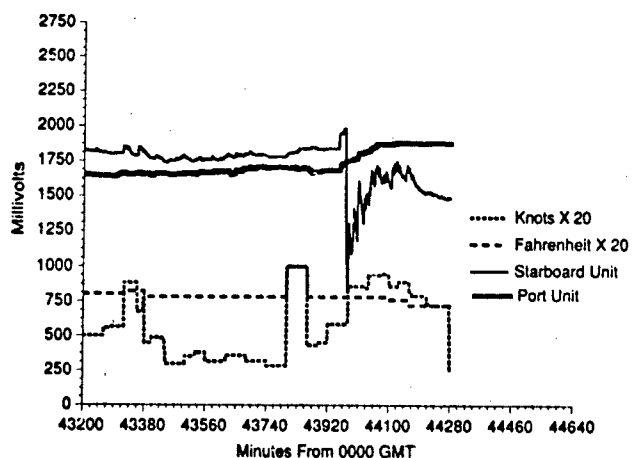


a. Main deck units, horizontal.

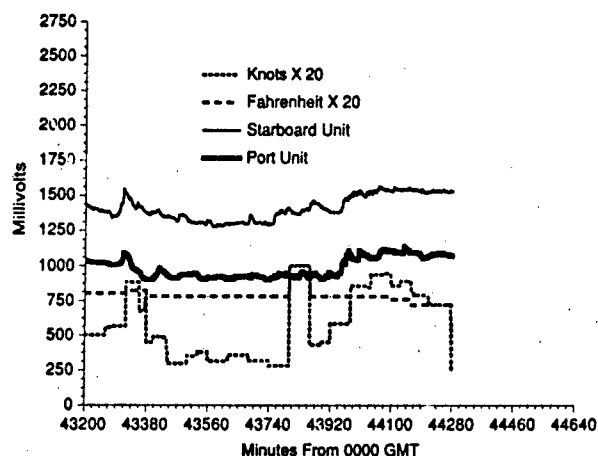


b. 02 Level units, horizontal.

Figure C23. 6 March 1990.

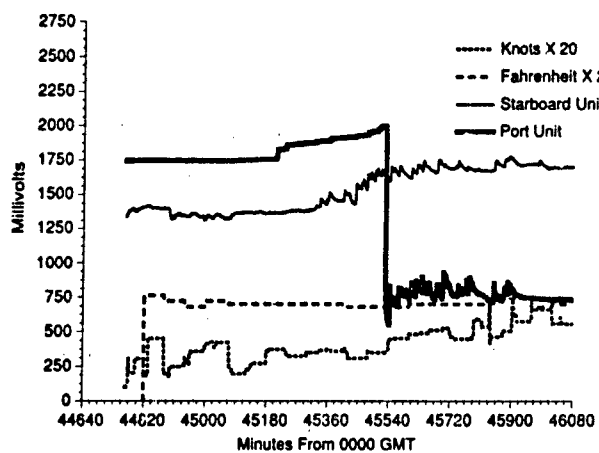


a. Main deck units, horizontal.

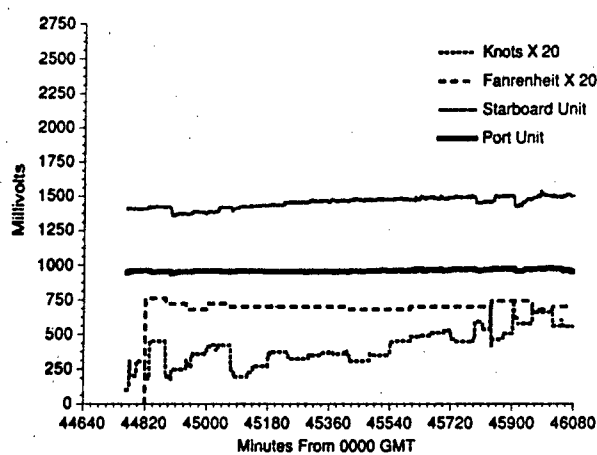


b. 02 Level units, horizontal.

Figure C24. 7 March 1990.

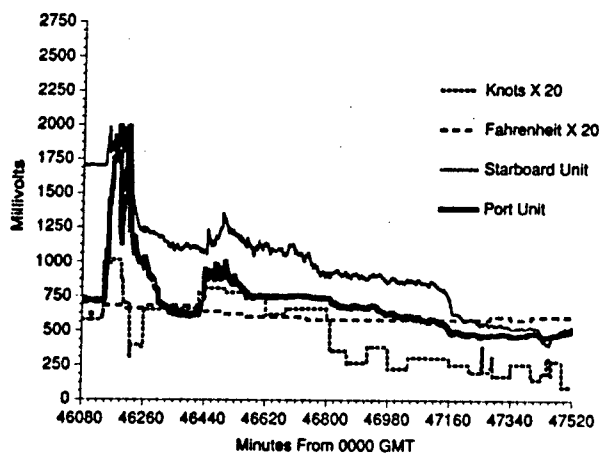


a. Main deck units, horizontal.

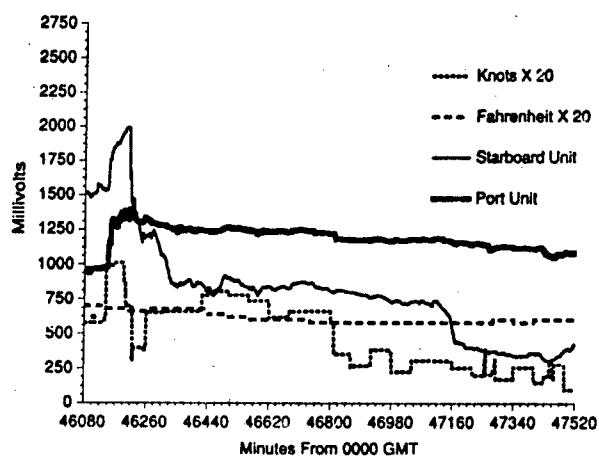


b. 02 Level units, horizontal.

Figure C25. 8 March 1990.

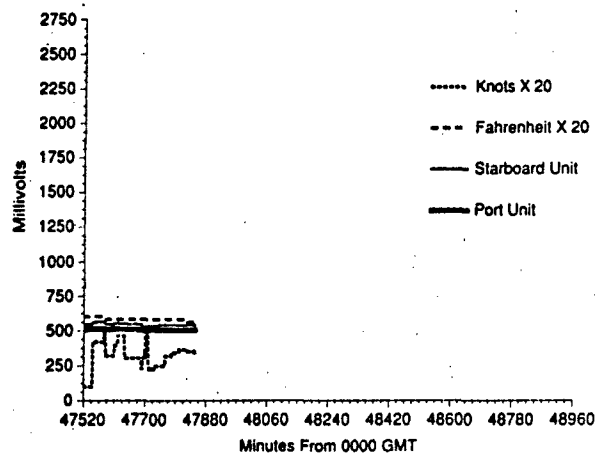


a. Main deck units, horizontal.

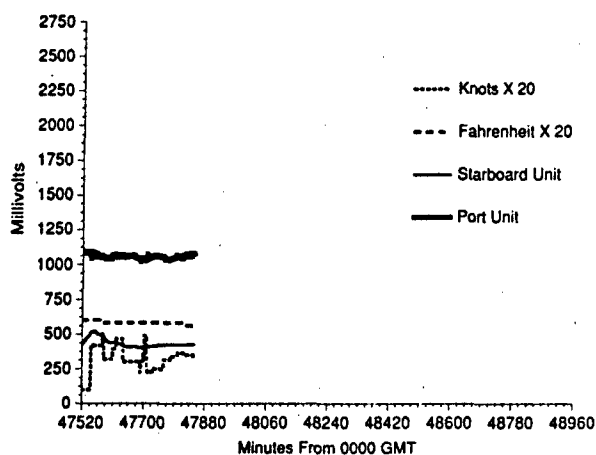


b. 02 Level units, horizontal.

Figure C26. 9 March 1990.

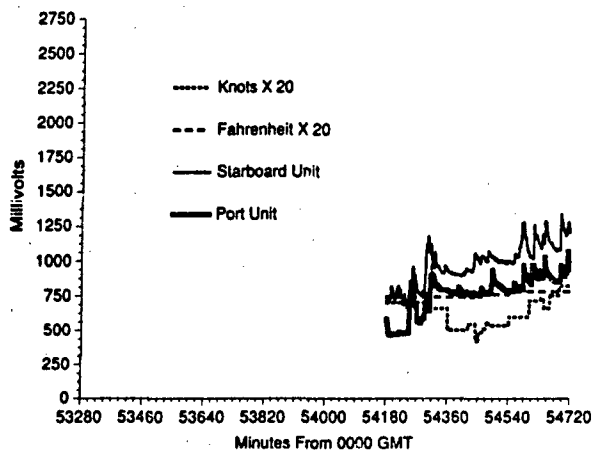


a. Main deck units, horizontal.

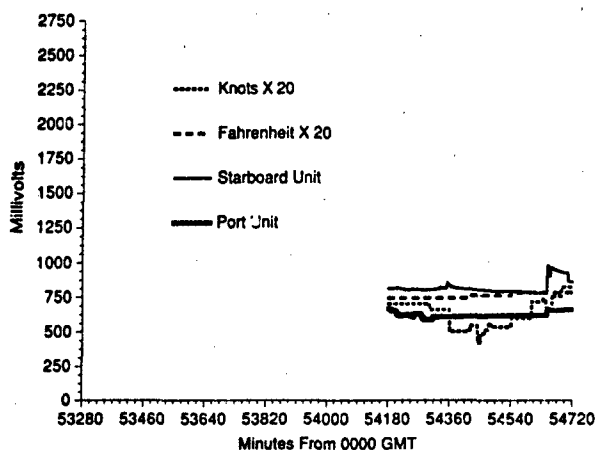


b. 02 Level units, horizontal.

Figure C27. 10 March 1990.



a. Main deck units, horizontal.



b. 02 Level units, horizontal.

Figure C28. 14 March 1990.

**APPENDIX D: POLYNOMIAL FITS FOR NOISY HORIZONTAL
COLLECTOR SPRAY TANK VOLTAGES FOR
SELECTED SEGMENTS OF THE MIDGETT RESEARCH CRUISE**

All plots begin at 0000 hours.

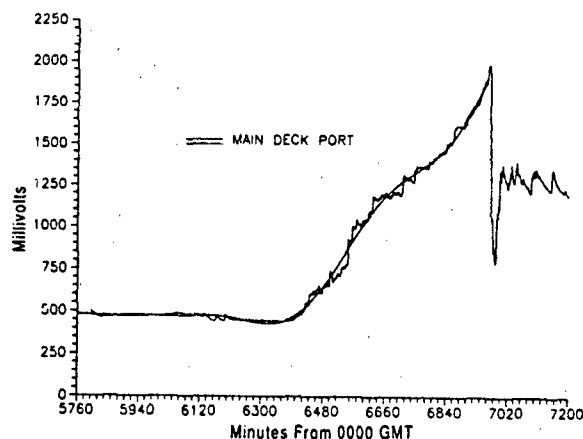


Figure D1. Main deck port unit, 9 February 1990.

Table D1. Polynomial fit statistics for main deck port unit, 9 February 1990.

Total points = 1440		Current data file: 1		X midpoint = 6380	
Points in fit interval = 1161		09FEB		X scale factor = 0.00344827586	
		Orthogonal		Recursion Factors	
Degree	Factors	Alpha		Beta	
0	901.388	0		0	
1	336.348	0		1.33563	
2	164.185	-6.87325E-017		1.06885	
3	-2.33138	9.00564E-017		1.03034	
4	-40.8347	6.24319E-018		1.01761	
5	8.20023	-3.76288E-016		1.01182	
6	33.296	2.87002E-016		1.0087	
7	8.14898	-1.20222E-017		1.00683	
8	-12.3482	-1.31348E-016		1.00561	
9	-7.99606	3.24561E-016		1.00477	
10	3.48147	-7.87857E-017		1.00416	

Total points = 1440		Current data file: 1		Fitting Interval Limits	
Points in fit interval = 1161		09FEB		5800 to 6960	
Degree	Sum of Squares of Residuals	Percent of Residuals about Mean Explained		Polynomial Coefficients	
0	2.26324E+008	0		9.94684E+013	
1	5.0897E+007	78		-1.53246E+011	
2	1232420	97		1.00962E+008	
3	6221480	97		-45289.5	
4	3367090	99		12.3451	
5	3248890	99		-0.00230589	
6	1283230	99		2.98899E-007	
7	1164680	99		-2.65494E-011	
8	890935	100		1.54632E-015	
9	775630	100		-5.33474E-020	
10	753676	100		8.27527E-025	

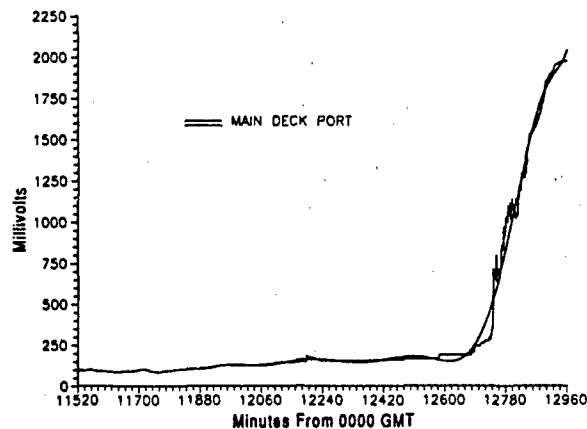


Figure D2. Main deck port unit, 13 February 1990.

Table D2. Polynomial fit statistics for main deck port unit, 13 February 1990.

Total points = 1440		Current data file: 1		X midpoint = 12419.5	
Points in fit interval = 1080		13FEB		X scale factor = 0.00370713624	
		Orthogonal		Recursion Factors	
Degree	Factors	Alpha	Beta		
0	414.53	0	0		
1	335.292	0	1.3358		
2	262.814	1.45909E-016	1.06864		
3	153.314	-6.65282E-017	1.03047		
4	34.7838	-8.72149E-017	1.01774		
5	-36.5628	1.19729E-016	1.01195		
6	-50.889	-5.47177E-016	1.00883		
7	-29.5643	3.46693E-016	1.00695		
8	-2.13003	-3.58547E-016	1.00573		
9	16.7378	-4.67567E-017	1.00489		
10	12.1643	3.46855E-016	1.00428		

Total points = 1440		Current data file: 1		Fitting Interval Limits	
Points in fit interval = 1080		13FEB		11880 to 12960	
Degree	Sums of Squares of Residuals	Percent of Residuals about Mean	Explained	Polynomial Coefficients	
0	3.18565E+008	0	0	5.02758E+017	
1	1.56379E+008	51	51	-4.0643E+014	
2	4.9889E+007	84	84	1.47835E+011	
3	1.25469E+007	96	96	-3.18622E+007	
4	1.05906E+007	97	97	4506.07	
5	8403320	97	97	-0.436933	
6	4128700	99	99	2.94186E-005	
7	2675940	99	99	-1.35807E-009	
8	2668350	99	99	4.11383E-014	
9	2197750	99	99	-7.38377E-019	
10	1948130	99	99	5.96313E-024	

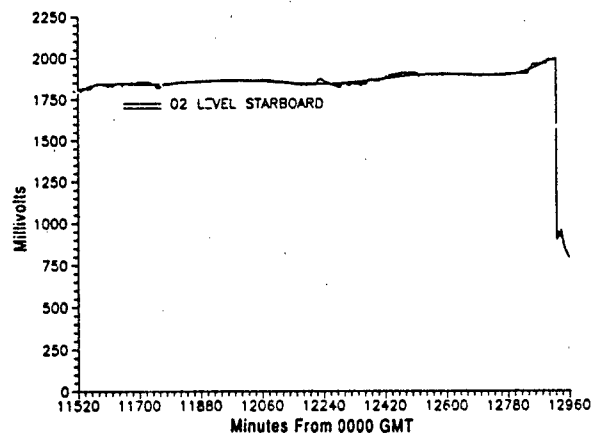


Figure D3. 02 Level starboard unit, 13 February 1990.

Table D3. Polynomial fit statistics for 02 level starboard unit, 13 February 1990.

Total points = 1440		Current data file: 1		X midpoint = 12210	
Points in fit interval = 1381		13FEB		X scale factor = 0.00289835072	
		Orthogonal		Recursion Factors	
Degree	Factors	Alpha		Beta	
0	1869.35	0		0	
1	23.1702	0		1.33527	
2	7.3597	-1.08855E-016		1.06821	
3	5.52179	3.71543E-016		1.03006	
4	-2.36155	-7.80935E-016		1.01734	
5	3.29304	9.87932E-016		1.01155	
6	6.77047	-1.05151E-015		1.00843	
7	5.44152	2.90207E-016		1.00656	
8	-3.68812	5.86689E-016		1.00534	

Total points = 1440		Current data file: 1		Fitting Interval Limits	
Points in fit interval = 1381		13FEB		11520 to 12900	
		Sum of Squares		Polynomial	
Degree	of Residuals	Percent of Residuals		Coefficients	
0	1487070	0		-9.38707E+012	
1	497099	67		6.13086E+009	
2	390405	74		-1751330	
3	328541	78		285.732	
4	317607	79		-0.0291399	
5	294964	80		1.901E-006	
6	198444	87		-7.74873E-011	
7	135687	91		1.80433E-015	
8	106704	93		-1.83761E-020	

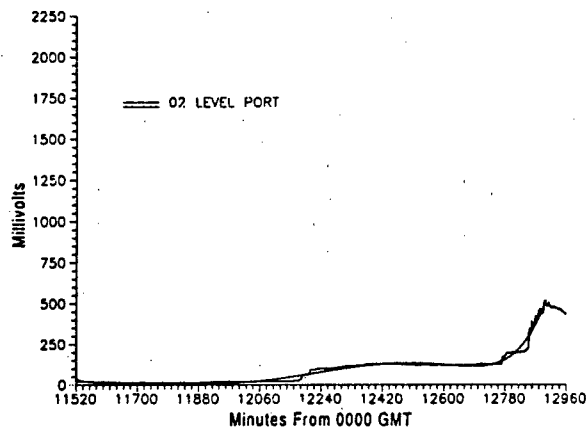


Figure D4. 02 Level port unit, 13 February 1990;

Table D4. Polynomial fit statistics for 02 level port unit, 13 February 1990.

Total points = 1440 Current data file: 1 X midpoint = 12210
 Points in fit interval = 1381 13FEB X scale factor = 0.00289855072

Degree	Orthogonal Factors	Alpha	Beta
0	85.2795	0	0
1	62.5968	0	1.33527
2	23.0434	-1.08855E-016	1.06821
3	7.809	3.71543E-016	1.03006
4	20.748	-7.80935E-016	1.01734
5	21.8471	9.87932E-016	1.01153
6	10.5954	-1.05151E-015	1.00843
7	1.22074	2.90207E-016	1.00656
8	1.51048	5.86689E-016	1.00534

Total points = 1440 Current data file: 1 Fitting Interval Limits
 Points in fit interval = 1381 13FEB 11520 to 12960

Degree	Sums of Squares of Residuals	PerCent of Residuals about Mean Explained	Polynomial Coefficients
0	1.07799E+007	0	3.63074E+012
1	3554460	67	-2.38624E+009
2	2503500	77	686104
3	2384770	79	-112.722
4	1496190	86	0.0115743
5	499592	93	-7.60576E-007
6	263208	98	3.12362E-011
7	260049	98	-7.33036E-016
8	255108	98	7.52595E-021

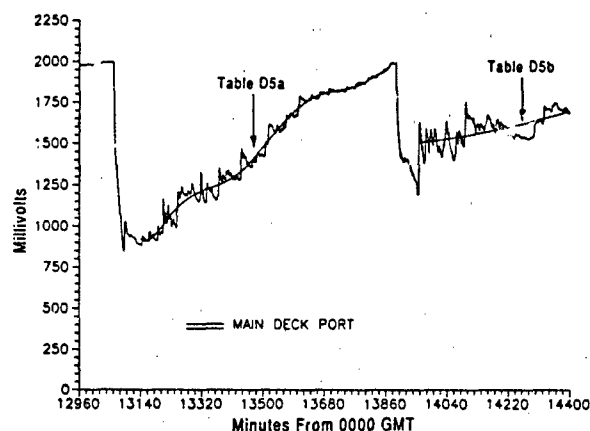


Figure D5. Main deck port unit, 14 February 1990.

Table D5. Polynomial fit statistics for main deck port unit, 14 February 1990.

a.

Total points = 1440			
Points in fit interval = 721			
Current data file: 1			
14FEB			
X midpoint = 13500			
X scale factor = 0.003555555556			
Orthogonal Factors			
Recursion Factors			
Degree	Alpha	Beta	
0	1476.28	0	0
1	275.711	0	1.33704
2	-19.8852	6.54154E-017	1.06962
3	-18.663	-2.3257E-016	1.03141
4	-10.1327	4.94402E-016	1.01267
5	18.2031	-7.57528E-016	1.01286
6	10.4578	1.00369E-015	1.00972
7	-11.741	-5.77175E-016	1.00783

Total points = 1440			
Points in fit interval = 721			
Current data file: 1			
14FEB			
Fitting Interval Limits			
13140 to 13860			
Degree	Sum of Squares of Residuals	Percent of Residuals about Mean Explained	Polynomial Coefficients
0	7.58008E+007	0	1.53359E+014
1	2520630	97	-8.20078E+010
2	2112900	97	1.81995E+007
3	1742470	98	-2243.68
4	1631240	98	0.165952
5	1267630	98	-7.36421E-006
6	1146480	98	1.81537E-010
7	992548	99	-1.91778E-015

b.*

Total points = 1440			
Points in fit interval = 440			
Current data file: 2			
14FEB			
Fitting Interval Limits			
13960 to 14396			
Degree	Sum of Squares of Residuals	Percent of Residuals about Mean Explained	Polynomial Coefficients
0	3183760	0	81907.9
1	1813790	43	-11.7694
2	1798810	44	0.000430503

* Orthogonal factors not needed for second degree polynomial.

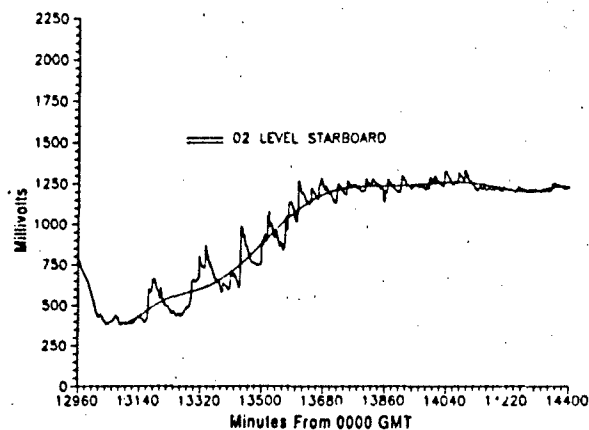


Figure D6. 02 Level starboard unit, 14 February 1990.

Table D6. Polynomial fit statistics for 02 level starboard unit, 14 February 1990.

Total points = 1440		Current data file: 1		X midpoint = 13749.5	
Points in fit interval = 1300		14FEB		X scale factor = 0.00307929176	
		Orthogonal		Recursion Factors	
Degree	Factors	Alpha		Beta	
0	1014.84	0		0	
1	220.454	0		1.33539	
2	-108.059	8.28829E-017		1.06831	
3	-11.3062	-2.17425E-016		1.03015	
4	35.0741	2.52902E-016		1.01743	
5	-1.93661	-2.3212E-016		1.01164	
6	-12.7114	1.35375E-016		1.00852	
7	14.6491	1.21617E-016		1.00663	
8	1.8798	-3.52359E-016		1.00543	
9	-9.74736	5.87633E-016		1.00459	

Total points = 1440		Current data file: 1		Fitting Interval Limits	
Points in fit interval = 1300		14FEB		13100 to 14400	
		Sums of Squares		Polynomial	
Degree	of Residuals	PerCent of Residuals		Coefficients	
0	1.14316E+008	0		4.25372E+015	
1	2.99461E+007	74		-2.78658E+012	
2	8290710	93		8.11208E+008	
3	8046490	93		-137734	
4	5655250	95		15.0314	
5	5647870	95		-0.00109243	
6	5327430	95		3.38196E-008	
7	4899020	96		-1.65241E-012	
8	4894010	96		3.00371E-017	
9	4702430	96		-2.4263E-022	

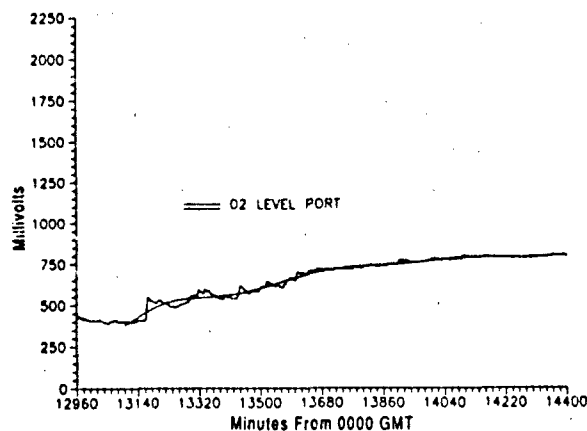


Figure D7. O2 Level port unit, 14 February 1990.

Table D7. Polynomial fit statistics for O2 level port unit, 14 February 1990.

Total points = 1440		Current data file: 1		X midpoint = 13749.5	
Points in fit interval = 1300		14FEB		X scale factor = 0.00307929176	
		Orthogonal		Recursion Factors	
Degree	Factors	Alpha		Beta	
0	676.179	0		0	
1	95.2221	0		1.33539	
2	-27.361	8.28829E-017		1.06631	
3	-1.64187	-2.17475E-016		1.03015	
4	0.636838	2.52902E-016		1.01743	
5	5.5995	-2.3212E-016		1.01164	
6	-6.28902	1.52375E-016		1.00852	
7	4.22817	1.21817E-016		1.00645	
8	2.49404	-3.52359E-016		1.00543	
9	-3.69007	5.87633E-016		1.00459	
10	-0.380555	-7.92849E-016		1.00399	

Total points = 1440		Current data file: 1		Fitting Interval Limits	
Points in fit interval = 1300		14FEB		13100 to 14400	
		Sums of Squares		Polynomial	
Degree	of Residuals	Percent of Residuals		Coefficients	
0	1.77113E+007	0		-5.37628E+013	
1	1970380	89		4.03471E+012	
2	582187	97		-1.36107E+009	
3	577037	97		2.71803	
4	576249	97		-35.3852	
5	514592	97		0.00319167	
6	436154	98		-1.98616E-007	
7	409464	98		8.468E-012	
8	387979	98		-2.36733E-016	
9	360522	98		3.91878E-021	
10	360229	98		-2.91893E-026	

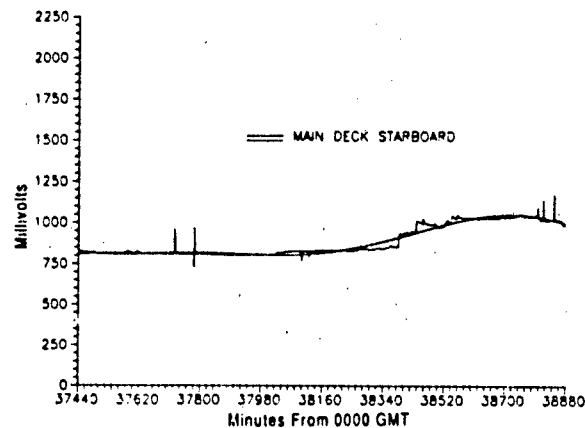


Figure D8. Main deck starboard unit, 3 March 1990.

Table D8. Polynomial fit statistics for main deck starboard unit, 3 March 1990.

Total points = 1440		Current data file: 1	Fitting Interval Limits
Points in fit interval = 1440		03MAR	12960 to 38879
Degree	Sums of Squares of Residuals	PerCent of Residuals about Mean Explained	Polynomial Coefficients
0	1.30979E+007	0	3.98747E+012
1	3253370	75	-9.39893E+008
2	1659010	87	61471.7
3	1359190	90	-2.1441
4	626894	95	4.20639E-005
5	568710	96	-4.48093E-010
6	530753	96	1.91843E-015

Total points = 1440		Current data file: 1	X midpoint = 38759.5
Points in fit interval = 1440		03MAR	X scale factor = 0.00277970813
Degree	Orthogonal Factors	Alpha	Beta
0	886.113	0	0
1	71.5557	0	1.33519
2	27.8628	5.86678E-017	1.06815
3	-11.9054	-6.74666E-017	1.03
4	-18.4475	-6.71813E-018	1.01728
5	-5.17029	-2.82322E-016	1.01149
6	4.15863	5.64758E-016	1.00838

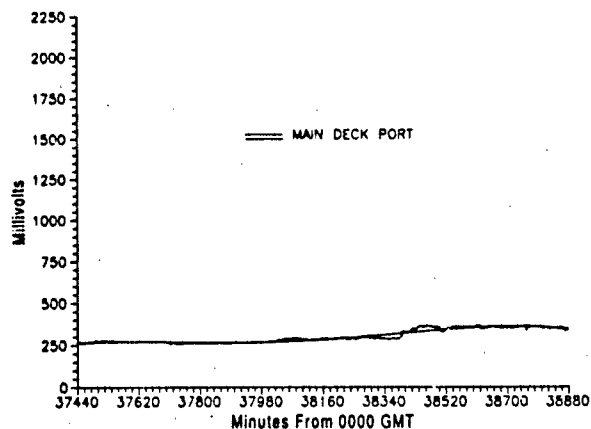


Figure D9. Main deck port unit, 3 March 1990.

Table D9. Polynomial fit statistics for main deck port unit, 3 March 1990.

Total points = 1440		Current data file: 1		X midpoint = 38159.5	
Points in fit interval = 1440		03MAR		X scale factor = 0.00277970813	
		Orthogonal		Recursion Factors	
Degree	Factors	Alpha		Beta	
0	301.816	0		0	
1	29.7743	0		1.33519	
2	7.92612	5.86678E-017		1.06815	
3	-6.93161	-6.74666E-017		1.03	
4	-5.50438	-6.71813E-018		1.01728	
5	-0.181603	-2.82322E-016		1.01149	

Total points = 1440		Current data file: 1		Fitting Interval Limits	
Points in fit interval = 1440		03MAR		37440 to 38879	
		Sums of Squares		Polynomial	
Degree	of Residuals	Percent of Residuals		Coefficients	
0	2144190	0		1.74935E+007	
1	439721	79		-247070	
2	310701	86		13.8907	
3	209067	90		-0.000388829	
4	143870	93		5.42169E-009	
5	143798	93		-3.01384E-014	

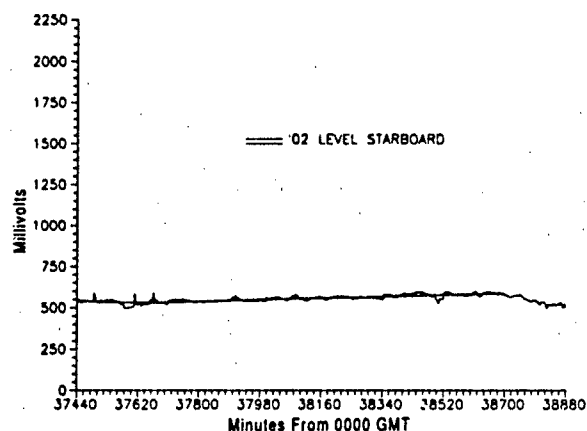


Figure D10. 02 Level starboard unit, 3 March 1990.

Table D10. Polynomial fit statistics for 02 level starboard unit, 3 March 1990.

Total points = 1446		Current data file: 1		X midpoint = 38070	
Points in fit interval = 1261		03MAR		X scale factor = 0.00317460317	
	Orthogonal		Recursion Factors		
Degree	Factors	Alpha	Beta		
0	335	0	0		
1	15.4899	0	1.33545		
2	1.80152	1.74049E-017	1.06836		
3	-1.78751	-2.86331E-017	1.0302		
4	-1.41935	-4.79203E-017	1.01748		
5	-1.25081	1.4506E-016	1.01169		

Total points = 1440		Current data file: 1		Fitting Interval Limits	
Points in fit interval = 1261		03MAR		37440 to 38700	
	Sums of Squares		Percent of Residuals		Polynomial
Degree	of Residuals		about Mean Explained		Coefficients
0	569810	0			3.25478E+010
1	183756	71			-4267130
2	139917	72			223.769
3	133995	73			-0.00586709
4	130195	74			7.69141E-008
5	147210	74			-4.03309E-013

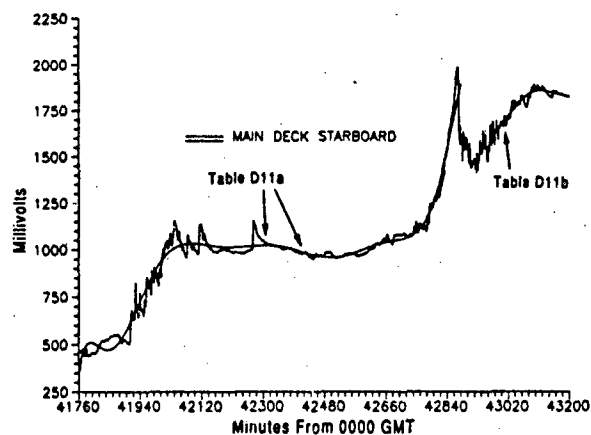


Figure D11. Main deck starboard unit, 6 March 1990.

Table D11. Polynomial fit statistics for main deck starboard unit, 6 March 1990.

a.

Total points = 1440		Current data file: 3	Fitting Interval Limits
Points in fit interval = 1121		06MAR	41760 to 42880
Degree	Sums of Squares of Residuals	PerCent of Residuals about Mean Explained	Polynomial Coefficients
0	7.46752E+007	0	5.33679E+059
1	2.95802E+007	60	1.0805E-169
2	2.90686E+007	61	1.4844E-312
3	8274860	89	1.0805E-169
4	5635290	92	1.4844E-312
5	5635270	92	7.44821E-304
6	3281180	96	1.89721E-320
7	3280490	96	2.07125E-317
8	3280390	96	2.07024E-317
9	3043170	96	1.16186E-086
10	2368920	97	2.26502E-317

Total points = 1440		Current data file: 1	X midpoint = 42320
Points in fit interval = 1121		06MAR	X scale factor = 0.00357142857
Degree	Orthogonal Factors	Alpha	Beta
0	968.145	0	0
1	173.542	0	1.33571
2	-17.8826	3.4404E-017	1.06837
3	112.386	4.21863E-017	1.0384
4	39.6641	4.52534E-017	1.01767
5	-0.0988627	-2.541E-017	1.01189
6	37.0751	-1.46484E-016	1.00876
7	0.632189	-1.65956E-017	1.00688
8	0.243888	2.47232E-017	1.00566
9	11.6675	3.68759E-016	1.00482
10	-19.6294	-6.72813E-016	1.00422

Table D11 (cont'd). Polynomial fit statistics for main deck starboard unit, 6 March 1990.

b.

Total points = 1440		Current data file: 2	Fitting Interval Limits
Points in fit interval = 240		06MAR	42960 to 43199
Degree	Sums of Squares of Residuals	PerCent of Residuals about Mean Explained	Polynomial Coefficients
0	2017540	0	-4.04982E+017
1	660556	67	5.63902E+013
2	172596	91	-3.27159E+009
3	172478	91	101231
4	168529	92	-1.76193
5	164433	92	1.63555E-005
6	161280	92	-6.32597E-011

Total points = 1440		Current data file: 2	X midpoint = 43079.5
Points in fit interval = 240		06MAR	X scale factor = 0.0167364017
Degree	Orthogonal Factors	Alpha	Beta
0	1780.05	0	0
1	64.8469	0	1.34449
2	-37.4969	-4.40404E-017	1.07554
3	0.573467	5.11842E-017	1.03703
4	3.27333	-1.48069E-016	1.02411
5	3.30267	3.85556E-017	1.01813
6	-2.87842	2.84018E-016	1.0148

Table D12. Polynomial fit statistics for main deck port unit, 6 March 1990.

a.

Total points = 1440		Current data file: 1	X midpoint = 42320
Points in fit interval = 1121		06MAR	X scale factor = 0.00357142857
Degree	Orthogonal Factors	Alpha	Beta
0	365.663	0	0
1	170.733	0	1.33571
2	115.204	3.4404E-017	1.06857
3	112.104	4.21883E-017	1.0304
4	67.8982	4.52534E-017	1.01767
5	27.0816	-2.541E-017	1.01189
6	27.2672	-1.46484E-016	1.00876
7	12.0371	-1.65956E-017	1.00688
8	-0.306615	2.47232E-017	1.00566
9	0.462808	3.68759E-016	1.00482

Total points = 1440		Current data file: 1	Fitting Interval Limits
Points in fit interval = 1121		06MAR	41760 to 42880
Degree	Sums of Squares of Residuals	PerCent of Residuals about Mean Explained	Polynomial Coefficients
0	9.75542E+007	0	-1.91475E+019
1	5.39072E+007	45	4.06938E+015
2	3.26719E+007	67	-3.84387E+011
3	1.19533E+007	88	2.11805E+007
4	4218140	96	-750.283
5	2973000	97	0.0177187
6	1699490	98	-2.7897E-007
7	1449850	99	2.82361E-012
8	1449680	99	-1.66716E-017
9	1449290	99	4.37501E-023

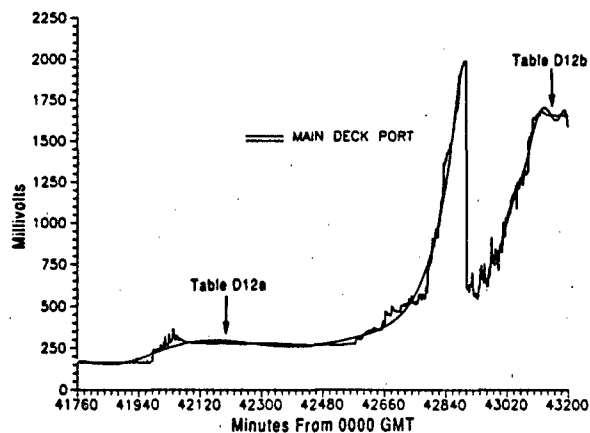


Figure D12. Main deck port unit, 6 March 1990.

Table D12 (cont'd). Polynomial fit statistics for main deck port unit, 6 March 1990.

b.

Total points = 1440		Current data file: 2	X midpoint = 43079.5	
Points in fit interval = 240		06MAR	X scale factor = 0.0167364017	
Orthogonal		Recursion Factors		
Degree	Factors	Alpha	Beta	
0	1321.43	0	0	
1	288.278	0	1.34449	
2	-75.2927	-4.40404E-017	1.07354	
3	-36.9751	5.11842E-017	1.03703	
4	8.58396	-1.46069E-016	1.02411	
5	17.9347	3.85556E-017	1.01813	
6	3.32435	2.84018E-016	1.0148	
7	-5.97245	-4.29141E-016	1.01269	
8	-17.6204	4.23762E-016	1.01122	

Total points = 1440		Current data file: 2		Fitting Interval Limits	
Points in fit interval = 240		06MAR		42960 to 43199	
		Sums of Squares		Polynomial	
Degree	of Residuals	Percent of Residuals		Coefficients	
0	2.9982E+007	0		-1.28607E+024	
1	3166070	89		2.38843E+020	
2	1198440	96		-1.9406E+016	
3	706590	98		9.08996E+011	
4	477935	98		-2.6145E+007	
5	359231	98		485.55	
6	355022	98		-0.00563585	
7	541266	98		3.73806E-008	
8	420186	99		-1.08471E-013	

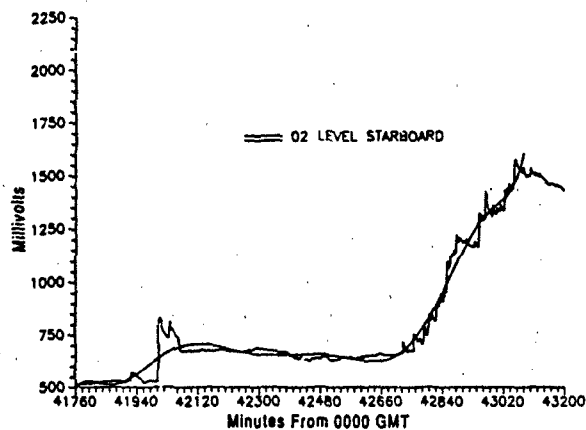


Figure D13. 02 Level starboard unit, 6 March 1990.

Table D13. Polynomial fit statistics for 02 level starboard unit, 6 March 1990.

Total points = 1440		Current data file: 1		X midpoint = 42420	
Points in fit interval = 1321		06MAR		X scale factor = 0.00303030303	
		Orthogonal		Recursion Factors	
Degree	Factors	Alpha		Beta	
0	764.319	0		0	
1	174.82	0		1.33535	
2	101.267	-7.78393E-017		1.06828	
3	86.6117	1.82708E-016		1.03013	
4	4.08265	1.83015E-018		1.0174	
5	-29.4833	-1.06132E-016		1.01162	
6	-8.69627	6.04582E-017		1.0085	
7	-9.327	-1.82639E-018		1.00462	
8	7.92578	-1.05096E-017		1.00341	
9	17.7469	-5.22653E-017		1.00457	

Total points = 1440		Current data file: 1		Fitting Interval Limits	
Points in fit interval = 1321		06MAR		41760 to 43080	
		Sums of Squares		Polynomial	
Degree	of Residuals	Percent of Residuals		Coefficients	
0	9.28977E+007	0		-1.69488E+020	
1	3.89862E+007	58		3.59606E+016	
2	1.96612E+007	79		-1.39258E+012	
3	5096570	95		1.867E+008	
4	5066050	95		-6604.89	
5	3329300	96		0.185772	
6	3176920	97		-2.44915E-006	
7	3000400	97		2.47542E-011	
8	2872360	97		-1.43946E-016	
9	2227020	98		3.82425E-022	

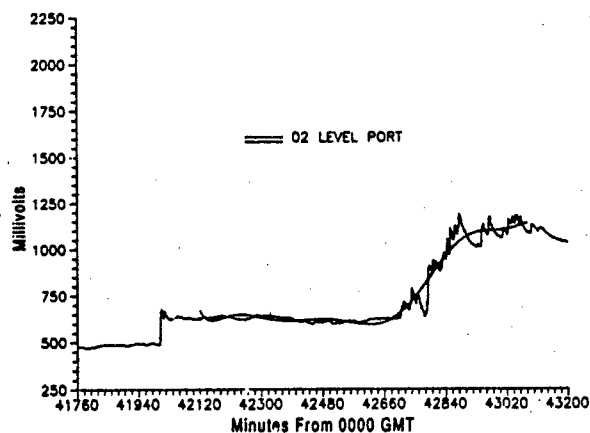


Figure D14. 02 Level port unit, 6 March 1990.

Table D14. Polynomial fit statistics for 02 level port unit, 6 March 1990.

Total points = 1440		Current data file: 1		X midpoint = 42600	
Points in fit interval = 961		06MAR		X scale factor = 0.00416666667	
		Orthogonal		Recursion Factors	
Degree	Factors	Alpha	Beta		
0	762.78	0	0		
1	144.524	0	1.33611		
2	79.3545	-4.56539E-017	1.05889		
3	-5.32057	2.71802E-017	1.03671		
4	-37.4039	-2.61193E-016	1.01797		
5	-14.5037	4.19412E-016	1.01218		
6	10.0308	-4.09491E-016	1.00905		
7	14.5226	4.20311E-016	1.00717		
8	3.88636	-6.18783E-016	1.00594		
9	-8.86232	5.91284E-016	1.0051		

Total points = 1440		Current data file: 1		Fitting Interval Limits	
Points in fit interval = 961		06MAR		42120 to 43080	
		Sums of Squares		Polynomial	
Degree	of Residuals	Percent of Residuals		Coefficients	
0	3.98535E+007	0		1.35337E+021	
1	1.30361E+007	47		-3.2811E+017	
2	4349940	89		3.0802E+013	
3	4305900	89		-1.68675E+009	
4	2295020	94		59378.8	
5	1795730	95		-1.39334	
6	1612500	95		2.18027E-005	
7	1509090	96		-2.19287E-010	
8	1477580	96		1.28655E-015	
9	1359940	97		-3.35472E-021	

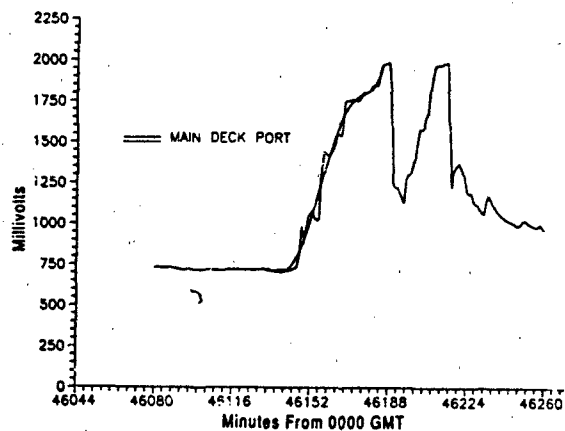


Figure D15. Main deck port unit, 9 March 1990.

Table D15. Polynomial fit statistics for main deck port unit, 9 March 1990.

Total points = 181		Current data file: 1		X midpoint = 46157.5	
Points in fit interval = 56		09MAR		X scale factor = 0.0727272727	
		Orthogonal		Recursion factors	
Degree	Factors	Alpha		Beta	
0	1269.2	0		0	
1	379.718	0		1.33162	
2	10.3424	4.59115E-017		1.1044	
3	-71.5622	0		1.06325	
4	14.6932	0		1.04778	
5	24.3458	3.73156E-017		1.03882	
6	-0.0358921	-1.79606E-016		1.03196	

Total points = 181		Current data file: 1		Fitting Interval Limits	
Points in fit interval = 56		09MAR		46130 to 46185	
		Sums of Squares		Polynomial	
Degree	of Residuals	PerCent of Residuals		Coefficients	
0	1.18579E+007	0		-9.03575E+019	
1	700536	94		1.15208E+016	
2	691394	94		-6.11819E+011	
3	226057	98		1.73217E+007	
4	203506	98		-275.74	
5	146884	99		0.00234002	
6	146884	99		-8.27035E-009	

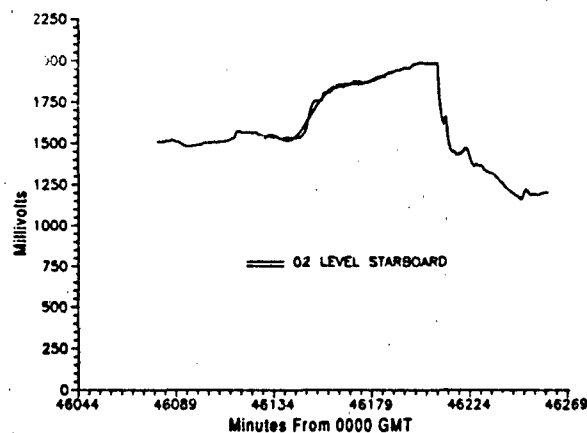


Figure D16. 02 Level starboard unit, 9 March 1990.

Table D16. Polynomial fit statistics for 02 level starboard unit, 9 March 1990.

Total points = 181		Current data file: 1	Fitting Interval Limits
Points in fit interval = 56		09MAR	46130 to 46185
	Sums of Squares of Residuals	Percent of Residuals about Mean Explained	Polynomial Coefficients
Degree			
0	1254260	0	-1.36232E+022
1	147397	88	2.02105E+018
2	129644	90	-1.10003E+016
3	70047.9	94	3.17751E+009
4	36905.7	97	-81628.7
5	31807.5	97	0.447399
6	19713.4	98	-1.61543E-006

Total points = 181		Current data file: 1	X midpoint = 46157.3
Points in fit interval = 56		09MAR	X scale factor = 0.0727272727
	Orthogonal Factors	Alpha	Beta
Degree			
0	1730.03	0	0
1	119.599	0	1.38182
2	-14.4127	4.59115E-017	1.1044
3	-25.61	0	1.06325
4	10.6351	0	1.04778
5	7.17971	3.73156E-017	1.03082
6	-10.917	-1.79606E-016	1.03196

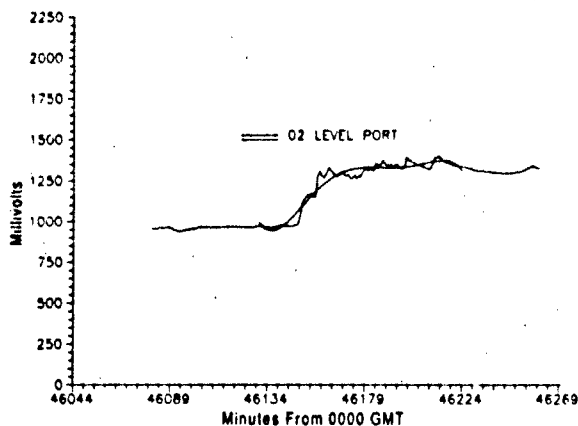


Figure D17. O2 Level port unit, 9 March 1990.

Table D17. Polynomial fit statistics for O2 level port unit, 9 March 1990.

Total points = 181		Current data file: 1	Fitting Interval Limits
Points in fit interval = 98		09MAR	46130 to 46224
Degree	Sum of Squares of Residuals	PerCent of Residuals about Mean Explained	Polynomial Coefficients
0	2888790	0	3.51818E+017
1	554120	73	-3.9746E+013
2	188000	91	2.38751E+009
3	156760	91	-36030.5
4	158937	92	0.606648
5	103073	93	-2.6273E+006

Total points = 181		Current data file: 1	X midpoint = 46177
Points in fit interval = 98		09MAR	X scale factor = 0.0423331913
Degree	Orthogonal Factors	Alpha	Beta
0	1240.58	0	0
1	100.919	0	1.3617
2	-50.9709	0	1.009
3	2.90323	1.26093E-017	1.04932
4	13.4791	-2.40289E-017	1.03576
5	-10.8299	9.2797E-017	1.02805

APPENDIX E: FORTRAN PROGRAM ORTHFLUX. FOR WITH SAMPLES OF INPUT AND OUTPUT FILES

The program begins by initializing double precision variables and character variables, and establishing a data array for generating daily spray flux file names. Input file MVASC.TXT, output file HRSPY.PLT and intermediate file FIXED.TXT are opened. MVASC.TXT is a time-series by minute file of the eight tank voltages in millivolts, written in free-format. MVASC.TXT is post-processed data logger output from the spray collectors consisting of minute averages of 12-second voltage readings from each tank (Walsh et al. 1992). MVASC.TXT is rewritten to FIXED.TXT in fixed format for easier processing. HRSPY.PLT is the destination of hourly spray flux computed within the program for later plotting.

Several flags are set next, and the first minute of recorded data is read from FIXED.TXT. If this minute is the first of a new hour, the sum of fluxes computed from the previous hour is written to HRSPY.PLT. The time in minutes is then computed, and the program determines if there has been a break in the data. The time in minutes is the number of minutes starting from 0000Z on 5 February. The ship departed Alameda, California, at about 2300Z on 5 February.

A break in the data is important because the current minute's tank voltage is compared to the previous minute's tank voltage to compute a change of voltage and spray flux. If the data are broken from downloading procedures, instrument downtime or subfreezing conditions, variable IFLAG is set to prevent computation of hourly sums and the baseline voltage is set to the current voltage to compute no voltage change. Voltages that have been established as unreliable are then set as missing, 9999.0, by time and collector.

The 20 polynomial fits to noisy horizontal collector data are now used to compute the current minute tank voltage in millivolts. If the current data minute for a given collector fit falls within the range of minutes for a given collector's polynomial fit curve, the orthogonal and recursive factors ALPHA, BETA, B, XFIT, XSCALE and XMID are read from the program and used by subroutine ORTHPOLY to compute the voltage. An explanation of ORTHPOLY is in the Grapher program manual (Golden Software Inc. 1988). ALPHA, BETA, B, XFIT, XSCALE and XMID are read from the program rather than from a data file because it was more efficient at the time the program was written.

Minute-to-minute voltage changes are computed in the following way. If voltage has increased from the previous minute, the difference in voltage is computed. If voltages have decreased, perhaps because of slight noise in the data, voltage change is set to zero. For the CRREL collectors, if voltages are less than 130 mV, or greater than 2100 mV, the voltage change is set as missing, 9999.0, because the tank voltage is out of range. If the Young voltages are less than 130 mV or greater than 2400 mV, voltage change is set to 9999.0. If voltages are missing for any unit for the current minute, voltage change is set to 9999.0.

The baseline reference voltage for computing voltage change to the next minute is set several ways. If the current voltage is greater than the previous minute's voltage, the baseline reference voltage variable AH equals the current minute's voltage. If current voltage is less than the previous minute's voltage by less than 25 mV, the new baseline reference voltage equals the current minute's voltage, the assumption being that the decrease may have been minor noise. This minor noise could greatly exaggerate the flux computed for the following minute if the following minute exhibited no noise, or noise in the opposite direction. The overall goal was to compute conservative voltage changes, and thus fluxes, if noise produced problems.

Larger decreases in voltage for the current minute from the previous minute were also dealt with conservatively. If the current voltage was 26 to 100 mV less than the previous voltage, the new baseline voltage was computed as 25% of the actual decrease. Although arbitrary, this was again done to minimize exaggeration of fluxes from data noise. This procedure underestimates spray flux, which we considered more acceptable than overestimating. Finally, if the current minute's voltage was more than 100 mV lower than the previous minute's, a drainage cycle was assumed to be happening and the current minute's voltage became the new baseline voltage.

Voltage changes per minute were converted to spray flux from the relationship between the change in voltage and the change in tank water volume necessary to cause the voltage changes. The CRREL collector voltages increased 0.215 mV/cm³ increase of water volume. The Young units changed 1000 mV/cm of precipitated water depth. Included in the flux computations were the area of the CRREL

vertical (0.0342 m^2) and horizontal (0.0856 m^2) collector openings and sea water density. All fluxes were computed in $\text{kg}/\text{m}^2 \text{ min}$. If voltage changes were missing (9999.0), flux was set equal to 9999.0. Minute fluxes were added to the hourly sum, or written to a file of minute fluxes ('DATE'.FLX). The following minute's voltage was then read from FIXED.TXT, and the entire process repeated. The program manages its files when minute fluxes are written to daily files. As days change, files are opened and closed for those days. The result is one file of spray flux for each day of spray data; however, the data file represents 24 consecutive hours of Julian time (GMT) rather than local clock time.

ORTHFLUX.FOR requires considerable modification for use on a ship with different cruise dates, numbers of collectors and types of collectors. See the following for suggested changes.

Definition of variables used in FORTRAN programs

Variable list

NWMO = Month number (GMT).
 NWDA = Day of month (GMT).
 NWHR = Hour of day on 24-hour clock (GMT).
 NWMIN = Minute of hour (GMT).
 COURSE = Ship heading in degrees azimuth.
 SPEED = Ship speed in knots.
 WD = True wind direction in azimuth.
 WS = True wind speed in knots.
 RWD = Relative wind direction in azimuth (relative to ship bow).
 RWV = Relative wind velocity in knots (relative to ship bow).
 PR = Air pressure in inches of mercury.
 DB = Dry bulb temperature in degrees Fahrenheit.
 WB = Wet bulb temperature in degrees Fahrenheit.
 WAVED = Wave direction (from which coming) in azimuth.
 WAVEH = Wave height in feet.
 SWELLD = Swell direction (from which coming) in azimuth.
 SWELLH = Swell height in feet.
 MSG = Warning message about spray flux calculation corrections for horizontal collectors using relative wind.
 LAT = Latitude in degrees, minutes and tenths of minute.

LONG = Longitude in degrees, minutes and tenths of minute.

WTEMP = Sea water temperature in degrees Celsius.

WSALIN = Sea water salinity in ppt.

NWMO, NWDA, NWHR, NWMIN = 24-hour clock = All GMT.

COURSE (AZIMUTH)—recorded when change occurs and on the 1/2 hour.

SPEED (KNOTS)—recorded when change occurs and on the 1/2 hour.

WD AND WS = Quartermasters converted relative wind to actual wind with calculator. Anemometer is an aerovane or similar, located on port yardarm on forward mast.

RWD AND RWV—azimuth—relative wind as computed from ship's course and speed and true wind direction and speed. (Late in the cruise RWD was estimated by the quartermasters because the readout dial failed in the bridge.)

Variable descriptions

PR = Air pressure. Measured with a standard aneroid barograph on the bridge. The ship's log indicates that pressure has been corrected to sea level. Recorded in inches of mercury hourly.

DB = Dry bulb temperature. Measured with a mercurial thermometer located on the starboard bridge wing about 0.5 m above the main deck. Recorded hourly.

WB = Wet bulb temperature. Measured initially with a mercurial thermometer in the same shelter as the dry bulb thermometer.

WAVED, WAVEH, SWELLD, SWELLH = Wave direction, wave height, swell direction, swell height. Estimated by quartermasters. Recorded hourly.

MSG = "FLUX NOT WIND CORRECTED" appears if relative wind could not be computed. The horizontal collectors (A,B,D,E) must be corrected for wind speed because their efficiency of collecting droplets decreases as wind speed increases. At a relative wind speed of 54 kn, spray flux could be underestimated by over 41% without this correction. Horizontal collector values are not to be trusted when this message appears. Where data are available, corrections have been made to the fluxes.

LAT, LONG = Latitude and longitude of ship from SATNAV in degrees, minutes and tenths of minutes. Recorded irregularly.

WTEMP = Sea water temperature in degrees Celsius. Readings were made by CRREL

onboard ship. Water temperatures in the logs were estimated by quartermasters from engine coolant inlets and are 1-4 degrees too high. CRREL temperature was measured with an accurate electronic thermometer. Water samples were from the surface, recorded as needed.

WSALIN = Water salinity at the surface measured from the water samples used to obtain water temperature.

A = Main deck starboard spray collector—horizontal flux—available by minute.

B = Main deck port spray collector—horizontal flux—available by minute.

C = 01 Level spray collector—vertical flux—available by minute.

D = 02 Level starboard spray collector—horizontal flux—available by minute.

E = 02 Level port spray collector—horizontal flux—available by minute.

F = Flying bridge collector—vertical flux—available by minute.

Program listing

```

FORTRAN PROGRAM ORTHFLUX.FOR

C PROGRAM ORTHFLUX.FOR COMPUTES MINUTE AND
C HOURLY FLUXES. HORIZONTAL UNITS NOT CORRECTED
C FOR WIND SPEED.
C
C UNIT IDENTIFICATION:
C A(1) - MAIN DECK STARBOARD - CRREL HORIZONTAL COLLECTOR
C A(2) - MAIN DECK PORT - CRREL HORIZONTAL COLLECTOR
C A(3) - 01 DECK - CRREL VERTICAL COLLECTOR
C A(4) - 02 DECK - STARBOARD - CRREL HORIZONTAL COLLECTOR
C A(5) - 02 DECK - PORT - CRREL HORIZONTAL COLLECTOR
C A(6) - FLYING BRIDGE - CRREL VERTICAL COLLECTOR
C A(7) - 01 DECK - YOUNG VERTICAL COLLECTOR
C A(8) - FLYING BRIDGE - YOUNG VERTICAL COLLECTOR
C

*****INITIALIZE VARIABLES

DOUBLE PRECISION A(8), AH(8), AD(8), AF(8), AHRF(8)
*,ALPHA(11),BETA(11),B(11),XMD,XSCALE,X
CHARACTER*9 OUTFIL
CHARACTER*2 IDAA(31)
DATA IDAA /'01','02','03','04','05','06',
*'07','08','09','10','11','12','13','14',
*'15','16','17','18','19','20','21','22',
*'23','24','25','26','27','28','29','30','31'/
C

*****OPEN FILES

C INPUT FILES
OPEN(5,FILE='MVASC.TXT')
C
C OUTPUT FILES
OPEN(6,FILE='FIXED.TXT')
OPEN(8,FILE='HRSPY.PLT')
C
C CREATE FILE OF FIXED FORMATS.
C
GO TO 88
ICNT = 0

*****READ FREE FORMAT VOLTAGE FILE MVASC.TXT

32 READ(5,*,END=33) IDAY,ITIME,IA,IB,IC,ID,IE,IF,IG,IH
ICNT = ICNT + 1

*****WRITE FIXED FORMAT VOLTAGE FILE FILE FIXED.TXT

WRITE(6,10) IDAY,ITIME,IA,IB,IC,ID,IE,IF,IG,IH
10 FORMAT(1X,I2,1X,I4,8(1X,I5))
GO TO 32
33 CLOSE (5)
88 REWIND 6
C
C CHECK FOR PROPER SEQUENCE MINUTE BY MINUTE
C ENABLING VOLTAGES FROM PREVIOUS MINUTES TO BE

```

```

C COMPARED TO CURRENT MINUTE.
C
  IDAPRE = 00
  IPRESQ = 1
  IPREHR = 1
  IFLAG = 1
  IHRFL = 1
  GO TO 36
35 IFLAG = 0

*****READ MINUTE OF VOLTAGES FROM FILE FIXED.TXT

36 READ(6,11,END=100) IDAY, IHR, MIN, (A(J), J=1, 8)
11 FORMAT(1X, I2, 1X, 2I2, 8(1X, F5.0))

*****IF NEW HOUR - PRINT TO HRSPY.PLT

  IHRSEQ = ((IDAY-36)*24)+IHR
  IF(IHRSEQ.EQ.(IPREHR+1)) GO TO 45
46 IPREHR = IHRSEQ

*****COMPUTE JULIAN MINUTE AND DETERMINE IF TIME INTERRUPTED

  JULIAN = ((IDAY-36)*1440)+(IHR*60)+MIN
  IF(JULIAN.NE.(IPRESQ+1)) IFLAG = 1
  IF(IFLAG.EQ.1) IHRFL = 1
  IPRESQ = JULIAN
  IF(IFLAG.EQ.0) GO TO 37

*****TIME BREAK - RESET BASELINE VOLTAGE TO CURRENT VOLTAGE

  DO 38 L=1, 8
  IF(A(L).LE.0.0) A(L) = 0.0
  AH(L) = A(L)
38 CONTINUE

C
C COMPUTE MINUTE FLUXES.
C FLUX COMPUTED FROM VOLTAGE INCREASES ABOVE LAST
C MAXIMUM VOLTAGE.
C REMOVE PERIODS WHEN DATA ARE UNRELIABLE.
C CRREL UNITS - 2100 MV MAX, 130 MV MIN
C YOUNG UNITS - ? NOISE, 2400 MV MAX, 130 MV MIN
C
C ESTABLISH PERIODS OF DATA TO USE FOR EACH INSTRUMENT DURING
C 1990 MIDGETT CRUISE

*****SET ALL UNRELIABLE DATA TO MISSING - 9999.0

C
37 IF(JULIAN.GE.6440) A(1) = 9999.0
  IF(JULIAN.GE.4300) A(2) = 9999.0
  IF(JULIAN.GE.7200.AND.JULIAN.LE.41760) A(3) = 9999.0
  IF(JULIAN.GE.46800) A(3) = 9999.0
  IF(JULIAN.GE.7200) A(4) = 9999.0
  IF(JULIAN.GE.7200) A(5) = 9999.0
  IF(JULIAN.GE.8640.AND.JULIAN.LE.11520) A(6) = 9999.0
  IF(JULIAN.GE.15840.AND.JULIAN.LE.41760) A(6) = 9999.0
  IF(JULIAN.GE.46800) A(6) = 9999.0
  IF(JULIAN.GE.8640.AND.JULIAN.LE.11520) A(7) = 9999.0
  IF(JULIAN.GE.15840.AND.JULIAN.LE.41760) A(7) = 9999.0
  IF(JULIAN.GE.46800) A(7) = 9999.0
  IF(JULIAN.GE.8640.AND.JULIAN.LE.11520) A(8) = 9999.0
  IF(JULIAN.GE.15840.AND.JULIAN.LE.41760) A(8) = 9999.0
  IF(JULIAN.GE.46800) A(8) = 9999.0

C
C COMPUTE MINUTE VOLTAGES FROM POLYNOMIAL FITS FOR SELECTED
C PORTIONS OF NOISY MAIN DECK AND 02 LEVEL HORIZONTAL SPRAY
C UNITS

*****COMPUTE VOLTAGES FROM POLYNOMIAL FIT ORTHOGONAL
*****FUNCTIONS IN SUBROUTINE ORTHPOLY

C
C POLYNOMIAL FIT - 09 FEB, MAIN DECK PORT
C

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IF(JULIAN.LT.5800.OR.JULIAN.GT.6960) GO TO 750
KFIT = 10
XSCALE = 0.00344827586
XMID = 6380.0
ALPHA(1) = 0.D0
ALPHA(2) = 0.D0
ALPHA(3) = -6.87325D-017
ALPHA(4) = 9.00564D-017
ALPHA(5) = 6.24319D-018
ALPHA(6) = -3.76288D-016
ALPHA(7) = 2.87002D-016
ALPHA(8) = -1.20222D-017
ALPHA(9) = -1.31348D-016
ALPHA(10) = 3.24561D-016
ALPHA(11) = -7.87857D-017
BETA(1) = 0.D0
BETA(2) = 1.33563
BETA(3) = 1.0685
BETA(4) = 1.03034
BETA(5) = 1.01761
BETA(6) = 1.01182
BETA(7) = 1.0087
BETA(8) = 1.00683
BETA(9) = 1.00561
BETA(10) = 1.00477
BETA(11) = 1.00416
B(1) = 801.388
B(2) = 336.348
B(3) = 164.185
B(4) = -2.53139
B(5) = -40.5347
B(6) = 8.20023
B(7) = 33.296
B(8) = 8.14898
B(9) = -12.3482
B(10) = -7.99606
B(11) = 3.48147
X = FLOAT(JULIAN)
CALL ORTHPOLY (X,A(2),ALPHA,BETA,B,XMID,XSCALE,KFIT)

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C
C POLYNOMIAL FIT - 13 FEB, MAIN DECK PORT
C

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750 IF(JULIAN.LT.11880.OR.JULIAN.GT.12960) GO TO 751
KFIT = 10
XSCALE = 0.00370713624
XMID = 12419.5
ALPHA(1) = 0.D0
ALPHA(2) = 0.D0
ALPHA(3) = 1.45909D-016
ALPHA(4) = -6.68282D-017
ALPHA(5) = -8.72149D-017
ALPHA(6) = 2.19729D-016
ALPHA(7) = -5.47177D-016
ALPHA(8) = 5.46693D-016
ALPHA(9) = -3.50547D-016
ALPHA(10) = -4.67567D-017
ALPHA(11) = 3.46855D-016
BETA(1) = 0.D0
BETA(2) = 1.3358
BETA(3) = 1.06864
BETA(4) = 1.03047
BETA(5) = 1.01774
BETA(6) = 1.01195
BETA(7) = 1.00883
BETA(8) = 1.00695
BETA(9) = 1.00573
BETA(10) = 1.00489
BETA(11) = 1.00428
B(1) = 414.53
B(2) = 335.292
B(3) = 262.818
B(4) = 153.314
B(5) = 34.7838
B(6) = -36.5628
B(7) = -50.889
B(8) = -29.5643
B(9) = -2.13003
B(10) = 16.7378

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      B(11) = 12.1643
      X = FLOAT(JULIAN)
      CALL ORTHPOLY (X,A(2),ALPHA,BETA,B,XMID,XSCALE,KFIT)
C
C POLYNOMIAL FIT - 13 FEB, 02 LEVEL STARBOARD
C
      751 IF(JULIAN.LT.11520.OR.JULIAN.GT.12900) GO TO 752
      KFIT = 8
      XSCALE = 0.00289855072
      XMID = 12210.0
      ALPHA(1) = 0.D0
      ALPHA(2) = 0.D0
      ALPHA(3) = -1.08855D-016
      ALPHA(4) = 3.71543D-016
      ALPHA(5) = -7.80935D-016
      ALPHA(6) = 9.87932D-016
      ALPHA(7) = -1.05151D-015
      ALPHA(8) = 2.90207D-016
      ALPHA(9) = 5.86689D-016
      BETA(1) = 0.D0
      BETA(2) = 1.33527
      BETA(3) = 1.06821
      BETA(4) = 1.03006
      BETA(5) = 1.01734
      BETA(6) = 1.01155
      BETA(7) = 1.00843
      BETA(8) = 1.00656
      BETA(9) = 1.00534
      B(1) = 1869.35
      B(2) = 23.1702
      B(3) = 7.3597
      B(4) = 5.52179
      B(5) = -2.30155
      B(6) = 3.29304
      B(7) = 6.77047
      B(8) = 5.44152
      B(9) = -3.68812
      X = FLOAT(JULIAN)
      CALL ORTHPOLY (X,A(4),ALPHA,BETA,B,XMID,XSCALE,KFIT)
C
C POLYNOMIAL FIT - 13 FEB, 02 LEVEL PORT
C
      752 IF(JULIAN.LT.12100.OR.JULIAN.GT.12910) GO TO 753
      KFIT = 8
      XSCALE = 0.00289855072
      XMID = 12210.0
      ALPHA(1) = 0.D0
      ALPHA(2) = 0.D0
      ALPHA(3) = -1.08855D-016
      ALPHA(4) = 3.71543D-016
      ALPHA(5) = -7.80935D-016
      ALPHA(6) = 9.87932D-016
      ALPHA(7) = -1.05151D-015
      ALPHA(8) = 2.90207D-016
      ALPHA(9) = 5.86689D-016
      BETA(1) = 0.D0
      BETA(2) = 1.33527
      BETA(3) = 1.06821
      BETA(4) = 1.03006
      BETA(5) = 1.01734
      BETA(6) = 1.01155
      BETA(7) = 1.00843
      BETA(8) = 1.00656
      BETA(9) = 1.00534
      B(1) = 85.2795
      B(2) = 62.5968
      B(3) = 23.0434
      B(4) = 7.809
      B(5) = 20.748
      B(6) = 21.8471
      B(7) = 10.5954
      B(8) = 1.22074
      B(9) = 1.51048
      X = FLOAT(JULIAN)
      CALL ORTHPOLY (X,A(5),ALPHA,BETA,B,XMID,XSCALE,KFIT)

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C
C POLYNOMIAL FIT - 14 FEB, MAIN DECK PORT - EARLY
C
753 IF (JULIAN.LT.13140.OR.JULIAN.GT.13860) GO TO 754
KFIT = 7
XSCALE = 0.005555555556
XMID = 13500.0
ALPHA(1) = 0.D0
ALPHA(2) = 0.D0
ALPHA(3) = 6.54154D-017
ALPHA(4) = -2.3257D-016
ALPHA(5) = 4.94402D-016
ALPHA(6) = -7.57528D-016
ALPHA(7) = 1.00369D-015
ALPHA(8) = -5.77175D-016
BETA(1) = 0.D0
BETA(2) = 1.33704
BETA(3) = 1.06962
BETA(4) = 1.03141
BETA(5) = 1.01867
BETA(6) = 1.01286
BETA(7) = 1.00972
BETA(8) = 1.00783
B(1) = 1476.28
B(2) = 275.711
B(3) = -19.8852
B(4) = -18.663
B(5) = -10.1327
B(6) = 18.2031
B(7) = 10.4578
B(8) = -11.741
X = FLOAT(JULIAN)
CALL ORTHPOLY (X,A(2),ALPHA,BETA,B,XMID,XSCALE,KFIT)
C
C POLYNOMIAL FIT - 14 FEB, MAIN DECK PORT - LATE
C
754 IF (JULIAN.GE.13960.AND.JULIAN.LE.14399)
*A(2) = 81907.9
*-(11.7694*FLOAT(JULIAN))
*+(0.000430505*(FLOAT(JULIAN)**2.0))
C
C POLYNOMIAL FIT - 14 FEB, 02 LEVEL STARBOARD
C
IF (JULIAN.LT.13100.OR.JULIAN.GT.14400) GO TO 755
KFIT = 9
XSCALE = 0.00307929176
XMID = 13749.5
ALPHA(1) = 0.D0
ALPHA(2) = 0.D0
ALPHA(3) = 8.28829D-017
ALPHA(4) = -2.17425D-016
ALPHA(5) = 2.52902D-016
ALPHA(6) = -2.3212D-016
ALPHA(7) = 1.55375D-016
ALPHA(8) = 1.21817D-016
ALPHA(9) = -3.52359D-016
ALPHA(10) = 5.87633D-016
BETA(1) = 0.D0
BETA(2) = 1.33539
BETA(3) = 1.06831
BETA(4) = 1.03015
BETA(5) = 1.01743
BETA(6) = 1.01164
BETA(7) = 1.00852
BETA(8) = 1.00665
BETA(9) = 1.00543
BETA(10) = 1.00459
B(1) = 1014.84
B(2) = 220.454
B(3) = -108.059
B(4) = -11.3062
B(5) = 35.0741
B(6) = -1.93661
B(7) = -12.7114
B(8) = 14.6491
B(9) = 1.5798
B(10) = -9.74736
X = FLOAT(JULIAN)
CALL ORTHPOLY (X,A(4),ALPHA,BETA,B,XMID,XSCALE,KFIT)

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C
C POLYNOMIAL FIT - 14 FEB, 02 LEVEL PORT
C
755 IF(JULIAN.LT.13100.OR.JULIAN.GT.14400) GO TO 756
KFIT = 10
XSCALE = 0.00307929176
XMID = 13749.5
ALPHA(1) = 0.D0
ALPHA(2) = 0.D0
ALPHA(3) = 8.28829D-017
ALPHA(4) = -2.17425D-016
ALPHA(5) = 2.52902D-016
ALPHA(6) = -2.3212D-016
ALPHA(7) = 1.55375D-016
ALPHA(8) = 1.21817D-016
ALPHA(9) = -3.52359D-016
ALPHA(10) = 5.87633D-016
ALPHA(11) = -7.92849D-016
BETA(1) = 0.D0
BETA(2) = 1.33539
BETA(3) = 1.06831
BETA(4) = 1.03015
BETA(5) = 1.01743
BETA(6) = 1.01164
BETA(7) = 1.00852
BETA(8) = 1.00665
BETA(9) = 1.00543
BETA(10) = 1.00459
BETA(11) = 1.00399
B(1) = 676.179
B(2) = 95.2221
B(3) = -27.361
B(4) = -1.64187
B(5) = 0.636838
B(6) = 5.5995
B(7) = -6.28902
B(8) = 4.22817
B(9) = 2.49404
B(10) = -3.69007
B(11) = -0.380555
X = FLOAT(JULIAN)
CALL ORTHPOLY (X,A(5),ALPHA,BETA,B,XMID,XSCALE,KFIT)

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C
C POLYNOMIAL FIT - 03 MAR, MAIN DECK STARBOARD
C
756 IF(JULIAN.LT.37440.OR.JULIAN.GT.38879) GO TO 757
KFIT = 6
XSCALE = 0.00277970813
XMID = 38159.5
ALPHA(1) = 0.D0
ALPHA(2) = 0.D0
ALPHA(3) = 5.86678D-017
ALPHA(4) = -6.74666D-017
ALPHA(5) = -6.71813D-018
ALPHA(6) = -2.82322D-016
ALPHA(7) = 5.64758D-016
BETA(1) = 0.D0
BETA(2) = 1.33519
BETA(3) = 1.06815
BETA(4) = 1.03
BETA(5) = 1.01728
BETA(6) = 1.01149
BETA(7) = 1.00838
B(1) = 886.113
B(2) = 71.5557
B(3) = 27.8628
B(4) = -11.9054
B(5) = -18.4475
B(6) = -5.17029
B(7) = 4.15863
X = FLOAT(JULIAN)
CALL ORTHPOLY (X,A(1),ALPHA,BETA,B,XMID,XSCALE,KFIT)

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C
C POLYNOMIAL FIT - 03 MAR, MAIN DECK PORT
C
757 IF(JULIAN.LT.37440.OR.JULIAN.GT.38879) GO TO 758
KFIT = 5
XSCALE = 0.00277970813
XMID = 38159.5

```

ALPHA(1) = 0.D0
 ALPHA(2) = 0.D0
 ALPHA(3) = 5.86678D-017
 ALPHA(4) = -6.74666D-017
 ALPHA(5) = -6.71813D-018
 ALPHA(6) = -2.82322D-016
 BETA(1) = 0.D0
 BETA(2) = 1.33519
 BETA(3) = 1.06815
 BETA(4) = 1.03
 BETA(5) = 1.01728
 BETA(6) = 1.01149
 B(1) = 301.816
 B(2) = 29.7743
 B(3) = 7.92612
 B(4) = -6.93161
 B(5) = -5.50438
 B(6) = -0.181603
 X = FLOAT(JULIAN)
 CALL ORTHPOLY (X,A(2),ALPHA,BETA,B,XMID,XSCALE,KFIT)

C
 C POLYNOMIAL FIT - 03 MAR, 02 LEVEL STARBOARD
 C

758 IF(JULIAN.LT.37440.OR.JULIAN.GT.38700) GO TO 759

KFIT = 5
 XSCALE = 0.00317460317
 XMID = 38070.0
 ALPHA(1) = 0.D0
 ALPHA(2) = 0.D0
 ALPHA(3) = 1.74049D-017
 ALPHA(4) = -2.86331D-017
 ALPHA(5) = -4.79203D-017
 ALPHA(6) = 1.4506D-016
 BETA(1) = 0.D0
 BETA(2) = 1.33545
 BETA(3) = 1.06836
 BETA(4) = 1.0302
 BETA(5) = 1.01748
 BETA(6) = 1.01169
 B(1) = 555.0
 B(2) = 15.4899
 B(3) = 1.80152
 B(4) = -1.78751
 B(5) = 1.41935
 B(6) = -1.25081
 X = FLOAT(JULIAN)
 CALL ORTHPOLY (X,A(4),ALPHA,BETA,B,XMID,XSCALE,KFIT)

C
 C POLYNOMIAL FIT - 06 MAR, MAIN DECK STARBOARD - EARLY
 C

759 IF(JULIAN.LT.41760.OR.JULIAN.GT.42880) GO TO 760

KFIT = 10
 XSCALE = 0.00357142857
 XMID = 42320.0
 ALPHA(1) = 0.D0
 ALPHA(2) = 0.D0
 ALPHA(3) = 3.4404D-017
 ALPHA(4) = 4.21883D-017
 ALPHA(5) = 4.52534D-017
 ALPHA(6) = -2.541D-017
 ALPHA(7) = -1.46484D-016
 ALPHA(8) = -1.65956D-017
 ALPHA(9) = 2.47232D-017
 ALPHA(10) = 3.68759D-016
 ALPHA(11) = -6.72813D-016
 BETA(1) = 0.D0
 BETA(2) = 1.33571
 BETA(3) = 1.06857
 BETA(4) = 1.0304
 BETA(5) = 1.01767
 BETA(6) = 1.01189
 BETA(7) = 1.00876
 BETA(8) = 1.00688
 BETA(9) = 1.00566
 BETA(10) = 1.00482
 BETA(11) = 1.00422
 B(1) = 968.145

B(2) = 173.542
 B(3) = -17.8826
 B(4) = 112.306
 B(5) = 39.6641
 B(6) = -0.0988627
 B(7) = 37.0751
 B(8) = 0.632189
 B(9) = 0.243588
 B(10) = 11.6675
 B(11) = -19.6294
 X = FLOAT(JULIAN)
 CALL ORTHPOLY (X,A(1),ALPHA,BETA,B,XMID,XSCALE,KFIT)

C
 C POLYNOMIAL FIT - 06 MAR, MAIN DECK STARBOARD - LATE

C
 760 IF(JULIAN.LT.42960.OR.JULIAN.GT.43199) GO TO 761

KFIT = 6
 XSCALE = 0.0167364017
 XMID = 43079.5
 ALPHA(1) = 0.00
 ALPHA(2) = 0.00
 ALPHA(3) = -4.040404D-017
 ALPHA(4) = 5.11842D-017
 ALPHA(5) = -1.48069D-016
 ALPHA(6) = 3.85556D-017
 ALPHA(7) = 2.84618D-016
 BETA(1) = 0.00
 BETA(2) = 1.34449
 BETA(3) = 1.07554
 BETA(4) = 1.03703
 BETA(5) = 1.02411
 BETA(6) = 1.01813
 BETA(7) = 1.0148
 B(1) = 1780.05
 B(2) = 64.8489
 B(3) = -37.4969
 B(4) = 0.573467
 B(5) = 3.27333
 B(6) = 3.30267
 B(7) = -2.87842
 X = FLOAT(JULIAN)
 CALL ORTHPOLY (X,A(1),ALPHA,BETA,B,XMID,XSCALE,KFIT)

C
 C POLYNOMIAL FIT - 06 MAR, MAIN DECK PORT - EARLY

C
 761 IF(JULIAN.LT.41760.OR.JULIAN.GT.42880) GO TO 762

KFIT = 9
 XSCALE = 0.00357142857
 XMID = 42320.0
 ALPHA(1) = 0.00
 ALPHA(2) = 0.00
 ALPHA(3) = 3.44040D-017
 ALPHA(4) = 4.21883D-017
 ALPHA(5) = 4.52534D-017
 ALPHA(6) = -2.541D-017
 ALPHA(7) = -1.46484D-016
 ALPHA(8) = -1.65956D-017
 ALPHA(9) = 2.47232D-017
 ALPHA(10) = 3.68759D-016
 BETA(1) = 0.00
 BETA(2) = 1.33571
 BETA(3) = 1.06857
 BETA(4) = 1.0304
 BETA(5) = 1.01767
 BETA(6) = 1.01189
 BETA(7) = 1.00876
 BETA(8) = 1.00688
 BETA(9) = 1.00566
 BETA(10) = 1.00482
 B(1) = 365.663
 B(2) = 170.733
 B(3) = 115.204
 B(4) = 112.104
 B(5) = 67.8982
 B(6) = 27.0816
 B(7) = 27.2672
 B(8) = 12.0371
 B(9) = -0.306615

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B(10) = 0.462808
X = FLOAT(JULIAN)
CALL ORTHPOLY (X,A(2),ALPHA,BETA,B,XMID,XSCALE,KFIT)
C
C POLYNOMIAL FIT - 06 MAR, MAIN DECK PORT - LATE
C
762 IF(JULIAN.LT.42960.OR.JULIAN.GT.43199) GO TO 763
KFIT = 8
XSCALE = 0.0167364017
XMID = 43079.5
ALPHA(1) = 0.D0
ALPHA(2) = 0.D0
ALPHA(3) = -4.40404D-017
ALPHA(4) = 5.11842D-017
ALPHA(5) = -1.48069D-016
ALPHA(6) = 3.85556D-017
ALPHA(7) = 2.84018D-016
ALPHA(8) = -4.29141D-016
ALPHA(9) = 4.23762D-016
BETA(1) = 0.D0
BETA(2) = 1.34449
BETA(3) = 1.07554
BETA(4) = 1.03703
BETA(5) = 1.02411
BETA(6) = 1.01813
BETA(7) = 1.0148
BETA(8) = 1.01269
BETA(9) = 1.61122
B(1) = 1321.43
B(2) = 288.278
B(3) = -75.2927
B(4) = -36.9751
B(5) = 8.50396
B(6) = 17.9347
B(7) = 3.32435
B(8) = -5.97245
B(9) = -17.6204
X = FLOAT(JULIAN)
CALL ORTHPOLY (X,A(2),ALPHA,BETA,B,XMID,XSCALE,KFIT)

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C
C POLYNOMIAL FIT - 06 MAR, 02 LEVEL STARBOARD
C
763 IF(JULIAN.LT.41760.OR.JULIAN.GT.43080) GO TO 764
KFIT = 9
XSCALE = 0.00303030303
XMID = 42420.0
ALPHA(1) = 0.D0
ALPHA(2) = 0.D0
ALPHA(3) = -7.75393D-017
ALPHA(4) = 1.52708D-016
ALPHA(5) = 1.83015D-018
ALPHA(6) = -1.06132D-016
ALPHA(7) = 6.04582D-017
ALPHA(8) = -3.52639D-018
ALPHA(9) = -1.05096D-017
ALPHA(10) = -5.22653D-017
BETA(1) = 0.D0
BETA(2) = 1.33535
BETA(3) = 1.06828
BETA(4) = 1.03013
BETA(5) = 1.0174
BETA(6) = 1.01162
BETA(7) = 1.0085
BETA(8) = 1.00662
BETA(9) = 1.00541
BETA(10) = 1.00457
B(1) = 764.319
B(2) = 174.82
B(3) = 101.267
B(4) = 86.6117
B(5) = 4.08265
B(6) = -29.4833
B(7) = -8.69629
B(8) = -9.3289
B(9) = 7.92378
B(10) = 17.7489
X = FLOAT(JULIAN)
CALL ORTHPOLY (X,A(4),ALPHA,BETA,B,XMID,XSCALE,KFIT)

```

```

C
C POLYNOMIAL FIT - 06 MAR, 02 LEVEL PORT
C
764 IF(JULIAN.LT.42120.OR.JULIAN.GT.42080) GO TO 765
      KFIT = 9
      XSCALE = 0.00416666667
      XMID = 42600.0
      ALPHA(1) = 0.00
      ALPHA(2) = 0.00
      ALPHA(3) = -4.56539D-017
      ALPHA(4) = 2.71802D-017
      ALPHA(5) = -2.61193D-016
      ALPHA(6) = 4.19412D-016
      ALPHA(7) = -4.09491D-016
      ALPHA(8) = 4.20311D-016
      ALPHA(9) = -6.18783D-016
      ALPHA(10) = 5.91284D-016
      BETA(1) = 0.00
      BETA(2) = 1.33611
      BETA(3) = 1.06889
      BETA(4) = 1.03071
      BETA(5) = 1.01797
      BETA(6) = 1.01218
      BETA(7) = 1.00905
      BETA(8) = 1.00717
      BETA(9) = 1.00594
      BETA(10) = 1.0051
      B(1) = 762.78
      B(2) = 144.524
      B(3) = 79.5545
      B(4) = -5.32057
      B(5) = -37.4059
      B(6) = -14.5837
      B(7) = 10.8308
      B(8) = 14.5226
      B(9) = 3.88656
      B(10) = -8.86252
      X = FLOAT(JULIAN)
      CALL ORTHPOLY (X,A(5),ALPHA,BETA,B,XMID,XSCALE,KFIT)
C
C POLYNOMIAL FIT - 09 MAR, MAIN DECK PORT - HIGH SPEED RUN
C
765 IF(JULIAN.LT.46130.OR.JULIAN.GT.46185) GO TO 766
      KFIT = 6
      XSCALE = 0.0727272727
      XMID = 46157.5
      ALPHA(1) = 0.00
      ALPHA(2) = 0.00
      ALPHA(3) = 4.59115D-017
      ALPHA(4) = 0.00
      ALPHA(5) = 0.00
      ALPHA(6) = 3.73156D-017
      ALPHA(7) = -1.79606D-016
      BETA(1) = 0.00
      BETA(2) = 1.38182
      BETA(3) = 1.1044
      BETA(4) = 1.06325
      BETA(5) = 1.04778
      BETA(6) = 1.03882
      BETA(7) = 1.03196
      B(1) = 1269.2
      B(2) = 379.718
      B(3) = 10.3424
      B(4) = -71.5622
      B(5) = 14.6922
      B(6) = 24.3458
      B(7) = -0.0558921
      X = FLOAT(JULIAN)
      CALL ORTHPOLY (X,A(2),ALPHA,BETA,B,XMID,XSCALE,KFIT)
C
C POLYNOMIAL FIT - 09 MAR, 02 LEVEL STARBOARD - HIGH SPEED RUN
C
766 IF(JULIAN.LT.46130.OR.JULIAN.GT.46185) GO TO 767
      KFIT = 6
      XSCALE = 0.0727272727

```

```

X MID = 46157.5
ALPHA(1) = 0.00
ALPHA(2) = 0.00
ALPHA(3) = 4.59115D-017
ALPHA(4) = 0.00
ALPHA(5) = 0.00
ALPHA(6) = 3.73156D-017
ALPHA(7) = -1.79606D-016
BETA(1) = 0.00
BETA(2) = 1.38182
BETA(3) = 1.1044
BETA(4) = 1.06325
BETA(5) = 1.04778
BETA(6) = 1.03882
BETA(7) = 1.03196
B(1) = 1730.05
B(2) = 119.599
B(3) = -14.4127
B(4) = -25.61
B(5) = 18.6351
B(6) = 7.17971
B(7) = -10.917
X = FLOAT(JULIAN)
CALL ORTHPOLY (X,A(4),ALPHA,BETA,B,XMID,XSCALE,KFIT)
C
C POLYNOMIAL FIT - 09 MAR, 02 LEVEL PORT - HIGH SPEED RUN
C
767 IF(JULIAN.LT.46130.OR.JULIAN.GT.46224) GO TO 768
KFIT = 5
XSCALE = 0.0425531915
X MID = 46177.0
ALPHA(1) = 0.00
ALPHA(2) = 0.00
ALPHA(3) = 0.00
ALPHA(4) = 1.26095D-017
ALPHA(5) = -2.40289D-017
ALPHA(6) = 9.2797D-017
BETA(1) = 0.00
BETA(2) = 1.3617
BETA(3) = 1.089
BETA(4) = 1.04952
BETA(5) = 1.03576
BETA(6) = 1.02885
B(1) = 1240.58
B(2) = 108.919
B(3) = -50.9789
B(4) = 2.90523
B(5) = 13.4791
B(6) = -13.8299
X = FLOAT(JULIAN)
CALL ORTHPOLY (X,A(5),ALPHA,BETA,B,XMID,XSCALE,KFIT)
C
*****COMPUTE VOLTAGE CHANGES EACH MINUTE
C
DO 39 L=1,8
IF(A(L).GT.AH(L)) AD(L) = A(L) - AH(L)
IF(A(L).LE.AH(L)) AD(L) = 0.0
IF(L.GE.7) GO TO 50
IF(A(L).LT.130.0.OR.A(L).GT.2100.0) AD(L)=9999.
50 IF(A(7).LT.130.0.OR.A(7).GT.2400.0) AD(7)=9999.
IF(A(8).LT.130.0.OR.A(8).GT.2400.0) AD(8)=9999.
IF(A(L).EQ.999.0) A(L) = 9999.9
C
*****COMPUTE NEW BASELINE REFERENCE VOLTAGE
C
IF(A(L).GE.AH(L)) AH(L) = A(L)
IF(A(L).LT.AH(L).AND.A(L).GE.(AH(L)-25.0))
*AH(L) = AH(L)
IF(A(L).LT.(AH(L)-25.0).AND.A(L).GE.(AH(L)-100.0))
*AH(L) = A(L) + ABS((AH(L) - A(L)) * 0.75)
IF(A(L).LT.(AH(L)-100.0)) AH(L) = A(L)
C
*****CONVERT MILLIVOLTS TO SPRAY FLUX
C ALL CRREL COLLECTORS CHANGED 0.215MV/CM**3
C ALL YOUNG GAUGES CHANGED 1000MV/CM PRECIP
C YOUNG KG/M**2 = 500 CM**2/M**2 DIVIDED BY 1000G/KG

```

```

C NOTE: CREL VOLTAGE RANGE FOR YOUNG GAUGE IS 2500 MV
C VERSUS THE 500 MV SPECIFIED BY YOUNG DUE TO DATA
C LOGGER VOLTAGE LIMITATIONS.
C AREA OF HORIZONTAL GAUGES (8") = 0.0324M**2
C AREA OF VERTICAL GAUGES (13") = 0.0856M**2
C AREA OF 01 LEVEL VERTICAL GAUGE BEFORE DAY 48 (17 FEB)
C (5.625") = 0.016M**2
C SEAWATER EQUALS ABOUT 1.03G/CM**3
C CONVERT ALL TO KG/M**2/MIN
C
  IF(L.LE.2) AF(L) = (AD(L)/0.215)*1.03*30.86*.001
  IF(L.EQ.4.OR.L.EQ.5) AF(L) = (AD(L)/0.215)*1.03*
    *30.86*.001
  IF(L.EQ.3.OR.L.EQ.6) AF(L) = (AD(L)/0.215)*1.03*
    *11.68*.001
  IF(L.EQ.3.AND.IDAY.LT.48) AF(L)=(AD(L)/0.215)*
    *1.03*62.5*.001
  IF(L.GE.7) AF(L) = (AD(L)) * 0.02 * 1.03
  IF(AD(L).EQ.9999.) AF(L) = 9999.
C
C ADD MINUTE VALUES IF NO PROBLEMS DURING HR
C
  AHRF(L) = AHRF(L) + AF(L)
  IF(IHRFL.EQ.1) AHRF(L) = 9999.
  IF(AHRF(L).GE.9999.) AHRF(L) = 9999.
  39 CONTINUE
C
C CREATE OUTPUT FILE FOR EACH DAY OF LOG
C
*****NEW DAY? THEN CLOSE OLD "DATE".SPY FILE

  IF(IDAY.EQ.IDAPRE) GO TO 42
  IDAPRE = IDAY
  CLOSE (7)
  MON = 03
  IF(IDAY.LE.59) MON = 02
  IDAE = IDAY - 31
  IF(MON.EQ.03) IDAE = IDAE - 28
  OUTFIL = IDAA(IDAE) //'FEB.SPY'
  IF(MON.EQ.03) OUTFIL = IDAA(IDAE) //'MAR.SPY'
  WRITE(*,70) OUTFIL
  70 FORMAT(' CREATING FILE ',A9)

*****OPEN NEW "DATE".SPY FILE

  OPEN(7,FILE=OUTFIL)

*****WRITE MINUTE OF SPRAY FLUX TO "DATE".SPY FILE

  42 WRITE(7,41)MON,IDAE,IHR,MIN,(AF(J),J=1,8),JULIAN
  41 FORMAT(4(1X,I2),8(1X,F9.4),1X,I8)
  GO TO 35
C
C PRINT HOURLY SUMS OF FLUXES
C
  45 IPREHR = IHRSEQ
  IF(IHRFL.NE.0) GO TO 49

*****WRITE HOURLY SPRAY FLUX SUM IN FILE MASPY.PLT

  WRITE(8,48)MON,IDAE,IHR,(AHRF(J),J=1,8),IHRSEQ
  48 FORMAT(3(1X,I2),8(1X,F10.4),1X,I8)
  49 DO 47 K=1,8
    AHRF(K) = 0.0
  47 CONTINUE
  IHRFL = 0
  GO TO 46
  100 CLOSE (6)
  CLOSE (7)
  CLOSE (9)
  STOP
  END
C

```

*****SUBROUTINE ORTHPOLY

C SUBROUTINE ORTHPOLY

```
C
  SUBROUTINE ORTHPOLY (X,VALUE1,ALPHA,
    *BETA,B,XMID,XSCALE,KFIT)
    REAL*8 ALPHA(*),BETA(*),B(*),XMID,XSCALE
    *,X,VALUE1,XX,YOLD,YNEW
    INTEGER KFIT
    XX = (X-XMID)*XSCALE
    YOLD = B(KFIT)
    YNEW = B(KFIT-1)+(XX-ALPHA(KFIT))*YOLD
    DO 8 K=KFIT-2,1,-1
    YSAV = YNEW
    YNEW = B(K) + (XX-ALPHA(K+1))*YNEW-BETA(K+1)*YOLD
    YOLD = YSAV
    VALUE1 = YNEW
    RETURN
  END
```

SAMPLE INPUT AND OUTPUT FILES FOR ORTHFLUX.FOR

*****FILE MVASC.TXT FROM (0045 - 0115 GMT) 7 FEBRUARY 1990

```
38,45,903,1016,681,694,377,660,635,544
38,46,903,1016,681,691,375,660,635,544
38,47,903,1016,681,690,375,661,635,544
38,48,903,1016,681,692,375,661,635,544
38,49,903,1016,681,692,376,661,635,544
38,50,903,1016,681,691,375,661,635,544
38,51,903,1016,681,691,375,660,635,544
38,52,903,1016,681,691,374,660,635,544
38,53,903,1016,681,691,375,660,635,544
38,54,903,1016,681,690,378,660,635,544
38,55,903,1016,681,692,377,660,635,544
38,56,903,1016,681,689,377,660,635,544
38,57,903,1016,681,693,375,660,635,544
38,58,903,1016,681,691,375,660,635,544
38,59,903,1016,681,689,377,660,635,544
38,100,903,1016,681,690,375,659,635,544
38,101,903,1017,680,688,377,661,635,544
38,102,904,1018,681,699,377,660,635,544
38,103,904,1018,680,697,376,660,635,544
38,104,904,1018,681,696,377,660,635,544
38,105,904,1018,681,697,376,660,635,544
38,106,904,1018,681,695,375,660,635,544
38,107,904,1018,680,694,378,660,635,544
38,108,904,1018,680,693,378,660,635,544
38,109,906,1019,681,696,381,661,635,544
38,110,905,1019,681,699,380,662,635,544
38,111,904,1019,682,701,378,661,635,544
38,112,902,1019,682,698,376,659,635,544
38,113,903,1019,682,700,380,660,635,544
38,114,903,1021,681,701,378,660,635,544
38,115,903,1021,680,702,380,660,635,544
```

*****FILE FIXED.TXT FROM (0045 - 0115 GMT) 7 FEBRUARY 1990

```
38 45 903 1016 681 694 377 660 635 544
38 46 903 1016 681 691 375 660 635 544
38 47 903 1016 681 690 375 661 635 544
38 48 903 1016 681 692 375 661 635 544
38 49 903 1016 681 692 376 661 635 544
38 50 903 1016 681 691 375 661 635 544
38 51 903 1016 681 691 375 660 635 544
38 52 903 1016 681 691 374 660 635 544
38 53 903 1016 681 691 375 660 635 544
38 54 903 1016 681 690 378 660 635 544
38 55 903 1016 681 692 377 660 635 544
38 56 903 1016 681 689 377 660 635 544
38 57 903 1016 681 693 375 660 635 544
38 58 903 1016 681 691 375 660 635 544
38 59 903 1016 681 689 377 660 635 544
38 100 903 1016 681 690 375 659 635 544
38 101 903 1017 680 688 377 661 635 544
38 102 904 1018 681 699 377 660 635 544
38 103 904 1018 680 697 376 660 635 544
```


38	104	904	1018	681	696	377	660	635	544
38	105	904	1018	681	697	376	660	635	544
38	106	904	1018	681	695	375	660	635	544
38	107	904	1018	680	694	378	660	635	544
38	108	904	1018	680	693	378	660	635	544
38	109	906	1019	681	696	381	661	635	544
38	110	905	1019	681	699	380	662	635	544
38	111	904	1019	682	701	378	661	635	544
38	112	902	1019	682	698	376	659	635	544
38	113	903	1019	682	700	380	660	635	544
38	114	903	1021	681	701	378	660	635	544
38	115	903	1021	680	702	380	660	635	544

*****FILE HRSFY.PLT FROM (0000 - 0012 GMT) 7 FEBRUARY 1990

2	7	1	0.1478	2.2176	0.0000	1.3306	1.7741
			0.0000	0.0412	0.0000	49	
2	7	2	0.2957	1.6263	0.0000	0.0000	1.7741
			0.0000	0.0206	0.0206	50	
2	7	3	1.0349	8.4269	0.0000	3.6129	1.0349
			0.0000	0.0000	0.0000	51	
2	7	4	0.5914	10.3489	0.0000	8.6949	3.1047
			0.0000	0.0206	0.0206	52	
2	7	5	0.2957	4.7309	0.0000	0.0445	1.6263
			0.0000	0.0000	0.0000	53	
2	7	6	2.9568	10.2010	0.0000	2.1783	0.8870
			0.0000	0.0000	0.0206	54	
2	7	7	3.9917	5.0266	0.0000	1.6263	0.2957
			0.0000	0.0206	0.0000	55	
2	7	8	4.1395	3.1047	0.0000	9.4618	1.3306
			0.0000	0.0206	0.0206	56	
2	7	9	1.9219	2.0698	0.0000	3.8439	3.1047
			0.0000	0.1854	0.0000	57	
2	7	10	0.7392	1.9219	0.0000	0.0000	1.1827
			0.0000	0.0412	0.0000	58	
2	7	11	0.8870	1.3306	0.0000	0.0000	0.8870
			0.0000	0.0206	0.0000	59	
2	7	12	1.9219	0.7392	0.0000	1.0349	0.0000
			0.0000	0.0000	0.0000	60	

ORTHFLUX.FOR Program Modification for Another Ship

FLOWCHART STEP - INITIALIZE VARIABLES:

Dimension variables A, AH, AD, AF, and AHRF for the number of spray collectors on the ship.

FLOWCHART STEP - OPEN FILES:

Rename MVASC.TXT to suit input file name.

FLOWCHART STEP - READ FREE FORMAT INPUT FILE MVASC.TXT:

Change the 32 READ statement to read the proper number of voltages, one for each collector. For example, if there are 4 collectors, variables I1, I2, I3, and I4 would be read and written, and the write format would be 4(1X,I5).

FLOWCHART STEP - WRITE FIXED FORMAT FILE FIXED.TXT:

Change the WRITE statement and the 10 FORMAT statement to read the proper number of voltages, one for each collector. For example, if there are 4 collectors, variables I1, I2, I3, and I4 would be read and written, and the write format would be 4(1X,I5).

FLOWCHART STEP - READ MINUTE OF VOLTAGES FROM FILE FIXEDF.TXT:

Change the implied DO in the 36 READ statement to read the number of spray collectors on the ship.

FLOWCHART STEP - IF NEW HOUR - PRINT TO HRSPY.PLT:

Adjust IHRSEQ equation to suit. Change (IDAY-36) to (IDAY - number of days from 1 January to first day of cruise) to minimize size of Julian hour numbers.

FLOWCHART STEP - COMPUTE JULIAN MINUTE AND DETERMINE IF TIME INTERRUPTED:

Adjust JULIAN equation to suit. Change (IDAY-36) to (IDAY - number of days from 1 January to first day of cruise) to minimize size of Julian minute numbers.

FLOWCHART STEP - TIME BREAK - RESET BASELINE VOLTAGE TO CURRENT VOLTAGE:

No changes.

FLOWCHART STEP - SET ALL UNRELIABLE DATA TO MISSING - 9999.0:

Change all JULIAN times to suit.

FLOWCHART STEP - COMPUTE VOLTAGES FROM POLYNOMIAL FIT ORTHOGONAL FUNCTIONS IN SUBROUTINE ORTHPOLY:

All equations will change because of different curve fits, if they are needed at all to smooth noisy data.

FLOWCHART STEP - COMPUTE VOLTAGE CHANGES EACH MINUTE:

Change minimum and maximum acceptable voltages to suit, and change the number of collectors to suit.

FLOWCHART STEP - COMPUTE NEW BASELINE REFERENCE VOLTAGE:

Several potential changes here. This step tests to determine if voltages are greater or less than voltages of the previous minute, and establishes a new baseline reference voltage for the following minute.

The test for voltages that have decreased are dependent upon noise in the data. In this program, voltages that have dropped less than 25 mv are considered in the reasonable noise realm. Voltages that drop more than 100 mv are considered tank drainage events.

If there are days when some spray collectors were considered unreliable, then voltages should be set to 9999.0 for this range of days. For example, on the MIDGETT cruise, spray collector 1 was unreliable between Julian days 40 and 59, and spray collector 2 was unreliable between Julian days 47 and 59.

FLOWCHART STEP - CONVERT MILLIVOLTS TO SPRAY FLUXES:

Changes in this section deal with the collector area openings. Change the areas for each collector to suit.

FLOWCHART STEPS - NEW DAY? THEN CLOSE OLD "DATE".SPY FILE AND OPEN NEW "DATE".SPY FILE:

Output files are created for each day of output for each month of the cruise. MON = 3 is the last month of the two month MIDGETT cruise. If the Julian day is less than 59, the month was February, or month 2. Files are named by the day and the month.

Month designators must be changed for the months of the cruise.
Always consider Leap Years when counting Julian days.

Change 41 FORMAT for the number of spray collectors on the ship.
For example, for 4 collectors, the format would be changed to read
4(1X,F9.4).

**FLOWCHART STEPS - WRITE MINUTE OF SPRAY FLUX TO "DATE".SPY FILE
AND WRITE HOURLY SPRAY FLUX SUM IN FILE HRPSY.PLT:**

Change WRITE statements and FORMAT statements to suit number of
collectors on ship.

FLOWCHART STEP - SUBROUTINE ORTHPOLY:

Largely derived from GRAPHER manual (Golden Software Inc. 1988).

APPENDIX F: FORTRAN PROGRAM WINDY.FOR WITH SAMPLES OF INPUT AND OUTPUT FILES

Character variables for file management are initialized, and the first date to be analyzed is read from file DATES.FIL. Input files 'IDATE'.SPY for spray flux, and 'IDATE'.DAY for log data, are opened for the date specified in DATES.FIL. Output files 'DATE'.FLX and 'DATE'.ALB are written.

'DATE'.FLX includes log data and spray flux for the six CRREL collectors and the two Young collectors. 'DATE'.ALB includes log data and spray flux for the six CRREL collectors only. 'DATE'.SPY is read to scratch file 'DATE'.SCR on a RAM disk for faster processing because the file must be searched repeatedly to find a minute of spray flux that matches a minute of log data. This can be accomplished on a computer with a RAM disk of sufficient size to hold the file.

A minute of log data is read from 'DATE'.DAY, and 'DATE'.SPY is scanned for a matching minute of spray data. If no matching spray data are found, log data are written to 'DATE'.ALB and 'DATE'.FLX, with 9999.0 inserted for the missing spray data. The log data for the minute being analyzed are tested for sufficient information to compute relative wind direction and speed. If insufficient data are available to compute relative wind, log and spray data are written to 'DATE'.ALB and 'DATE'.FLX files with the message "FLUX NOT WIND CORRECTED" as a warning that horizontal spray collected fluxes may be underestimated.

If sufficient data are available to compute relative wind direction and speed across the ship bow for a given minute, subroutine RELATIVE is called. Variables necessary to compute relative wind speed and direction are true wind direction and speed, and ship speed and heading. True wind speed and direction were measured by an anemometer on the port yardarm of the forward mast. Wind speeds were not altered for the difference in height of the anemometer and horizontal spray collectors above the water. Wind direction was also not corrected

for turbulence around the ship superstructure that may have altered relative wind direction at each collector opening.

Subroutine RELATIVE computes relative wind direction and speed by calculating the x, y components of the ship course and speed and the reciprocal true wind vector. The apparent wind vector x, y components and the magnitude of the apparent wind vector are then computed. If special cases of wind directions from 0, 90 or 270° occur, the reciprocal of the wind direction is computed to find the relative wind direction. For other directions, the direction of the apparent wind vector is computed, tests are made to determine if the direction is in the second or third Cartesian quadrants, and, if true, wind direction is corrected by adding 180°. The reciprocal of the wind direction is then computed, as for the special cases above, to find the relative wind direction. Finally, wind direction is adjusted for ship course.

In the main program, relative wind direction is then corrected for collector orientation. Each horizontal collector was not mounted with the collector opening exactly facing the bow—each was angled 5 to 25° towards the bulwarks. Relative wind speed is then computed at each collector opening. Relative wind speeds were computed as calm if the relative wind direction was more than 90° off the collector opening.

The collection efficiency of each horizontal collector is then computed from a Walsh et al. (1992) equation, and the corrected spray flux is determined. The corrected horizontal collector flux, uncorrected vertical collector flux and log data are then written to 'DATE'.FLX and 'DATE'.ALB, and the next minute of log data is read.

**Definition of variables used in
FORTRAN programs**
See Appendix E.

Program listing:

FORTRAN PROGRAM WINDY.FOR

```
C*****
C PROGRAM WINDY.FOR CORRECTS MINUTE INTERVAL SPRAY FLUX
C FOR RELATIVE WIND AT HORIZONTAL MIDGETT COLLECTORS.
C UNITS ARE CORRECTED FOR THE WIND BY UTILIZING
C MINUTE SHIP SPEED AND HEADING AND HOURLY WEATHER LOGS.
C WINDS ARE ASSUMED UNIFORM FOR ALL LOCATIONS AND
C HEIGHTS. WIND WAS MEASURED ON THE FORWARD YARDARM.
C
```

```

*****INITIALIZE  VARIABLES

      CHARACTER*5 IDATE
      CHARACTER*9 ILOGFL, ISPYFL, IFLXFL, LAT, LONG
      *,IPZFIL
      CHARACTER*11 IRAMD
C
C OPEN EXISTING DAILY FILES FOR LOGS AND SPRAY DATA
C AND OPEN NEW DAILY FILE FOR FLUX DATA
C

*****READ DATES TO ANALYZE FROM FILE DATES.FIL

      OPEN(4,FILE='DATES.FIL')
80 READ(4,81,END=100)IDATE
81 FORMAT(1X,A5)
      CLOSE (5)
      CLOSE (6)
      CLOSE (7)
      CLOSE (9,STATUS='DELETE')

*****OPEN  FILES

      IFLXFL = IDATE//'.FLX'
      ILOGFL = IDATE//'.DAY'
      ISPYFL = IDATE//'.SPY'
      IPZFIL = IDATE//'.ALB'
      IRAMD = 'D:/'//IDATE//'.SCR'
      OPEN(5,FILE=IFLXFL)
      OPEN(6,FILE=ILOGFL)
      OPEN(7,FILE=ISPYFL)
      OPEN(8,FILE=IPZFIL)
C

*****COPY "DATE".SPY TO RAM DISK FOR FASTER PROCESSING

C COPY SPRAY FILES TO RAM DRIVE
C
      OPEN(9,FILE=IRAMD)
      WRITE(*,86)IRAMD
86 FORMAT(' WRITING FILE TO RAM DRIVE, FILE = ',A12)
87 READ(7,2,END=88)MO,IDA,IHR,MIN,A,B,C,D,E,F,G,H
      WRITE(9,2)MO,IDA,IHR,MIN,A,B,C,D,E,F,G,H
      GO TO 87
88 WRITE(*,84)IFLXFL, IPZFIL, ILOGFL, ISPYFL
84 FORMAT(' CREATING ',A9,' AND ',A9,' FROM ',A9,' AND ',A9)
C
C MERGE LOGS AND SPRAY FLUXES UNCORRECTED FOR WIND
C MINUTE BY MINUTE
C
C MIDGETT SPRAY UNIT IDENTIFICATION:
C   A - MAIN DECK STARBOARD - CRREL HORIZONTAL COLLECTOR
C   B - MAIN DECK PORT - CRREL HORIZONTAL COLLECTOR
C   C - 01 DECK - CRREL VERTICAL COLLECTOR
C   D - 02 DECK - STARBOARD - CRREL HORIZONTAL COLLECTOR
C   E - 02 DECK - PORT - CRREL HORIZONTAL COLLECTOR
C   F - FLYING BRIDGE - CRREL VERTICAL COLLECTOR
C   G - 01 DECK - YOUNG VERTICAL COLLECTOR
C   H - FLYING BRIDGE - YOUNG VERTICAL COLLECTOR
C
      GO TO 23
21 REWIND (9)

*****READ MINUTE OF LOG DATA FROM FILE "DATE".DAY

23 READ(6,71,END=80)NWMO,NWDA,NWHR,NWMIN,COURSE,SPEED,WD,
      *WS,PR,DB,WB,WAVED,WAVEH,SWELLD,SWELLH,LAT,LONG,
      *WTEMP,WSALIN
71 FORMAT(4(1X,I2),11(1X,F7.2),2(1X,A9),2(1X,F7.2))

*****SCAN "DATE".SPY FOR MINUTE OF SPRAY DATA TO MATCH
*****CURRENT MINUTE OF LOG DATA

31 READ(9,2,END=32)MO,IDA,IHR,MIN,A,B,C,D,E,F,G,H
2 FORMAT(4(1X,I2),8(F10.4))

```

*****WERE SPRAY DATA FOUND TO MATCH LOG DATA?

IF(IHR.NE.NWHR) GO TO 31
IF(MIN.NE.NWMIN) GO TO 31
GO TO 33

*****IF SPRAY DATA MISSING, WRITE LOG DATA WITH SPRAY
*****AS MISSING VALUES - 9999.0

32 WRITE(5,1)NWMO,NWDA,NWHR,NWMIN,COURSE,SPEED,WD,WS,PR,
*DB,WB,WAVED,WAVEH,SWELLD,SWELLH,LAT,LONG,WTEMP,WSALIN
1 FORMAT(4(1X,I2),4(1X,F7.2),16X,/,F8.2,6(1X,F7.2),/,24X,
*2(1X,A9),2(1X,F6.1),/,
*' 9999.00 9999.00 9999.00 9999.00 9999.00 9999.00'
*' 9999.00 9999.00')
WRITE(8,111)NWMO,NWDA,NWHR,NWMIN,COURSE,SPEED,WD,WS,PR,
*DB,WB,WAVED,WAVEH,SWELLD,SWELLH,LAT,LONG,WTEMP,WSALIN
111 FORMAT(4(1X,I2),4(1X,F7.2),16X,/,F8.2,6(1X,F7.2),/,24X,
*2(1X,A9),2(1X,F6.1),/,
*' 9999.00 9999.00 9999.00 9999.00 9999.00 9999.00'
GO TO 21

C
C COMPUTE RELATIVE WIND AND SPRAY FLUX
C

33 IF(WS.EQ.0.0) WS = 0.5
IF(WS.LE.0.0) GO TO 52
IF(WD.EQ.0.0) WD = 1.0
IF(WD.LE.0.0) GO TO 52
IF(SPEED.EQ.0.0) SPEED = 0.5
IF(SPEED.LE.0.0) GO TO 52
IF(COURSE.EQ.0.0) COURSE = 1.0
IF(COURSE.LE.0.0) GO TO 52

*****CALL SUBROUTINE RELATIVE TO COMPUTE RELATIVE WIND
*****SPEED AND DIRECTION FOR SHIP

CALL RELATIVE(WS,WD,SPEED,COURSE,RMV,RWD)

C
C CORRECT RELATIVE WIND FOR OFF AXIS POSITION OF HORIZONTAL
C COLLECTORS FROM SHIP CENTER LINE.
C MAIN DECK STARBOARD UNIT ORIENTED 22.0 STARBOARD DEGREES
C OF CENTERLINE
C MAIN DECK PORT UNIT ORIENTED 24.8 PORT DEGREES
C OF CENTERLINE
C 02 DECK STARBOARD UNIT ORIENTED 6.3 DEGREES STARBOARD
C OF CENTERLINE
C 02 DECK PORT UNIT ORIENTED 4.98 DEGREES PORT
C OF CENTERLINE

*****COMPUTE RELATIVE WIND DIRECTION FOR STARBOARD COLLECTORS

C
C RELATIVE WIND STARBOARD MAIN DECK AND 02 LEVEL UNITS
C

IF(RWD.LE.180.0) RWDMDS = ABS(RWD - 22.0)
IF(RWD.GT.180.0.AND.RWD.LE.360)
*RWDMDS = ABS((360.0 - RWD) + 22.0)

C
IF(RWD.LE.180.0) RWD2LS = ABS(RWD - 6.3)
IF(RWD.GT.180.0.AND.RWD.LE.360)
*RWD2LS = ABS((360.0 - RWD) + 6.3)

*****COMPUTE RELATIVE WIND DIRECTION FOR PORT COLLECTORS

C
C RELATIVE WIND PORT MAIN DECK AND 02 LEVEL UNITS
C

IF(RWD.LE.180.0) RWDMDP = ABS(RWD + 24.8)
IF(RWD.GT.180.0.AND.RWD.LE.360)
*RWDMDP = ABS((360.0 - RWD) - 24.8)

C
IF(RWD.LE.180.0) RWD2LP = ABS(RWD + 4.98)
IF(RWD.GT.180.0.AND.RWD.LE.360)
*RWD2LP = ABS((360.0 - RWD) - 4.98)

*****COMPUTE RELATIVE WIND SPEED FOR ALL SPRAY COLLECTORS

C
C COMPUTE WIND SPEED FOR HORIZONTAL UNITS
C

```
RADD = 3.14159/180.0
IF (RWDMD5.GT.90.0) RWDMD5 = 90.0
IF (RWDMDP.GT.90.0) RWDMDP = 90.0
IF (RWD2LS.GT.90.0) RWD2LS = 90.0
IF (RWD2LP.GT.90.0) RWD2LP = 90.0
RWVMD5 = RWV * COS(RWDMD5*RADD)
RWVMDP = RWV * COS(RWDMDP*RADD)
RWV2LS = RWV * COS(RWD2LS*RADD)
RWV2LP = RWV * COS(RWD2LP*RADD)
```

*****COMPUTE COLLECTION EFFICIENCY FOR EACH HORIZONTAL
*****SPRAY COLLECTOR

C
C COMPUTE COLLECTION EFFICIENCY FOR HORIZONTAL UNITS
C

```
IF (RWVMD5.LE.6.5) EFFMDS = .9925
IF (RWVMDP.LE.6.5) EFFMDP = .9925
IF (RWV2LS.LE.6.5) EFF2LS = .9925
IF (RWV2LP.LE.6.5) EFF2LP = .9925
IF (RWVMD5.GT.6.5) EFFMDS = 0.01 * (98.5 -
*((1.854 * RWVMD5) - 12.0) * 0.4545))
IF (RWVMDP.GT.6.5) EFFMDP = 0.01 * (98.5 -
*((1.854 * RWVMDP) - 12.0) * 0.4545))
IF (RWV2LS.GT.6.5) EFF2LS = 0.01 * (98.5 -
*((1.854 * RWV2LS) - 12.0) * 0.4545))
IF (RWV2LP.GT.6.5) EFF2LP = 0.01 * (98.5 -
*((1.854 * RWV2LP) - 12.0) * 0.4545))
```

*****COMPUTE CORRECTED SPRAY FLUX FOR EACH HORIZONTAL
*****COLLECTOR

C
C CORRECT THE FOUR HORIZONTAL UNITS FOR RELATIVE WIND
C

```
IF (A.LT.9000.0) A = A * (1.0/EFFMDS)
IF (B.LT.9000.0) B = B * (1.0/EFFMDP)
IF (D.LT.9000.0) D = D * (1.0/EFF2LS)
IF (E.LT.9000.0) E = E * (1.0/EFF2LP)
```

*****WRITE ALL WIND-CORRECTED SPRAY FLUXES AND LOG DATA
*****TO FILES "DATE".FLX AND "DATE".SPY

C
WRITE (5,38) NWMO, NWDA, NWHR, NWMIN, COURSE, SPEED, WD, WS,
*RWD, RWV, PR, DB, WB, WAVED, WAVEH, SWELLD, SWELLH,
*LAT, LONG, WTEMP, WSALIN, A, B, C, D, E, F, G, H
WRITE (8,38) NWMO, NWDA, NWHR, NWMIN, COURSE, SPEED, WD, WS,
*RWD, RWV, PR, DB, WB, WAVED, WAVEH, SWELLD, SWELLH,
*LAT, LONG, WTEMP, WSALIN, A, B, C, D, E, F
38 FORMAT (4 (1X, I2), 6 (1X, F7.2), /, F8.2, 6 (1X, F7.2),
*/, 24X, 2 (1X, A9), 2 (1X, F6.1), /, 8 (1X, F8.2))
GO TO 23
52 WRITE (5,39) NWMO, NWDA, NWHR, NWMIN, COURSE, SPEED, WD, WS,
*PR, DB, WB, WAVED, WAVEH, SWELLD, SWELLH,
*LAT, LONG, WTEMP, WSALIN, A, B, C, D, E, F, G, H
WRITE (8,39) NWMO, NWDA, NWHR, NWMIN, COURSE, SPEED, WD, WS,
*PR, DB, WB, WAVED, WAVEH, SWELLD, SWELLH,
*LAT, LONG, WTEMP, WSALIN, A, B, C, D, E, F
39 FORMAT (4 (1X, I2), 4 (1X, F7.2), 16X, /, F8.2, 6 (1X, F7.2),
*/, ' FLUX NOT WIND CORRECTED',
*2 (1X, A9), 2 (1X, F6.1), /, 8 (1X, F8.2))
GO TO 23
100 CLOSE (4)
CLOSE (5)
CLOSE (6)
CLOSE (7)
CLOSE (8)
STOP
END

```

*****SUBROUTINE  RELATIVE

C
C*****
C
      SUBROUTINE RELATIVE(VTW,TWIND,VS,SCRS,VA,DWA)
C
C COMPUTE RELATIVE WIND (FROM LCDR P. LONGO)
C
C VTW = TRUE WIND VELOCITY(KTS)
C TWIND = DIRECTION OF TRUE WIND (AZIMUTH DEGREES)
C VS = SHIP SPEED (KTS)
C SCRS = SHIP COURSE (AZIMUTH DEGREES)
C VA = VELOCITY OF RELATIVE WIND (KTS)
C DWA = DIRECTION OF RELATIVE WIND (AZIMUTH DEGREES)
C
      RADD = 3.14159/180.0

*****CALCULATE RECIPROCAL OF TRUE WIND DIRECTION

      TWINDR = TWIND+180.0
      IF(TWINDR.GT.360.0) TWINDR = TWINDR - 360.0

*****CALCULATE X, Y COMPONENTS OF SHIP COURSE/SPEED
*****VECTOR AND RECIPROCAL OF TRUE WIND VECTOR

      XTWR = VTW * SIN((TWINDR)*RADD)
      YTWR = VTW * COS((TWINDR)*RADD)
      XVS = VS*SIN((SCRS)*RADD)
      YVS = VS*COS((SCRS)*RADD)

*****DETERMINE X, Y COMPONENTS OF APPARENT WIND VECTOR

      XA = XTWR - XVS
      YA = YTWR - YVS

*****DETERMINE MAGNITUDE OF APPARENT WIND VECTOR

      VA = SQRT((XA**2.0) + (YA**2.0))

*****TEST FOR SPECIAL CASES OF DIRECTION

      IF(YA.EQ.0.0.AND.XA.LT.0.0) DWA = 270.0
      IF(YA.EQ.0.0.AND.XA.LT.0.0) GO TO 51
      IF(YA.EQ.0.0.AND.XA.GT.0.0) DWA = 090.0
      IF(YA.EQ.0.0.AND.XA.GT.0.0) GO TO 51
      IF(YA.EQ.0.0.AND.XA.EQ.0.0) DWA = 000.0
      IF(YA.EQ.0.0.AND.XA.EQ.0.0) GO TO 51

*****COMPUTE DIRECTION OF APPARENT WIND VECTOR

      DWA = ATAN(XA/YA)*(1.0/RADD)

*****SOLUTIONS IN SECOND OR THIRD QUADRANT

      IF(XA.LT.0.0.AND.YA.LT.0.0) DWA = DWA + 180.0
      IF(XA.GT.0.0.AND.YA.LT.0.0) DWA = DWA + 180.0

*****CONVERT WIND DIRECTION BY ADDING 180 DEGREES
*****TO RESULTANT

      51 DWA = DWA + 180.0

*****COMPUTE RECIPROCAL OF WIND VECTOR TO DETERMINE
*****DIRECTION FROM WHICH WIND COMES

      IF(DWA.GT.360.0) DWA = DWA - 360.0

*****ADJUST FOR SHIP COURSE

      DWA = DWA - SCRS
      IF(DWA.LT.0.0) DWA = DWA + 360.0
      RETURN
      END
*****

```


sample input and output files for WINDY.FOR

*****FILE DATES.FIL LISTING DAYS TO BE ANALYZED

06FEB
07FEB
08FEB
09FEB
10FEB
13FEB
14FEB
15FEB
16FEB
20FEB
21FEB
22FEB
25FEB
26FEB
28FEB
01MAR
02MAR
03MAR
04MAR
06MAR
07MAR
08MAR
09MAR
10MAR
14MAR
15MAR

*****FILE 07FEB.LOG OF SHIP LOG FROM (0045 - 0115 UT)
7 FEBRUARY 1990

2	7	0	45	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	46	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	47	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	48	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	49	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	50	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	51	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	52	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	53	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	54	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	55	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	56	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	57	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	58	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	0	59	2.00	15.00	268.00	5.50	30.18	41.00	40.00	280.00
4.00	280.00	15.00	41	42.5	125	18.1	-99.0	-99.0			
2	7	1	0	2.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00
4.00	275.00	15.00	41	58.3	125	00.4	-99.0	-99.0			
2	7	1	1	2.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00
4.00	275.00	15.00	41	58.3	125	00.4	-99.0	-99.0			
2	7	1	2	30.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00
4.00	275.00	15.00	41	58.3	125	00.4	-99.0	-99.0			
2	7	1	3	30.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00
4.00	275.00	15.00	41	58.3	125	00.4	-99.0	-99.0			
2	7	1	4	30.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00
4.00	275.00	15.00	41	58.3	125	00.4	-99.0	-99.0			
2	7	1	5	30.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00
4.00	275.00	15.00	41	58.3	125	00.4	-99.0	-99.0			
2	7	1	6	30.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00
4.00	275.00	15.00	41	58.3	125	00.4	-99.0	-99.0			
2	7	1	7	30.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00

4.00	275.00	15.00	41 58.3	125 00.4	-99.0	-99.0			
2 7 1 8	30.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00	
4.00	275.00	15.00	41 58.3	125 00.4	-99.0	-99.0			
2 7 1 9	30.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00	
4.00	275.00	15.00	41 58.3	125 00.4	-99.0	-99.0			
2 7 1 10	30.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00	
4.00	275.00	15.00	41 58.3	125 00.4	-99.0	-99.0			
2 7 1 11	0.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00	
4.00	275.00	15.00	41 58.3	125 00.4	-99.0	-99.0			
2 7 1 12	0.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00	
4.00	275.00	15.00	41 58.3	125 00.4	-99.0	-99.0			
2 7 1 13	0.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00	
4.00	275.00	15.00	41 58.3	125 00.4	-99.0	-99.0			
2 7 1 14	0.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00	
4.00	275.00	15.00	41 58.3	125 00.4	-99.0	-99.0			
2 7 1 15	0.00	15.00	262.00	8.00	30.16	42.00	40.00	280.00	
4.00	275.00	15.00	41 58.3	125 00.4	-99.0	-99.0			

*****FILE 07FEB.SPY (0045 - 0115 UT) 7 FEBRUARY 1990

2 7 0 45	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2925				
2 7 0 46	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2926				
2 7 0 47	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2927				
2 7 0 48	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2928				
2 7 0 49	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2929				
2 7 0 50	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2930				
2 7 0 51	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2931				
2 7 0 52	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2932				
2 7 0 53	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2933				
2 7 0 54	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2934				
2 7 0 55	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2935				
2 7 0 56	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2936				
2 7 0 57	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2937				
2 7 0 58	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2938				
2 7 0 59	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2939				
2 7 1 0	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2940				
2 7 1 1	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2941				
2 7 1 2	.0000	.1478	.0000	.0000	.0000	.0000
.0000	.0000	2942				
2 7 1 3	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2943				
2 7 1 4	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2944				
2 7 1 5	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2945				
2 7 1 6	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2946				
2 7 1 7	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2947				
2 7 1 8	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2948				
2 7 1 9	.2957	.1478	.0000	.0000	.2957	.0000
.0000	.0000	2949				
2 7 1 10	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2950				
2 7 1 11	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2951				
2 7 1 12	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2952				
2 7 1 13	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2953				

2 7 1 14	.0000	.2957	.0000	.0000	.0000	.0000
.0000	.0000	2954				
2 7 1 15	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	2955				

*****FILE 07FEB.FLX FROM (0045 - 0115 UT) 7 FEBRUARY 1990

2 7 0 45	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 46	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 47	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 48	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 49	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 50	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 51	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 52	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 53	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 54	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 55	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 56	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 57	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 58	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 0 59	2.00	15.00	268.00	5.50	339.43	15.61	
30.18	41.00	40.00	280.00	4.00	280.00	15.00	
			41 42.5	125 18.1	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 1 0	2.00	15.00	262.00	8.00	329.94	15.73	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 1 1	2.00	15.00	262.00	8.00	329.94	15.73	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 1 2	30.00	15.00	262.00	8.00	327.96	11.88	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.16	.00	.00	.00	.00	.00	.00

2 7 1 3	30.00	15.00	262.00	8.00	327.96	11.88	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 1 4	30.00	15.00	262.00	8.00	327.96	11.88	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 1 5	30.00	15.00	262.00	8.00	327.96	11.88	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 1 6	30.00	15.00	262.00	8.00	327.96	11.88	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 1 7	30.00	15.00	262.00	8.00	327.96	11.88	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 1 8	30.00	15.00	262.00	8.00	327.96	11.88	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 1 9	30.00	15.00	262.00	8.00	327.96	11.88	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.30	.16	.00	.00	.31	.00	.00	.00
2 7 1 10	30.00	15.00	262.00	8.00	327.96	11.88	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 1 11	1.00	15.00	262.00	8.00	330.11	15.86	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 1 12	1.00	15.00	262.00	8.00	330.11	15.86	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 1 13	1.00	15.00	262.00	8.00	330.11	15.86	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00
2 7 1 14	1.00	15.00	262.00	8.00	330.11	15.86	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.33	.00	.00	.00	.00	.00	.00
2 7 1 15	1.00	15.00	262.00	8.00	330.11	15.86	
30.16	42.00	40.00	280.00	4.00	275.00	15.00	
			41 58.3	125 00.4	-99.0	-99.0	
.00	.00	.00	.00	.00	.00	.00	.00

*****FILE 07FEB.ALB FROM (0045 - 0115 UT) 7 FEBRUARY 1990

2 7 0 45	2.00	15.00	268.00	5.50	339.43	15.61
30.18	41.00	40.00	280.00	4.00	280.00	15.00
			41 42.5	125 18.1	-99.0	-99.0
.00	.00	.00	.00	.00	.00	.00
2 7 0 46	2.00	15.00	268.00	5.50	339.43	15.61
30.18	41.00	40.00	280.00	4.00	280.00	15.00
			41 42.5	125 18.1	-99.0	-99.0
.00	.00	.00	.00	.00	.00	.00
2 7 0 47	2.00	15.00	268.00	5.50	339.43	15.61
30.18	41.00	40.00	280.00	4.00	280.00	15.00
			41 42.5	125 18.1	-99.0	-99.0
.00	.00	.00	.00	.00	.00	.00
2 7 0 48	2.00	15.00	268.00	5.50	339.43	15.61
30.18	41.00	40.00	280.00	4.00	280.00	15.00
			41 42.5	125 18.1	-99.0	-99.0
.00	.00	.00	.00	.00	.00	.00
2 7 0 49	2.00	15.00	268.00	5.50	339.43	15.61
30.18	41.00	40.00	280.00	4.00	280.00	15.00
			41 42.5	125 18.1	-99.0	-99.0
.00	.00	.00	.00	.00	.00	.00
2 7 0 50	2.00	15.00	268.00	5.50	339.43	15.61
30.18	41.00	40.00	280.00	4.00	280.00	15.00

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30.16 42.00 40.00 280.00 4.00 275.00 15.00
      41 58.3 125 00.4 -99.0 -99.0
      .00      .00      .00      .00      .00      .00
2 7 1 11 1.00 15.00 262.00 8.00 330.11 15.86
30.16 42.00 40.00 280.00 4.00 275.00 15.00
      41 58.3 125 00.4 -99.0 -99.0
      .00      .00      .00      .00      .00      .00
2 7 1 12 1.00 15.00 262.00 8.00 330.11 15.86
30.16 42.00 40.00 280.00 4.00 275.00 15.00
      41 58.3 125 00.4 -99.0 -99.0
      .00      .00      .00      .00      .00      .00
2 7 1 13 1.00 15.00 262.00 8.00 330.11 15.86
30.16 42.00 40.00 280.00 4.00 275.00 15.00
      41 58.3 125 00.4 -99.0 -99.0
      .00      .00      .00      .00      .00      .00
2 7 1 14 1.00 15.00 262.00 8.00 330.11 15.86
30.16 42.00 40.00 280.00 4.00 275.00 15.00
      41 58.3 125 00.4 -99.0 -99.0
      .00      .33      .00      .00      .00      .00
2 7 1 15 1.00 15.00 262.00 8.00 330.11 15.86
30.16 42.00 40.00 280.00 4.00 275.00 15.00
      41 58.3 125 00.4 -99.0 -99.0
      .00      .00      .00      .00      .00      .00

```

WINDY FOR PROGRAM MODIFICATION FOR ANOTHER SHIP:

FLOWCHART STEP - INITIALIZE VARIABLES:

Change only CHARACTER*11 if the file name represented by IRAMD changes in length.

FLOWCHART STEP - READ DATES TO ANALYZE FROM DATES.FIL:

Change the dates listed in DATES.FIL to reflect the current cruise. Dates are listed, on to each line, with a space, a 2 integer day, and a three letter month.

FLOWCHART STEP - OPEN FILES:

Change file extensions to suit. Remove D: if files are not copied to RAM disk drive "D" in following step.

FLOWCHART STEP - COPY "DATE".SPY TO RAM DISK FOR FASTER PROCESSING:

"DATE".SPY must be searched repeatedly for data to match the log in time. Copying the file to RAM disk on a personal computer speeds processing. Comment out all lines if RAM disk is not used.

FLOWCHART STEP - READ MINUTE OF LOG DATA FROM FILE "DATE".DAY:

No changes.

FLOWCHART STEP - SCAN "DATE".SPY FOR MINUTE OF SPRAY DATA TO MATCH CURRENT MINUTE OF LOG DATA:

In READ statement 31, and FORMAT statement 2, the number of spray collectors should be changed if 6 were not used (A through F). Change 6(F10.4) in the FORMAT statement to reflect the number of spray collectors in the read statement.

FLOWCHART STEP - WERE SPRAY DATA FOUND TO MATCH LOG DATA?

No changes.

FLOWCHART STEP - IF SPRAY DATA MISSING, WRITE LOG DATA WITH SPRAY AS MISSING VALUES - 9999.0.

Change FORMAT statement 1 to reflect the number of spray collectors by changing the number of 9999.0 s. The WRITE statement does not require changing.

FLOWCHART STEP - CHECK IF SUFFICIENT DATA TO COMPUTE RELATIVE WIND:

No changes except to WRITE statement. If relative wind cannot be computed the ship log and uncorrected spray fluxes are written with the message 'FLUX NOT WIND CORRECTED.' Change the number of spray collectors if other than 6 (A-F) and the FORMAT statement at 6(1X,F8.2).

FLOWCHART STEP - SUBROUTINE RELATIVE:

No changes necessary if ANSI FORTRAN 77 is used.

FLOWCHART STEP - COMPUTE RELATIVE WIND DIRECTION RELATIVE TO EACH OFF-AXIS HORIZONTAL SPRAY COLLECTOR ACCORDING TO ITS ORIENTATION:

The following statements must be changed. For horizontal spray collectors off axis to starboard only, each collector requires the following two statements:

```
IF(RWD.LE.180.0) RWD2LS = ABS(RWD - ANGLE)
IF(RWD.GT.180.0.AND.RWD.LE.360)
  *RWD2LS = ABS((360.0 - RWD) + ANGLE)
```

where ANGLE is the angle between the ship's longitudinal axis and the spray collector axis orientation to starboard.

For horizontal spray collectors off axis to port only, each collector requires the following two statements:

```
IF(RWD.LE.180.0) RWD2LS = ABS(RWD + ANGLE)
IF(RWD.GT.180.0.AND.RWD.LE.360)
  *RWD2LS = ABS((360.0 - RWD) - ANGLE)
```

where ANGLE is the angle between the ship's longitudinal axis and the spray collector axis orientation to port.

FLOWCHART STEP - COMPUTE RELATIVE WIND SPEED FOR ALL HORIZONTAL SPRAY COLLECTORS:

The following two statements are necessary for each horizontal spray collector:

```
IF(RWD2LP.GT.90.0) RWD2LP = 90.0
RWV2LP = RWV * COS(RWD2LP*RADD)
```

where RWD2LP is the relative wind direction at the 02 level, port side, and RWV2LP is the relative wind velocity at the 02 level, port side. RWD2LP and RWV2LP changes in name for each collector location.

FLOWCHART STEP - COMPUTE COLLECTION EFFICIENCY AT HORIZONTAL SPRAY COLLECTOR:

The following pair of statements are needed for each horizontal collector:

```
IF(RWVMDS.GT.6.5) EFFMDS = 0.01 * (98.5 -
  *(((1.854 * RWVMDS) - 12.0) * 0.4545))
```

where RWV is Relative Wind Velocity at MDS, Main Deck Starboard. Change variable names to suit.

FLOWCHART STEP - COMPUTE CORRECTED SPRAY FLUX FOR EACH HORIZONTAL COLLECTOR:

The following statement is needed for each horizontal collector:

IF (A.LT.9000.0) A = A * (1.0/EFFMDS)

where A is the main deck starboard spray collector, and EFFMDS is Efficiency at the Main Deck Starboard horizontal collector. Change variable names to suit.

FLOWCHART STEP - WRITE ALL WIND-CORRECTED SPRAY FLUXES AND LOG DATA TO FILES "DATE".FLX AND "DATE".ALB:

No changes except to WRITE statements. Change the number of spray collectors if other than 6 (A-F) and the FORMAT statements at 6(1X,F8.2).

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestion for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE December 1992		3. REPORT TYPE AND DATES COVERED	
4. TITLE AND SUBTITLE Ship Superstructure Icing: Data Collection and Instrument Performance on USCGC <i>Midgett</i> Research Cruise				5. FUNDING NUMBERS	
6. AUTHORS Charles C. Ryerson and Paul D. Longo					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Cold Regions Research and Engineering Laboratory 72 Lyme Road Hanover, New Hampshire 03755-1290				8. PERFORMING ORGANIZATION REPORT NUMBER CRREL Report 92-23	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Ship Structures and Protection Department U.S. Navy David W. Taylor Naval Ship Research Center (DTRC) Bethesda, Maryland 20084-5000				10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited. Available from NTIS, Springfield, Virginia 22161				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Spray generated by the collision of a ship's bow with waves freezes on decks, bulkheads and ship's components. It is most common on smaller vessels, where it has been known to cause sinking, typically by capsizing. Superstructure icing may also reduce the operating efficiency or mission performance of larger vessels. The ability to predict the environmental conditions under which icing may occur, the location of icing on a vessel under those conditions, and the rate at which ice will accrete may allow vessels to avoid hazardous conditions or operate in a manner so as to minimize the accretion of ice. This report describes how spray delivery and superstructure icing were measured during a research cruise on the U.S. Coast Guard Cutter <i>Midgett</i> , operating in the Gulf of Alaska and Bering Sea in February-March 1990, to support the validation and calibration of a numerically based icing prediction model being developed for the U.S. Navy. This research cruise represents the first such measurements on a vessel significantly larger than fishing trawlers, the basis for prior work. Development of the instrumentation, its placement on the <i>Midgett</i> , and ancillary equipment used to supplement the principal measurements are discussed. Data collection and problems encountered in the process are covered extensively. Finally, measurement error is discussed, with conclusions drawn concerning corrections to the data and their validity.					
14. SUBJECT TERMS Bering Sea Coast Guard cutter Icing Measurement error Bow spray Cold regions Instrumentation Ship superstructure icing				15. NUMBER OF PAGES 142	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL		

NSN 7540-01-280-5500

*U.S. GOVERNMENT PRINTING OFFICE: 1993-700-059/80043

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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