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Automated Control of Shipboard Ventilation Systems: Phase 2 Part A Test Results

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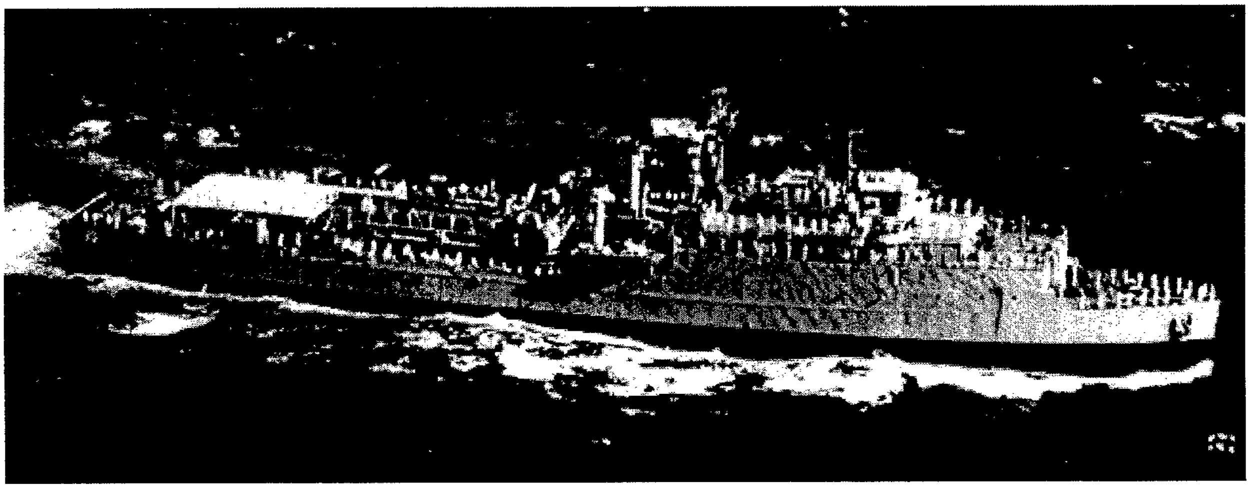

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14. ABSTRACT

A ship's ventilation system is critical to some Damage Control (DC) situations. Smoke and heat management is critical in successful DC operations. Ventilation techniques employed by doctrine vary depending on the overall situation. Two fundamental principles define smoke and heat control: zone pressurization and air flow. Smoke ejection systems have been designed, but not automated into the Advanced Damage Control, Automation. This report describes an initial step in the automation of ventilation.

15. SUBJECT TERMS

Ventilation; Damage control; Smoke management; Zone pressurization; Air flow

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AUTOMATED CONTROL OF SHIPBOARD VENTILATION SYSTEMS: PHASE 2 PART A TEST RESULTS

1.0 INTRODUCTION

Ventilation is defined as "The movement of air from the weather into the ship or from the ship out to the weather by supply fans, exhaust fans, or ductwork, or a combination thereof" [1]. Ventilation is also defined as providing "conditions for human thermal comfort" where "thermal comfort is that condition of mind that expresses satisfaction with the thermal environment" [2]

Ventilation systems not only control their respective environments for the purpose of comfort, but a ship's ventilation system is critical to some Damage Control situations. For example, in the event a fire ignites, ventilation is used in accordance with Navy doctrine to maximize the ability of the ship to survive the threat. Smoke management is one area of concern. Smoke management is "the application of all methods to modify smoke movement for the benefit of occupants and fire fighters, as well as, the reduction of property damage" [3]. Ventilation techniques employed by doctrine vary depending on the overall situation.

Two fundamental principles can define smoke control. The first is zone pressurization and the second, air flow [4]

The principle of pressurization is to develop a relatively higher pressure in zones surrounding a fire affected zone. If a fire-affected zone is lower in pressure than its surroundings, air from the surroundings will migrate into the fire-affected zone. This migration of air will prevent smoke from dispersing out from the fire-affected zone.

The principle of airflow is most applicable when a fire-affected zone contains an opening. Adequate air velocity into an opening can prevent the migration of smoke out of a fire-affected zone through that same opening [5].

Smoke control systems can be classified as one of two systems, dedicated or non-dedicated. "Dedicated" refers to the concept the smoke control system is a separate system of air-moving and distribution equipment that does not function under normal operating conditions. "Non-dedicated" refers to the concept the smoke control system shares components with the other heating, ventilation, and air conditioning (HVAC) components of the facility [4]

The non-dedicated smoke control system is the best for Navy shipboard installations for several reasons. Overall costs are lower, space requirements are less, and because much of the system is part of the regular HVAC system, any component failures are likely to be repaired promptly. One disadvantage of a non-dedicated system is the system controls are more complex as compared to a dedicated smoke control system.

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In the late 1980's, and again in the late 1990's the U.S. Navy developed and tested two smoke control systems aboard the ex-USS *Shadwell* [6]. These systems are referred to as smoke ejection systems (SES). The first effort was to be implemented on the Arleigh Burke Class Destroyer DDG 51. The second effort was intended for use aboard the multi-purpose amphibious class ship LPD 17. Numerous fire tests have been performed using both of these systems [7-14]. The tests demonstrated the philosophy that smoke can be controlled as long as the ventilation system is adequately configured. Both SES systems were examples of non-dedicated smoke control systems.

The two SES systems tested on ex-*Shadwell* had different levels of complexity. In more practical terms they had a different quantity of configurations that could be implemented. The current SES design (LPD 17) has numerous supply and exhaust fans for air movement and thirty-one motorized dampers to control flow direction. These dampers are named Smoke Control Dampers (SCD) and Smoke Purge Dampers (SPD). There are seventeen SCDs and fourteen SPDs. Under normal (non-fire) conditions, the system is configured in the Collective Protection System (CPS) mode, in which the seventeen SCDs are opened and the fourteen SPDs are closed. In the event of fire, the ventilation system is reconfigured to provide smoke control. With the flip of one electrical switch the seventeen SCDs close and the fourteen SPDs open. In short, this SES design has two different and distinct configurations.

The earlier SES system (DDG 51) had roughly the same fans as the LPD 17 system and a system of motorized dampers as well. Compared to the LPD 17 system, the DDG 51 system had at least eight electrical switches to control the system's dampers. The eight control switches increased the quantity of configurations possible, but made the system more difficult to properly use. In summary, the current LPD17 system with one control switch produces only two different configurations. The earlier DDG 51 system with approximately eight control switches was capable of many configurations, but was susceptible to inadequate usage from insufficient information, insufficient training, or operator error.

The use of a non-dedicated smoke control system aboard Navy ships holds several advantages over a dedicated system. First and foremost, the system requires less space. Secondly, the non-dedicated system will have lower overall costs. In contrast, one of the greatest challenges associated with a non-dedicated system is the control system complexity. Because the non-dedicated smoke control system also serves as the regular HVAC system, it has to be flexible and responsive to a variety of environmental conditions. The ongoing efforts of this project are targeted at meeting the challenges of these demands.

In Phase 1, a variety of control networks were evaluated and LonWorks was chosen [15]. The capability and applicability of LonWorks related to ventilation control was demonstrated in Phase 1 [16].

Phase 1 testing was performed onboard the ex-USS *Shadwell* 17] during the 2000 DC-ARM Demonstration [18]. LonWorks proved to be a very capable network, which led to this Phase 2 Part A effort. This report documents the findings of the fire tests conducted on the ex-USS *Shadwell* during the week of January 6, 2002.

2.0 BACKGROUND

2.1 Phase 1 Review

Phase 1 of this program was conducted in Fiscal Year 2000 of the Navy's Damage Control-Automation for Reduced Manning (DC-ARM) program [18]. Phase 1 focused on a small-scale ventilation arrangement.

A significant task in undertaking Phase 1 was choosing a suitable network. This was accomplished with a report on the evaluation of communication systems [15]. This report documented the research conducted on several networks. The networks were analyzed for their potential in automating ventilation systems onboard the ex-*Shadwell*. A powerful and robust peer-to-peer control network was the standard set for the analysis. Although several networks were satisfactory for data networks or master/slave control networks, only a few met the standard for automating the ventilation system. LonWorks emerged as the network of choice.

Designing and implementing the network with a limited number of fans, dampers and sensors was then the main task at hand. The basis of the design was a peer-to-peer control network that allowed sensors and devices to communicate and react to a damage scenario, namely controlling heat and smoke in one small, contaminated zone (3 compartments). The sensors indicating damage were three thermocouples, three optical density meters (ODMs) and three pressure transducers. The devices controlling the damage were three actuators, corresponding ventilation dampers and a frequency drive, which controlled an exhaust fan.

The sensors and devices were able to communicate through LonWorks control modules using the LonTalk Protocol. In addition, a remote laptop computer was used to monitor and override network commands using the fiber optic backbone aboard ex-*Shadwell*. An i.LON 1000 made this possible by acting as a router to send messages in LonTalk Protocol over an IP network allowing communication over the fiber optic backbone.

2.2 Phase 2 Part A Overview

In Phase 2 Part A, the control of the ventilation was expanded to allow for real smoke control in more than one compartment. The previous phase proved the capability and applicability of a LonWorks peer-to-peer network as it relates to ventilation control in damage scenarios. Building on those capabilities, Phase 2 Part A was to demonstrate larger-scale damage control with a portion of the ventilation system. The peer-to-peer network was uploaded with different control programs to allow for different levels and types of automated control.

The efforts of Phase 1 created an automated control system that networked three actuators, one frequency drive controller (operating an exhaust fan) and nine sensors. The first objective of Phase 2 Part A has implemented this same technology throughout a larger portion of the existing SES system aboard ex-*Shadwell*. Instead of just three actuators, one frequency drive and nine sensors, the automated control system was applied to ten actuators, two frequency drives and eight sensors. The most significant objective of Phase 2 Part A was to explore in greater detail the concept of ventilation system reconfiguration to maximize the ship's ability to control smoke. The concept proposed involves taking ventilation from an area (or zone) where it is deemed less important momentarily and applying it to an area (or zone) where it is deemed more important. In general terms, it is a method of establishing priorities and using the ship's capabilities to best mitigate potential damage.

2.3 Phase 2 Part A Details

In the DC-ARM test area aboard the ex-*Shadwell* exists the LPD 17 SES system [14]. This smoke ejection system serves the 01 Level down to the 4th Deck between FR 9 through 36. The system includes seventeen Smoke Control Dampers and fourteen Smoke Purge Dampers, which are controlled by motorized actuators.

Most of the ventilation terminals serve the Main and 2nd Decks, and to a lesser extent, the 01 Level, 3rd and 4th Decks. Under the existing control system the SES system is capable of two modes of operation, CPS and SES. Two modes, SES and CPS, will be addressed by algorithms in the new Automated Ventilation Control Program. These two modes will mimic the current SES and CPS modes aboard ex-*Shadwell.* Two other modes have been developed as part of this scope of work. These two new modes have been designated DC-ARM and AUTO modes.

For budgetary reasons, it has been the philosophy of this effort to use the existing ventilation ductwork and fans basically as they already exist. Without some ship alterations, optimum ventilation effectiveness is prevented; however, the "proving grounds" for system automation is present.

3.0 OBJECTIVES

The objectives for this test series include:

1) Demonstrate the capabilities and flexibility of the network by providing different control modes.
2) Investigate a different ventilation technique than that used in the current CPS/SES system. This different technique is one of compartment independent exhaust ventilation, as opposed to the previous technique of exhaust in combination with supply ventilation.

4.0 EXPERIMENTAL SETUP

4.1 Test Area

The test area included the 2nd Deck from FR15 to FR29. The 2nd Deck represented the Damage Control (DC) Deck with the port and starboard longitudinal passageways serving as the DC Deck passageways (see Figure 1):

Passageway 2-15-1-L (Starboard side FR15-22),
Passageway 2-22-3-L (Starboard side FR22-29),
Passageway 2-15-2-L (Port side FR15-22), and
Passageway 2-22-4-L (Port side FR22-29).

4.2 Ventilation

The ventilation serving the test areas was controlled by ten automated dampers and two frequency drive controlled fans. The dampers are:

SCD 1-15-2,
SCD 2-15-2,
SPD 2-17-2,
SCD 2-18-2
SPD 2-27-2,
SCD 1-16-1,
SCD 2-15-1,
SCD 2-15-3,
SCD 2-16-1,
SPD 2-17-1.

The locations of the SES exhaust terminals for the 2nd Deck are shown in Figure 2. The terminals employed for smoke control are located in both of the DC Deck passageways labeled as 4E (starboard side) and 5D (port side). Exhaust terminal 4E is located on the outboard side of the starboard passageway near FR18. Exhaust terminal 5D is located on the outboard side of the port passageway near FR17. Automated dampers SPD 2-17-1 and SPD 2-17-2 directly control the airflow through terminals 4E and 5D, respectively. Two automated dampers, SCD 1-15-2 and SCD 1-16-1, control airflow out of the port and starboard fan discharges (TPES 1-16-4 and TPES 1-16-1, respectively). See Figures 2 and 3. The remaining six automated dampers are used to isolate exhaust ventilation to only those damage areas requiring it and to secure (shut off) supply ventilation from damage areas.

Table 1 displays how CPS and SES alignments relate to the actual physical position (open or close) of the damper. This is beneficial in understanding how the "exhaust only" technique is accomplished in AUTO Mode (independent, exhaust only).

Table 1. Actual damper position corresponding to mode and damage scenario

DC-ARM Mode			
CPS		SES	
Open	Close	Open	Close
SCD 2-15-1	SPD 2-17-1	SPD 2-17-1	SCD 2-15-1
SCD 2-15-2	SPD 2-17-2	SPD 2-17-2	SCD 2-15-2
SCD 2-15-3	SPD 2-27-2	SPD 2-27-2	SCD 2-15-3
SCD 2-16-1	SCD 1-15-2	SCD 1-15-2	SCD 2-16-1
SCD 2-18-2	SCD 1-16-1	SCD 1-16-1	SCD 2-18-2

Auto Mode			
Damage to STBD side		Damage to PORT side	
Open	Close	Open	Close
SCD 1-16-1	SCD 1-15-2	SCD 1-15-2	SCD 1-16-1
SCD 2-15-2	SCD 2-15-1	SCD 2-15-1	SCD 2-15-2
SPD 2-17-1	SCD 2-15-3	SCD 2-15-3	SPD 2-17-1
SCD 2-18-2	SCD 2-16-1	SCD 2-16-1	SCD 2-18-2
	SPD 2-17-2	SPD 2-17-2	SPD 2-27-2
	SPD 2-27-2		
Damage to BOTH sides			
Open	Close		
SCD 1-15-2	SCD 2-15-1		
SCD 1-16-1	SCD 2-15-2		
SPD 2-17-1	SCD 2-15-3		
SPD 2-17-2	SCD 2-16-1		
	SCD 2-18-2		
	SPD 2-27-2		

The frequency drive controlled fans are TPES 1-16-1 and TPES 1-16-4. See Figure 3.

4.3 Sensors

Two types of sensors were used to indicate damage, thermocouples and optical density meters (ODMs). One sensor set containing one thermocouple and one ODM were placed in each of the four passageways in the test area. The four locations were approximately FR19 in both Passageways 2-15-1-L and 2-15-2-L and FR25 in both Passageways 2-22-3-L and 2-22-4-L. For logging sensor data, it was necessary to use duplicate sensors connected to the ex-*Shadwell's* data collection system (Masscomp). Bi-Direction Flow Probes, cameras, and additional thermocouples were also used to assist in monitoring network performance. See Figure 4.

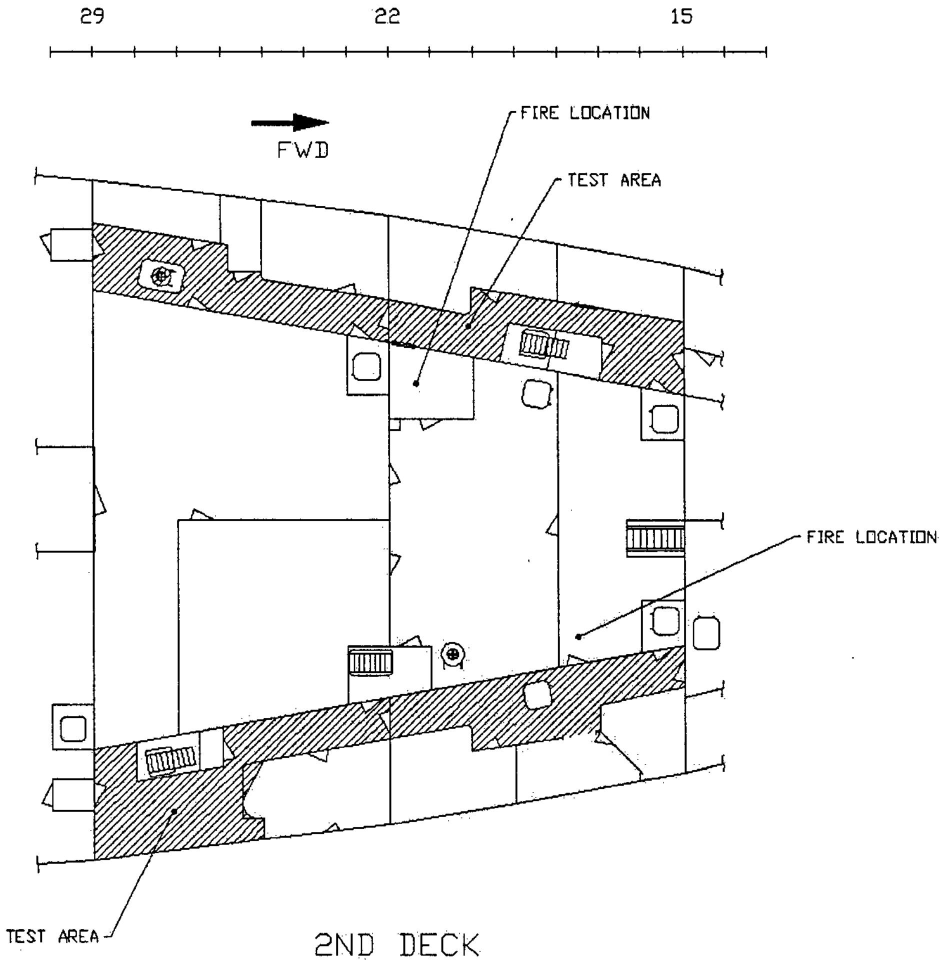

Figure 1. Test Area - Automated Ventilation Control Test Series 1

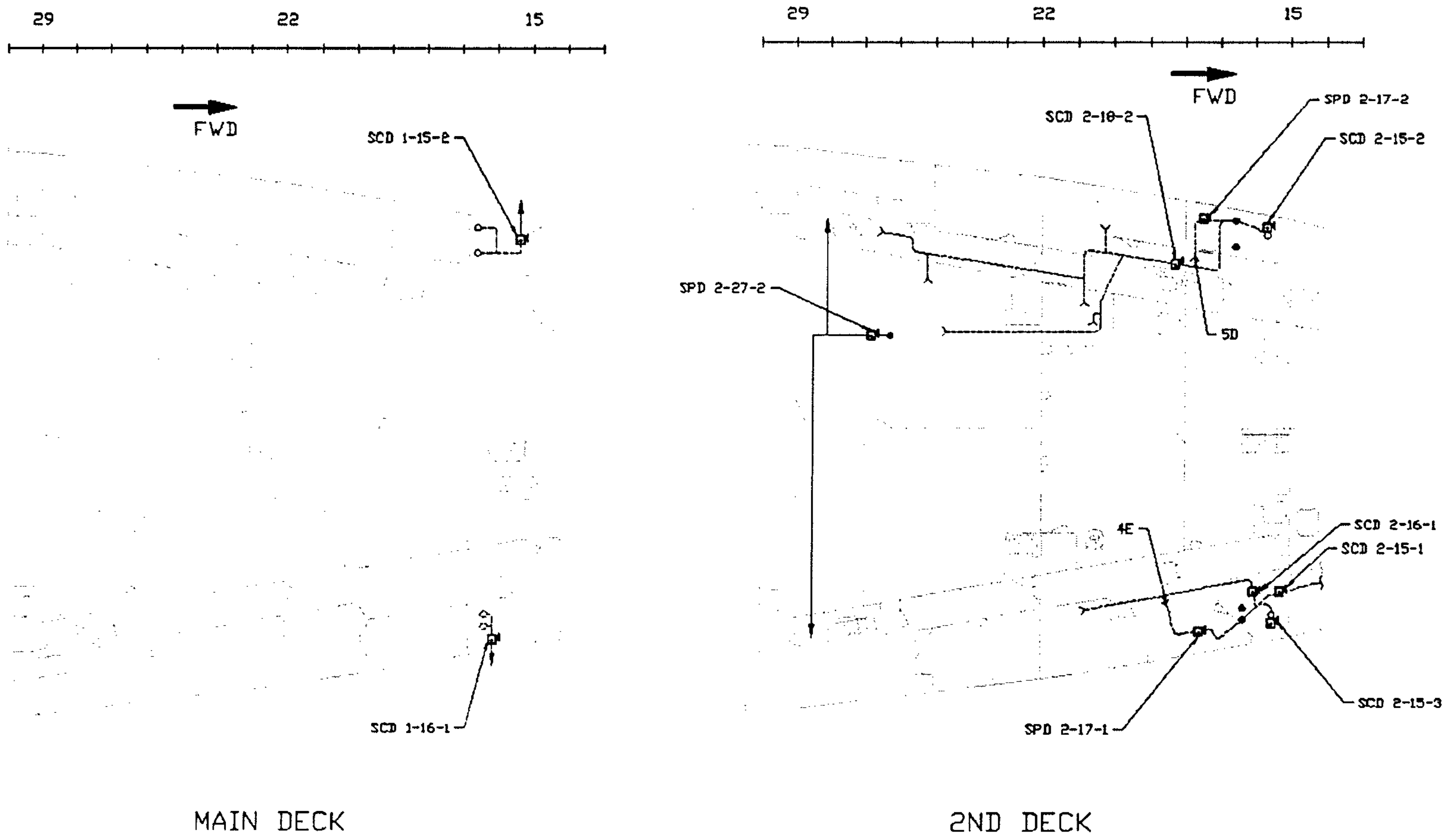

Figure 2. Exhaust Terminals - Automated Ventilation Control Test Series 1

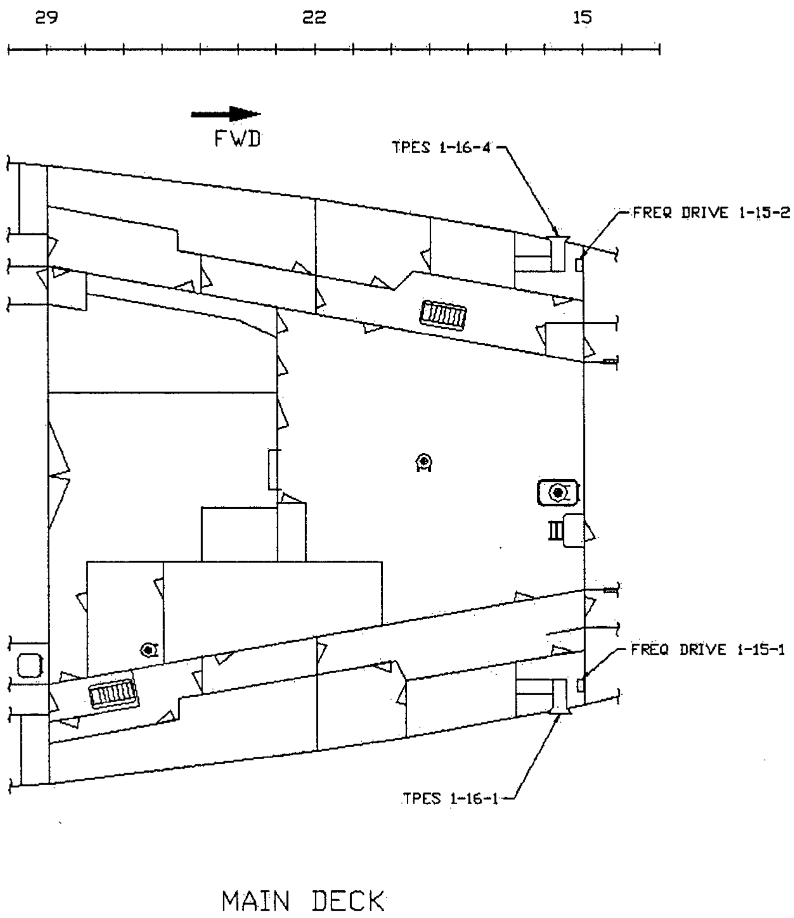

Figure 3. Frequency Drive Controlled Fans - Automated Ventilation Control Test Series 1

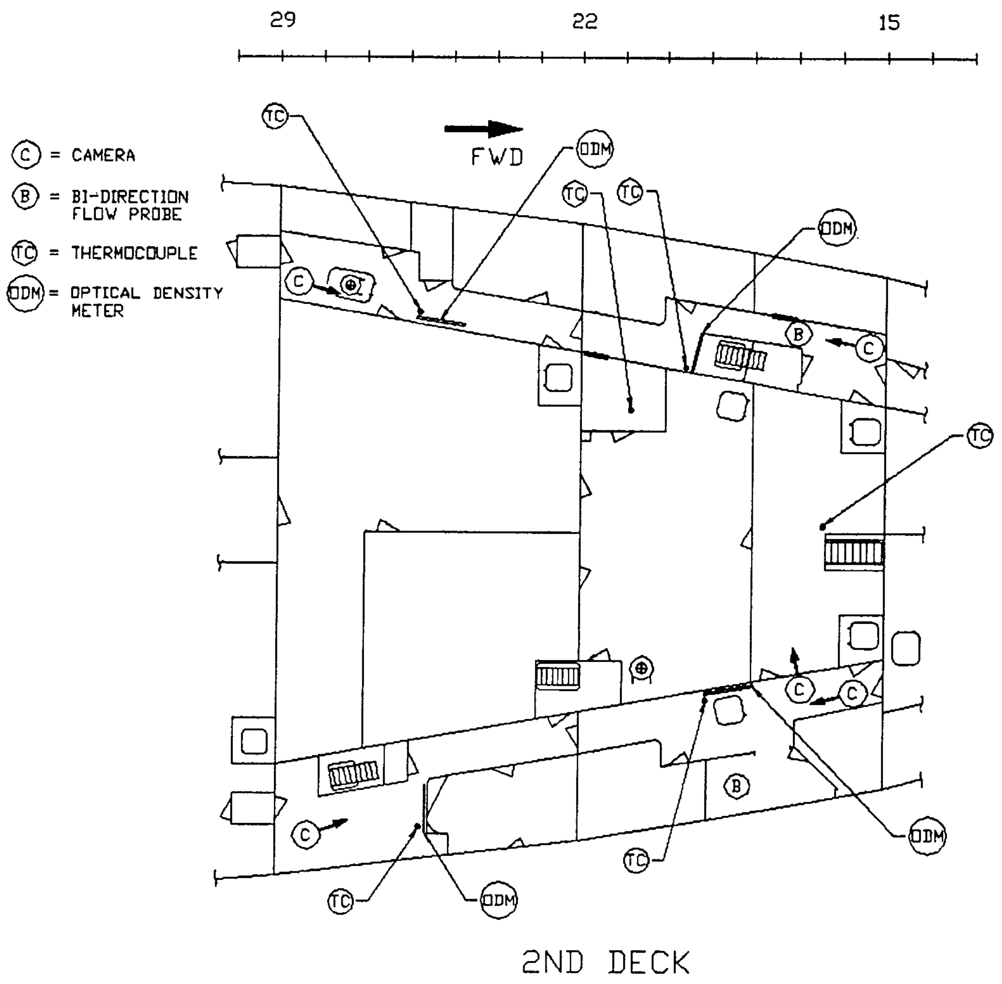

Figure 4. Sensor Locations - Automated Ventilation Control Test Series 1

5.0 LONWORKS AND THE ACSVS LNS APPLICATION

The control box responsible for the starboard passageway's sensors and frequency drive was located in the starboard 2nd Deck Node Room. See Figure 5. The 2nd Deck Port Node Room was the location of the control box responsible for the port passageways' sensors and frequency drive. See Figure 5. The third control box, responsible for the actuators, was in the Scullery on the 01 Level. Each control box was connected to the ex-USS *Shadwell* fiber optic backbone via an i.LON 1000 Internet Server. The i.LON 1000 allows the LonWorks network to send LonTalk packets over a TCP/IP channel.

LonWorks control boxes 2-18-2 and 2-20-1 in the 2nd Deck node rooms were identical in content and function. They were different only in the fact they served different DC Passageways. Each control box had two analog input modules (AI-10) each containing two analog inputs. These two AI-10s accepted the ODM and thermocouple inputs from their respective passageways. The thermocouples were wired into thermocouple signal conditioners, which converted the thermocouple millivolt signal to a 0-10 V signal. The thermocouple signal conditioners sent signals to the AI-10s. Each control box also contained a third AI-10, one (1) analog output module (AO-10), one (1) digital input/output module (DIO-10), an i.LON 1000 Web Server, and a 24 VDC power supply (to power the control modules and i.LON 1000). The AO-10 sent out an analog speed control signal to the respective frequency drive. The DIO-10 transmitted a digital signal to turn on the corresponding exhaust fan and the third AI-10 accepted speed feedback from the respective frequency drives. The third LonWorks control box located in the Scullery included ten (10) DIO-10s and a 24 VDC power supply. Each DIO-10 module accepted feedback from its respective actuator limit switches and sent control signals to the actuator through the 3-way switch (see 3-way switch description in reference (19)). Two i.LON 1000s, acting as routers, were located in the Control Room on the 02 Level. One of the i.LON 1000s was connected to the actuator control box in the Scullery via a twisted pair cable. The second i.LON 1000 was connected to the AutoVent Laptop allowing monitoring, override and configuration capability.

The purpose of the ACSVS (Automated Control of Shipboard Ventilation Systems) LNS Application was to control the LonWorks network aboard the ex-USS *Shadwell.* This software allowed the control of the frequency drive speeds, the control of fans turning on and off and the control of actuator alignment. Depending on the control mode, the control of the frequency drive speed and actuator position was accomplished manually through the LNS software automated by sensor input.

The ACSVS LNS Application was written using Microsoft Visual C++ 6.0 in conjunction with Echelon's LNS Application Developer's Tool Kit 3.x. The ACSVS LNS application interfaces with Echelon's LNS Server that contains the logical LNS Network Database. Appendix A contains programming details for the ACSVS LNS application.

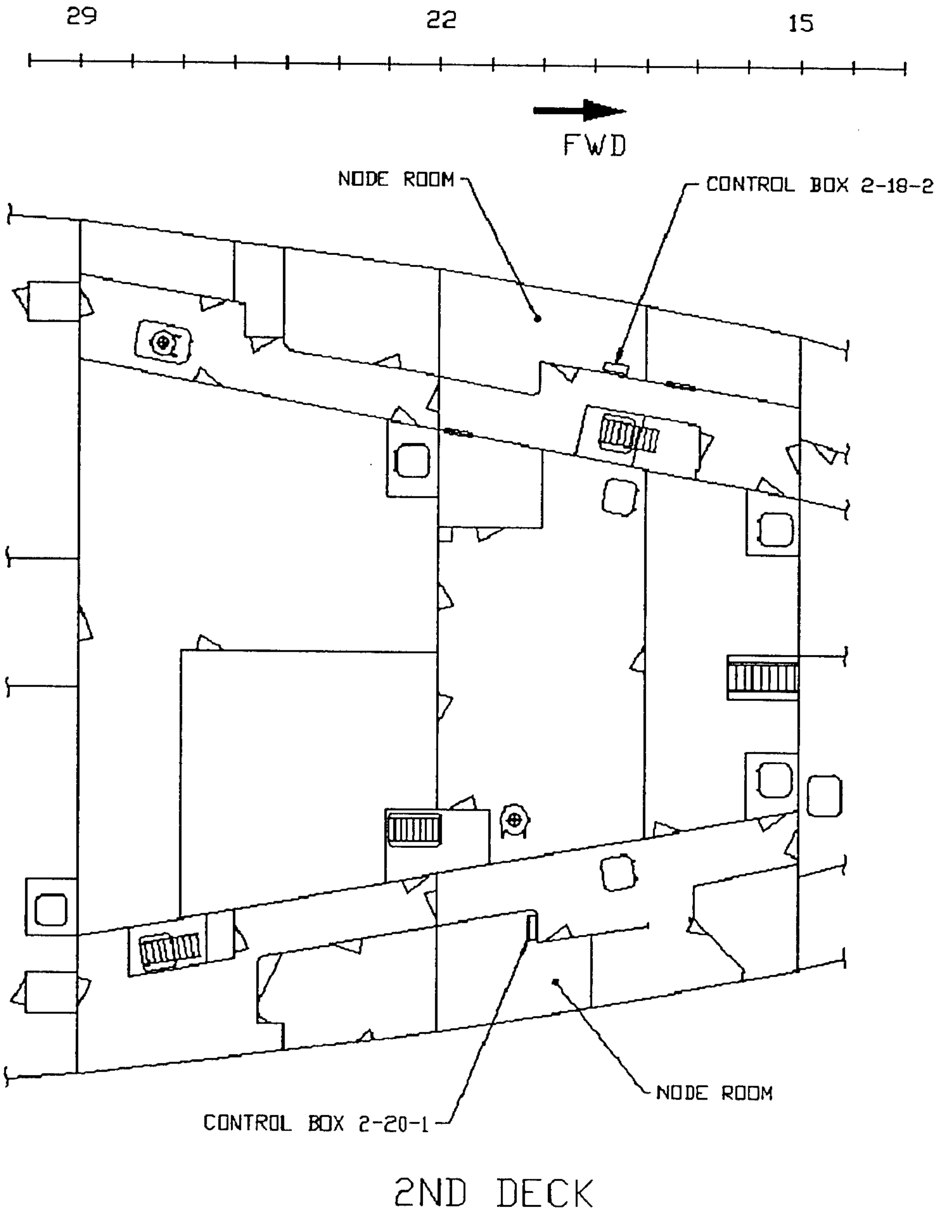

Figure 5. Starboard and Port Control Box Locations - Automated Ventilation Control Test Series 1

6.0 TEST SCENARIOS

The damage scenarios were conducted using small Class B fires in the ex- *Shadwell* 2nd Deck test area. One fire location was the starboard side of CPO Living, FR17. The second fire location was on port side in the CIC Vestibule, FR 21 (Figure 1).

Passageways 2-15-1-L and 2-22-3-L were open to each other, but were otherwise secured except for the closure leading to the fire location. The fire location for the starboard side was in CPO Living (Figure 1), so closure 2-17-1 was opened to passageway 2-15-1-L.

Passageways 2-15-2-L and 2-22-4-L were open to one another, but otherwise secured as well. The closure 2-21-2 to the port side fire location (Figure 1), was open, which opened the CIC Vestibule to passageway 2-15-2-L.

Test scenarios consisted of four different ventilation modes (programs). Each is described below.

6.1 CPS Mode

This mode was to mimic the control of the existing smoke ejection system when the manual electrical switch was in the CPS position. It is not a sensory reactive mode. It is simply the incorporation of the former manual system into the new automated control network. CPS mode was only tested for its actuator alignment and frequency drive speed.

6.2 SES Mode

This mode was to mimic the control of the existing smoke ejection system when the manual electrical switch was in the SES position. Like the CPS Mode, this mode is not a sensory reactive mode, and like the CPS Mode it is simply the incorporation of the former manual system into the new automated control network. The SES mode was tested for its actuator alignment, frequency drive speed, and, in addition, automatically starting exhaust fans TPES 1-16-1 and TPES 1-16-4.

6.3 DC-ARM Mode

DC-ARM mode is basically an automated CPS and SES ventilation system, as it applies to damper alignment and frequency drive speed. The former manual system on ex-USS *Shadwell* required personnel to flip an electrical switch to change from CPS to SES modes, and vice versa. In this DC-ARM mode, changing the ventilation system between CPS and SES was automated based on damage indication. Damage indication was determined based on critical setpoints. The sensor data was compared to the setpoints to determine if there was damage. The thermocouple setpoint was 43.33 °C (110 °F) and the ODM setpoint was 75% visibility (25% obscuration). DC-ARM mode was tested for proper operation as it functions in CPS and SES modes. Because DC-ARM is a sensory reactive mode, it was tested with normal and damage scenarios as shown in the test matrix of Table 2.

6.4 AUTO Mode

AUTO Mode is a sensory reactive mode as is DC-ARM Mode, but it uses different damper alignments and variable frequency drive speeds. AUTO Mode uses different ventilation techniques than exist with the current CPS/SES system on the ex-USS *Shadwell*. The ventilation technique in AUTO Mode is to use only exhaust ventilation for smoke and heat removal. In contrast, the existing CPS/SES system uses both supply and exhaust to create air sweeps. In this new AUTO Mode, damper alignment and frequency drive operation are compartment independent. That is, if sensors indicate damage in a compartment, only ventilation components related to that compartment are activated. Ventilation components to all other compartments do not react until damage is indicated in the respective compartment. Damage was indicated as stated in paragraph 6.3 (DC-ARM Mode). In comparison, the former CPS/SES system had all ventilation components react regardless of damage location. AUTO Mode was tested for proper operation as defined by the program, but also for smoke and heat removal capability. AUTO Mode was tested with normal and damage scenarios as outlined in Table 2.

7.0 PROCEDURE AND SAFETY

At the beginning of each day, the daily checklist was completed. Prior to each test, the fire area was cleared of all personnel not involved with testing. When the fuel package was prepared and the safety team was in position, videos were initiated and the data acquisition system started. During the test, test personnel made visual observations of the source. Each test was terminated when the test director determined the objectives for that test were sufficiently evaluated.

The safety team consisted of two people. These personnel were members of ex-USS *Shadwell's* ship force. They were responsible for ensuring that all tests were conducted in a safe manner and notifying the Test Director of any unsafe conditions. Also, all test personnel were briefed for the purpose of explaining the test scenario and any safety precautions.

8.0 RESULTS AND ANALYSIS

This analysis is based on the objectives set forth in section 3.0. Each test is analyzed individually and then statements regarding problems encountered, suggested fixes and general suggestions follows. Additional information regarding sensor data and the compartment temperature data can be found in Appendices B and C respectively.

Table 2. Automated Ventilation Test Matrix – Series 1

Test ID	Ventilation Status	Evaluation Location	Fuel Load	Fire Location	Comments
AVENT01	CPS Mode		No Fire	N/A	To verify proper actuator & fan operations
AVENT02	SES Mode		No Fire	N/A	To verify proper actuator & fan operations
AVENT03	DC-ARM Mode	2nd Deck test zone in general	No Fire	N/A	Normal Conditions, establish background
AVENT04	DC-ARM Mode	Passageways 2-15-1-L & 2-22-3-L	No. 1	See Fig. 1	Evaluate response based on heat conditions
AVENT07	DC-ARM Mode	Passageways 2-15-2-L & 2-22-4-L	No. 3	See Fig. 1	Evaluate response based on heat & smoke conditions
AVENT08	AUTO Mode (independent, exhaust only)	2nd Deck test zone in general	No Fire	N/A	Normal Conditions, establish background
**AVENT10	AUTO Mode (independent, exhaust only)	Passageways 2-15-2-L & 2-22-4-L	No. 1	See Fig. 1	Evaluate response based on heat conditions
AVENT11	AUTO Mode (independent, exhaust only)	Passageways 2-15-1-L & 2-22-3-L	No. 3	See Fig. 1	Evaluate response based on heat & smoke conditions
**AVENT12	AUTO Mode (independent, exhaust only)	Passageways 2-15-2-L & 2-22-4-L	No. 2	See Fig. 1	Evaluate response based on heat & smoke conditions
**AVENT13	AUTO Mode (independent, exhaust only)	Passageways 2-15-1-L & 2-22-3-L Passageways 2-15-2-L & 2-22-4-L	No. 3	See Fig. 1	Ignite fuel load to starboard side first, 10 minutes later ignite fuel load to port side

Fuel Loads:
No. 1 = 26.5 L (7 gal) methyl alcohol in 0.6 m (2 ft) diameter pan
No. 2 = 15.1 L (4 gal) diesel & 1.9 L (0.5 gal) n-Heptane in 0.6 m (2 ft) diameter pan
No. 3 = 7.6 L (2 gal) diesel & 1.9 L (0.5 gal) n-Heptane in 0.6 m (2 ft) diameter pan
* Tests removed due to redundancy and time constraints
** Fuel loads modified as described in Section 8.0

Note: All sensor data represented in tables and graphs are not from the sensors connected to the control network. The duplicate sensors used for logging data through the Masscomp provided the data for the report. The two different sets of sensors (AutoVent sensors and Masscomp sensors) were located near each other. However, there were slight differences between the data the control network was using and the data the Masscomp was using at any discrete time period.

8.1 AVENT01

This first test was to verify proper actuator and fan operations as they applied to CPS Mode. The only deviation from standard CPS Mode was the fans were not automatically started. This was only to allow for verification of the manual starting of the fans from the computer through the ACSVS LNS application.

The ventilation system was in AUTO Mode (independent, exhaust only) prior to initiating CPS Mode. AUTO Mode was the last mode used during mockups. CPS Mode was initiated at 09:01:38 and fully executed by 09:10:40, for a total initialization and execution time of 9 minutes and 2 seconds. All dampers were verified to be in CPS by the green LEDs (Light Emitting Diodes) on the CPS/SES control panel in the control room. See Figure 6. The two light indicators for TPES fans 1-16-1 & 1-16-4 were not illuminated, indicating the fans were off, which was visually verified by test personnel at the fan locations.

At 09:11:26 the fans were manually started from the ACSVS LNS application. The control room light indicators for both fans illuminated, indicating both fans were on. This was also verified by test personnel at the fan locations. The test personnel also verified frequency drive speeds of 43 Hz for TPES 1-16-1 and 39 Hz for TPES 1-16-4.

The test was terminated with a manual stopping of the fans from the ACSVS LNS application at 09:13:17.

8.2 AVENT02

The second test was for similar verification purposes as AVENT01, except as it applied to SES Mode. CPS and SES Modes were programmed as two separate modes, rather than one mode with two different actuator settings.

The ventilation system was in CPS Mode before initializing SES Mode. At 09:15:25 SES Mode was initiated. Both fans turned on at 09:19:28 and SES Mode was fully executed by 09:21:12, for a total initialization and execution time of 5 minutes and 47 seconds. The LEDs on the CPS/SES panel verified the actuators were all in SES Mode (red). See Figure 7. Both fans started automatically as indicated by the light indicators in the control room. Test personnel at the fan locations verified the "on" status and reported the frequency drive speeds as 43 Hz for TPES 1-16-1 and 39 Hz for TPES 1-16-4. The fans were manually stopped from the ACSVS LNS application at 09:22:39 to end the test.

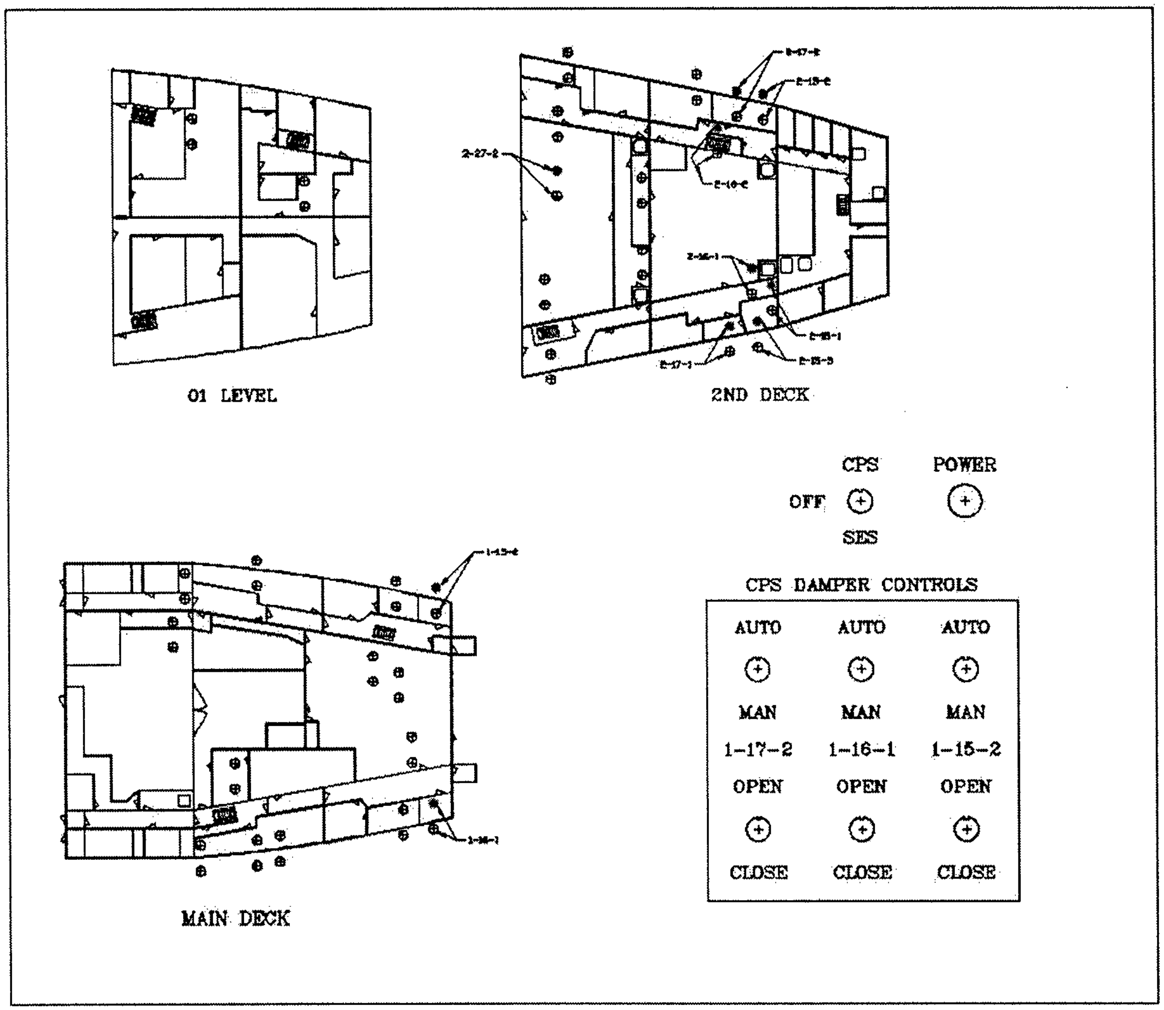

Figure 6. Actuator Alignment – CPS Mode

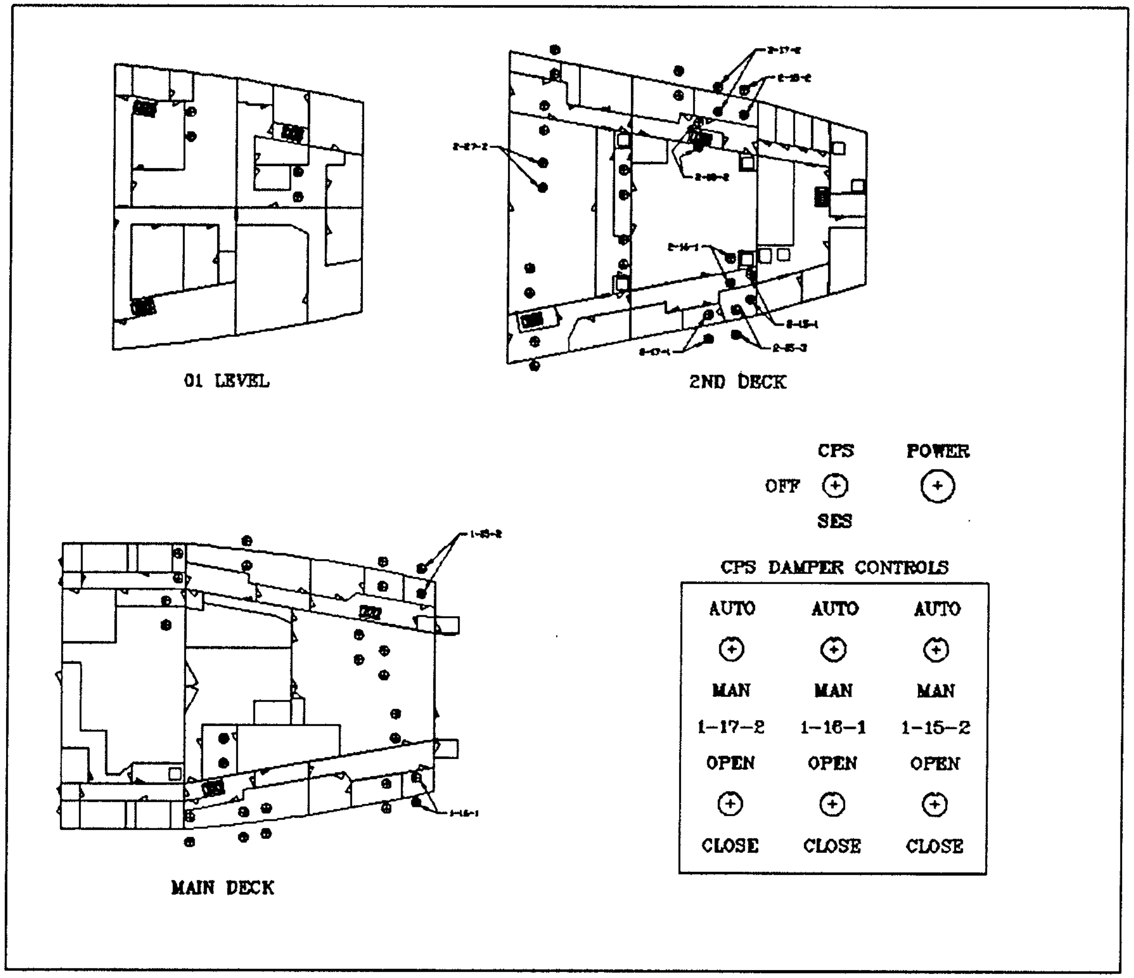

Figure 7. Actuator Alignment – SES Mode

8.3 AVENT03

This test was to verify proper operation of the DC-ARM Mode ventilation control as it applied to the CPS and SES Modes based on normal (non-damage) conditions. DC-ARM Mode is an automated mode, which relies on sensors to indicate normal or damage conditions. No manual intervention was required.

The ventilation system was in SES Mode with the fans "off" prior to initiating DC-ARM Mode. DC-ARM Mode was initiated at 09:23:49 and was completely executed at 09:51:30. A total initialization and execution time of 27 minutes, 41 seconds. The test scenario was "normal conditions" and, as expected, the actuators aligned in CPS, indicated by the CPS/SES panel LEDs (green). See Figure 6. The fans did not turn on, which was expected.

After all operations were verified, the test was terminated at 09:51:50.

8.4 AVENT04

The second DC-ARM Mode test was again to verify proper operation of the ventilation system regarding CPS and SES Modes, but based on damage conditions. The damage conditions were provided by an alcohol fire (7 gallons methyl alcohol) to produce high temperatures, but minimal smoke. The source was located on the starboard side of CPO Living. See Figure 1. The source was initiated at 10:06:20. The thermocouple was only sensing temperatures below the set point of 43°C (110°F) through the first 20 minutes of the test. As expected, the fire was producing minimal smoke; therefore, the ODMs continually indicated near 100% visibility. At 10:22:00, thermocouple 2-19-1 was raised to a height of approximately 8 feet, allowing it to reach the set point quicker. Fans first turned on at 10:31:40 and turned off again at 10:31:41, at which time the dampers began to cycle to SES then went back to CPS. The fans reacted to the input from thermocouple 2-19-1. See Figure 8. The fans turned back on at 10:33:29 and off immediately. The ventilation system was cycling between CPS and SES because the thermocouple temperature was cycling around the set point. For this reason, the thermocouple was raised even higher to approximately 9 feet at 10:34:49 in an attempt to stabilize the temperature in a hotter environment. At 10:34:49, the fans turned back on and then back off at 10:35:40. The fans stabilized for a short time beginning at 10:36:13 and the actuators stabilized in SES Mode at 10:36:37. The actuator alignment was observed from the CPS/SES control panel in the control room. See Figure 7. By 10:37:05, the ventilation removed enough heat to drop the temperature below the set point. The ventilation system reacted by turning the fans off and actuators returning to CPS Mode. Test secured at 10:38:41. Table 3 displays selected tabular data for the sensors, frequency drive status and comments for AVENT04.

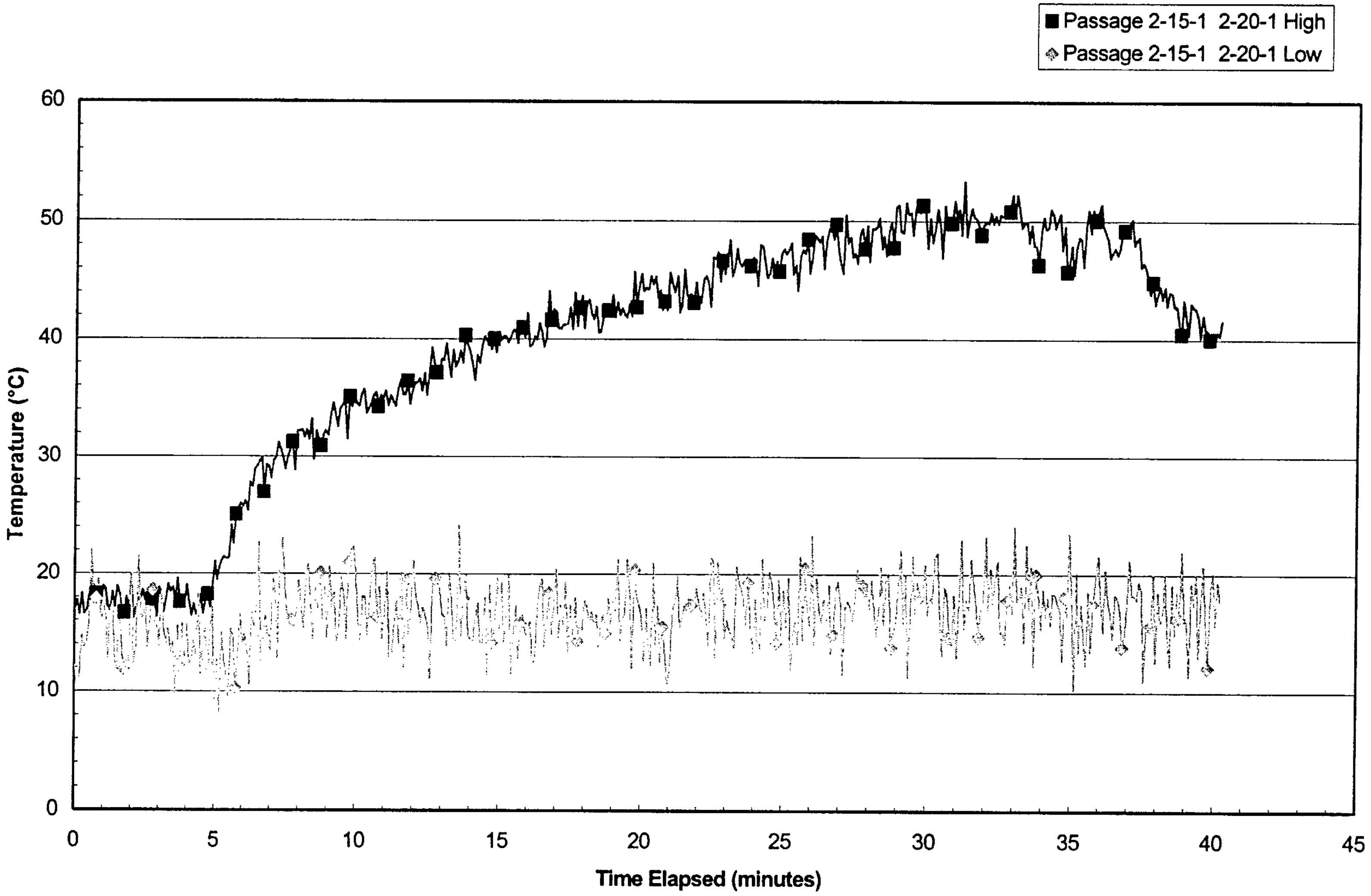

Figure 8. PWAY 2-20-1 TC - AVENT04 - 5 sec filter

Table 3. Test AVENT04 – Sensor Data

		13a	17a	25b	29b	118b	100b	42b	46b			
Time Change	Time	TC 2-20-1 High	TC 2-25-1 High	ODM 2-19-1 1.524 m (5ft)	ODM 2-25-1 1.524 m (5ft)	TC 2-20-2 High	TC 2-24-2 Low	ODM 2-15-2 1.524 m (5ft)	ODM 2-24-2 1.524 m (5ft)	Frequency Drive 1-15-1 Speed	Frequency Drive 1-15-2 Speed	Comments
(min)	(hr:min:sec)	(°C)	(°C)	(% Trans)	(% Trans)	(°C)	(°C)	(% Trans)	(% Trans)	(Hz)	(Hz)	
0.00	10:02:09	17	16	100	100	16	19	101	99	00	00	Masscomp data acquisition started
4.18	10:06:20	17	18	101	100	17	18	191	199	00	00	Source ignited
19.85	10:22:00	44	22	100	100	17	18	99	99	00	00	TC 2-19-1 raised to approx. 8' from deck
29.35	10:31:30	47	23	98	100	21	20	98	99	00	00	AutoVent TC 2-19-1 at 43°C
29.52	10:31:40	52	26	98	100	17	19	99	99	on	on	---
29.53	10:31:41	51	25	98	100	17	18	99	99	off	off	Some dampers cycled
31.33	10:33:29	40	25	98	100	20	19	101	99	on-off	on-off	---
32.67	10:34:49	51	25	98	100	21	19	101	99	43	39.00	TC 2-19-1 raised to approx. 9' from deck
32.87	10:35:01	52	24	98	99	20	20	100	99	43	39	---
33.52	10:35:40	47	23	98	100	21	20	21	99	off	off	---
34.07	10:36:13	51	24	98	100	16	20	99	99	43	39	---
34.47	10:36:37	48	23	98	100	20	20	99	99	43	39.00	All dampers in SES
34.93	10:37:05	49	25	98	100	18	19	100	99	off	off	All dampers in CPS
36.53	10:38:41	48	24	98	100	20	19	100	99	---	---	---
38.10	10:40:15	45	23	98	100	20	18	100	99	---	---	Source terminated

8.5 AVENT07

This was the third and final test for DC-ARM Mode. Again, it was evaluated for proper operation of the ventilation system with regards to CPS and SES Modes based on damage conditions. The damage conditions were provided by a diesel fire (2 gallons diesel, 0.5 gallons heptane) in the port fire location (CIC Vestibule). See Figure 1.

The source was initiated at 11:09:30. The ventilation system reacted at 11:10:10. Both fans turned on and actuators aligned in SES Mode. The actuator alignment was observed from the CPS/SES control panel in the control room. See Figure 7. This was in reaction to the thermocouples sensing temperatures in excess of the 43°C (110°F) setpoint. See Figure 9. The ventilation system was unable to remove the smoke and heat load with the current configuration.

> Note: The automated ventilation system only controls 10 actuators and 2 exhaust fans. During testing, the remaining 20+ actuators and supply fans were not used, therefore the complete SES system was not being activated to remove smoke and/or heat. The objective of the DC-ARM Mode testing was to show correct ventilation system reaction to sensory input, not to demonstrate effectiveness of smoke and heat control.

The ventilation system remained in SES Mode with the fans on due to the low visibility and high temperatures indicated by the sensors. See Figures 9, 10, and 11. The test was terminated at 11:16:56. At 11:19:20, the ventilation system returned to CPS Mode, after additional ventilation was used to remove the smoke and heat. Table 4 summarizes sensor data, frequency drive status and comments for test AVENT07. Actuator SCD 2-18-2 did not return to CPS Mode from SES. SCD 2-18-2 was previously found to be troublesome. It was found that the cable running into the actuator might have had some wires shorting out on occasion. The probable cause is heat damage from numerous fire tests. After wiggling the cable, the actuator returned to CPS Mode.

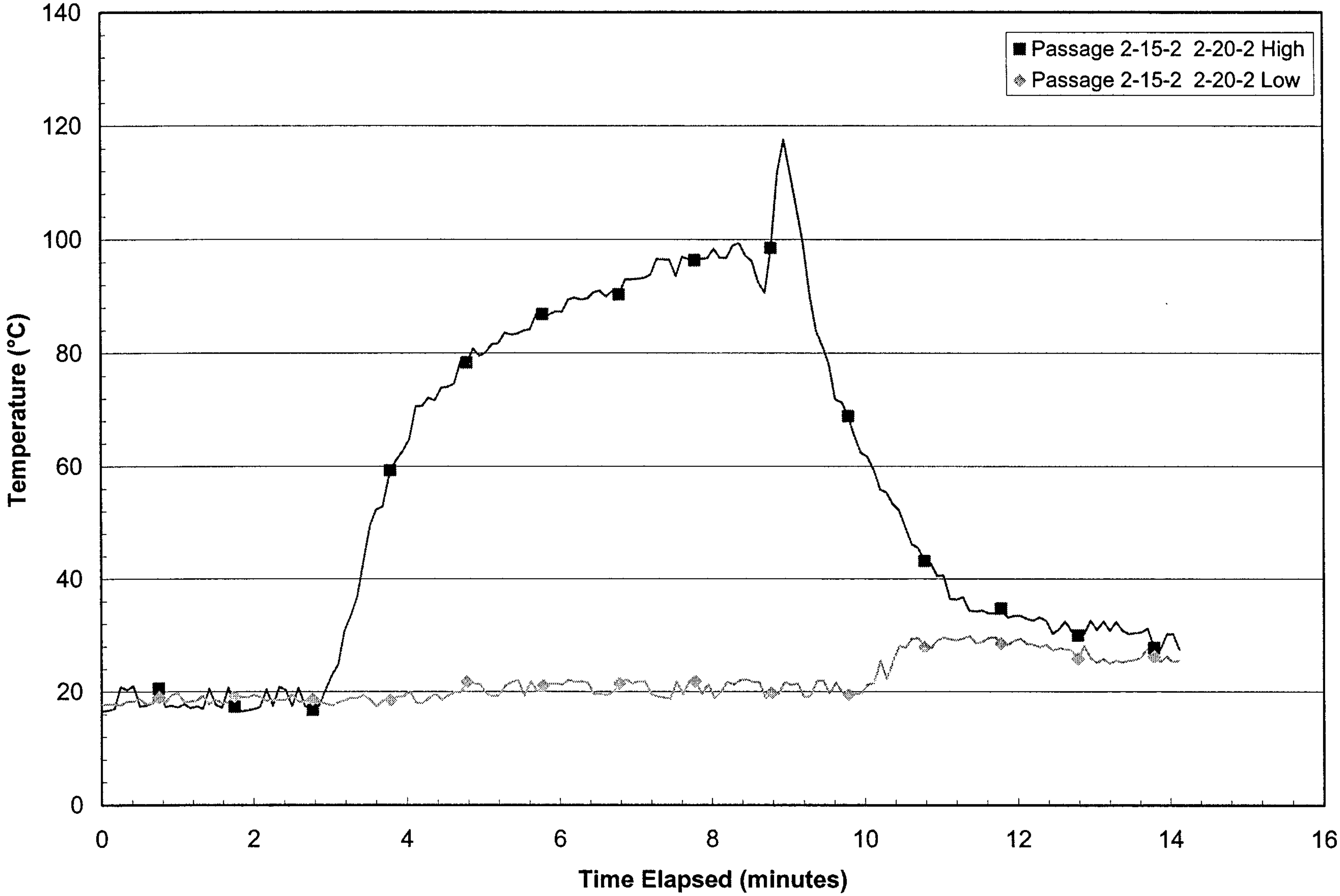

Figure 9. PWAY 2-20-2 TC - AVENT07 - 5 sec filter

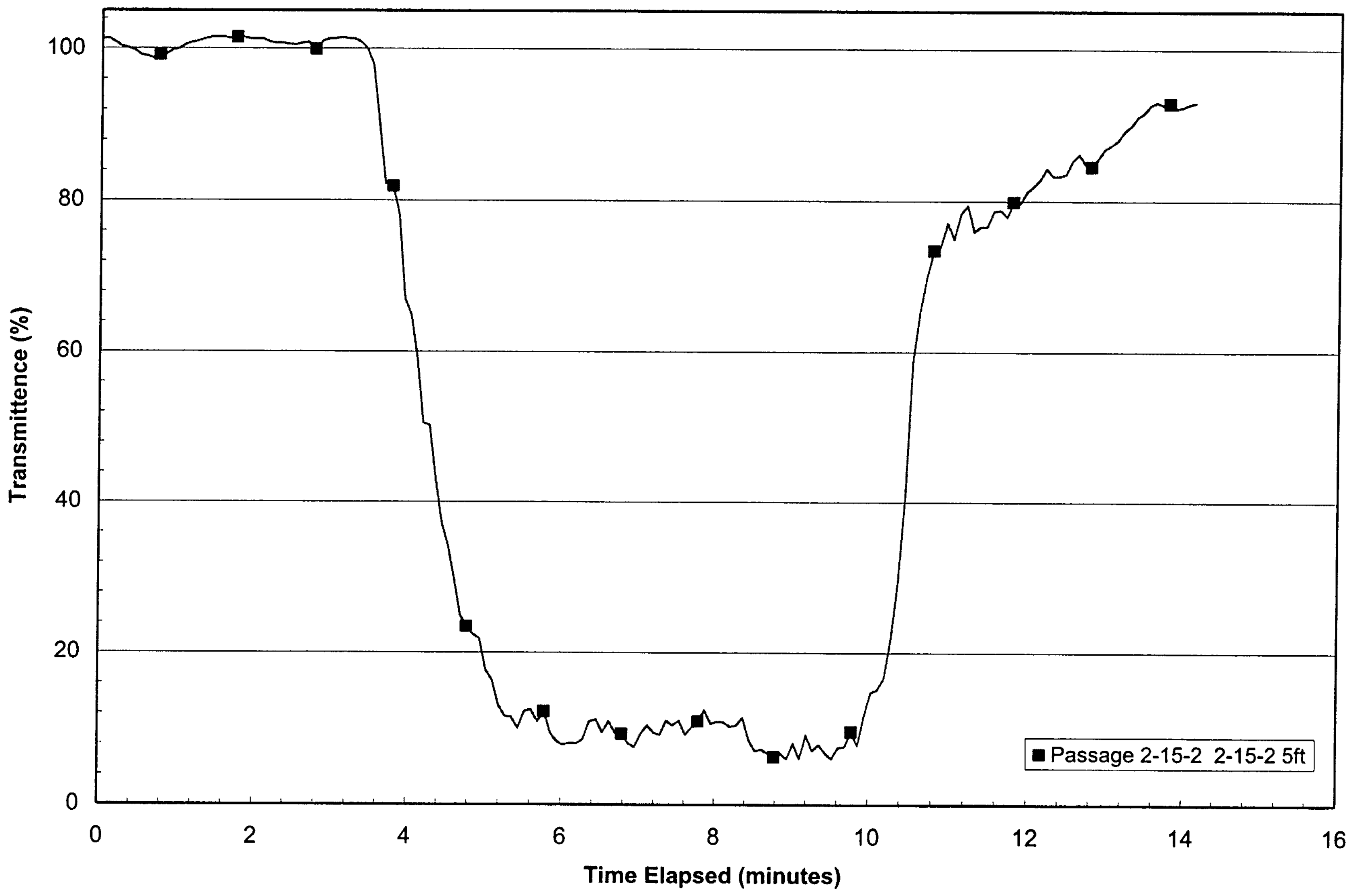

Figure 10. ODM PWAY 2-15-2 - AVENT07 - 5 sec filter

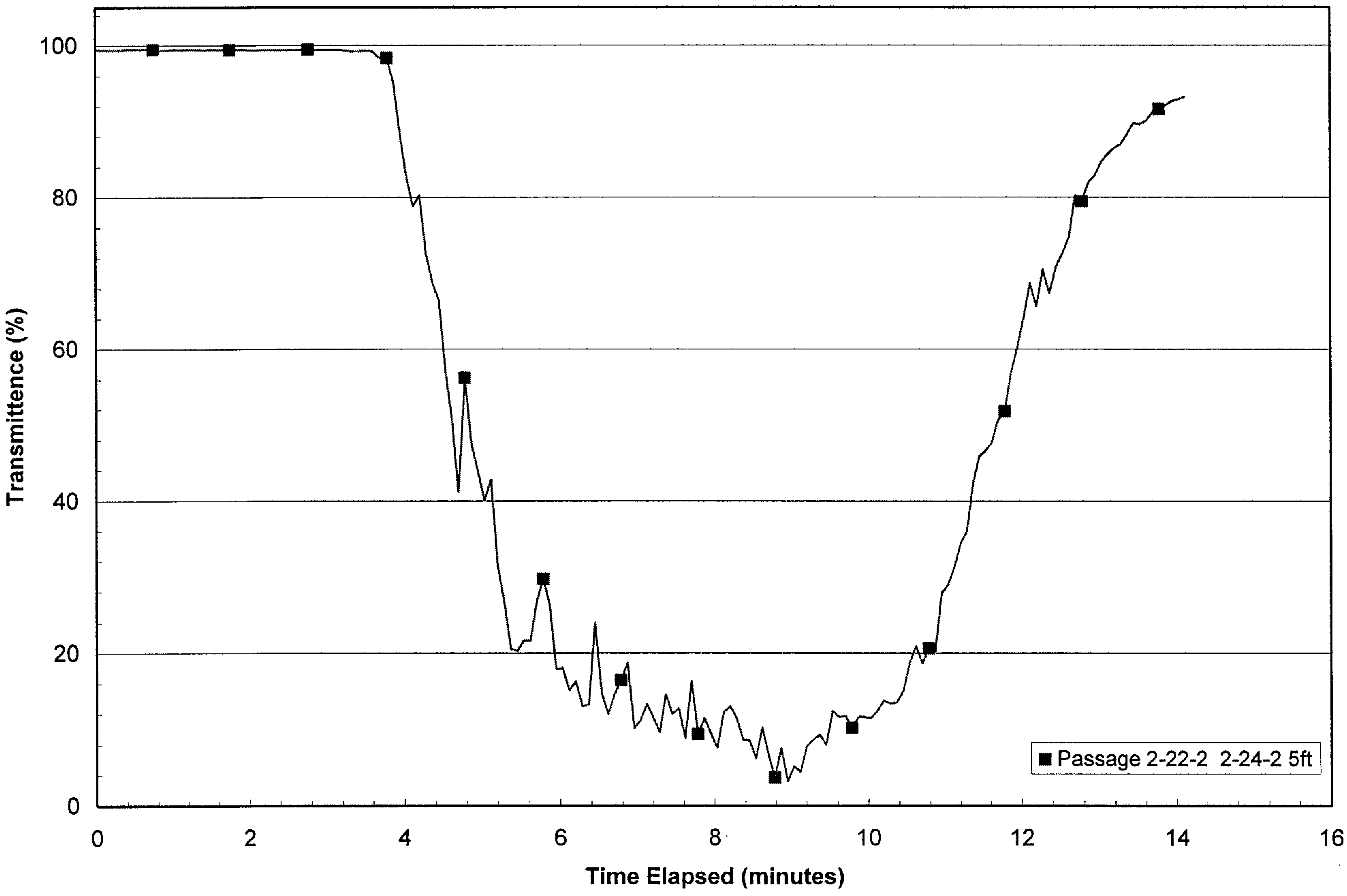

Figure 11. ODM PWAY 2-25-2 - AVENT07 - 5 sec filter

Table 4. Test AVENT07 – Sensor Data

		118b	100b	42b	46b	13a	17a	25b	29b			
Time Change	Time	TC 2-20-2 High	TC 2-24-2 Low	ODM 2-15-2 1.524 m (5ft)	ODM 2-24-2 1.524 m (5ft)	TC 2-20-1 High	TC 2-25-1 High	ODM 2-19-1 1.524 m (5ft)	ODM 2-25-1 1.524 m (5ft)	Frequency Drive 1-15-1 Speed	Frequency Drive 1-15-2 Speed	Comments
(min)	(hr:min:sec)	(°C)	(°C)	(% Trans)	(% Trans)	(°C)	(°C)	(% Trans)	(% Trans)	(Hz)	(Hz)	
0.000	11:06:31	17	19	101	99	26	19	100	100	00	00	Masscomp data acquisition started
2.98	11:09:30	20	19	101	99	26	20	100	100	00	00	Ignition
3.65	11:10:10	53	28	83	99	27	20	100	100	43	39	All dampers in SES
7.48	11:14:00	94	49	11	11	25	22	100	100	43	39	Source Terminated
10.42	11:16:56	53	28	40	15	23	19	98	82	43	39	Ventilate with 1-15-2
12.82	11:19:20	33	23	85	80	23	20	96	98	00	00	All dampers in CPS (except 2-18-2)

8.6 AVENT08

The testing of AUTO Mode (independent, exhaust only) was to accomplish three objectives: proper operation of the ventilation system as it applied to the "exhaust only" technique of smoke and heat removal, monitor and analyze the capabilities of an "exhaust only" smoke and heat removal technique and demonstrate the ability to provide compartment independent ventilation as described in paragraph 6.4.

This first test was to verify operation of the ventilation system based on normal conditions. The ventilation system was in DC-ARM Mode prior to initializing AUTO Mode. AUTO Mode was initiated at 11:29:01 and was completely executed at 11:53:15, for a total initialization and execution time of 24 minutes and 14 seconds. As expected, the ventilation system aligned in CPS Mode and the fans remained off. See Figure 6. The test was terminated after the ventilation alignment was verified.

8.7 AVENT10

The second AUTO Mode (independent, exhaust only) test was performed using damage conditions. The damage conditions were created with a methyl alcohol fire (4 gallons methyl alcohol) to produce high temperatures, but little smoke.

The Port side fire location, CIC Vestibule (See Figure 1), was used and the source was initiated at 12:55:36. The ventilation system reacted at 12:58:40 with TPES 1-16-4 turning on and the frequency drive speed accelerating to 37 Hz. (Note: TPES 1-16-1 remained off for the duration of the test, as expected.) The reaction was in response to the thermocouple input. See Figure 12. Four actuators (SCD 1-15-2, SCD 2-15-2, SPD 2-17-2 and SCD 2-18-2) aligned in SES Mode, which was expected according to the AUTO Mode logic. See Figure 13. As the temperature continued to rise, the frequency drive speed continued to accelerate. However, the acceleration was in such small increments, the ventilation was unable to keep up with the heat load. Table 5 shows selected time, frequency drive speeds, and temperatures throughout the span of the test.

At 13:15:45, a cigarette lighter was used to heat AutoVent thermocouple 2-25-2 to verify higher frequency drive speeds for extreme temperatures. This cannot be seen in any table or on any figure. The lighter flame was applied to the AutoVent thermocouple to induce a desired system response. The AutoVent thermocouple data was not being logged, which made it necessary for the duplicate thermocouples as described in paragraph 4.4. Except for this one case using a point heat load directly on one thermocouple, all other logged sensor data was a good representation of the AutoVent sensor data. The frequency drive continued to accelerate until it reached the high speed limit of approximately 51 Hz (thermocouple 2-25-2 was sensing approximately 649°C (1200°F)). The lighter was removed at approximately 13:21:00 and the source was terminated at 13:22:58. The frequency drive decelerated proportional to the decrease in temperature. The ventilation system automatically returned to CPS Mode with the fan turning off at 13:25:19.

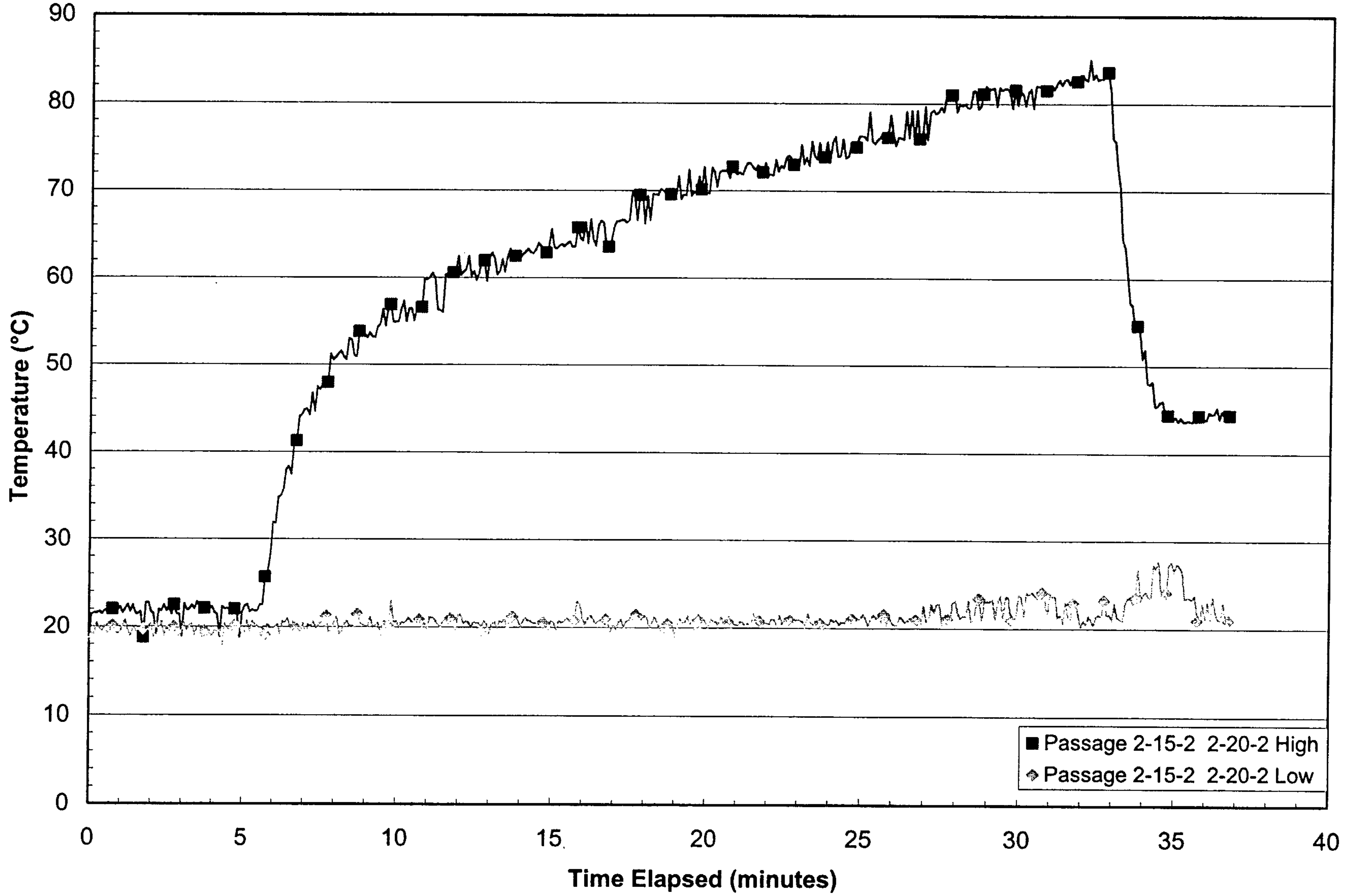

Figure 12. PWAY 2-20-2 TC - AVENT10 - 5 sec filter

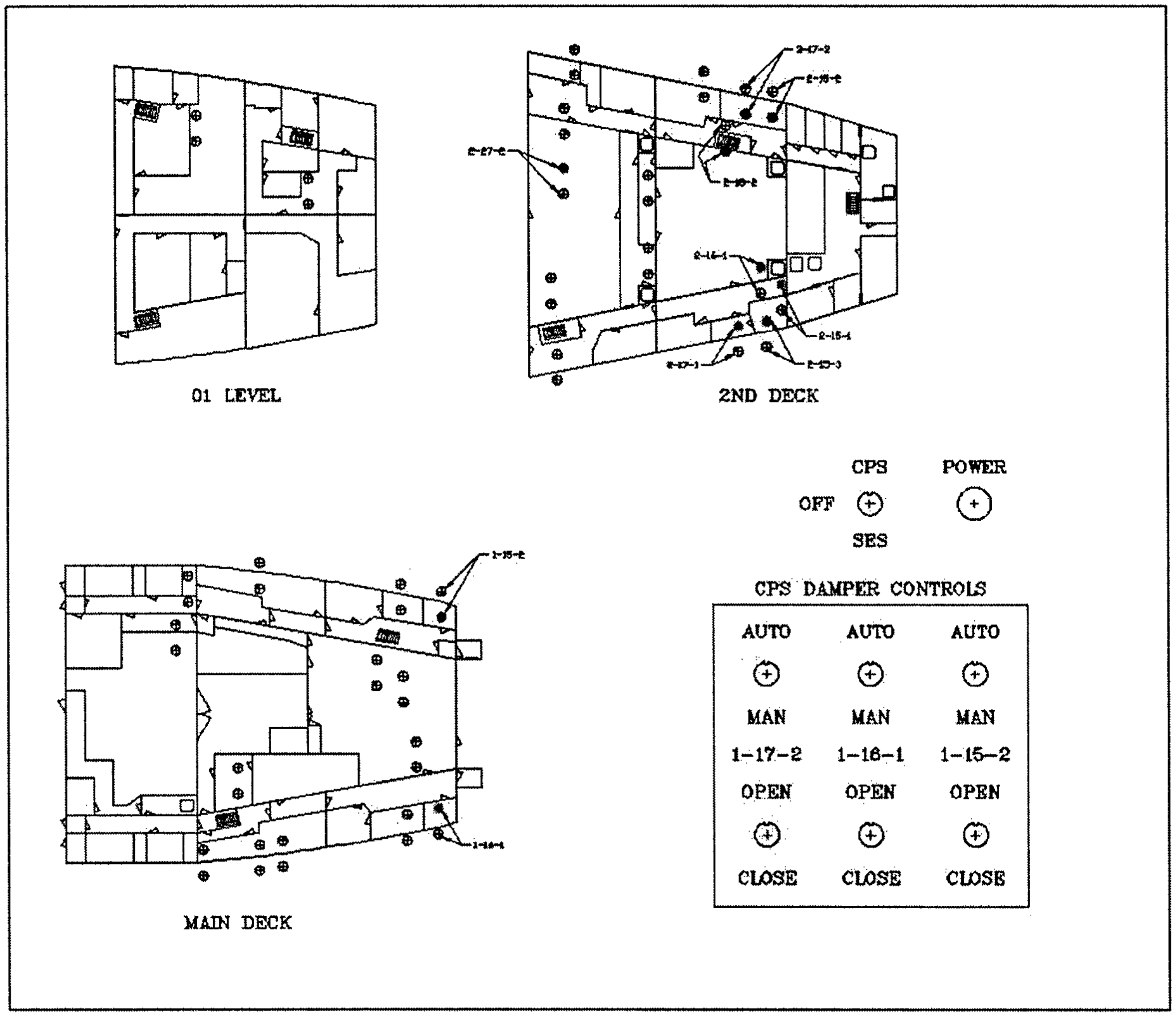

Figure 13. Actuator Alignment – AUTO Mode, Port side damage

Table 5. Test AVENT10 – Sensor Data

		118b	100b	42b	46b	13a	17a	25b	29b			
Time Change	Time	TC 2-20-2 High	TC 2-24-2 Low	ODM 2-15-2 1.524 m (5ft)	ODM 2-24-2 1.524 m (5ft)	TC 2-20-1 High	TC 2-25-1 High	ODM 2-19-1 1.524 m (5ft)	ODM 2-25-1 1.524 m (5ft)	Frequency Drive 1-15-1 Speed	Frequency Drive 1-15-2 Speed	Comments
(min)	(hr:min:sec)	(°C)	(°C)	(% Trans)	(% Trans)	(°C)	(°C)	(% Trans)	(% Trans)	(Hz)	(Hz)	
0.00	12:50:09	18	21	101	101	20	16	100	100	00	00	Masscomp data acquisition started
5.45	12:55:36	22	23	100	100	16	17	100	100	00	00	Source ignited
7.87	12:58:01	51	31	99	101	22	20	100	100	00	00	---
3.52	12:58:40	53	30	101	101	22	20	100	100	00	37	4 dampers in SES (1-15-2, 2-15-2, 2-18-2, 2-17-2)
10.93	13:01:05	60	30	100	101	23	21	100	100	00	37	---
12.32	13:02:28	61	24	101	100	22	21	100	100	00	37	---
13.02	13:03:10	62	30	101	101	21	21	100	100	00	37	---
15.97	13:06:07	66	27	98	101	24	21	100	100	0.00	38	---
17.98	13:08:08	70	34	100	101	22	21	100	100	0.00	38	---
19.48	13:09:38	70	31	99	100	23	20	100	100	00	38	---
21.25	13:11:24	73	34	98	199	23	21	100	100	00	38	---
24.85	13:15:00	79	38	99	100	23	19	100	100	00	38	---
25.60	13:15:45	76	38	100	100	23	20	100	100	00	---	Lighter used to heat AutoVent TC 2-25-2
25.98	13:16:08	79	38	101	100	22	20	100	100	00	38	---
26.45	13:16:36	76	40	101	100	24	18	100	100	00	39	---
26.63	13:16:47	76	41	100	100	22	22	100	100	00	39	---
27.17	13:17:19	80	42	99	199	23	21	199	199	00	---	Lighter moved 1" closer to AutoVent TC 2-25-2
28.18	13:18:20	79	41	98	100	22	21	100	100	00	44	---
28.43	13:18:35	82	41	98	100	21	222	100	100	00	48	---
29.65	13:19:48	80	37	101	100	23	22	100	100	00	51	AutoVent TC 2-25-2 at 1200°C
30.43	13:20:35	82	37	100	100	24	21	100	100	00	51	---
31.85	13:22:00	83	40	100	100	23	21	100	100	00	38	---
32.82	13:22:58	82	37	98	100	21	19	100	100	00	---	Source Terminated
35.17	13:25:19	44	28	100	100	22	22	100	100	0.00	off	All dampers in CPS

The small increments of increase by the frequency drive speed were due to the scaling used. The scaling used the range 0°C (32°F) to 649°C (1200°F) as 0% to 100% damage. Therefore, the control did not view the range of 0°C (32°F) to 300°C (572°F) as very high damage and did not increase the frequency drive speed by very large increments. The frequency drive speed range was approximately 60% to 90% full scale (60 Hz) in relation to the 0% to 100% damage. A more aggressive frequency drive speed reaction would be obtained by adjusting the temperature scaling to 0°C (32°F) to 200°C (392°F) or some other range to be determined.

8.8 AVENT11

This AUTO Mode (independent, exhaust only) test was performed based on damage conditions produced by smoke and heat. The damage conditions were simulated with a diesel fire (2 gallons diesel, 0.5 gallons heptane). The source was located at the starboard fire location, CPO Living (see Figure 1) and was initiated at 13:52:05. The ventilation system reacted at 13:53:28 to both the ODM and thermocouple inputs. See Figures 14 and 15. TPES 1-16-1 turned on and the frequency drive accelerated to 41 Hz and 5 actuators (SCD 1-16-1, SCD 2-15-1, SCD 2-15-3, SCD 2-16-1, and SPD 2-17-1) aligned in SES Mode as expected. See Figure 16. (NOTE: TPES 1-16-4 remained off as expected.)

Table 6 shows the increase of frequency drive speed as the ODMs indicated a decrease in visibility and the thermocouples sensed an increase in temperature. At 13:57:50, a member of the test personnel opened closure 2-15-1 to verify the level of visibility. This caused an inrush of clean make-up air, which temporarily cleared the smoke from ODM 2-19-1 (seen in Figure 15 as a spike around 8 minutes) and pushed the smoke aft. By 14:00:20, the smoke was so dense the percent of transmission was near 0%, which, as expected, caused the fan to accelerate to and maintain maximum automated speed (~53 Hz). At this point, the ventilation operation was verified and the smoke and heat removal capability was noted (the ventilation system was unable to keep up with the smoke and heat load).

The opportunity to test the affects of an open closure was taken at this time, so the test was not yet terminated. At 14:04:45, closure 2-15-1 was opened again. This can be seen in Figure 15 as an increase in percent of transmission around 15 minutes and a decrease in visibility in Figure 17. This again caused the smoke to be pushed aft as indicated by the increased visibility at ODM 2-15-1 and the decrease in visibility at ODM 2-25-1. Beginning at 14:07:19, the ventilation system began cycling as the fuel load dwindled and was spent at 14:07:57. The ventilation system continued to cycle as smoke and heat was removed (with the fuel load spent, smoke and heat were no longer being produced) until the test was terminated at 14:14:27.

The frequency drive speed was primarily driven by the ODM input, which indicated greater damage level due to smoke than the thermocouples due to heat. This was largely due to the more aggressive and more desirable scaling of the ODM input. The percent transmission of 100% to 0% corresponded to 0% to 100% damage. The frequency drive scaling was the same as documented in test AVENT10 and was independent of sensor type. The ODM scaling range can still be adjusted towards a more aggressive scale if one is desired. As in the other tests, the

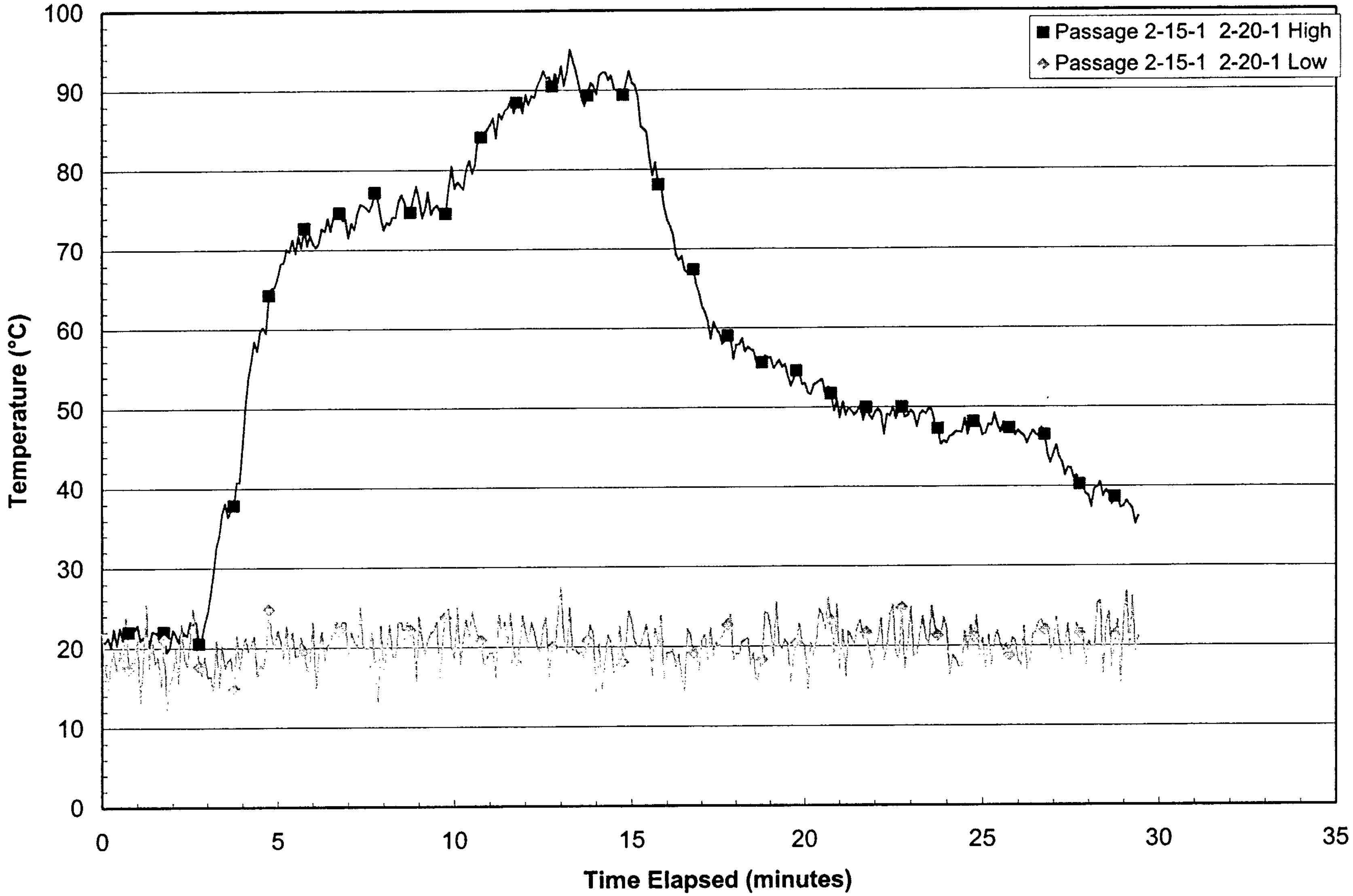

Figure 14. PWAY 2-20-1 TC - AVENT11 - 5 sec filter

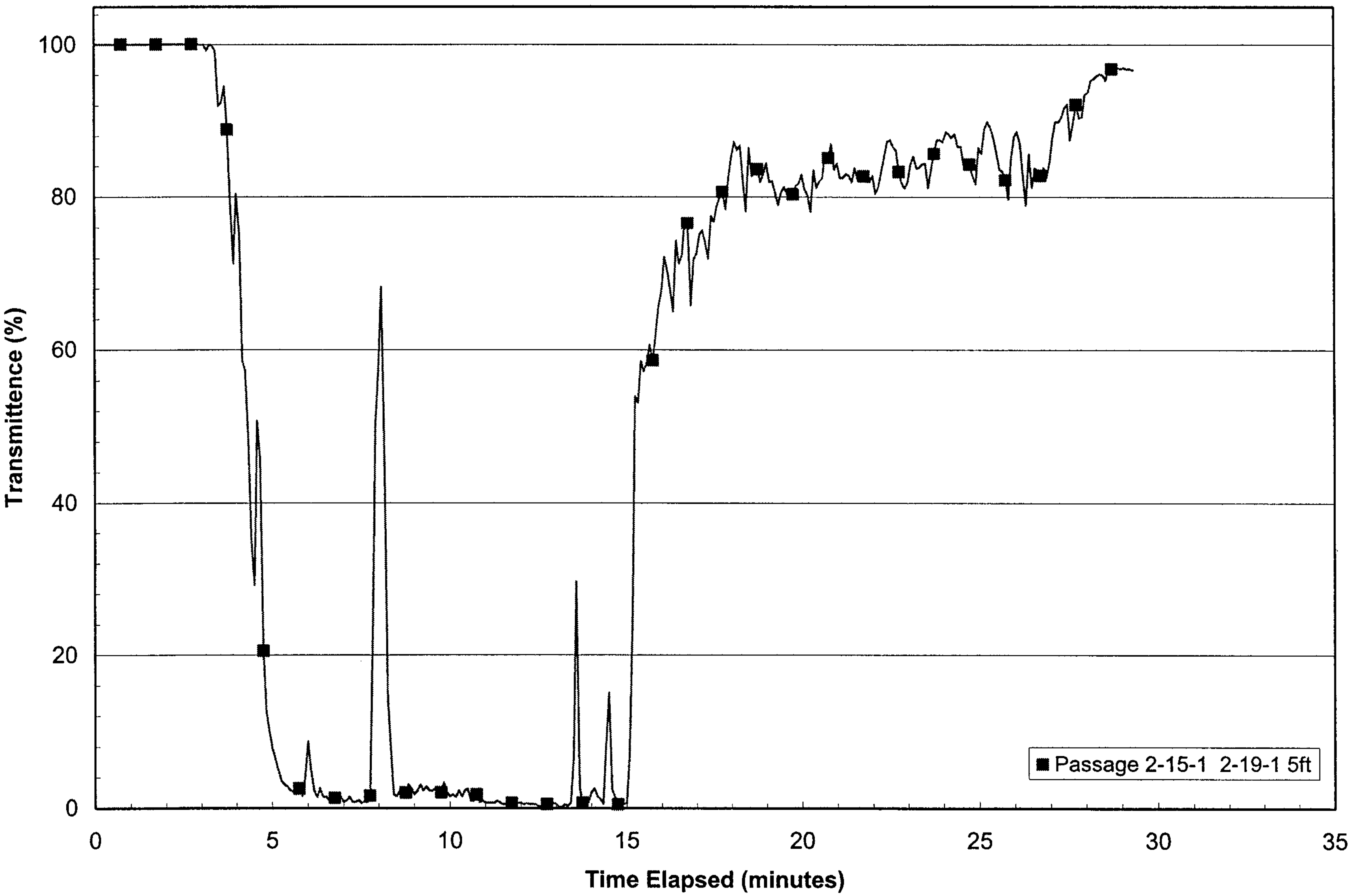

Figure 15. ODM PWAY 2-19-1 - AVENT11 - 5 sec filter

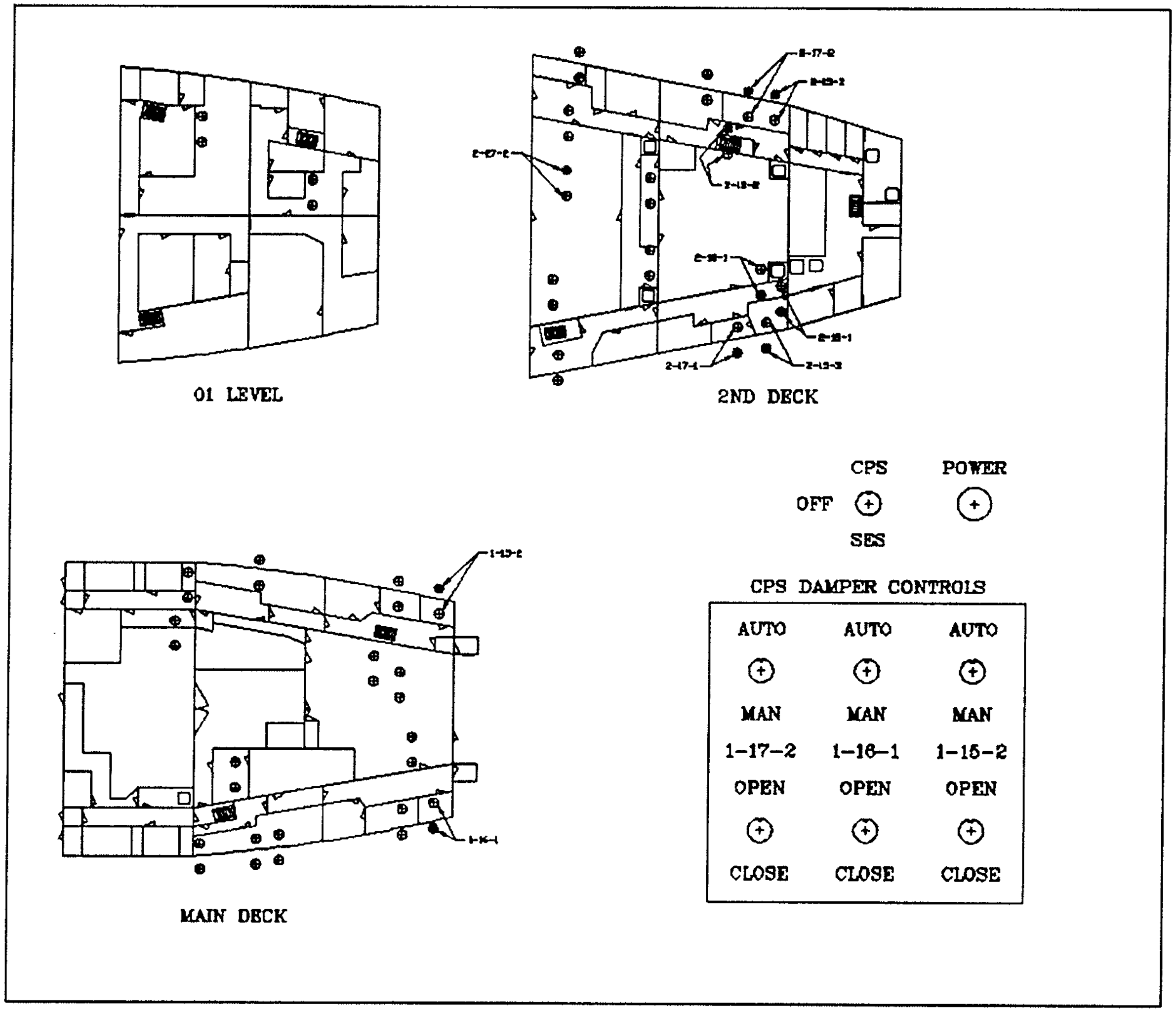

Figure 16. Actuator Alignment – AUTO Mode, Starboard damage

Table 6. Test AVENT11 – Sensor Data

		13a	17a	25b	29b	118b	100b	42b	46b			
Time Change	Time	TC 2-20-1 High	TC 2-25-1 High	ODM 2-19-1 1.524 m (5ft)	ODM 2-25-1 1.524 m (5ft)	TC 2-20-2 High	TC 2-24-2 Low	ODM 2-15-2 1.524 m (5ft)	ODM 2-24-2 1.524 m (5ft)	Frequency Drive 1-15-1 Speed	Frequency Drive 1-15-2 Speed	Comments
(min)	(hr:min:sec)	(°C)	(°C)	(% Trans)	(% Trans)	(°C)	(°C)	(% Trans)	(% Trans)	(Hz)	(Hz)	
0.00	13:49:28	21	20	100	9100	29	19	100	100	00	00	Masscomp data acquisition started
2.62	13:52:05	24	19	100	100	29	22	98	100	00	00	Ignition
4.02	13:53:28	48	20	80	100	29	22	99	100	41	00	5 dampers in SES (1-16-1, 2-15-1, 2-15-3, 2-16-1, 2-17-1)
4.65	13:54:07	60	21	51	100	29	22	98	100	47	00	---
4.95	13:54:25	67	20	9	100	29	20	99	100	50	00	---
5.20	13:54:40	69	22	5	100	32	16	100	100	52	00	---
6.82	13:56:17	74	20	2	100	30	21	98	100	53	00	---
8.37	13:57:50	75	23	5	100	32	19	98	100	45	00	Closure 2-15-1briefly opened
8.70	13:58:10	76	21	2	100	30	19	97	100	53	00	---
10.87	14:00:20	84	22	0.8	100	29	22	100	100	53	00	---
15.28	14:04:45	83	23	59	99	29	23	100	100	---	00	Closure 2-15-1permanently opened
15.50	14:04:58	82	23	57	99	29	20	100	100	45	00	---
17.85	14:07:19	59	22	79	86	29	21	99	100	Off-on	00	---
18.23	14:07:42	57	22	67	82	29	21	99	100	on	00	---
18.48	14:07:57	57	22	85	80	30	15	99	100	---	00	Fire out
18.63	14:08:06	56	22	32	78	29	19	98	100	off	00	All dampers in CPS
18.83	14:08:18	56	22	82	75	29	23	97	100	on	0.00	5 dampers in SES (1-16-1, 2-15-1, 2-15-3, 2-16-1, 2-17-1)
19.03	14:08:30	54	21	83	71	29	22	98	100	off	00	---
19.30	14:08:46	56	23	79	70	29	13	100	100	on	00	---
22.30	14:11:46	49	23	83	77	29	22	99	100	off	00	All dampers in CPS
23.12	14:12:35	49	22	85	77	28	14	97	100	on-off	00	---
24.98	14:14:27	46	23	86	82	30	22	100	100	on-off	00	---
26.45	14:15:55	46	23	83	85	29	22	97	100	On-off	00	Ventilate with 1-15-1

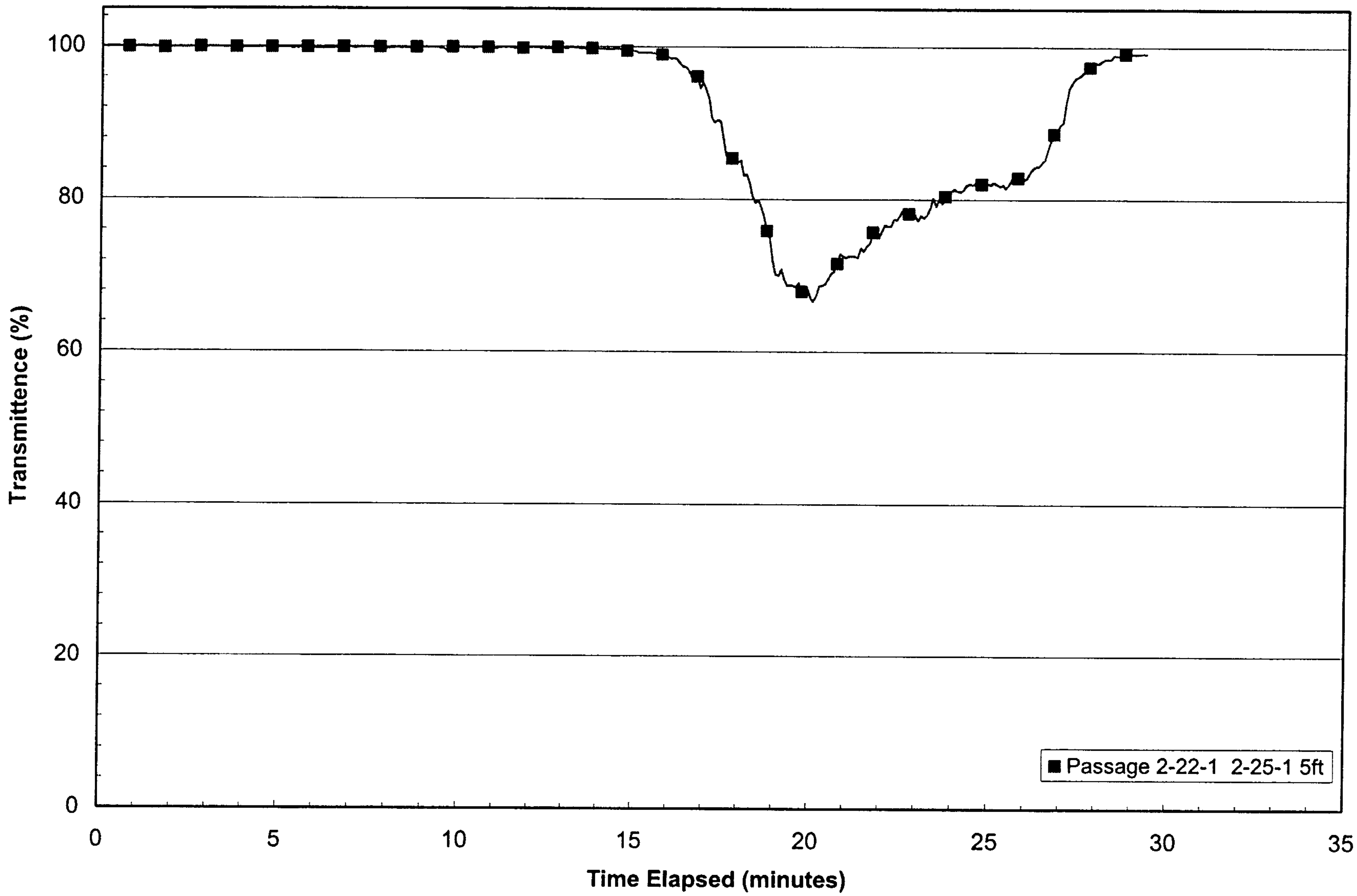

Figure 17. ODM PWAY 2-25-1 - AVENT11 - 5 sec filter

ventilation system tended to cycle once the smoke and/or heat was diminished to near set point levels.

8.9 AVENT12

The fourth AUTO Mode (independent, exhaust only) test, AVENT12, was conducted in similar fashion as AVENT11, but from the port side fire location, CIC Vestibule (see Figure 1) and with a modified fuel load (3 quarts diesel, 0.5 gallons heptane). The objectives demonstrated in AVENT12 were identical to the previous AUTO Mode tests.

The source was initiated at 14:43:15 and the system reacted first to high temperature at 14:44:20. See Figure 18. TPES 1-16-4 turned on, frequency drive accelerated to 42 Hz and 4 actuators (SCD 1-15-2, SCD 2-15-2, SCD 2-18-2 and SPD 2-17-2) aligned in SES Mode as expected. See Figure 13. Table 7 shows the increase in frequency drive speed as the ODMs indicated decreasing visibility and the thermocouples sensed increasing temperatures. At 14:55:29, the fuel load was significantly diminished and the ventilation began to overcome the smoke and heat load. The source was spent by 14:57: 00. The ventilation system cycled briefly before stabilizing in CPS Mode at 14:58:15 when the test was terminated. TPES 1-16-1 remained off during the duration of the test as expected.

This test again demonstrated the variable speed of the frequency drive in proportion to damage indication. In reaction to the ODM inputs, the frequency drive speed was significantly more aggressive and desirable than in its reaction to thermocouple inputs (test AVENT10). The decrease in visibility was the driving factor (see Figure 19) as its scaling was much more aggressive.

Actuator SCD 2-18-2 was again troublesome at the end of the test when it did not return to CPS Mode. This was temporarily corrected before the start of the final test, AVENT13.

Table 7. Test AVENT12 – Sensor Data

		118b	100b	42b	46b	13a	17a	25b	29b			
Time Change	Time	TC 2-20-2 High	TC 2-24-2 Low	ODM 2-15-2 1.524 m (5ft)	ODM 2-24-2 1.524 m (5ft)	TC 2-20-1 High	TC 2-25-1 High	ODM 2-19-1 1.524 m (5ft)	ODM 2-25-1 1.524 m (5ft)	Frequency Drive 1-15-1 Speed	Frequency Drive 1-15-2 Speed	Comments
(min)	(hr:min:sec)	(°C)	(°C)	(% Trans)	(% Trans)	(°C)	(°C)	(% Trans)	(% Trans)	(Hz)	(Hz)	
0.00	14:40:58	28	22	98	100	32	21	99	100	00	00	Masscomp data acquisition started
2.28	14:43:15	27	26	97	100	31	22	99	100	00	00	Ignition
3.37	14:44:20	65	38	87	98	32	23	99	100	00	42	4 dampers in SES (1-15-2, 2-15-2, 2-18-2, 2-17-2)
3.87	14:44:50	67	35	73	92	31	23	100	100	00	47	---
4.70	14:45:40	68	39	56	84	31	22	99	100	00	50	---
6.17	14:47:08	65	33	41	76	31	22	99	99	00	51	---
12.00	14:52:58	76	41	26	34	31	23	99	99	00	51	---
14.52	14:55:29	56	29	41	63	32	24	99	100	00	48	---
15.25	14:56:13	52	30	53	80	33	21	99	99	00	46	---
15.68	14:56:39	46	29	57	87	30	21	99	99	00	43	---
16.03	14:57:00	45	29	64	91	31	24	99	99	00	40	Fire out
16.42	14:57:23	46	25	70	92	31	21	99	99	00	off	3 dampers in SES (1-15-2, 2-15-2, 2-17-2)
17.28	14:58:15	46	29	79	95	32	24	99	99	00	on-off	---
18.25	14:59:13	47	29	83	90	32	23	99	99	00	00	Ventilate with 1-15-2

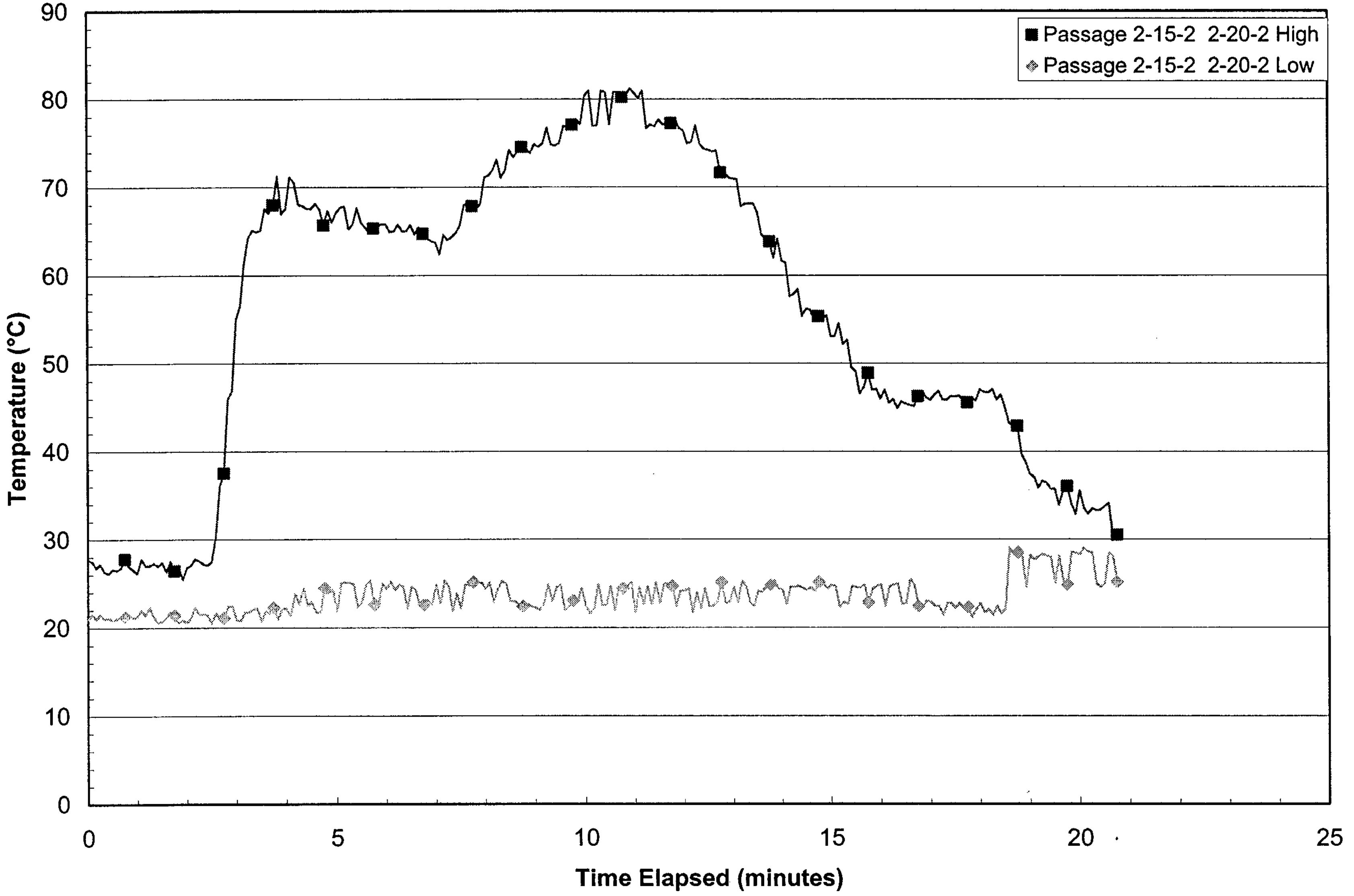

Figure 18. PWAY 2-20-2 TC - AVENT12 - 5 sec filter

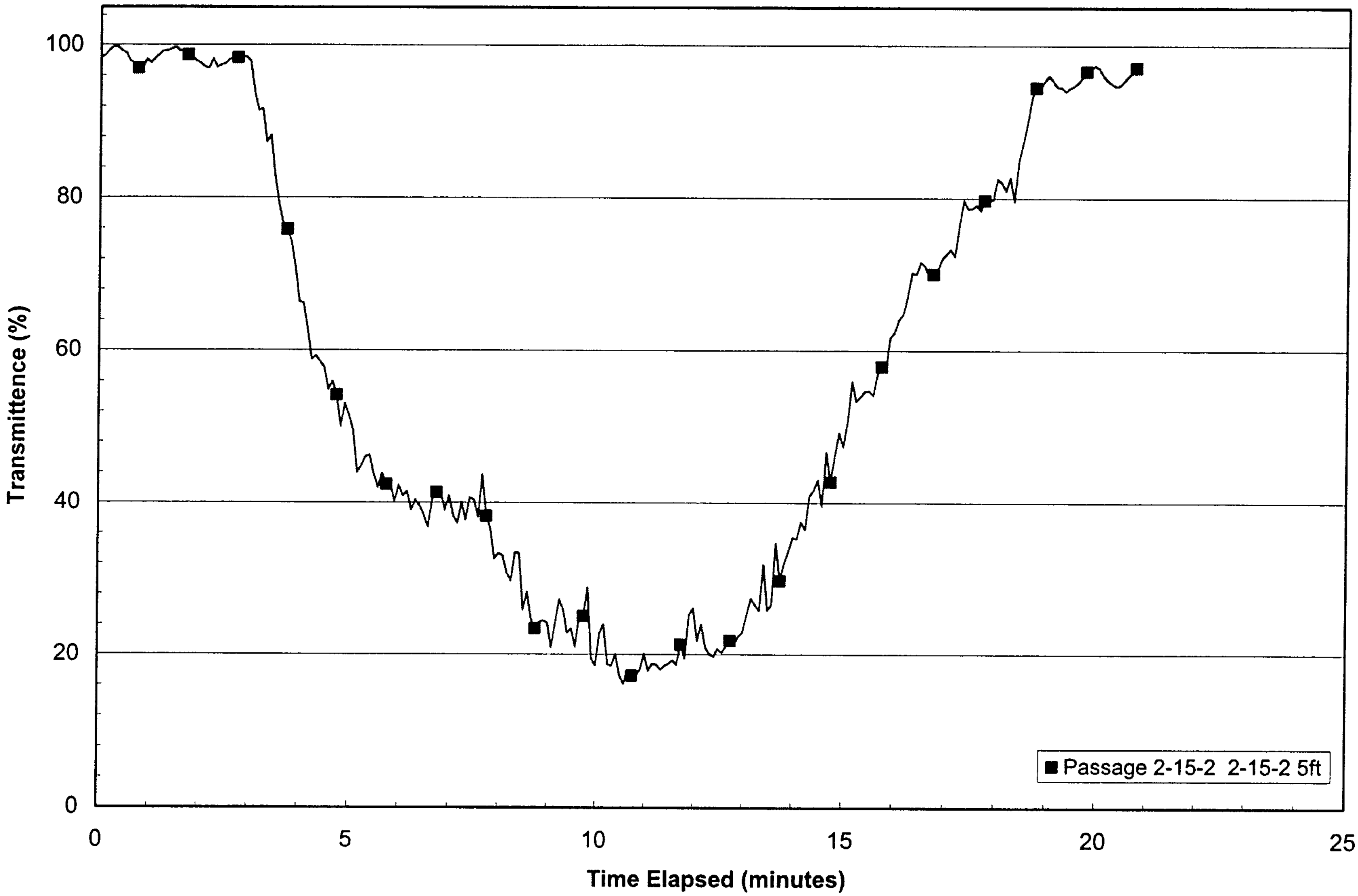

Figure 19. ODM PWAY 2-15-2 - AVENT12 - 5 sec filter

8.10 AVENT13

In addition to demonstrating the objectives in the previous tests, test AVENT13 better demonstrated the compartment independent ventilation alignment capabilities of the system. This was accomplished by providing damage conditions in both starboard and port test areas, but with a time delay between initiating the two sources. This scenario was used to demonstrate the ventilation system reaction to damage in a "zone" (compartment) with only the exhaust ventilation components serving that zone reacting. When damage was later indicated in another zone, the exhaust ventilation components serving that zone reacted.

The damage conditions were provided by a modified fuel load (2 quarts diesel, 1 quart heptane) in both starboard (CPO Living) and port (CIC Vestibule) fire locations. See Figure 1. The starboard source was designated Source A, and the port source was designated Source B.

Source A was initiated at 15:19:30. TPES 1-16-1 turned on at 15:20:45, frequency drive speed accelerated to 40 Hz, and 5 actuators (SCD 1-16-1, SCD 2-15-1, SCD 2-15-3, SCD 2-16-1 and SPD 2-17-1) aligned in SES Mode. The starboard side ventilation reacted to both ODM 2-19-1 and thermocouple 2-19-1. See Figures 20 and 21. Source B was initiated at 15:21:45. TPES 1-16-4 turned on at 15:22:45, frequency drive speed accelerated to 42 Hz and 4 more actuators (SCD 1-15-2, SCD 2-15-2, SCD 2-18-2 and SPD 2-17-2) aligned in SES Mode. See Figure 22. The port side ventilation initially reacted to thermocouple 2-19-2 and then was primarily driven by ODM 2-19-2. See Figures 23 and 24. Table 8 documents the increasing and decreasing of both frequency drive speeds in relation to the increasing and decreasing damage indicated by the ODMs and thermocouples. At 15:27:39, Source A began to diminish and terminated at 15:28:34. Source B began to diminish at 15:28:00 and terminated at 15:30:50. Ventilation components for both zones began cycling as the smoke and heat was removed. The port ventilation lagged the starboard ventilation as expected due to their different damage conditions in real time. The test was terminated at 15:33:10 and the ventilation system returned to CPS Mode.

As demonstrated in previous AUTO Mode tests, the ventilation system reacted in proportion to the damage. This test also better demonstrated the independent reaction of the ventilation system to the starboard and port zones.

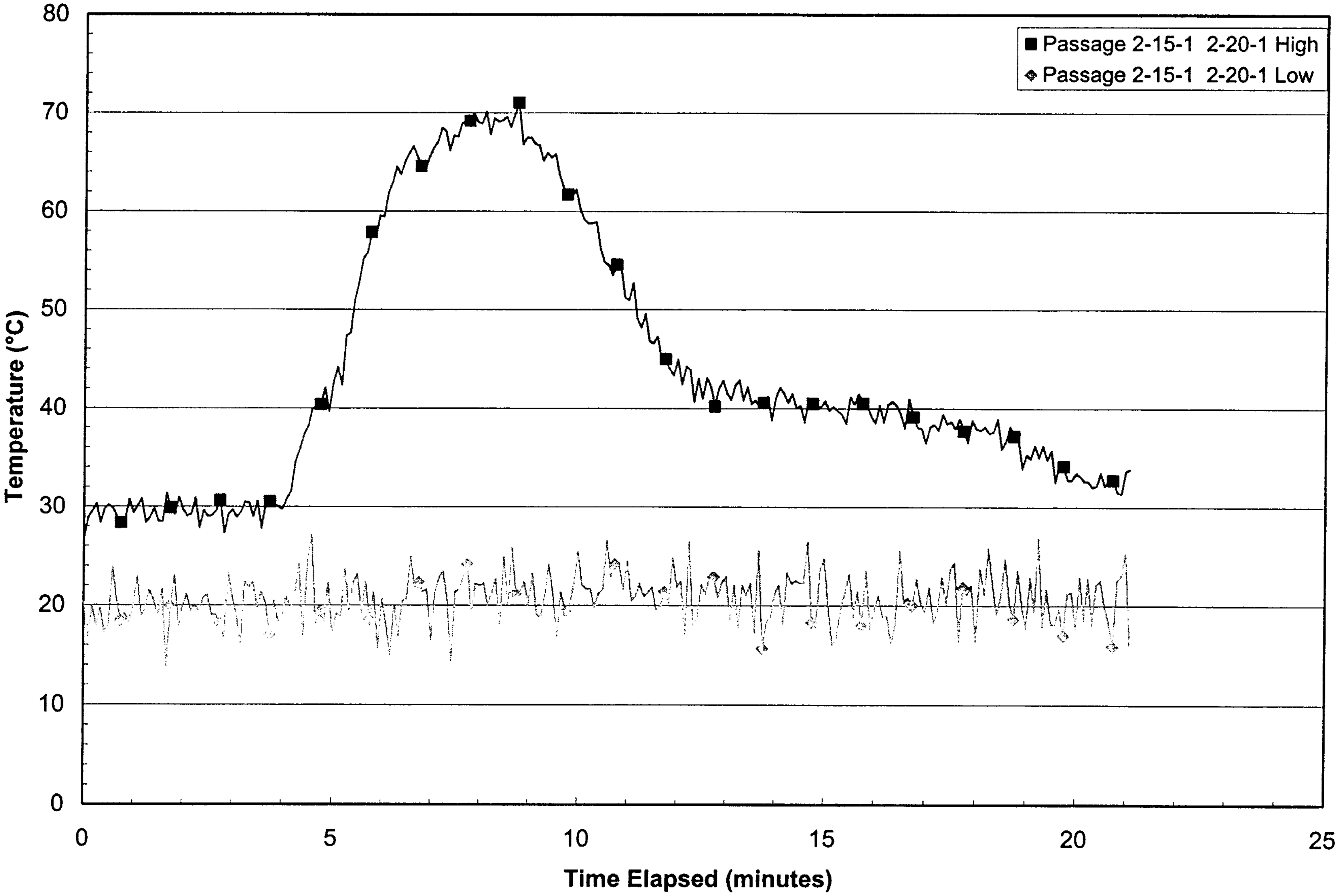

Figure 20. PWAY 2-20-1 TC - AVENT13 - 5 sec filter

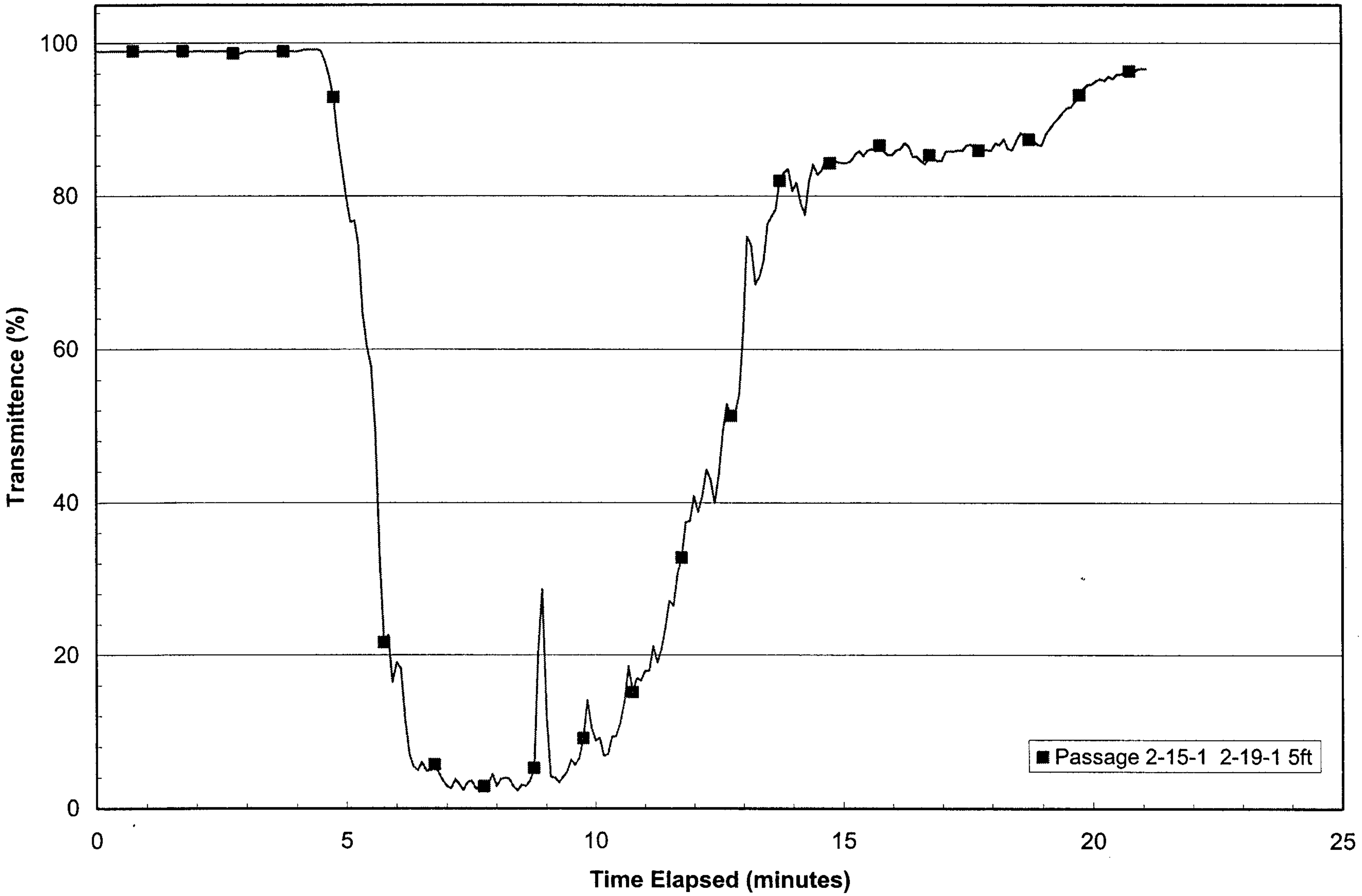

Figure 21. ODM PWAY 2-19-1 - AVENT13 - 5 sec filter

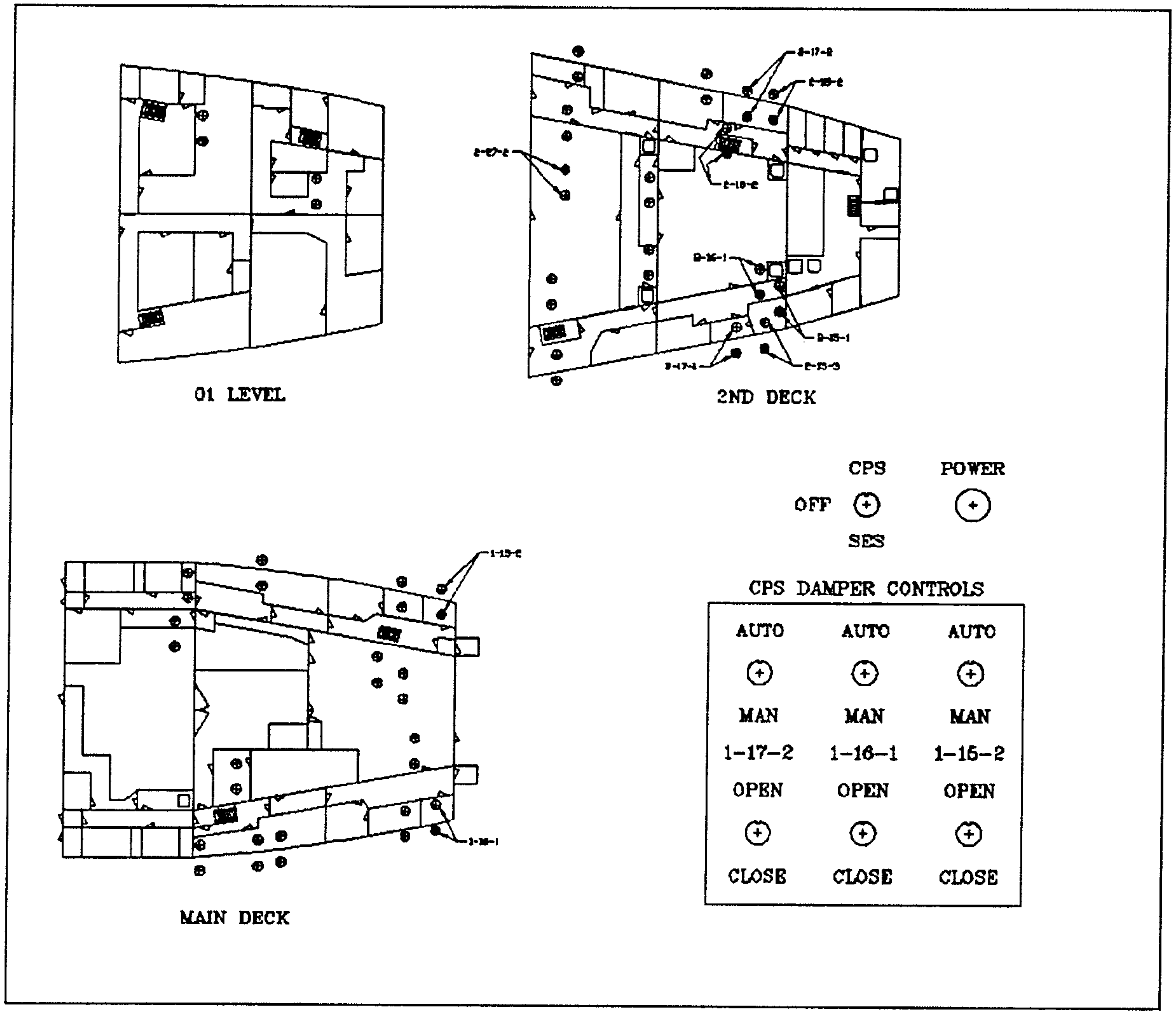

Figure 22. Actuator Alignment – AUTO Mode, Port and Starboard Damage

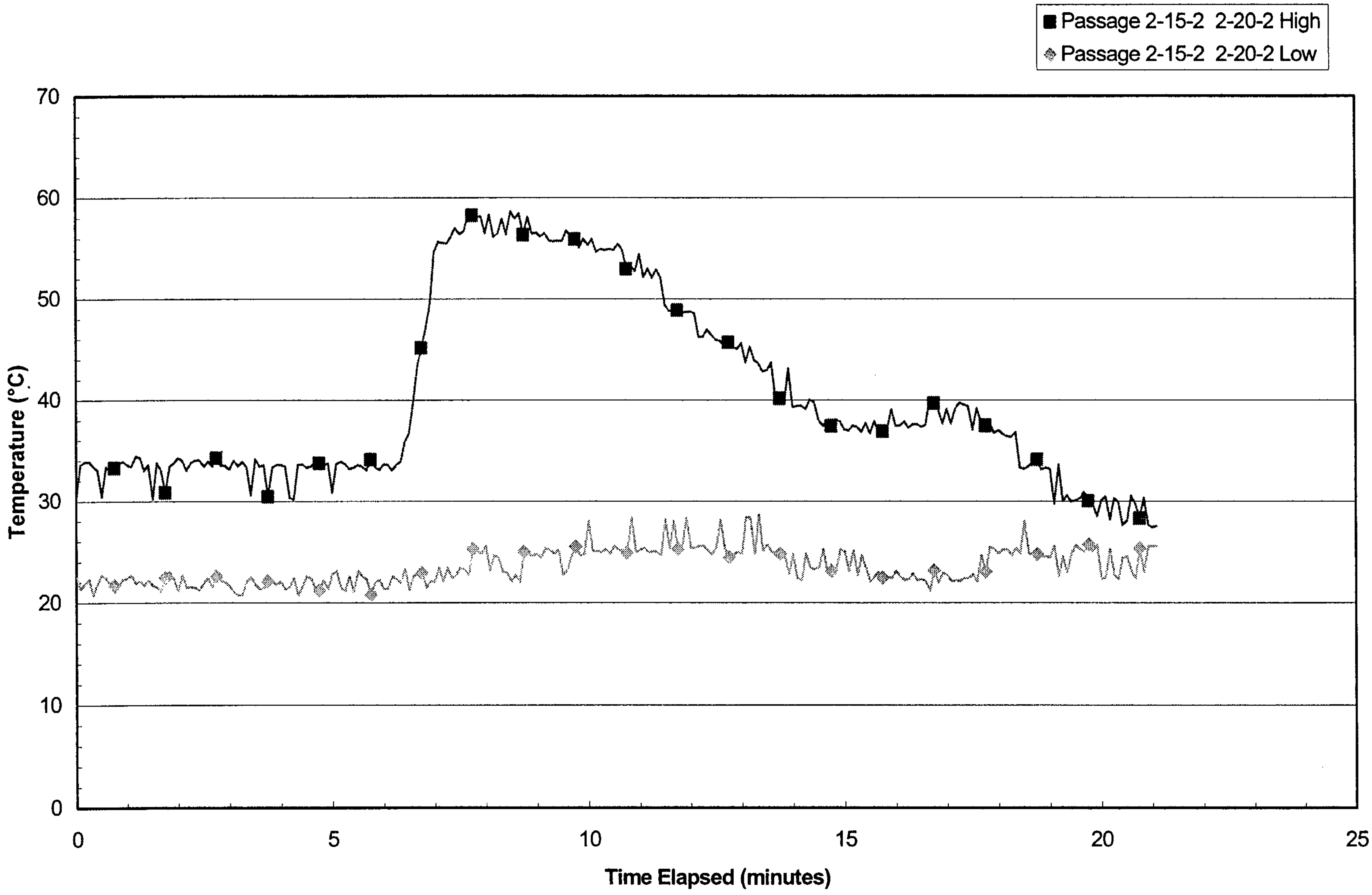

Figure 23. PWAY 2-20-2 TC - AVENT13 - 5 sec filter

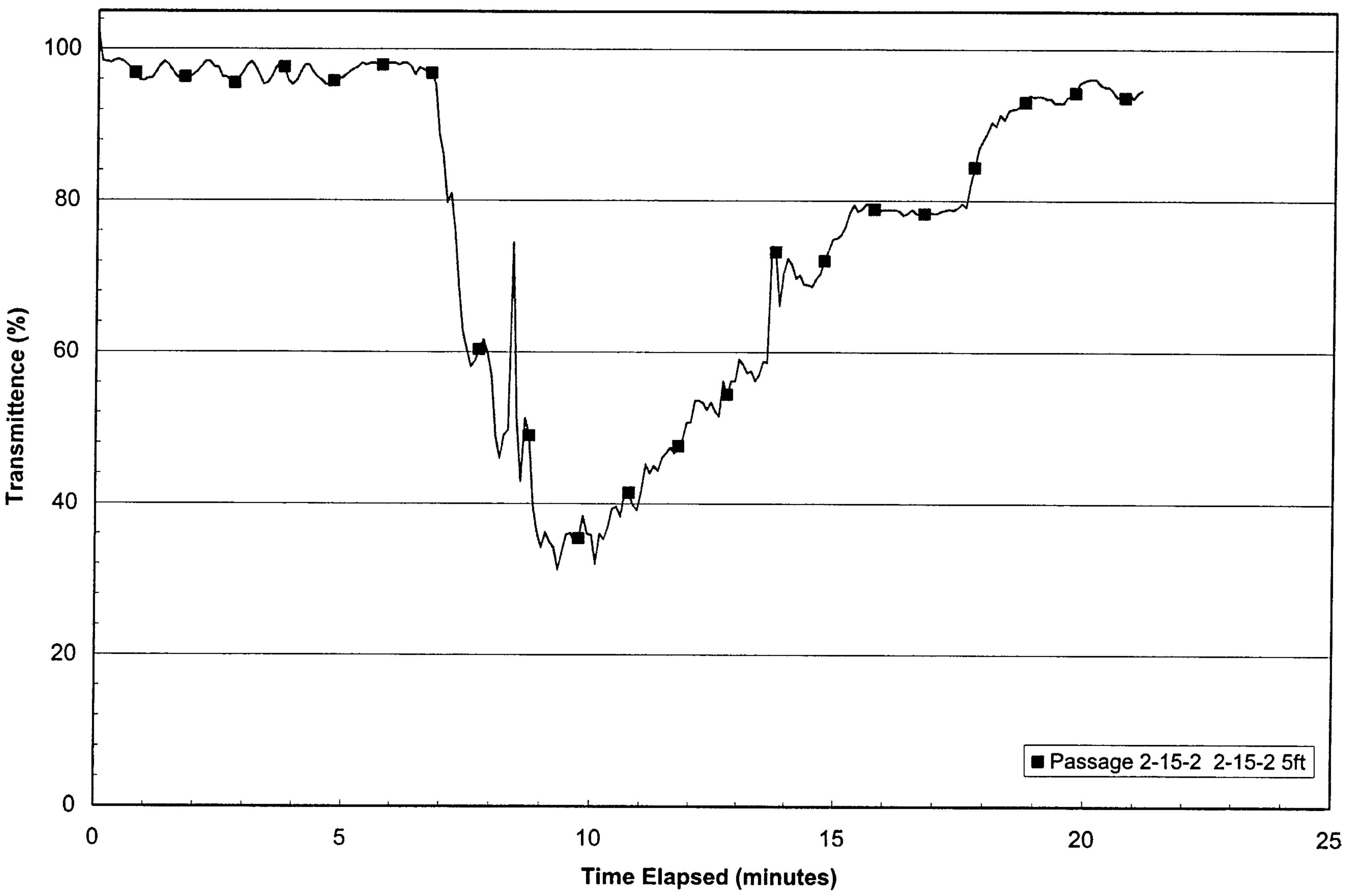

Figure 24. ODM PWAY 2-15-2 - AVENT13 - 5 sec filter

Table 8. Test AVENT13 – Sensor Data

		13a	17a	25b	29b	118b	100b	42b	46b			
Time Change	Time	TC 2-20-1 High	TC 2-25-1 High	ODM 2-19-1 1.524 m (5ft)	ODM 2-25-1 1.524 m (5ft)	TC 2-20-2 High	TC 2-24-2 Low	ODM 2-15-2 1.524 m (5ft)	ODM 2-24-2 1.524 m (5ft)	Frequency Drive 1-15-1 Speed	Frequency Drive 1-15-2 Speed	Comments
(min)	(hr:min:sec)	(°C)	(°C)	(% Trans)	(% Trans)	(°C)	(°C)	(% Trans)	(% Trans)	(Hz)	(Hz)	
0.00	15:15:41	27	20	99	99	30	26	102	100	00	00	Masscomp data acquisition started
3.817	15:19:30	30	22	99	99	34	23	97	100	00	00	Ignition STBD
5.067	15:20:45	42	25	76	99	33	26	97	100	40	00	5 dampers in SES (1-16-1, 2-15-1, 2-15-3, 2-16-1, 2-17-1)
6.133	15:21:49	62	21	13	99	33	23	98	100	51	00	Ignition PORT
7.067	15:22:45	70	22	3	100	55	33	85	94	---	42	9 dampers in SES (1-15-2, 1-16-1, 2-15-1, 2-15-2, 2-15-3, 2-16-1, 2-17-1, 2-17-2, 2-18-2)
7.733	15:23:25	70	23	3	99	59	32	60	74	---	51	---
7.950	15:23:38	66	24	4	39	58	33	60	75	53	---	---
9.483	15:25:10	65	23	8	96	56	31	35	69	---	51	---
9.800	15:25:29	62	24	8	94	56	33	36	60	52	---	---
11.967	15:27:39	43	23	37	81	47	29	49	70	46	---	---
12.317	15:28:00	45	23	41	32	46	29	52	72	---	49	---
12.883	15:28:34	42	23	52	80	46	31	60	76	---	---	Fire out
13.317	15:29:00	31	23	68	80	32	32	57	80	42	---	---
13.650	15:29:20	40	23	77	80	43	30	60	77	off	45	---
14.100	15:29:47	41	24	82	78	39	23	72	81	on-off	---	---
14.817	15:30:30	40	25	84	74	38	26	73	84	---	41	---
15.017	15:30:42	38	25	84	79	37	26	75	83	---	off	---
15.150	15:30:50	39	23	85	77	37	26	76	82	---	---	---
15.233	15:30:55	40	24	85	77	38	26	78	84	---	on-off	All dampers in CPS
16.317	15:32:00	40	25	87	75	27	29	79	84	on-off	---	5 dampers in SES (1-16-1, 2-15-1, 2-15-3, 2-16-1, 2-17-1)
17.483	15:33:10	41	24	86	82	39	29	79	85	00	00	Ventilate 1-15-2, All dampers in CPS
18.233	15:33:55	37	24	87	83	34	22	90	95	00	00	Ventilate 1-15-1

9.0 OBSERVATIONS

The test series AVENT01-AVENT13 was very successful in demonstrating its objectives. Every mode reacted according to its programmed logic and all attached hardware (actuators and frequency drives) reacted according to the manual or sensory input (depending on the mode) it received. This was a success in itself and a testament to the stability of ACSVS LNS Application and the LonWorks Network.

All testing, even if it is successful reveals weaknesses or undesirable traits within the general program. This test series likewise revealed a few areas to be reworked within the control program and the ventilation technique.

9.1 ACSVS LNS Application Issues

The most obvious weakness of the control program was its lack of two different sensory set points for activating the ventilation. A set point of 43°C (110°F) was used as the single set point by which the thermocouple temperatures were compared. The ODM percent visibility was compared to a single set point of 75%. These single set points for both sensors caused the ventilation system to cycle back and forth between modes as the actual temperature or visibility would cycle below and above the set point. This feature was not adequately addressed in the ACSVS LNS Application. A few time delays were included in the logic, but were not sufficient on their own to accomplish the task. One potential solution would be two setpoints for each sensor: one setpoint for activating the ventilation system (43°C (110°F) temperature and 75% visibility), and the second for deactivating the ventilation system (29°C (85°F) temperature and 95-97% visibility).

The second issue with the control program was regarding fan control. When normal conditions were indicated by the sensors, the ventilation system was aligned in CPS Mode, but the fans were turned "off." This was a deliberate function within the logic to show control of the fans by starting them either manually through ACSVS LNS Application or automatically by sensory input. Normally, under CPS Mode, the fans would be "on." This will easily be remedied in the future.

The third issue was the separation of CPS and SES Modes. Because each was its own program, to go from CPS to SES and vice versa took approximately 5.5 minutes. The application had to re-execute control when switching between CPS and SES Modes, which requires it to cycle through a large number of algorithms several times. A much more desirable approach would be combining CPS and SES into one mode and simply using a control button to align the actuators correctly. This change also can be remedied in the future.

The ACSVS LNS application should also be revamped to make it more user friendly, intuitive and robust. Enhancing the application is to be expected, since this was the first version produced.

9.2 Ventilation Technique Issues

AUTO Mode (independent, exhaust only) was the only mode to apply a different ventilation technique than currently used on the ex-USS *Shadwell* for CPS and SES Modes. This technique was comprised of two concepts. The first concept was compartment (zone) independent ventilation. That is, only ventilation components serving a particular zone will react if that zone is damaged. All other ventilation components will remain in normal state as long as the zone they are serving does not become damaged. This concept allows ventilation resources (exhaust and/or supply fan capability) not being used in other zones to be redirected to assist with the damaged zone. This is assuming the ventilation arrangement is such that redirecting resources is possible. This concept was demonstrated quite well.

The second concept was using "exhaust only" ventilation. Based on the AUTO Mode testing, it appeared the "exhaust only" ventilation was not able to keep up with the smoke and heat load produced by diesel fires. It should be noted that the fires were fairly close in proximity to the forward ODMs and thermocouples. Also, only one closure was open from each fire space to the test area, forcing the full smoke and heat load past the forward ODMs and thermocouples as it was exhausted. The heat and smoke loads were much less in the aft portions of the test areas. To prove or disprove this concept of ventilation would require much more rigorous testing. An interesting observation was made during test AVENT11. At approximately 8 minutes into the test (time based on Masscomp data acquisition start) test personnel opened closure 2-15-1 to verify level of visibility. The inrush of make-up air cleared the smoke from the forward end of the compartment as seen by the spike in % transmittance in Figure 15. Later in the test, at approximately 15 minutes the same closure was again opened to investigate the scenario more in depth. Figures 15 and 17 show the affect this had on the smoke migration. The smoke was quickly cleared from the forward end of the compartment, but was pushed to the aft end of the compartment. This shows one possible advantage of the "exhaust only" technique as it applies to the movements of firefighters. Regardless of where a firefighter entered the zone/compartment, the "wind" (make-up air) would be at their back, clearing the smoke and heat in front of them. This would give them a great advantage in identifying and reacting to the situation.

10.0 CONCLUSIONS

The LonWorks Network proved dependable and stable during this test series. There was no loss of communication, either within the network or between the monitoring laptop and the network. The network also reacted promptly to all changes in damage scenarios. There were no noticeable lags in reaction from the time the network sensed a change in damage scenario to the networks reaction to the situation.

The ACSVS LNS Application also performed satisfactorily. The programs correctly recognized damage based on the sensory input and reacted correctly with proper operation of devices (dampers and fans). The application also allowed the loading of different control programs without error.

Based on the success of the LonWorks Network, the ACSVS LNS Application, and the successful demonstration of the objectives (see paragraph 2.0, OBJECTIVES), this test series was successful. This test series was also a step towards a complete automated ventilation system.

11.0 REFERENCES

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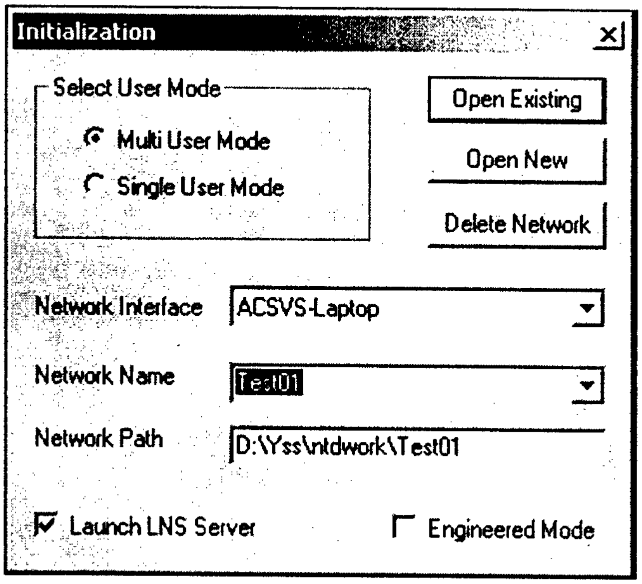
APPENDIX A – PROGRAMMING DETAILS FOR THE ACSVS LNS APPLICATION

ACSVS LNS Application Initialization Screen



Select User Mode
● Multi User Mode
○ Single User Mode

Network Interface: ACSVS-Laptop
Network Name: Test01
Network Path: D:\Yss\nldwork\Test01

☑ Launch LNS Server
☐ Engineered Mode

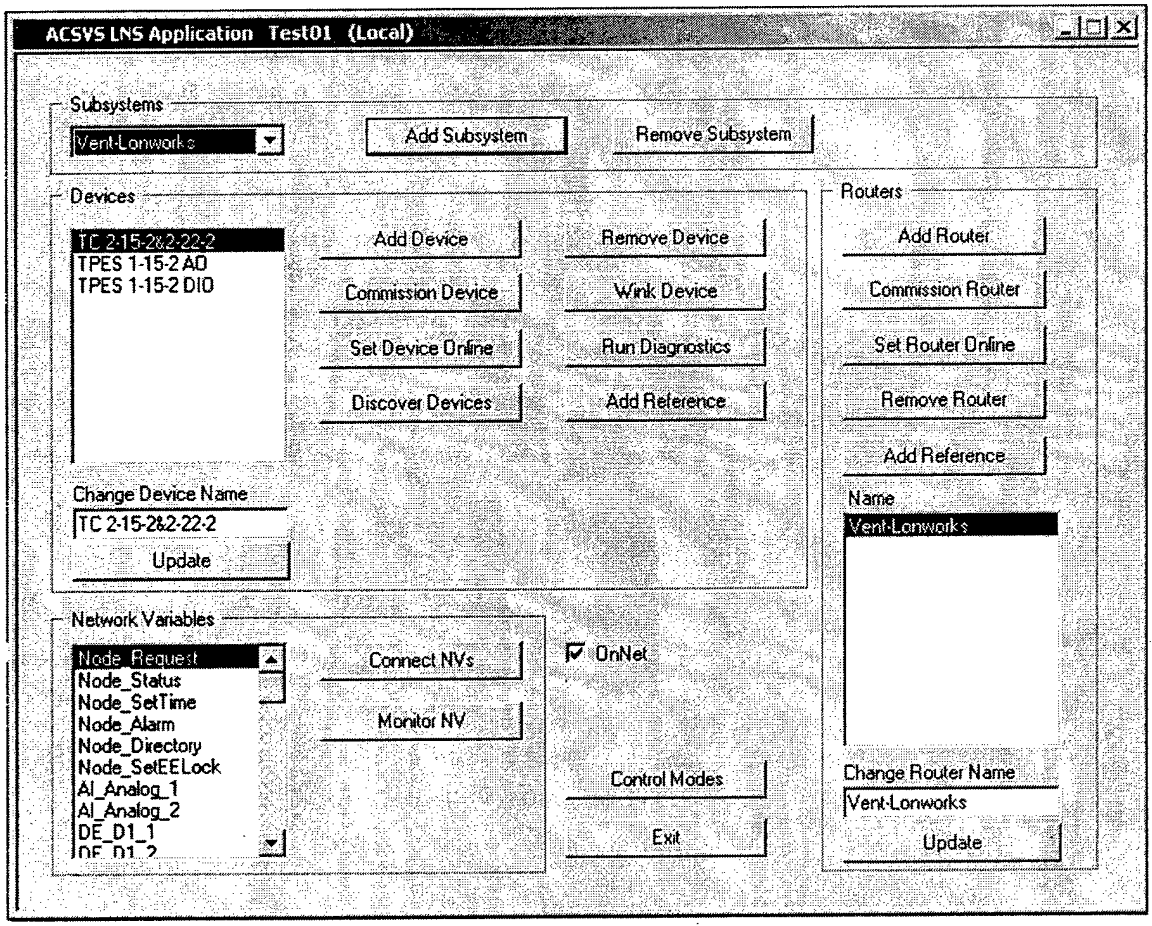
The Initialization Screen is the first screen to appear when the ACSVS LNS Application is started. This allows the user to open an existing LNS Network Database, create a new LNS Network Database, or delete an existing LNS Network Database. In addition, the Initialization Screen allows the user to Launch the LNS server or proceed in engineering mode when opening an existing Network Database or creating a new Network Database. The Visual C++ class used when the Initialization Screen is opened is the **CInitDlg** class. The Visual C++ class member that executes when the Initialization Screen is opened is the **CInitDlg::OnInitDialog()** class member.

The Visual C++ member function that executes when the ‘Open Existing’ button is pressed is the **CInitDlg::OnOpenExistDbBtn()** member function. This member function allows the user to open an existing network selected from the ‘Network Name’ drop down list.

The Visual C++ member function that executes when the ‘Open New’ button is pressed is the **CInitDlg::OnOpenNewDbBtn()** member function. This member function allows the user to open a new network. This requires the user to enter a new network name in the ‘Network Name’ dialog box.

The Visual C++ member function that executes when the ‘Delete Network’ button is pressed is the **CInitDlg::OnDeleteDBBtn()** member function. This member function allows the user to delete an existing network database selected from the ‘Network Name’ drop down list.

ACSVS LNS Application Main Screen



ACSVS LNS Application Test01 (Local)

Subsystems: Vent-Lonworks

Devices:
- TC 2-15-2&2-22-2
- TPES 1-15-2 AD
- TPES 1-15-2 DIO

Change Device Name: TC 2-15-2&2-22-2

Network Variables:
- Node_Request
- Node_Status
- Node_SetTime
- Node_Alarm
- Node_Directory
- Node_SetEELock
- AI_Analog_1
- AI_Analog_2
- DE_D1_1

☑ OnNet

Routers

Name:
- Vent-Lonworks

Change Router Name: Vent-Lonworks

The ACSVS LNS Application Main Screen (Main Screen) is the screen that appears after the ‘Open Existing’ button or the ‘Open New’ button has been pressed on the Main Screen. From this screen the user has the ability to build and Control an entire LNS Network Database. The user can create subsystems, add routers and devices to a subsystem, run diagnostics on devices, and monitor and control network variables. The Visual C++ class used when the Main Screen is opened is the **CMainDlg** class. The Visual C++ class member that executes when the Initialization Screen is opened is the **CMainDlg::OnInitDialog()** class member.

The Visual C++ member function that executes when the ‘Remove Subsystem’ button is pressed is the **CMainDlg::OnRemSubsysBtn()** member function. This member function allows the user to remove a subsystem from the logical LNS network database.

The Visual C++ member function that executes when the 'Remove Device' button is pressed is the **CMainDlg::OnRemDevBtn()** member function. This member function allows the user to remove a device from the logical LNS network database.

The Visual C++ member function that executes when the 'Commission Device' button is pressed is the **CMainDlg::OnCommDevBtn()** member function. This member function allows the user to commission the highlighted device on the network.

The Visual C++ member function that executes when the 'Set Device Online' button is pressed is the **CMainDlg::OnOnOfflineDevBtn()** member function. This member function allows the user to set the highlighted device online.

The Visual C++ member function that executes when the 'Discover Devices' button is pressed is the **CMainDlg::OnDiscDevBtn()** member function. This member function allows the user to discover new devices on the network.

The Visual C++ member function that executes when the 'Wink Device' button is pressed is the **CMainDlg::OnWinkDevBtn()** member function. This member function allows the user to test communication of the highlighted device.

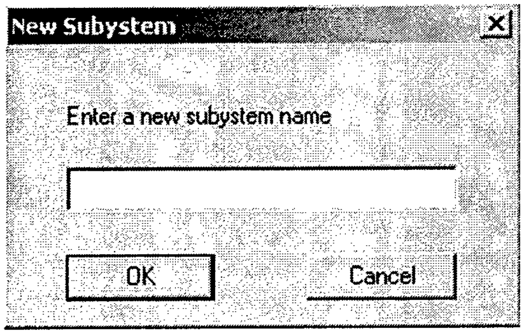
The Visual C++ member function that executes when the 'Commission Router' button is pressed is the **CMainDlg::OnCommRouterBtn()** member function. This member function allows the user to commission the highlighted router.

The Visual C++ member function that executes when the 'Set Router Online' button is pressed is the **CMainDlg::OnOnOfflineRouterBtn()** member function. This member function allows the user to set the highlighted router online.

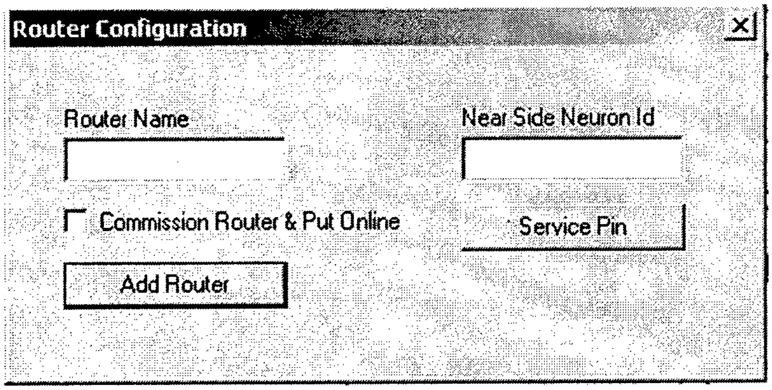
The Visual C++ member function that executes when the 'Remove Router' button is pressed is the **CMainDlg::OnRemoveRouterBtn()** member function. This member function allows the user to remove a router from the logical LNS network database.

In the 'Router' section, the Visual C++ member function that executes when the 'Update' button is pressed is the **CMainDlg::OnUpdateRnPb()** member function. This member function allows the user to change the name of the router.

In the 'Devices' section, the Visual C++ member function that executes when the 'Update' button is pressed is the **CMainDlg::OnUpdateDnPb()** member function. This member function allows the user to change the name of the device.



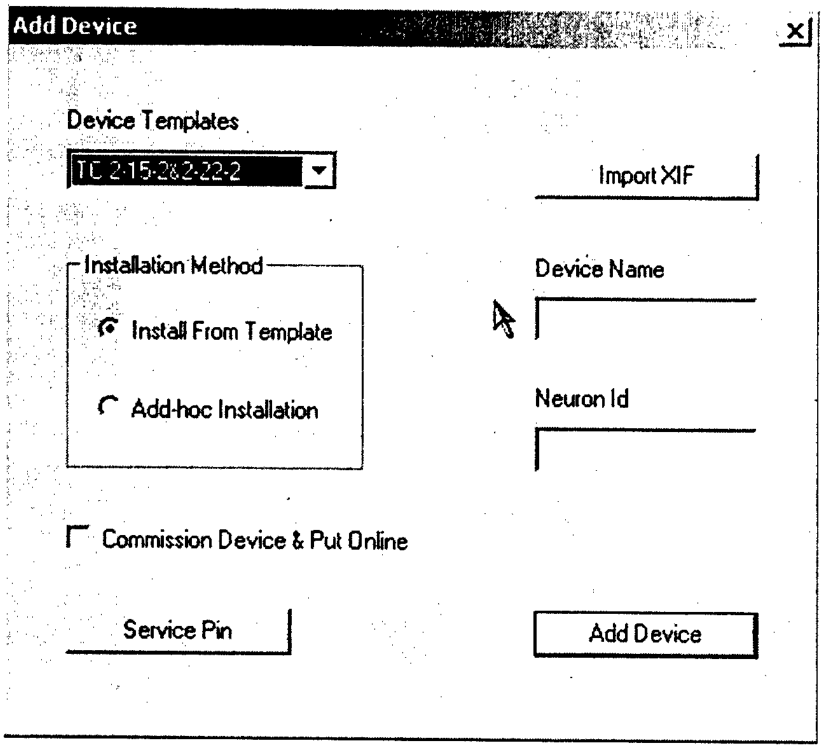
The 'New Subsystem' window pops-up when the 'Add Subsystem' button is pressed from the Main Screen. This window allows the user to create new subsystems in the LNS network database. The Visual C++ member function that executes when the 'Add Subsystem' button is pressed is the **CMainDlg::OnAddSubsysBtn()** member function.



The 'Router Configuration' window pops-up when the 'Add Router' button is pressed from the Main Screen. This window is designed to add routers to the LNS network database by service pinning the router. If the 'Commission Router & Put Online' checkbox is checked, the router will automatically be commissioned and set online when the 'Add Router' button is pressed from the 'Router Configuration' window. The Visual C++ member function that executes when the ‘Router Configuration’ button is pressed is the **CMainDlg::OnAddRouterBtn()** member function.

The Visual C++ member function that executes when the ‘Service Pin’ button is pressed is the **CAddRouterDlg::OnServicePinBtn()** member function. This member function allows the user to service pin a router, which retrieves the neuron ID so the router can be added to the network.

The Visual C++ member function that executes when the ‘Add Router’ button is pressed is the **CAddRouterDlg::OnAddRouterBtn()** member function. This member function allows the user to add a router to the network.


Device Templates: TC 2-15-2&2-22-2

Installation Method:
● Install From Template
○ Add-hoc Installation

☐ Commission Device & Put Online

Device Name:

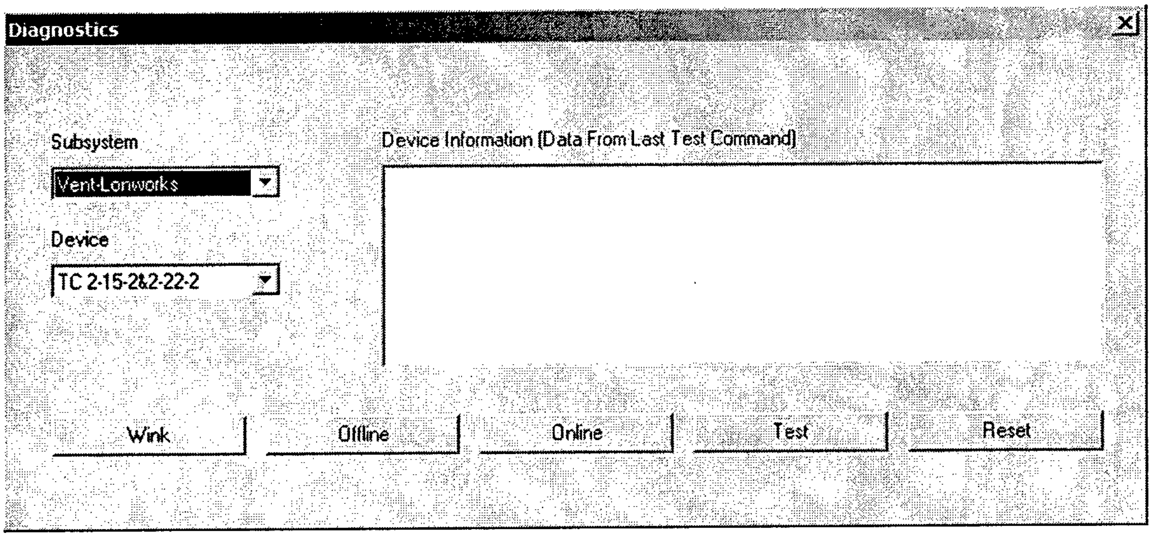
Neuron Id:

The ‘Add Device’ window pops-up when the ‘Add Device’ button is pressed from the Main Screen. This window is designed to add devices to the LNS network database by service pinning the device (Add-hoc Installation) or from a template. If the ‘Commission Device & Put Online’ checkbox is checked, the device will automatically be commissioned and set online when the ‘Add Device’ button is pressed from the ‘Add Device’ window. The Visual C++ member function that executes when the ‘Add Device’ button is pressed is the **CMainDlg::OnAddDevBtn()** member function.

The Visual C++ member function that executes when the 'Service Pin' button is pressed is the **CAddDevDlg::OnServicePinBtn()** member function. This member function allows the user to service pin a device, which retrieves the neuron ID so the device can be added to the network.

The Visual C++ member function that executes when the 'Add Device' button is pressed is the **CAddDevDlg::OnAddDevBtn()** member function. This member function allows the user to add a device to the network.

The Visual C++ member function that executes when the 'Import XIF' button is pressed is the **CAddDevDlg::OnImportXifBtn()** member function. This member function allows the user to add a device to the network by using a XIF template selected from a file dialog box that pops-up.



The 'Diagnostics' window pops-up when the 'Run Diagnostics' button is pressed from the Main Screen. This window allows the user to test the device to see if it is functioning and communicating properly with the LNS network. The Visual C++ member function that executes when the 'Run Diagnostics' button is pressed is the **CMainDlg::OnDiagDevBtn()** member function.

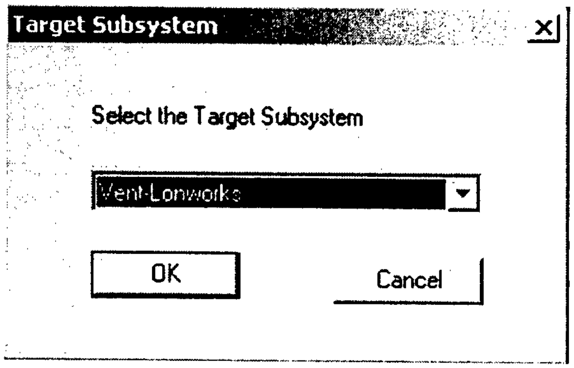
The Visual C++ member function that executes when the 'Wink' button is pressed is the **CDiagnosticsDlg::OnWinkDevBtn()** member function. This member function will test the communication between the device and the network.

The Visual C++ member function that executes when the 'Offline' button is pressed is the **CDiagnosticsDlg::OnOfflineDevBtn()** member function. This member function will set the selected device offline.

The Visual C++ member function that executes when the 'Online' button is pressed is the **CDiagnosticsDlg::OnOnlineDevBtn()** member function. This member function will set the selected device online.

The Visual C++ member function that executes when the 'Test' button is pressed is the **CDiagnosticsDlg::OnTestDevBtn()** member function. This member function will test the diagnostics of the selected device.

The Visual C++ member function that executes when the 'Reset' button is pressed is the **CDiagnosticsDlg::OnResetDevBtn()** member function. This member function will reset the status of the selected device.



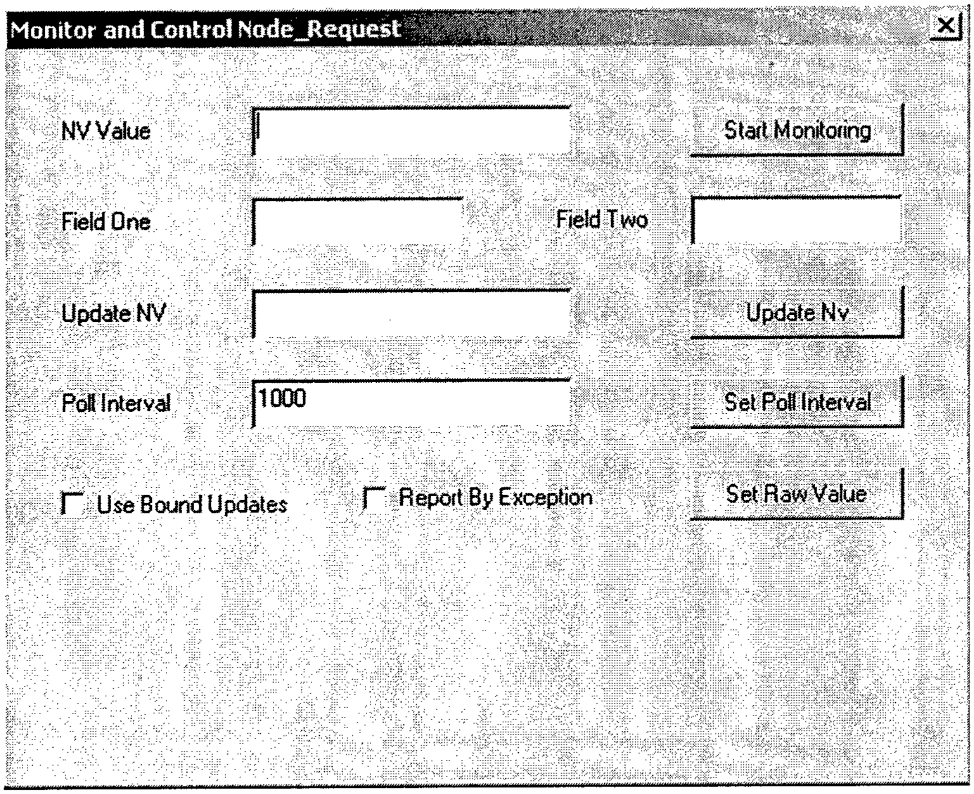
Select the Target Subsystem

Vent-Lonworks

When the 'Add Reference' button is pressed from the Main Screen, the 'Target Subsystems' window pops-up. This window allows the user to reference devices and routers from other subsystems and copy them into the selected subsystem from the drop down list. Note: There are two 'Add Reference' buttons on the Main Screen. One is located in the 'Devices' section and the other is located in the 'Routers' section. If the 'Add Reference' button is pressed in the 'Devices' section then a device will be referenced. Likewise, if the 'Add Reference' button is pressed in the 'Routers' section then a router will be referenced.

In the 'Devices' section, the Visual C++ member function that executes when the 'Add Reference' button is pressed is the **CMainDlg::OnAddrefDevBtn()** member function.

In the 'Routers' section, the Visual C++ member function that executes when the 'Add Reference' button is pressed is the **CMainDlg::OnAddrefRtrBtn()** member function.



Poll Interval: 1000

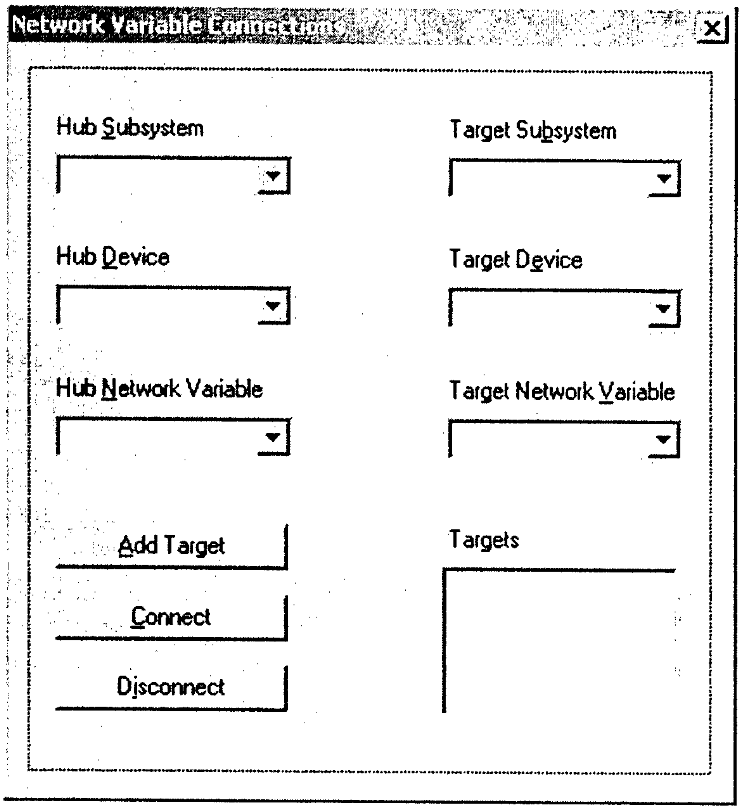
The 'Monitor and Control' window pops-up when the 'Monitor NV' button is pressed on the Main Screen. This window allows the user to Monitor and Control a particular network variable that was highlighted on the Main Screen. The Visual C++ member function that executes when the 'Monitor NV' button is pressed is the **CMainDlg::OnMonNvBtn()** member function.

The Visual C++ member function that executes when the 'Start Monitoring' toggle button is pressed is the **CMonitorDlg::OnMonitorBtn()** member function. This member function will toggle between 'Start Monitoring' and 'Stop Monitoring' of the selected network variable.

The Visual C++ member function that executes when the 'Update NV' button is pressed is the **CMonitorDlg::OnUpdateNvBtn()** member function. This member function will update the selected network variable to the data entered in the 'Update NV' field.

The Visual C++ member function that executes when the 'Set Poll Interval' button is pressed is the **CMonitorDlg::OnPollIntervalBtn()** member function. This member function will set the poll interval of how often the application should check the values of the selected network variable being monitored.

The Visual C++ member function that executes when the 'Set Raw Value' button is pressed is the **CMonitorDlg::OnSetRawValue()** member function. This member function will set the Raw Values of the selected network variable being monitored rather than setting the monitor point values.



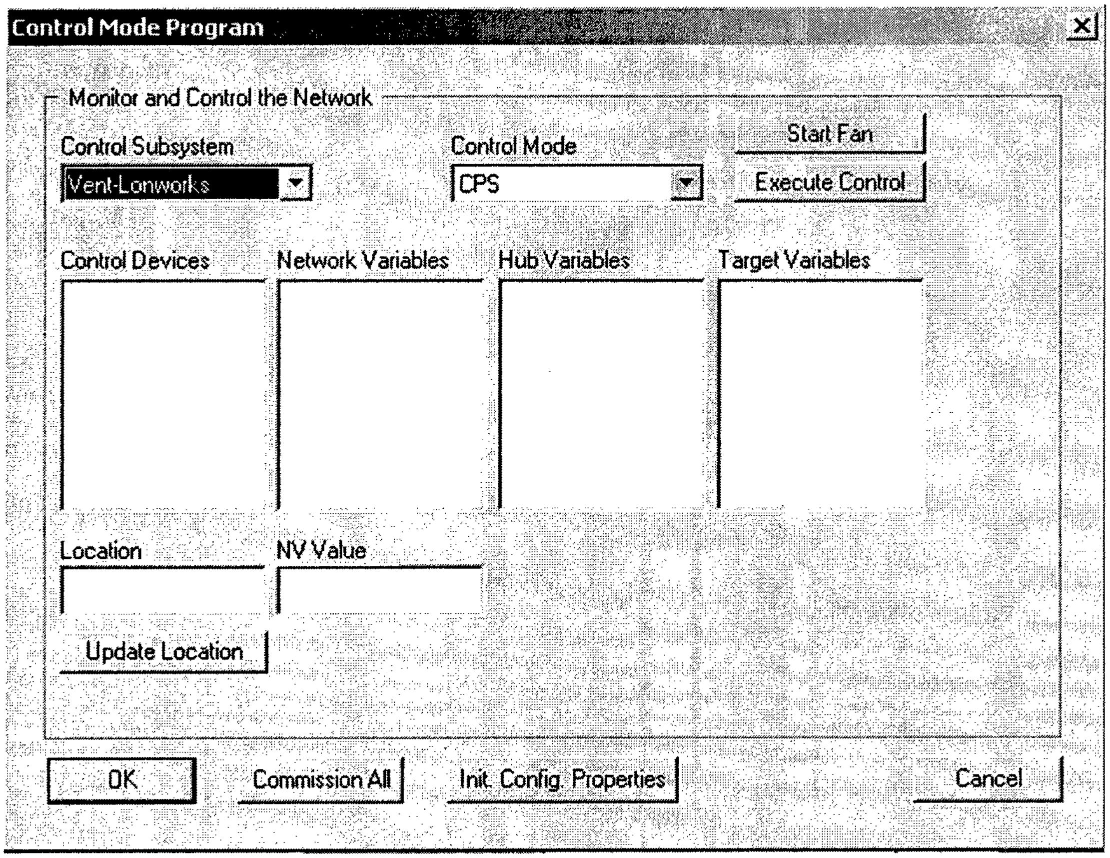
The 'Network Variables Connection' window pops-up when the 'Connect NV' button is pressed on the Main Screen. This window allows the user to Connect Hub and Target network variables together. The Visual C++ member function that executes when the 'Connect NV' button is pressed is the **CMainDlg::OnConnNvBtn()** member function.

The Visual C++ member function that executes when the 'Add Target NV' button is pressed is the **CConnectDlg::OnAddTargetBtn()** member function. This member function allows the user to add network variable targets to the Hub network variable as selected from the drop down lists.

The Visual C++ member function that executes when the 'Connect' button is pressed is the **CConnectDlg::OnConnBtn()** member function. This member function allows the user to connect Target network variables to the Hub network variable as selected from the drop down lists.

The Visual C++ member function that executes when the 'Disconnect' button is pressed is the **CConnectDlg::OnDiscBtn()** member function. This member function allows the user to disconnect Target network variables from the Hub network variable as selected from the drop down lists.

ACSVS LNS Application Control Mode Program Screen



Control Subsystem: Vent-Lonworks

Control Mode: CPS

The Control Mode Program Screen allows the user to choose from four different modes to control the ACSVS LNS Network. The four control modes are as follows:

- CPS
- SES
- DC-Arm
- Auto

The Visual C++ member function that executes when the 'Control Modes' button is pressed from the Main Screen is the **CMainDlg::OnCMPb()** member function. This creates a multi-threaded process that then opens the Control Mode Program Screen. The Visual C++ class used when the Control Mode Program Screen is opened is the **CControlModes** class. The Visual C++ class member that executes when the Control Mode Program Screen is opened is the **CControlModes::OnInitDialog()** class member.

The Visual C++ member function that executes when the 'Commission All' button is pressed is the **CControlModes::OnCommAllBtn()** member function. The 'Commission All' button when pressed will loop through all the devices on the entire network and synchronize the physical devices with the logical devices in the database located on the computer. This is necessary when switching between multiple networks so the application can distinguish which network it is controlling.

The Visual C++ member function that executes when the 'Init. Config. Properties' button is pressed is the **CControlModes::OnAutoDCArmInitCpBtn()** member function. The 'Init. Config. Properties' button when pressed initializes the names of the function block and network variable configuration properties so that when a mode is executed, the application knows what function block values and network variable configuration properties to set. Note: Before executing the control in a particular mode, the user must first initialize the configuration properties for the particular mode that is chosen from the 'Control Mode' drop down list.

The Visual C++ member function that executes when the 'Execute Control' button is pressed is the **CControlModes::OnControlBtn()** member function. The 'Execute Control' button is used to execute the control mode chosen from the 'Control Mode' drop down list. During execution, this process will connect the appropriate network variables, set the required network variable values, and set the necessary function block values for the chosen control mode. The physical network will then contain the appropriate logic for the chosen control mode.

The Visual C++ member function that executes when the ‘Start Fan’ button is pressed is the **CControlModes::OnFanOnOffBtn()** member function. The ‘Start Fan’ button is a toggle button that when pressed will turn on the fans that are not running. Likewise, if the toggle button says ‘Stop Fan’, and is pressed, the fans that are running will stop running.

The Visual C++ member function that executes when the ‘Update Location’ button is pressed is the **CControlModes::OnUpdLocBtn()** member function. The ‘Update Location’ button is used as a description of where the device is physically located on the ship.

APPENDIX B – SELECTED GRAPHS OF SENSOR DATA

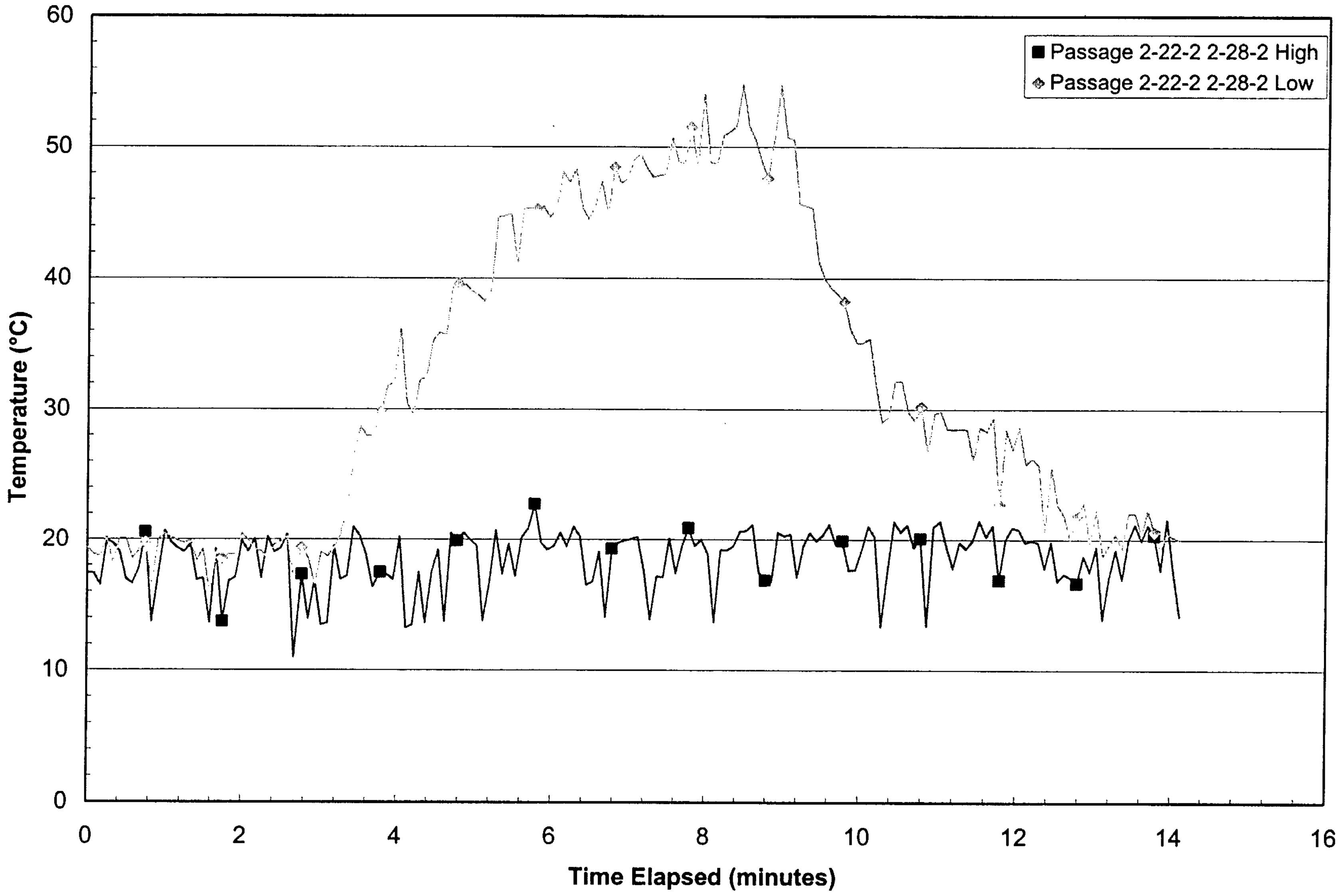


Figure B-1. PWAY 2-24-2 TC - AVENT07 - 5 sec filter

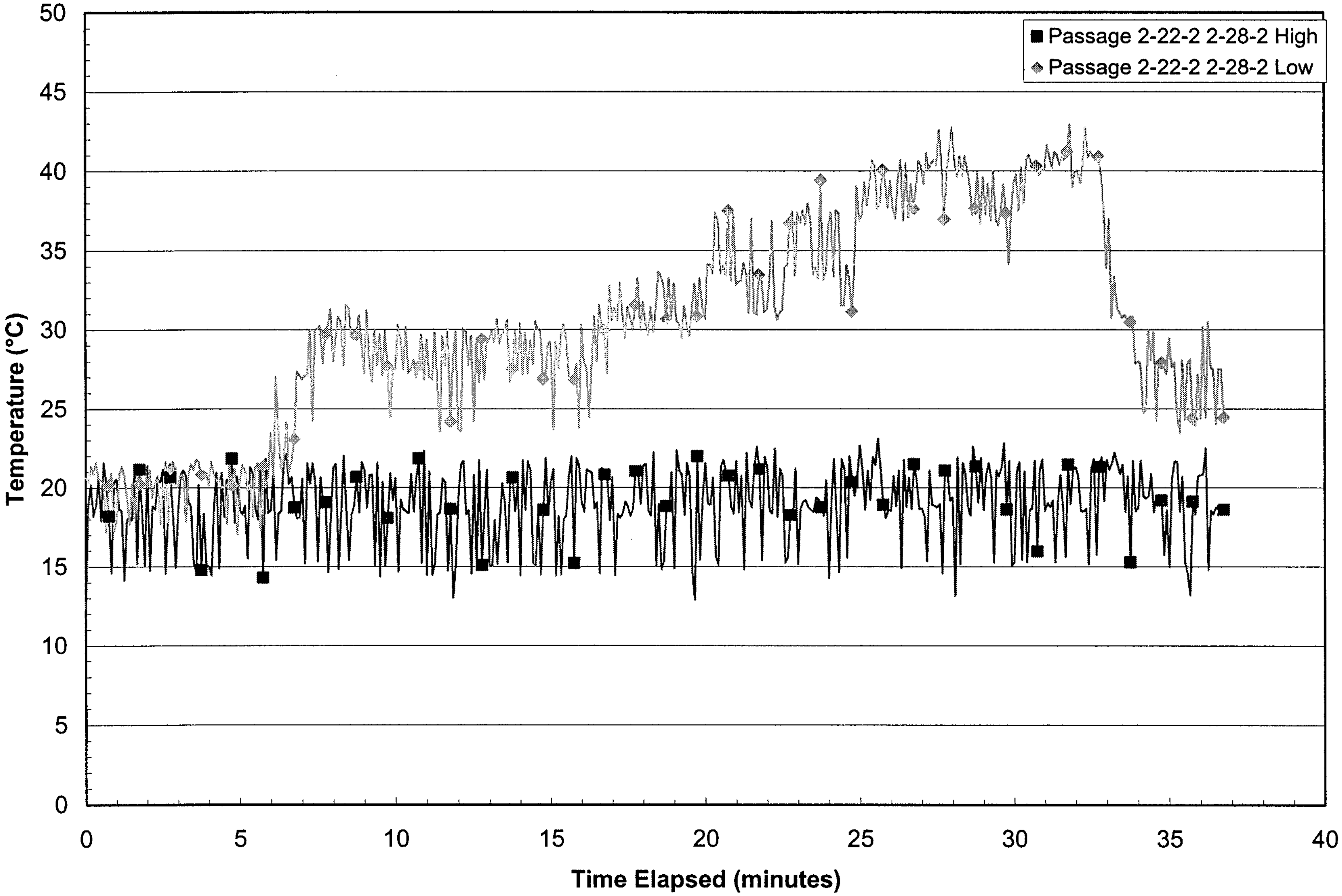


Figure B-2. PWAY 2-24-2 TC - AVENT10 - 5 sec filter

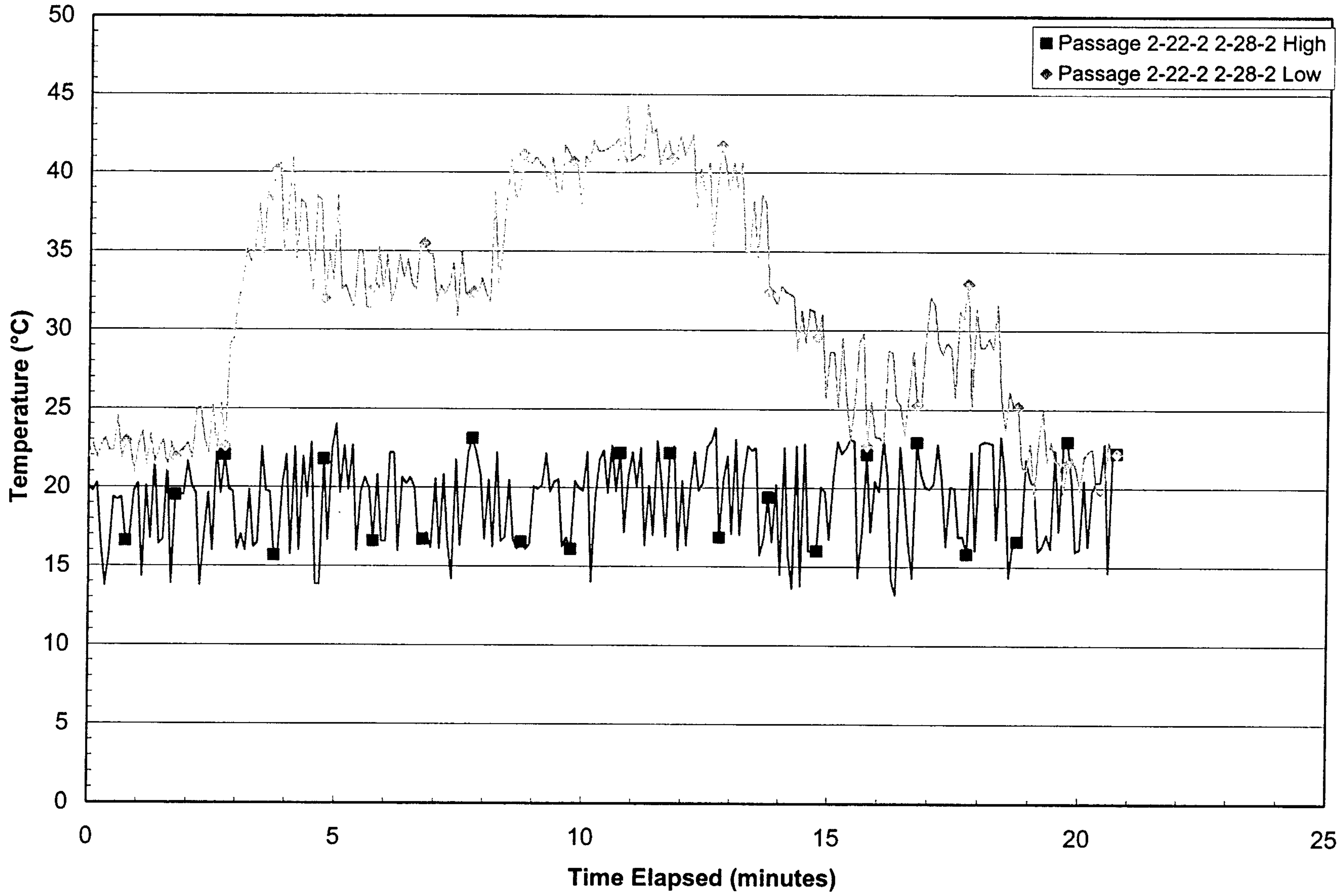


Figure B-3. PWAY 2-24-2 TC - AVENT12 - 5 sec filter

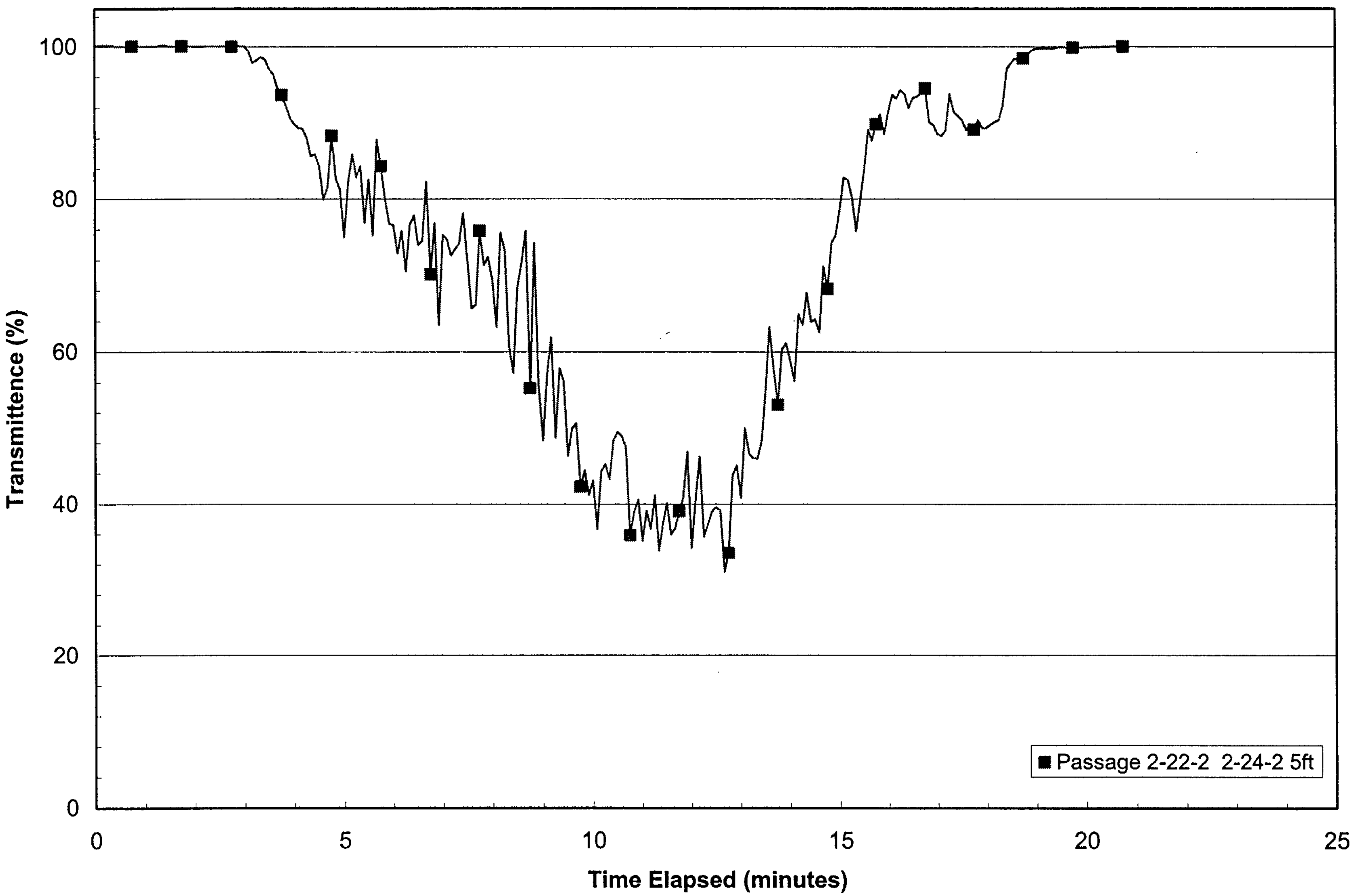


Figure B-4. ODM PWAY 2-25-2 - AVENT12 - 5 sec filter

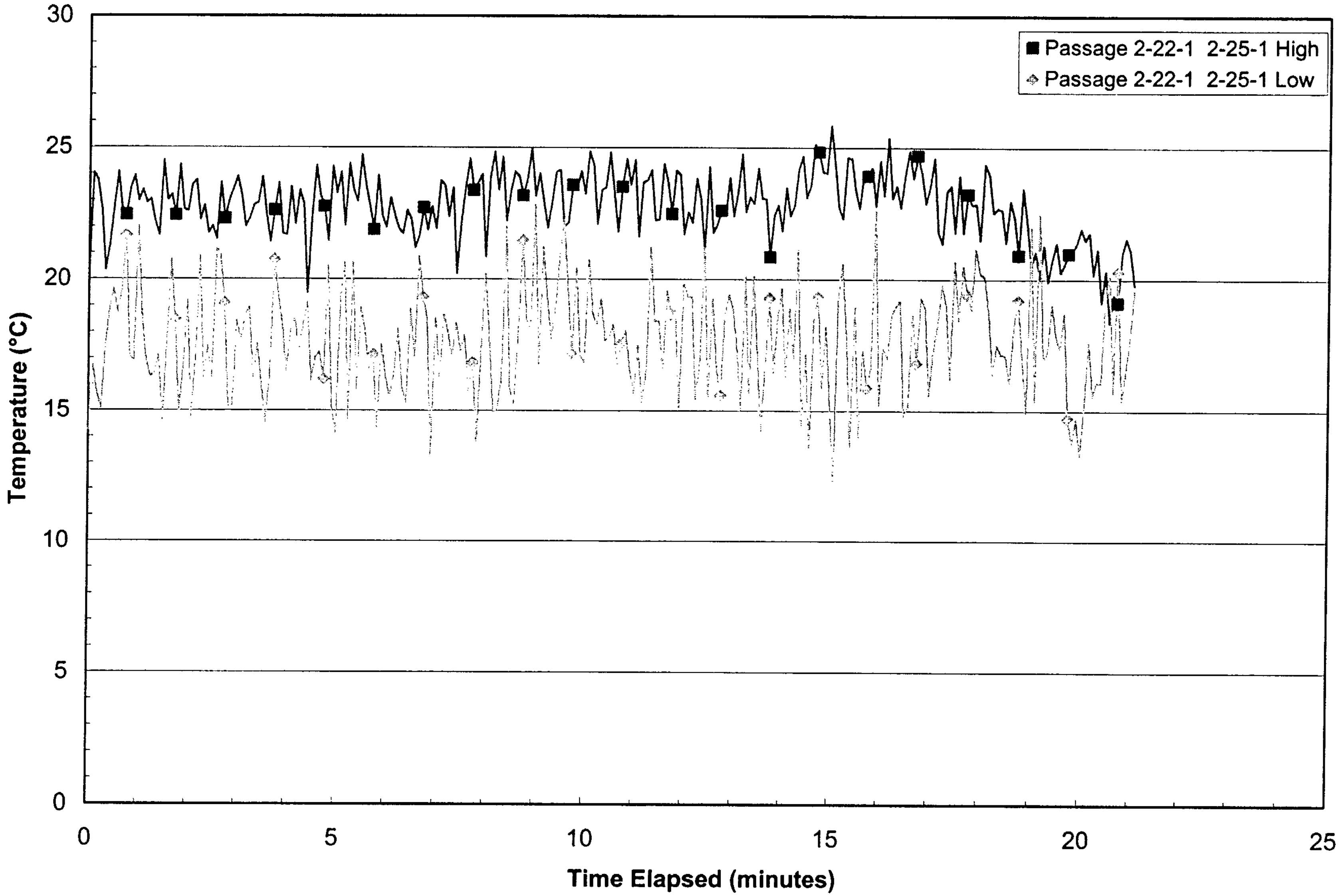


Figure B-5. PWAY 2-25-1 TC - AVENT13 - 5 sec filter

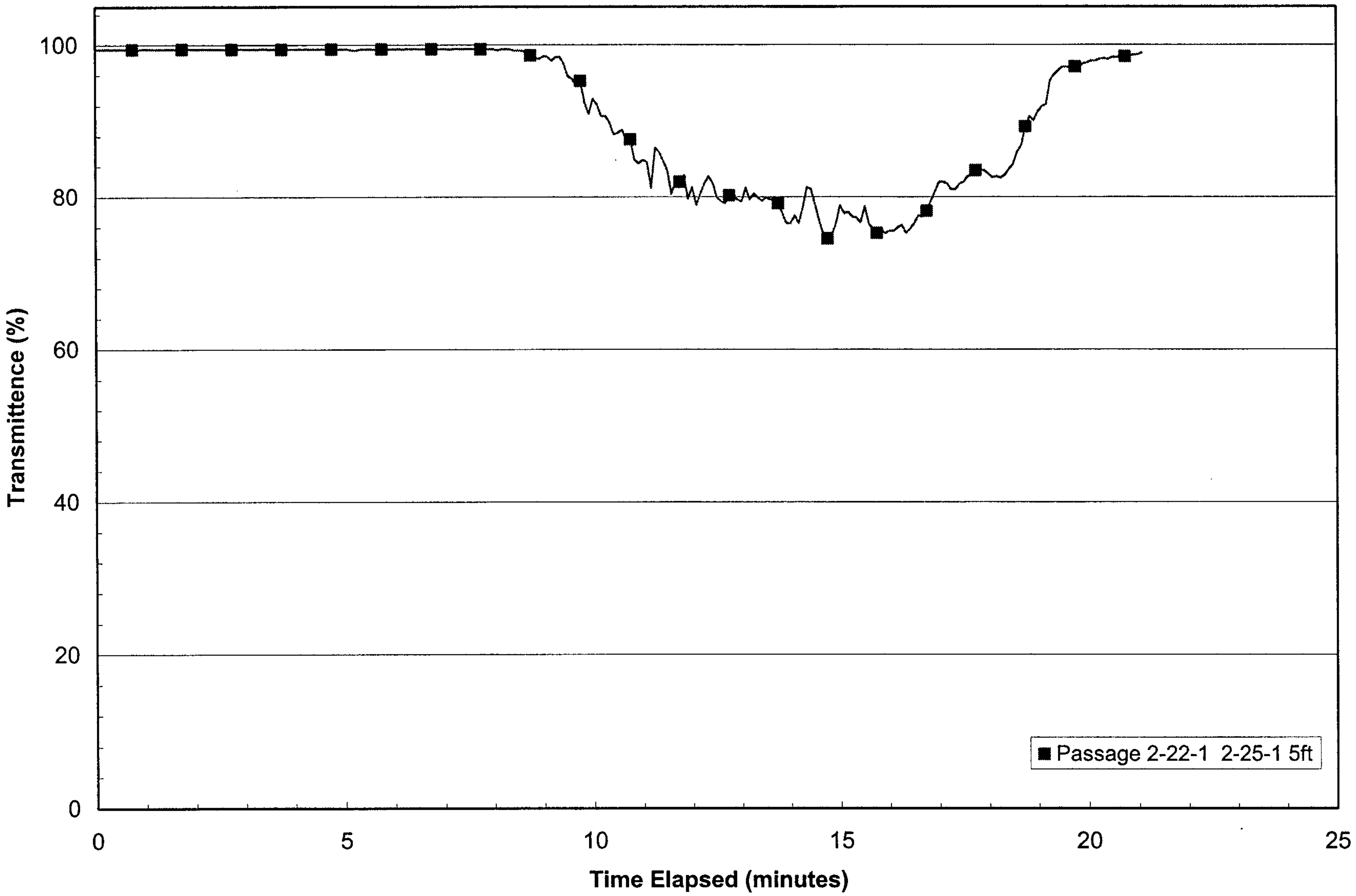


Figure B-6. ODM PWAY 2-25-1 - AVENT13 - 5 sec filter

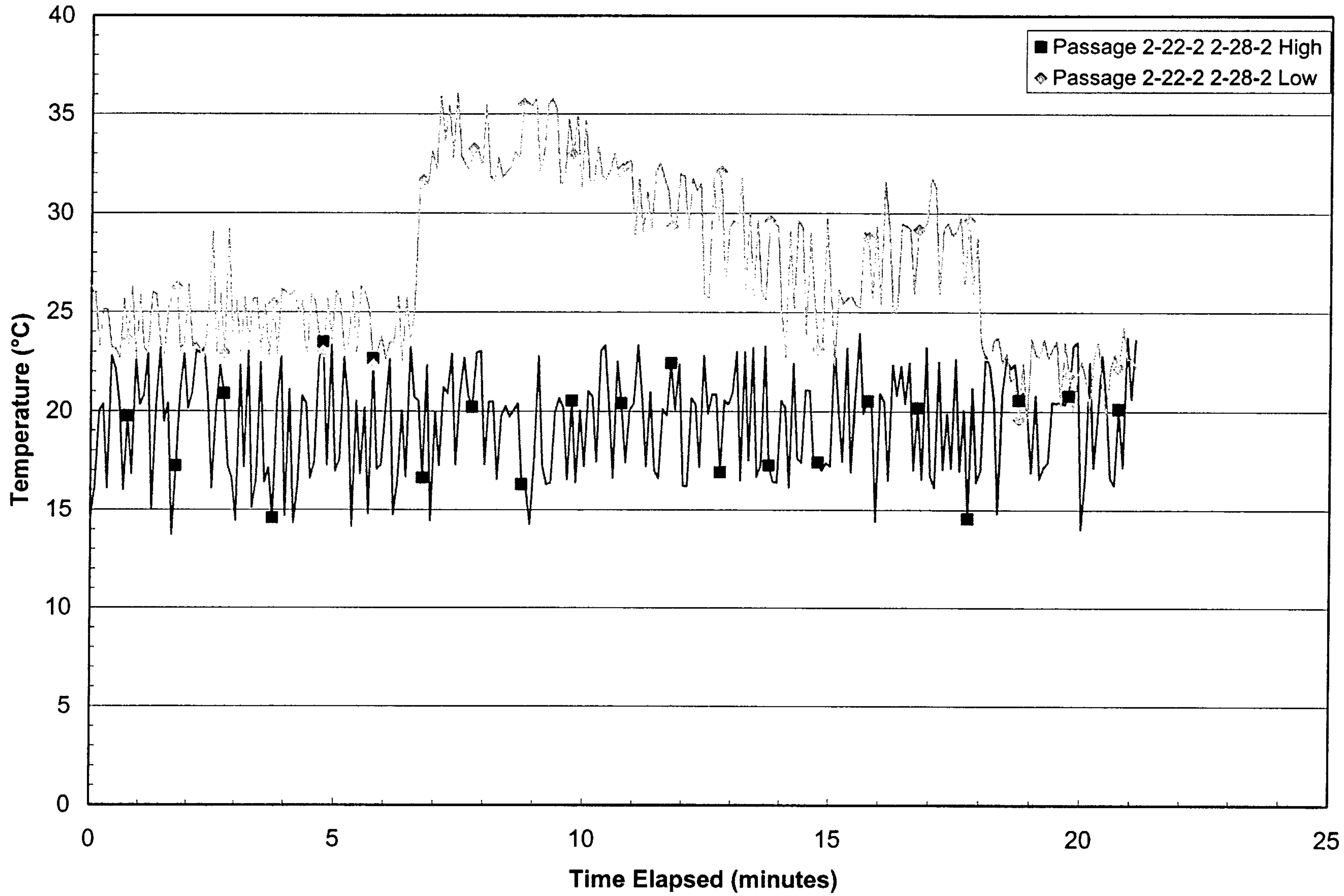


Figure B-7. PWAY 2-24-2 TC - AVENT13 - 5 sec filter

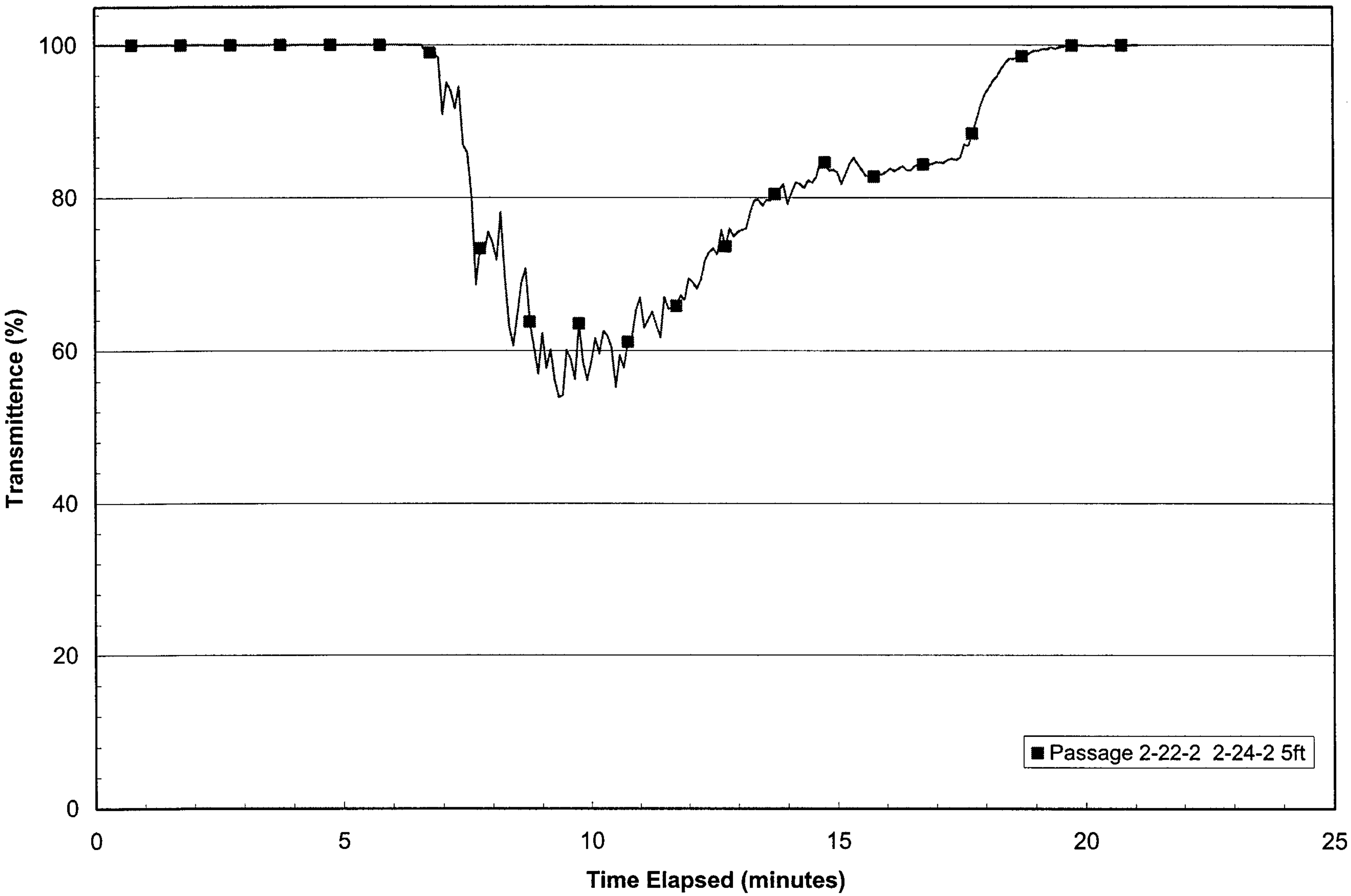


Figure B-8. ODM PWAY 2-25-2 - AVENT13 - 5 sec filter

APPENDIX C – GRAPHS OF FLAME AND FIRE COMPARTMENT TEMPERATURE DATA

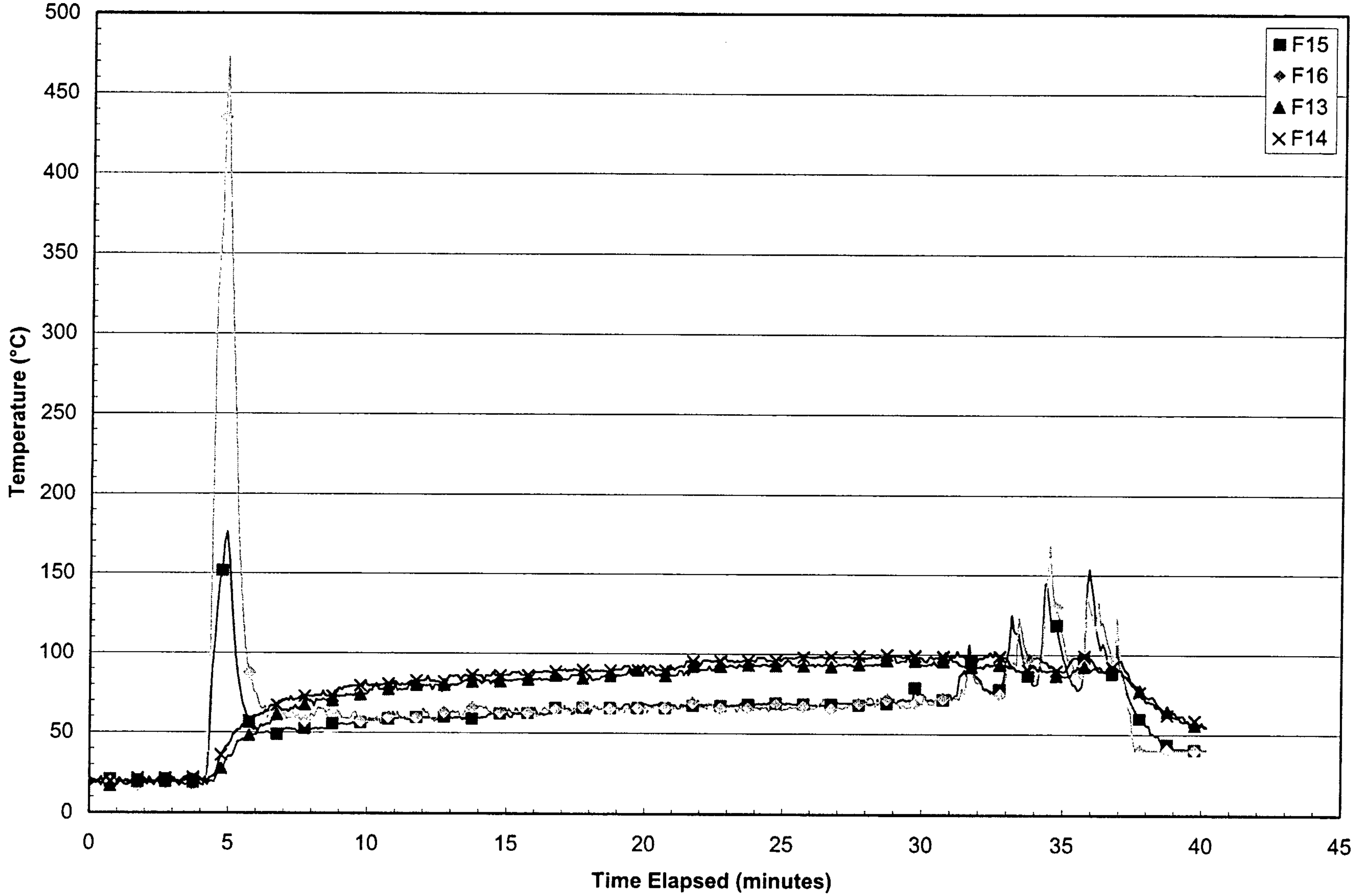


Figure C-1. CPO Flame TC - AVENT04 - 5 sec filter

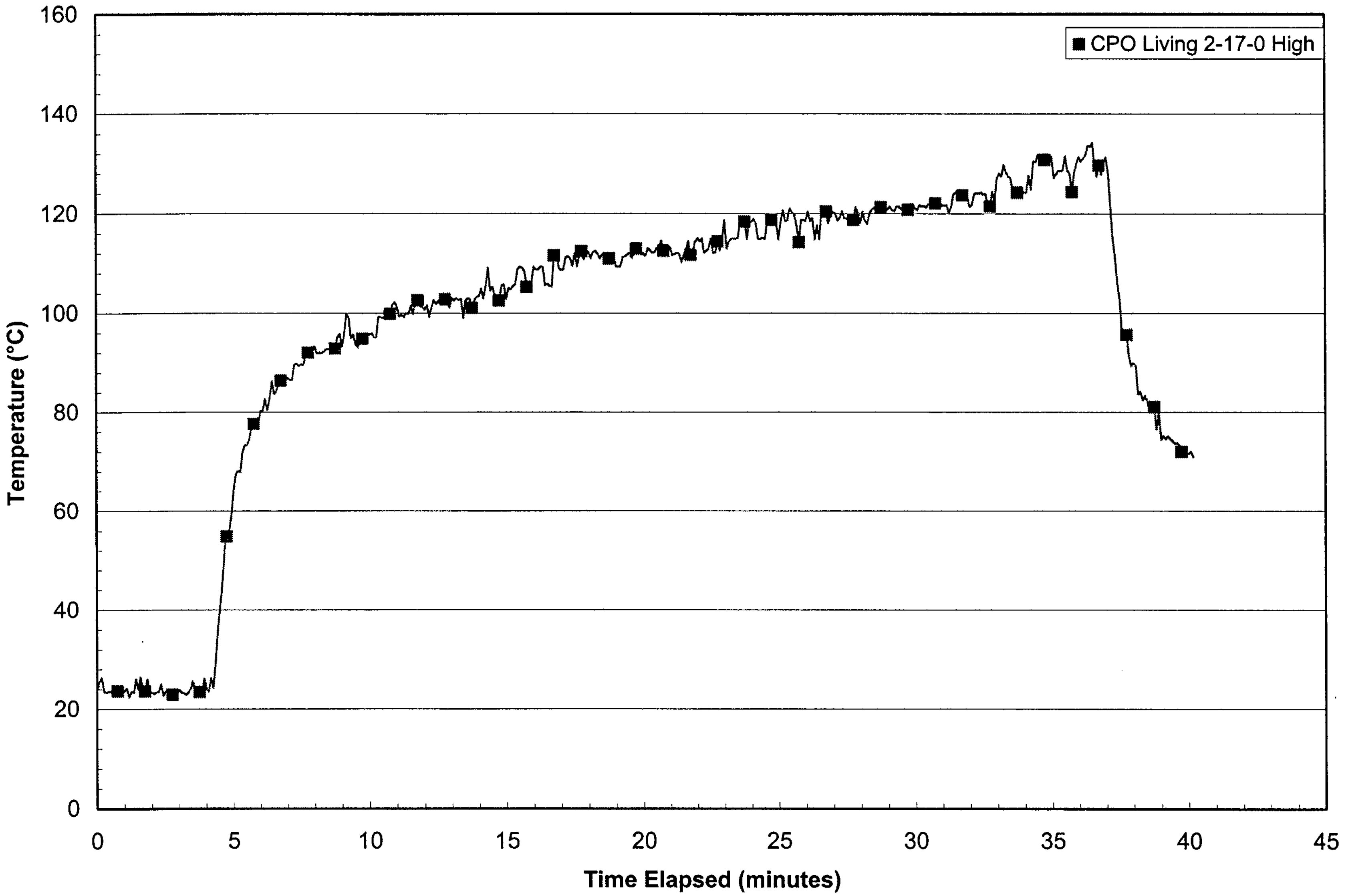


Figure C-2. CPO Living – AVENT04 – 5 sec filter

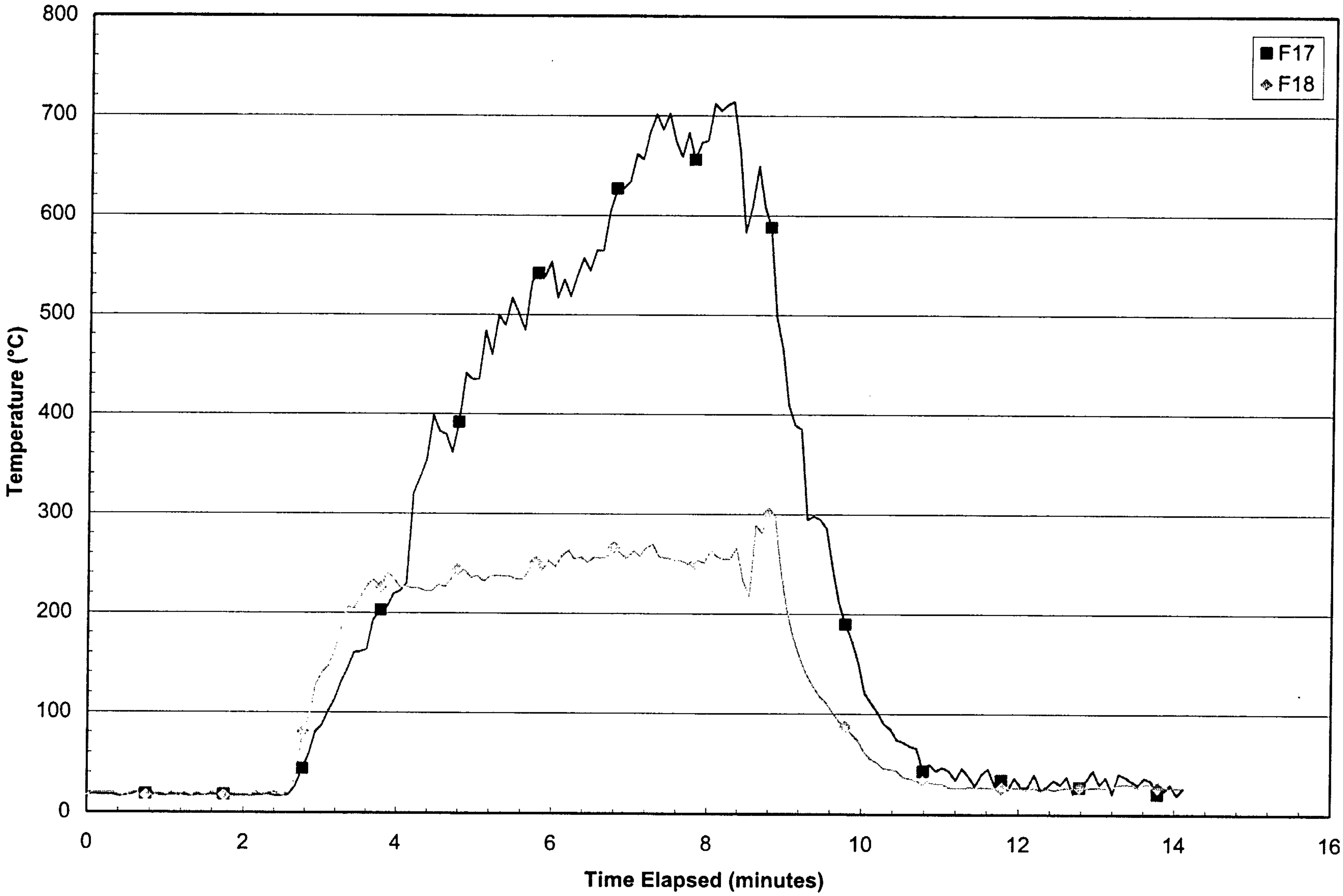


Figure C-3. Vestibule CIC Flame TC - AVENT07 - 5 sec filter

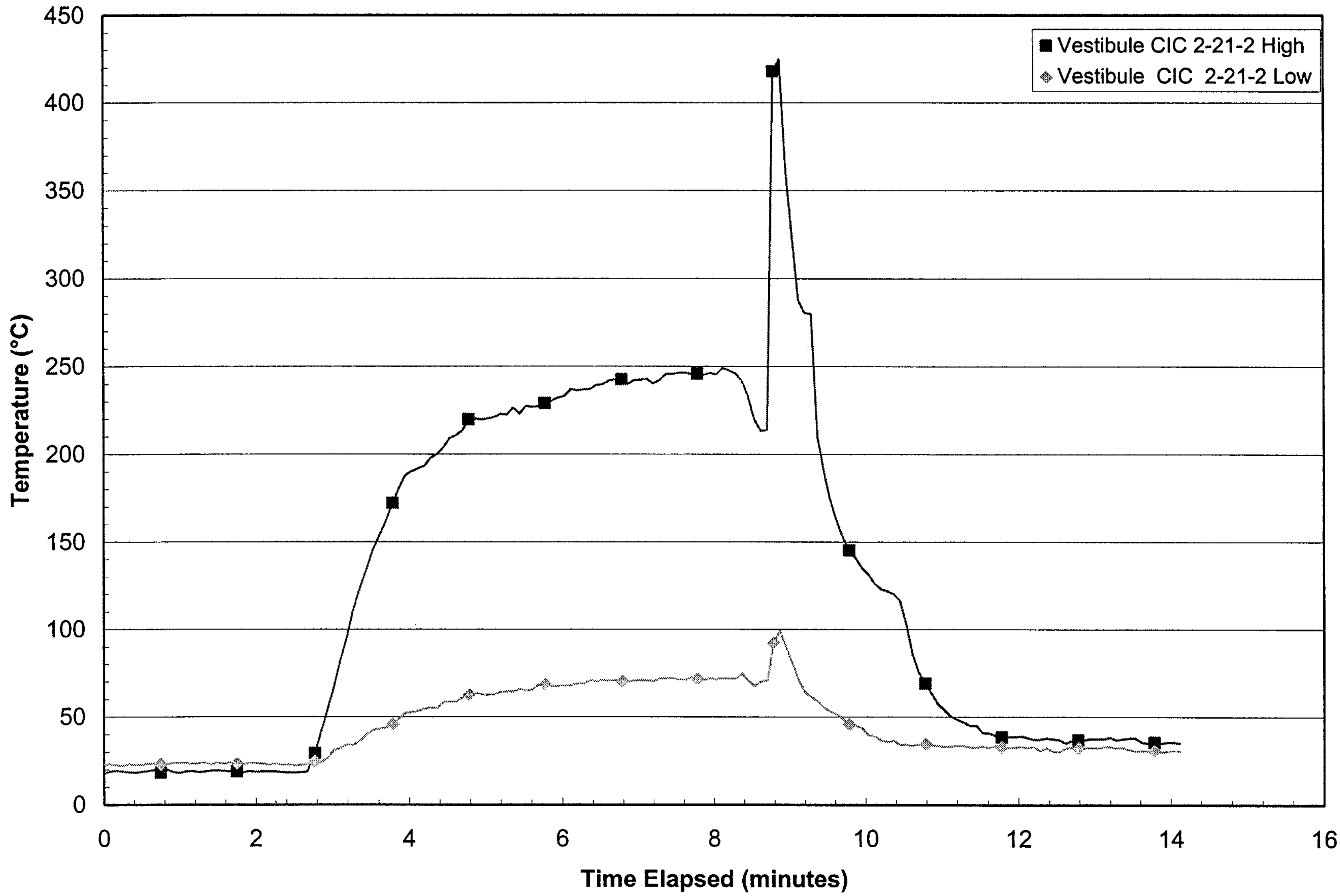


Figure C-4. Vestibule CIC TC - AVENT07 - 5 sec filter

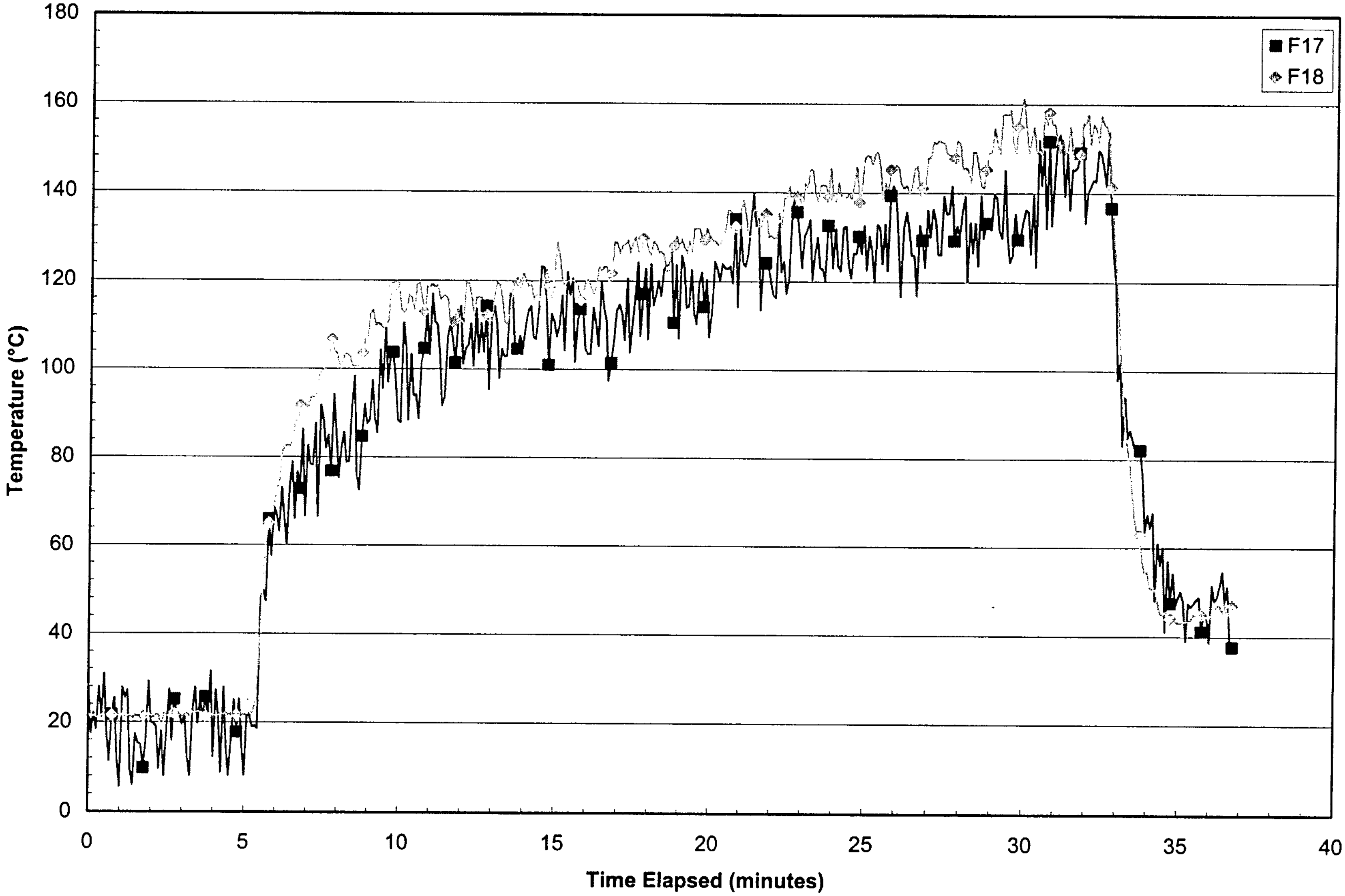


Figure C-5. Vestibule CIC Flame TC - AVENT10 - 5 sec filter

D. APPENDIX D – LIST OF TABLES

E. APPENDIX E – LIST OF FIGURES