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Airplane Tests of Enhanced Emergency Smoke Venting

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16. Abstract
This airplane test program evaluated the capability of certain air conditioning (environmental control) system modifications to enhance the venting of neutral or buoyant smoke that may be continuously injected into the passenger cabin during an inflight fire emergency. The program used a Boeing 757 airplane modified by adding an outflow valve in the forward upper lobe fuselage and changing to high-flow control valves in both air conditioning packs. Artificially generated smoke, neutral and with helium added to simulate buoyancy, was released at various passenger cabin locations. Data from the ground tests showed that an upper lobe outflow valve controls either neutral or buoyant smoke. Cruise/descend/land test results showed that neutral smoke can be controlled with either an upper or lower lobe outflow valve if the outflow valve and the smoke source are at the same end of the passenger cabin; this capability is not changed significantly by a 30% increase to the current pack flow rate. The results also showed that maintaining pack flow while doors are open for passenger evacuation causes an undesirable increase in the rate of smoke spreading into the smoke free portions of the cabin. Keywords: smoke abatement, Aircraft Fires. (GC)

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NOTE: Appendices A through E are contained in a separate unpublished document, DOT/FAA/CT-89/9-A. The appendices contain the raw source material (handwritten observations by the test personnel and raw smoke data) as well as flight test documentation (insurance documents listing test participants, weight and balance sheets for the flight tests, and acceptance test documentation for the flow control valves) that served as some of the basis for this report. The document is on file at both Boeing Commercial Airplanes and FAA Technical Center Library.

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EXECUTIVE SUMMARY

This report presents the data and results of an airplane test program to evaluate the capability of an added outflow valve and a high-flow air conditioning system to enhance the venting of neutral or buoyant smoke that may be injected into the passenger cabin during an inflight fire emergency. This program was a follow-on to the smoke venting study reported in DOT/FAA/CT-88/22. The tests were conducted by Boeing Commercial Airplanes and FAA personnel in accordance with the terms and schedules of Contract No. DTFA03-88-C-00056.

The program used the Boeing-owned Model 757, Airplane NA001, modified by adding an outflow valve in the forward upper lobe fuselage and replacing existing flow control valves in both air conditioning packs with high-flow control valves. Artificially generated smoke, with and without helium added to simulate buoyancy, was released at four locations in the passenger cabin. Smoke density meters, video cameras and manual notes recorded smoke movement during ground and flight testing.

Six ground tests were conducted using buoyant smoke with various combinations of smoke release locations, outflow valve locations and pack flow rates. The results showed that although buoyant smoke was not controlled when the lower lobe outflow valve was used with either current or 30% increased pack flow, an upper lobe outflow valve was able to control buoyant smoke.

Ten cruise/descend/land tests were conducted using neutral smoke with various combinations of smoke release locations, outflow valve locations, pack flow rates and door opening to simulate passenger evacuation. The results showed that neutral smoke can be controlled with either an upper or lower lobe outflow valve if the outflow valve and the smoke source are at the same end of the passenger cabin; this capability is not changed significantly by a 30% increase to the current pack flow rate. When the outflow valve and the smoke source are at opposite ends of the passenger cabin, none of the cabin will be free of smoke.

The test results also showed that maintaining pack flow while doors at the cabin end opposite the smoke generator are open for passenger evacuation causes an undesirable increase in the rate of smoke spreading into the smoke free portions of the cabin.

After testing, the airplane was refurbished to essentially the pre-test configuration except for the structural repairs and external skin doubler on the fuselage where the upper lobe outflow valve had been installed.

1. INTRODUCTION

This report presents the results of a program of airplane tests of enhanced emergency smoke venting conducted by Boeing Commercial Airplanes for the FAA Technical Center under Contract No. DTFA03-88-C-00056. The Boeing 757 test airplane was modified and tested to evaluate the venting of neutral or buoyant smoke that may be continuously injected into the passenger cabin during an inflight fire emergency. The test purpose was to provide smoke venting test data for evaluation by comparing the effects of:

- Forward versus aft outflow valves
- Upper versus lower lobe outflow valves
- Current versus 30% increased air conditioning flow rates
- Neutral versus buoyant smoke
- Air conditioning packs ON versus OFF during passenger evacuation.

The airplane modifications and smoke venting tests have their origin in a study documented in FAA Report No. DOT/FAA/CT-88/22 that considered two design changes to aircraft that might lead to enhanced emergency smoke venting capability. In that study, one approach involved increasing the cabin ventilation air supply rate (Concept A) and the other approach involved addition of a fan that could bring outside ram air directly into the cabin air distribution system and continue running on battery power after the aircraft engines were shut down (Concept B). Both concepts also included the installation of an additional outflow valve on the underside of the fuselage at the opposite end of the airplane from the current outflow valve. These changes were analyzed and costed on a fleet-wide basis.

Early in the study the expectations were that Concept A would both prove itself superior to Concept B and would also offer clearly upgraded smoke evacuation capability. However, the analysis in the end indicated that neither concept offered much improvement. The study contract had an option clause for fabrication of parts for the most promising concept for later installation in a test airplane. The findings of the study had a direct bearing on how the option clause was to be employed by the FAA. Rather than focusing on flight testing to demonstrate a concept, the FAA realigned its plans toward a more research oriented flight test program that might uncover improved methods of smoke evacuation. The approach taken was to test both concepts against current procedures. Additionally, use of helium to provide buoyancy for the smoke was made part of the plan, and this decision made it logical that the added outflow valve be mounted in the upper lobe of the fuselage (rather than in the normal lower lobe position). The Concept A approach was taken because it would allow Concept B to be simulated in a test program by leaving the airplane engines on after the aircraft stopped and doors were open. The work performed under the optional phase consisted primarily of structural design and parts manufacturing for the upper lobe outflow valve and modifying of the two air pack flow control valves by the original equipment manufacturer.

The parts manufactured or modified under the option were installed on the Boeing-owned 757 and tested under the contract that is the subject of this report. A number of unusual, untried, or differently applied elements were brought together for the actual airplane tests. The upper lobe outflow valve and the enhanced airflow capability are obvious examples. Instead of testing smoke removal in level flight, the decision was made to simulate entire inflight fire scenarios from cruise through descent, landing, and a two-minute passenger evacuation period. The aircraft was outfitted with ten smoke meters which had been developed by the FAA for earlier work with the USAF. How well they would perform in this type of testing was unknown. For these tests, the FAA developed a helium smoke mixing chamber that would provide a 200 cubic foot per minute source of smoke with buoyancy equivalent to air at approximately 475 F.

Boeing Commercial Airplanes was supported by the FAA in conducting this program. The FAA provided and operated the smoke generator, the helium mixing chamber and the smoke meters and recording system. Also, FAA personnel approved certain deletions/additions to the contracted test conditions and recorded manual notes while witnessing all of the tests.

2. TEST CONFIGURATION

2.1 AIRPLANE

2.1.1 GENERAL

The test vehicle was a Model 757-200, Airplane NA001. As shown by the following descriptions, the airplane interior and air distribution systems were not entirely standard, but the features important to smoke venting were representative of a production 757 configuration.

The intent of a service bulletin to close the lightening holes in the sidewall air outlet grills of production airplanes was satisfied by using speed tape. From Station 460 to 560 on the right side, the sidewall outlet grill was removed entirely, and the sidewall air distribution diffusers at Stations 470, 490 and 510 on the right side were relocated upwards to accommodate the forward outflow valve installation (see Figure 2.1.1-1).

The large opening in the flight deck aft bulkhead was sealed with a sheet of opaque plastic held in place with duct tape. Also, the flight deck door was installed, closed and sealed around its edges with duct tape to prevent smoke from reaching the flight crew during the test conditions.

A non-production left recirculation fan was installed. This fan produced slightly higher than production flow and was stall sensitive. Recirculation fans were on only for checkout tests in which the effect of the higher flow was considered negligible. The return air grills were in the production configuration.

The interior was laid out as follows (dimensions and Station locations are approximate). Immediately aft of Door 1 there was one coach class triple seat assembly on the left side at Station 380. At Station 650, there was one complete coach class seat row, one "triple" on each side; immediately behind this seat row was a class divider at Station 680.

A table was located on the right side just forward of the video recorder pallet with its forward edge at Station 870 (see Figure 2.1.1-2).

An instrumentation rack with two accompanying seats containing the FAA's ACRO smoke density data acquisition system, their laptop computer and a round dial pressure gauge, was located on the left side with its forward edge at Station 1080 (see Figures 2.1.1-3 and 2.1.1-4). Behind this rack about four feet, there was one business/first class double seat assembly, also on the left side.

An 80-inch long fin cone reel pallet with the reel attached was mounted on the right side with its forward edge at Station 1340. The reel was approximately 78 inches in diameter and was mounted with its axis perpendicular to the aircraft's longitudinal axis and roughly parallel to the floor (i.e. on its edge). On the left side opposite the fin cone reel was an instrumentation rack with no accompanying seats with its forward edge at Station 1386 (see Figure 2.1.1-5).

Two instrumentation racks were located with their forward edges at Station 1448, one on each side of the aircraft. The one on the left (see Figure 2.1.1-6) had two accompanying seats while the one on the right (see Figure 2.1.1-7) had no seats but a worktable where the outboard seat would have been. Two more instrumentation racks, each with two accompanying seats, were located with their forward edges at Station 1548, one on each side of the aircraft (left side, see Figure 2.1.1-8; right side, see Figure 2.1.1-9). A high speed pulse code modulation tape drive was located on the left side just aft of Door 4 and just forward of the aft pressure bulkhead (see Figure 2.1.1-10).

No stowage bins were installed between Doors 2 and 3. Additionally, two bins were removed on the right side in the vicinity of the forward outflow valve (see Figure 2.1.1-11).

Although the interior and air distribution system was not entirely production, the resulting airflow behavior, especially its effect on cabin smoke movement, was considered representative of a production 757.

2.1.2 MODIFICATIONS

Airplane modifications for this test of enhanced smoke venting (see Figure 2.1.2-1) included special pack flow control valves to allow increased pack flow (215% as well as the usual 100% and 165%). The 100% flow rate equals the current airplane flow rate during normal flight with recirculation ON. The 165% rate equals the current airplane flow during passenger cabin emergency smoke evacuation with recirculation OFF. The 215% rate equals the Concept A or B rates for enhanced smoke evacuation and is a 30% increase above the 165% rate currently used for smoke venting. The data sheets from the vendor's and Boeing's acceptance tests for both valves are provided in Appendix E. The special pack control system includes the pack protection features incorporated in current airplane except that the 147% flow rate to limit the compressor outlet temperature to about 425 F was not available: the low limit control valve limited the temperature to 450 F. As shown during the earlier study contract, the 757 system was capable of being modified to increase the air conditioning pack flow rate. Both of the pack flow control valves in the test airplane were replaced with modified valves. Each flow control valve had the pneumatic control circuits changed by installing a larger sonic nozzle and replacing three adjustable orifices before recalibrating the valve. The test operations were limited to 20,000 feet or below to preclude potential altitude effects on the over-temperature protection during the increased flow rates.

Other modifications for this test included a 737 type outflow valve in the forward cabin at Station 490, right butt line 55.1 and water line 281.9 (see Figure 2.1.2-2), a 737 cabin pressure controller for the forward outflow valve (Station 450, right side, see Figure 2.1.2-3), and an additional control panel in the flight deck for the packs and the forward outflow valve. These modifications added 113 pounds to the airplane weight. The airplane structure required major modification to install the outflow valve. An approximately 60.0 x 60.0 inches external skin doubler was added to reinforce four frames (at stations 460, 480, 500 and 520) and six stringers (numbers 5 thru 10) surrounding the added valve. Numerous other interior reinforcements were added to the frames and stringers in addition to a machined support ring that matched the contours of the airplane skin and the outflow valve mounting flange. The opening through the ring and the airplane skin was about 10.5 x 14.7 inches to accommodate the valve which had a wide open flow area of about 84 sq. in.

The airplane modifications, as installed for these tests, would not be suitable for production airplanes because:

- The upper lobe outflow valve would have unacceptable characteristics for rain/ice/snow exposure.

- The installation of the upper lobe outflow valve was not consistent with production design for fatigue/strength.

- Control of the upper lobe outflow valve was not integrated with the existing cabin pressure control system. Integration would require significant design changes.

- The location of the upper lobe outflow valve was not consistent with the requirements for cabin interiors such as stowage bins and service units.

- The upper lobe outflow valve was a potential hazard to nearby passengers because anything that might inadvertently block the outflow path could be expelled from the airplane by the cabin pressure differential deforming the blocking object and/or by the outflow valve driving open in response to the blockage.

- The flow control valve changes were not acceptable to production because certain protective systems were replaced by the system to provide higher flows.

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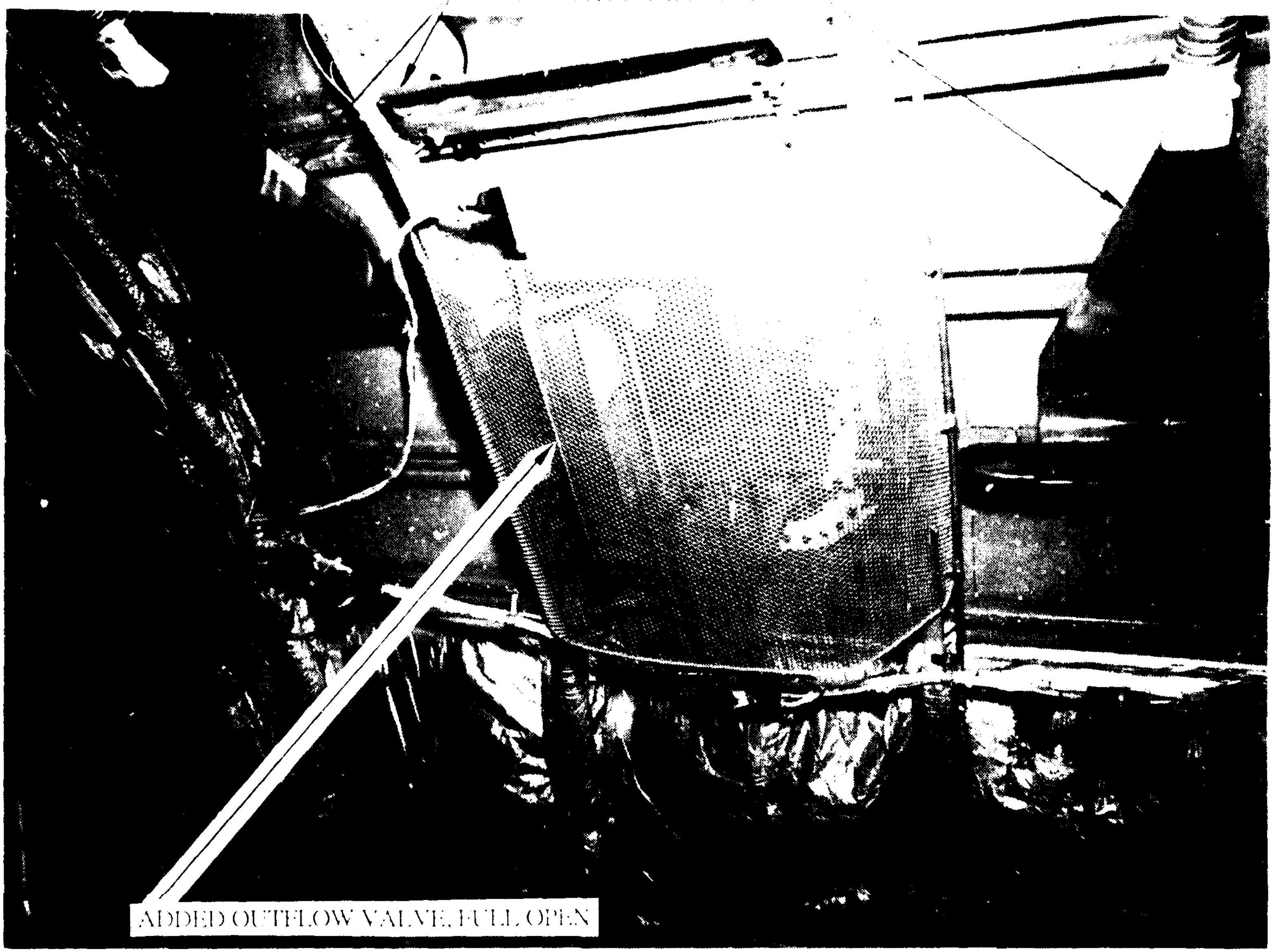

FIGURE 2.1.1-1 FORWARD CABIN MODIFICATIONS

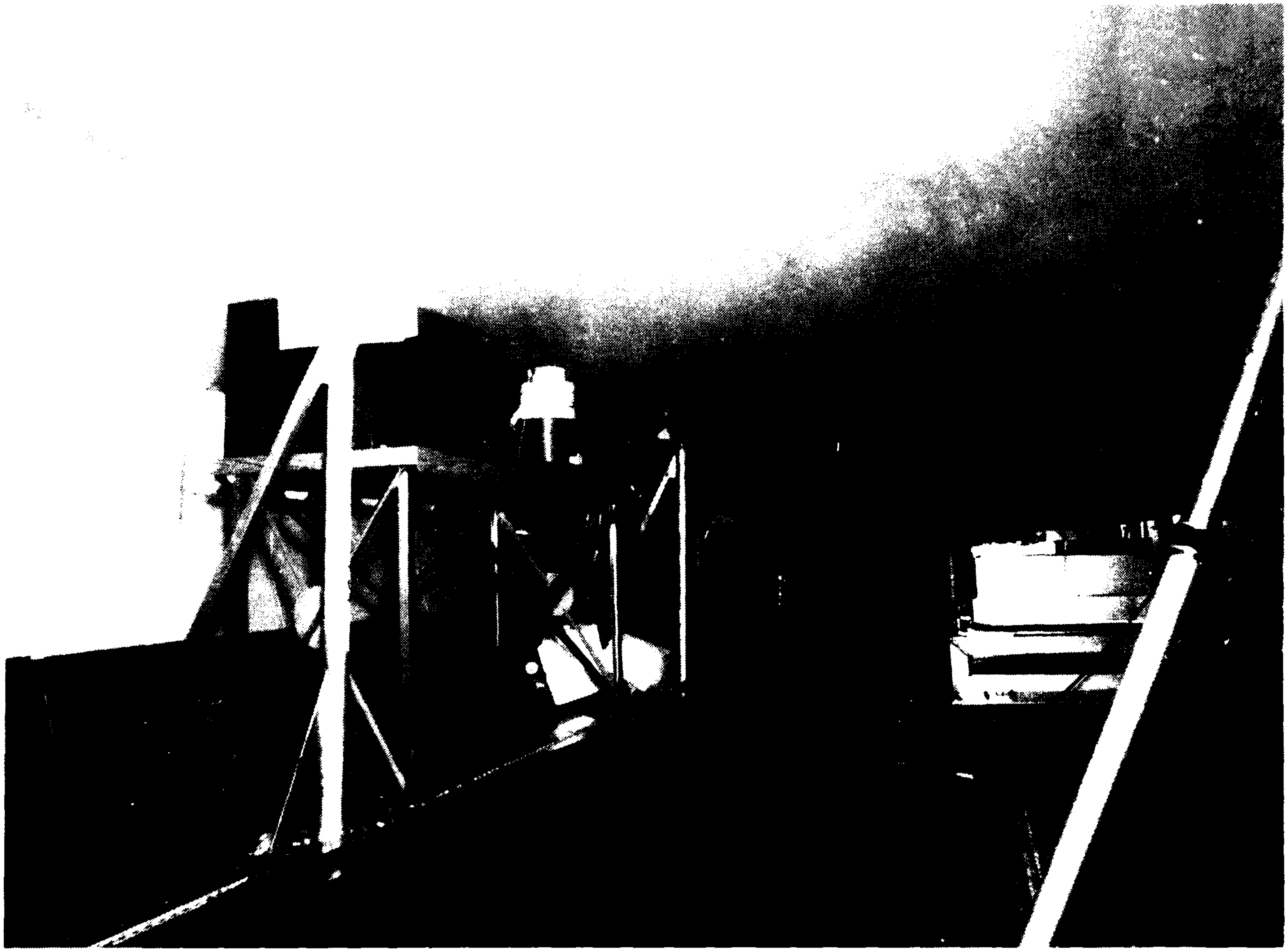

FIGURE 2.1.1-2 TABLE AT STATION 870

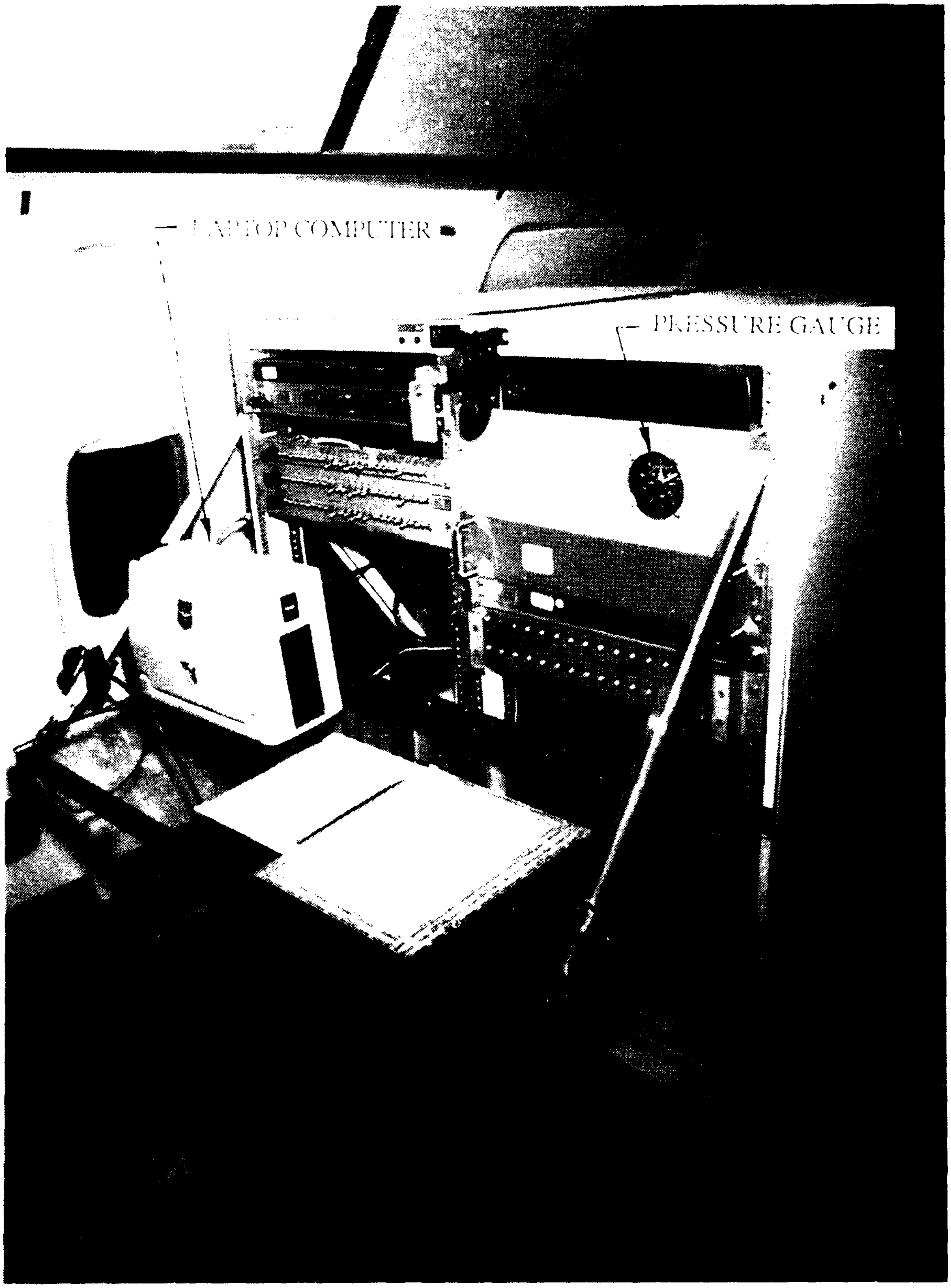

FIGURE 2.1.3 INSTRUMENT RACK, STATION 1080, AFT FACE

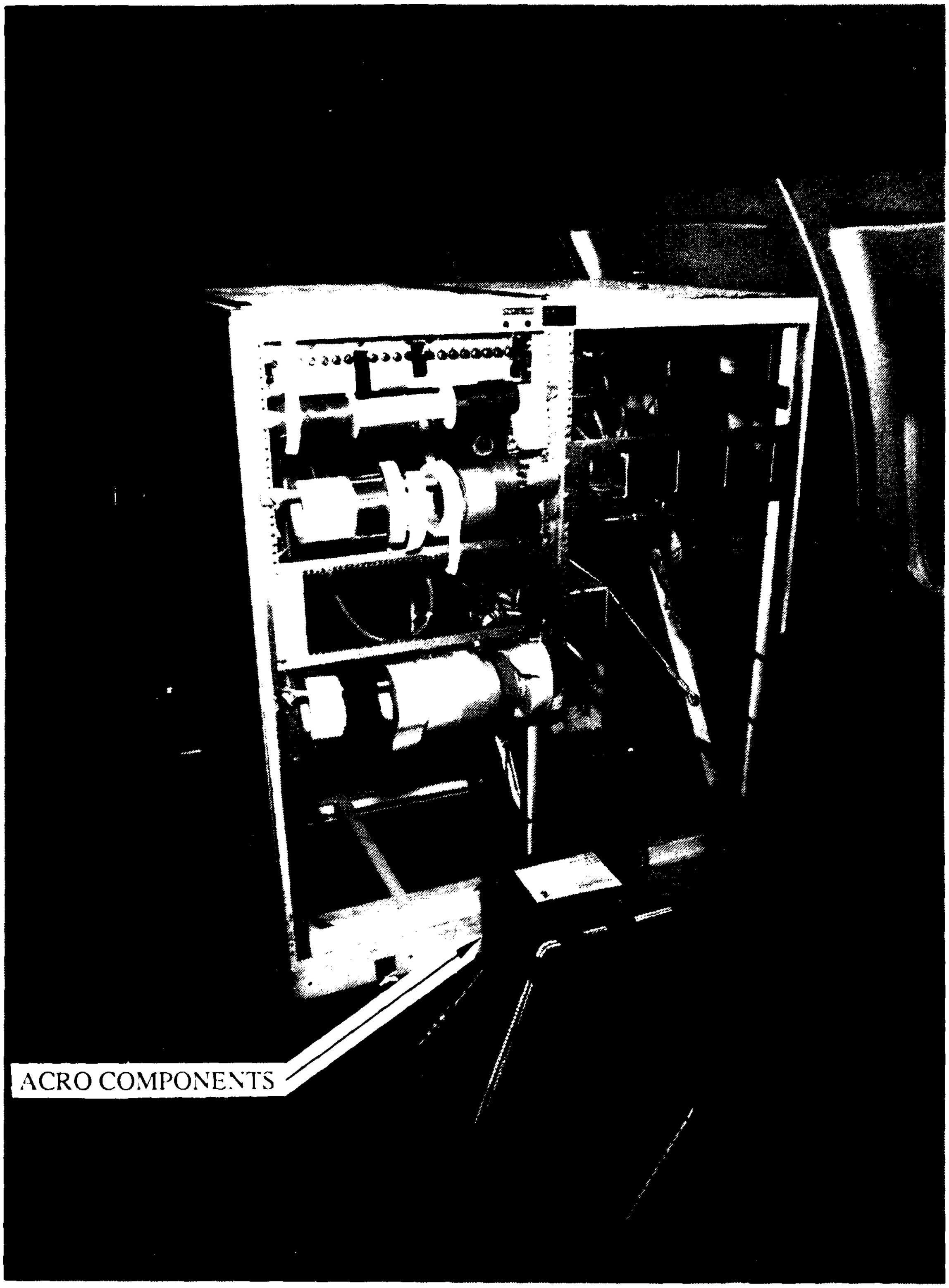

FIGURE 2.1.1-4 INSTRUMENT RACK, STATION 1080, FWD FACE

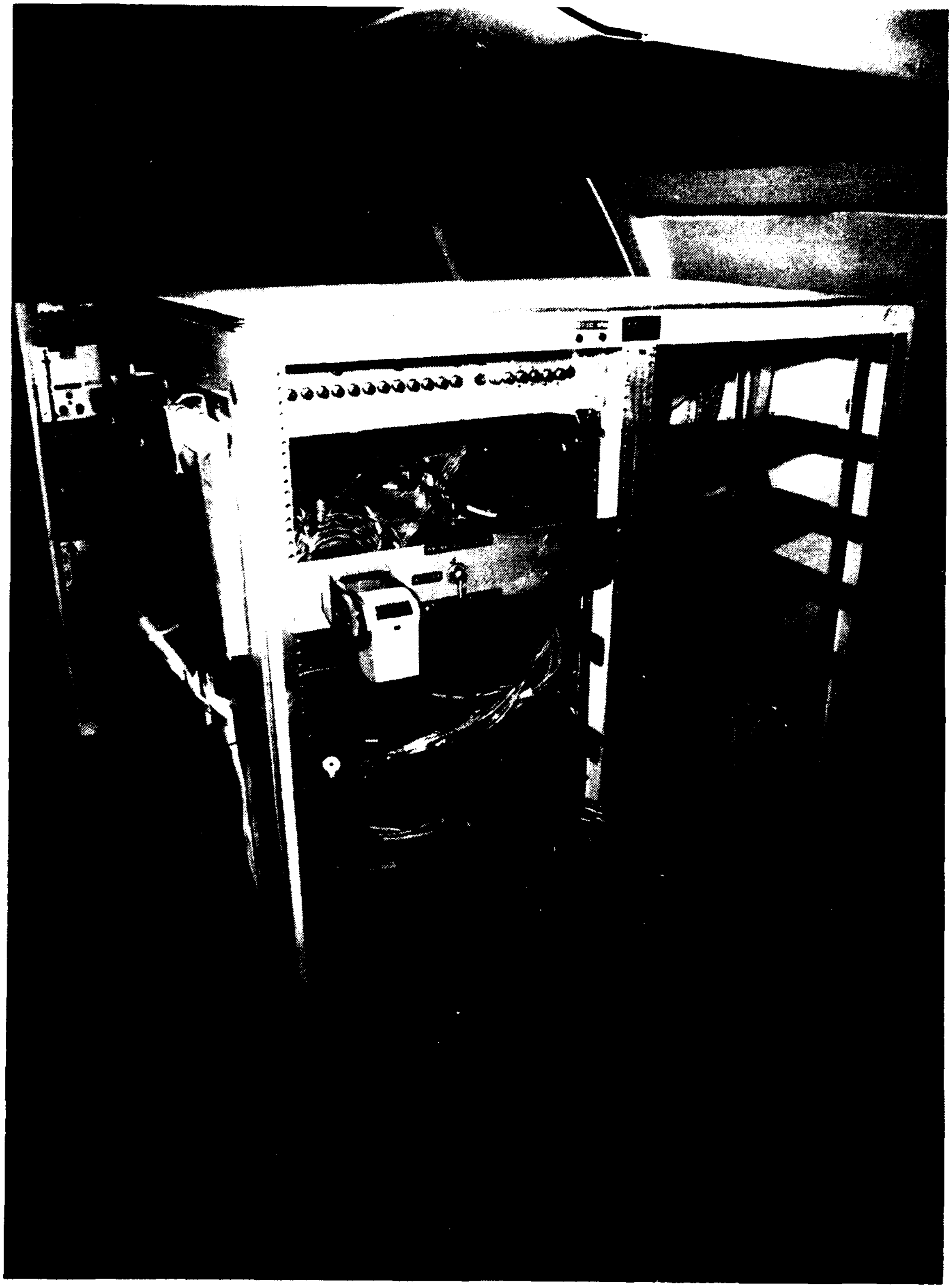

FIGURE 2.1.1-5 INSTRUMENT RACK, STATION 1386, LEFT SIDE

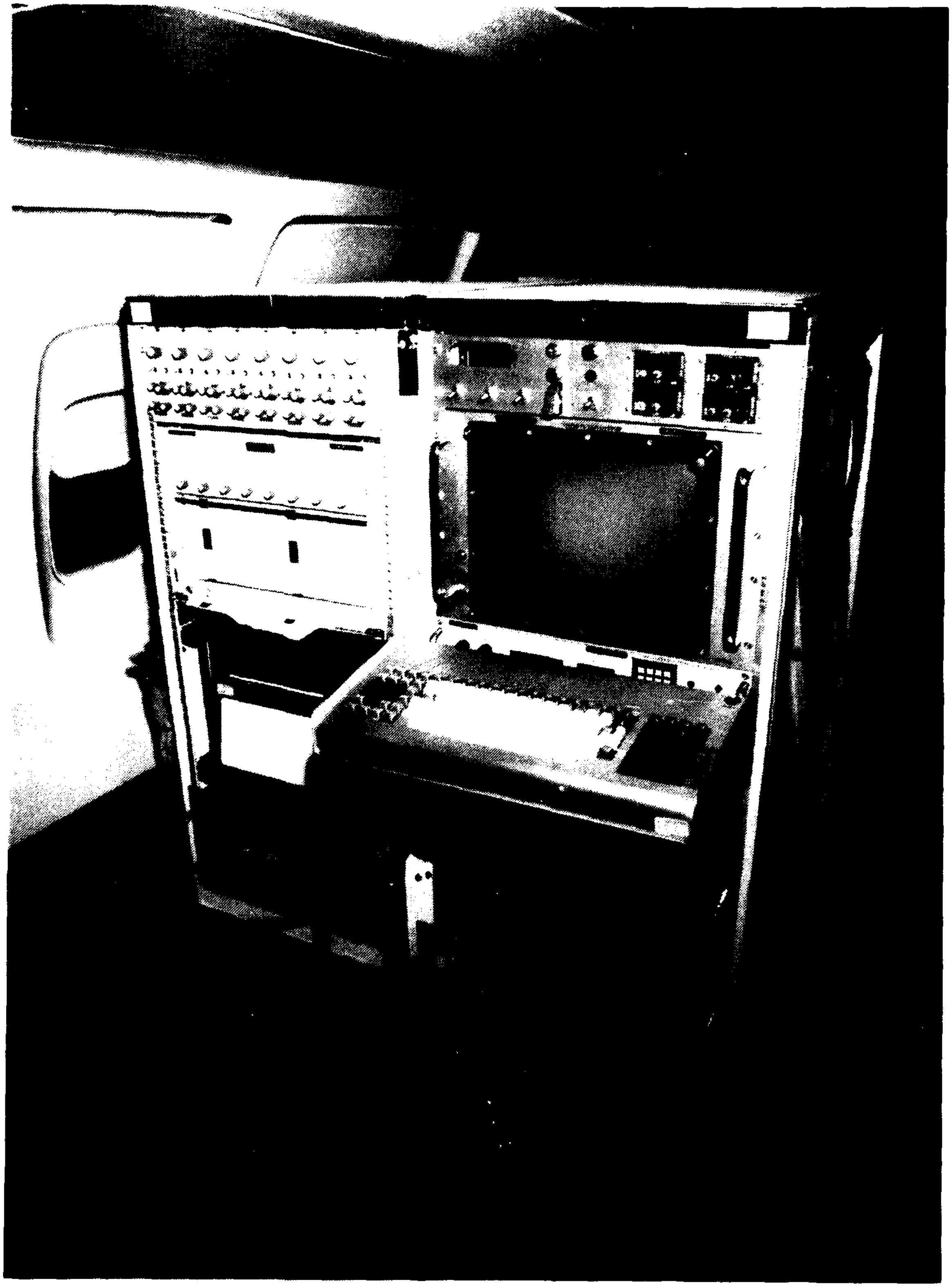

FIGURE 2.1.1-6 INSTRUMENT RACK, STATION 1448, LEFT SIDE

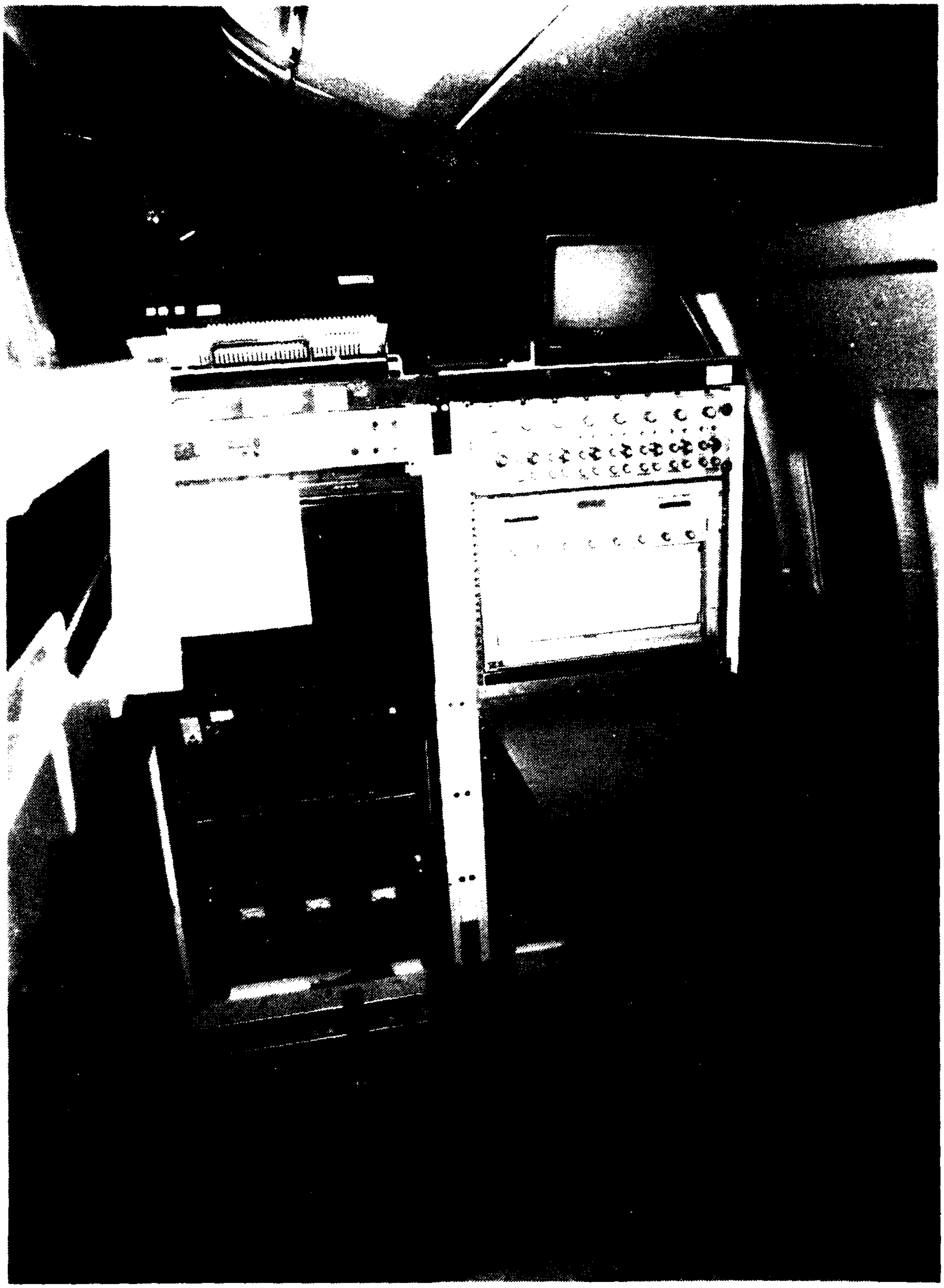

FIGURE 2.1.1-7 INSTRUMENT RACK, STATION 1448, RIGHT SIDE

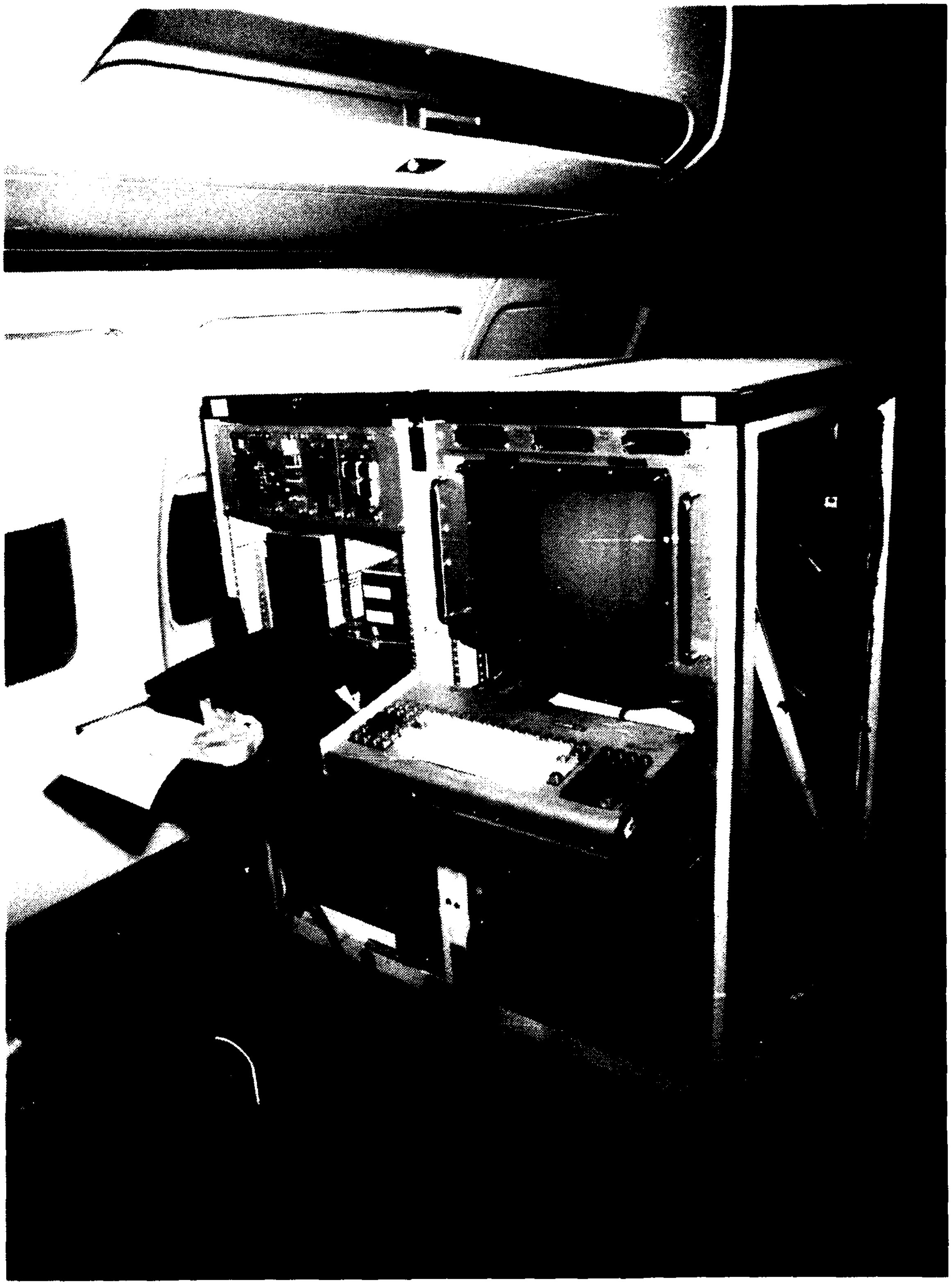

FIGURE 2.1.1-8 INSTRUMENT RACK, STATION 1548, LEFT SIDE

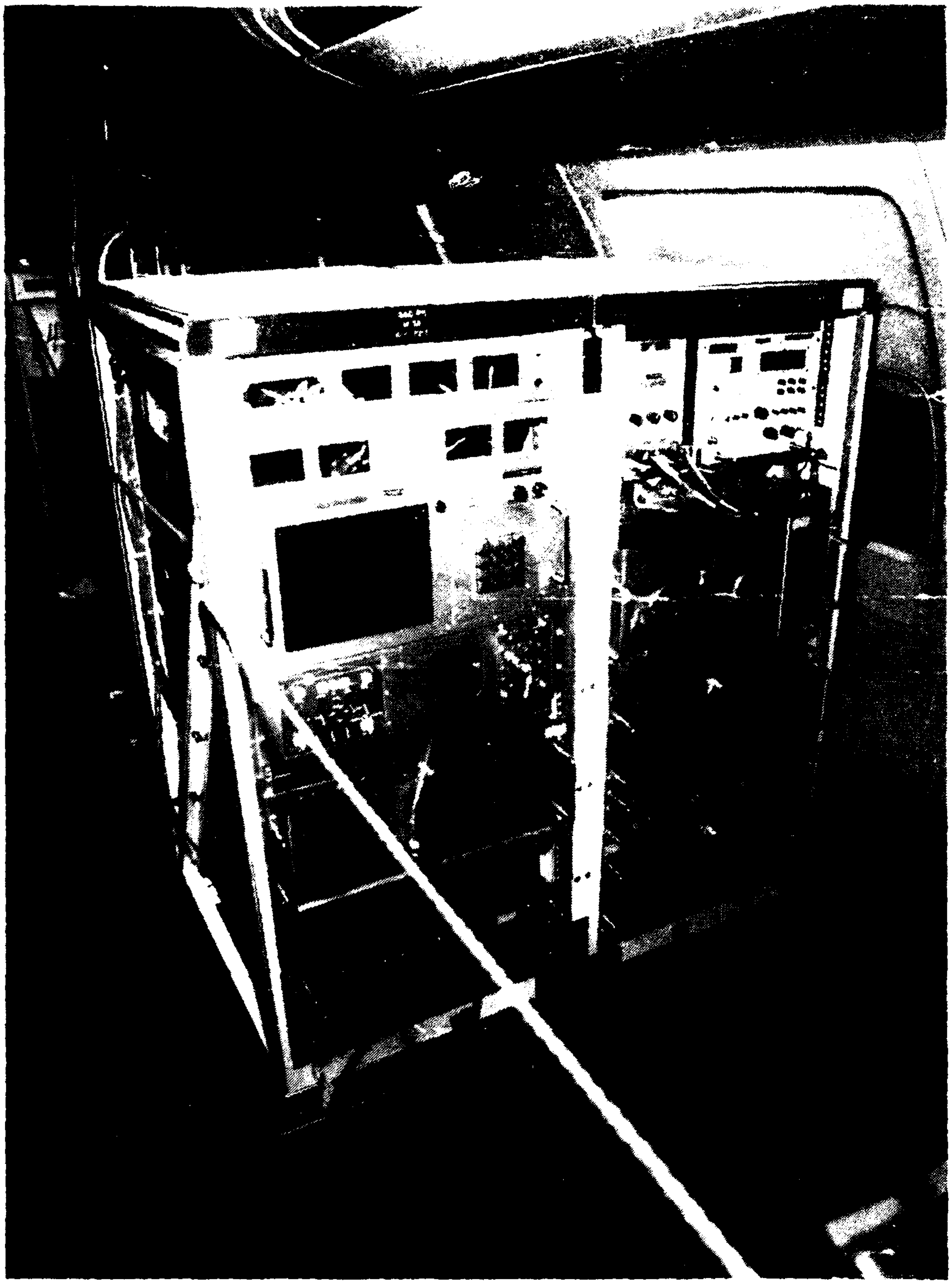

FIGURE 2.1.1.9 INSTRUMENT RACK, STATION [illegible] RIGHT SIDE

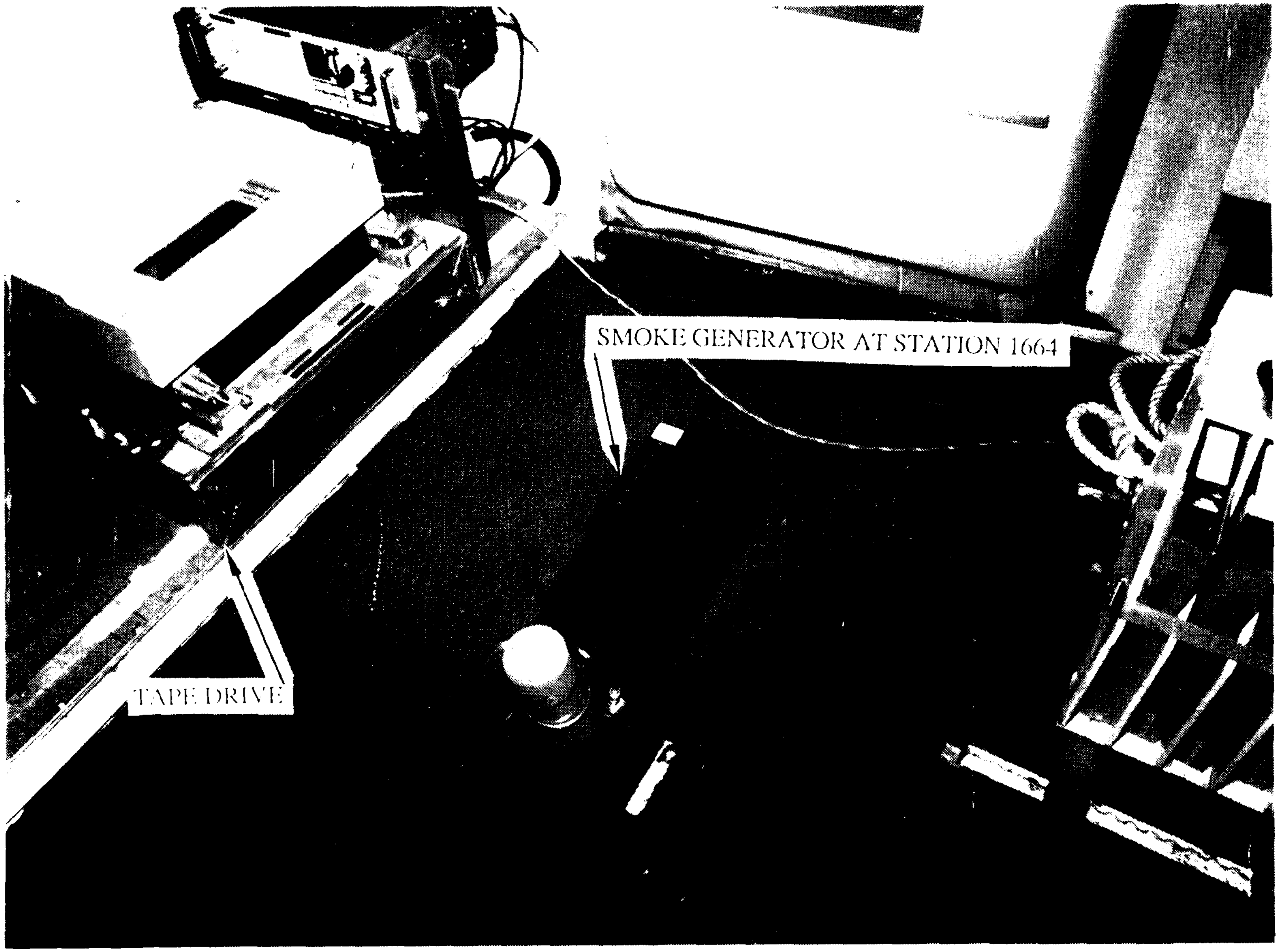

FIGURE 2.1.1-10 TAPE DRIVE

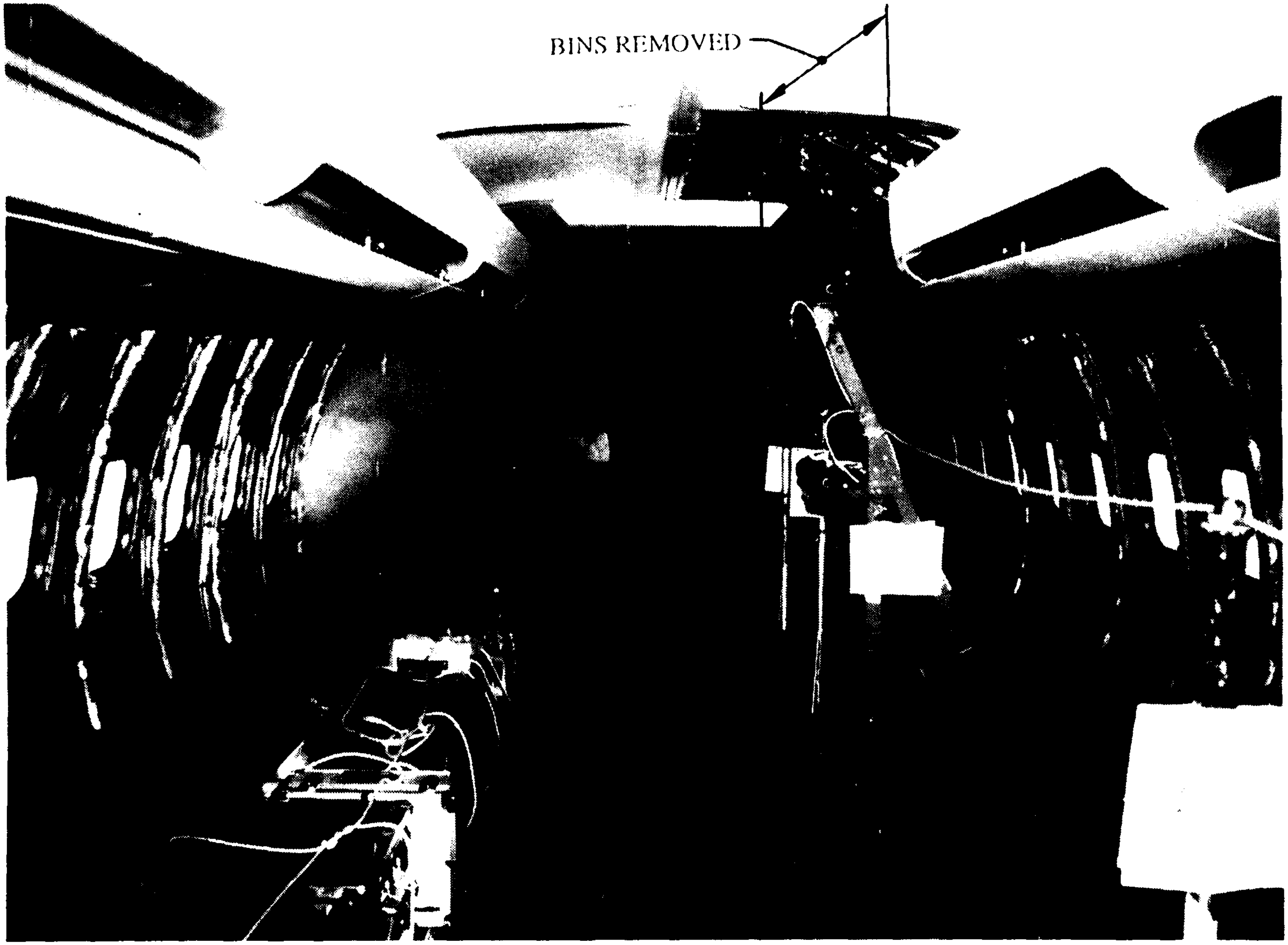

FIGURE 2.1.1-11 FORWARD BINS REMOVED

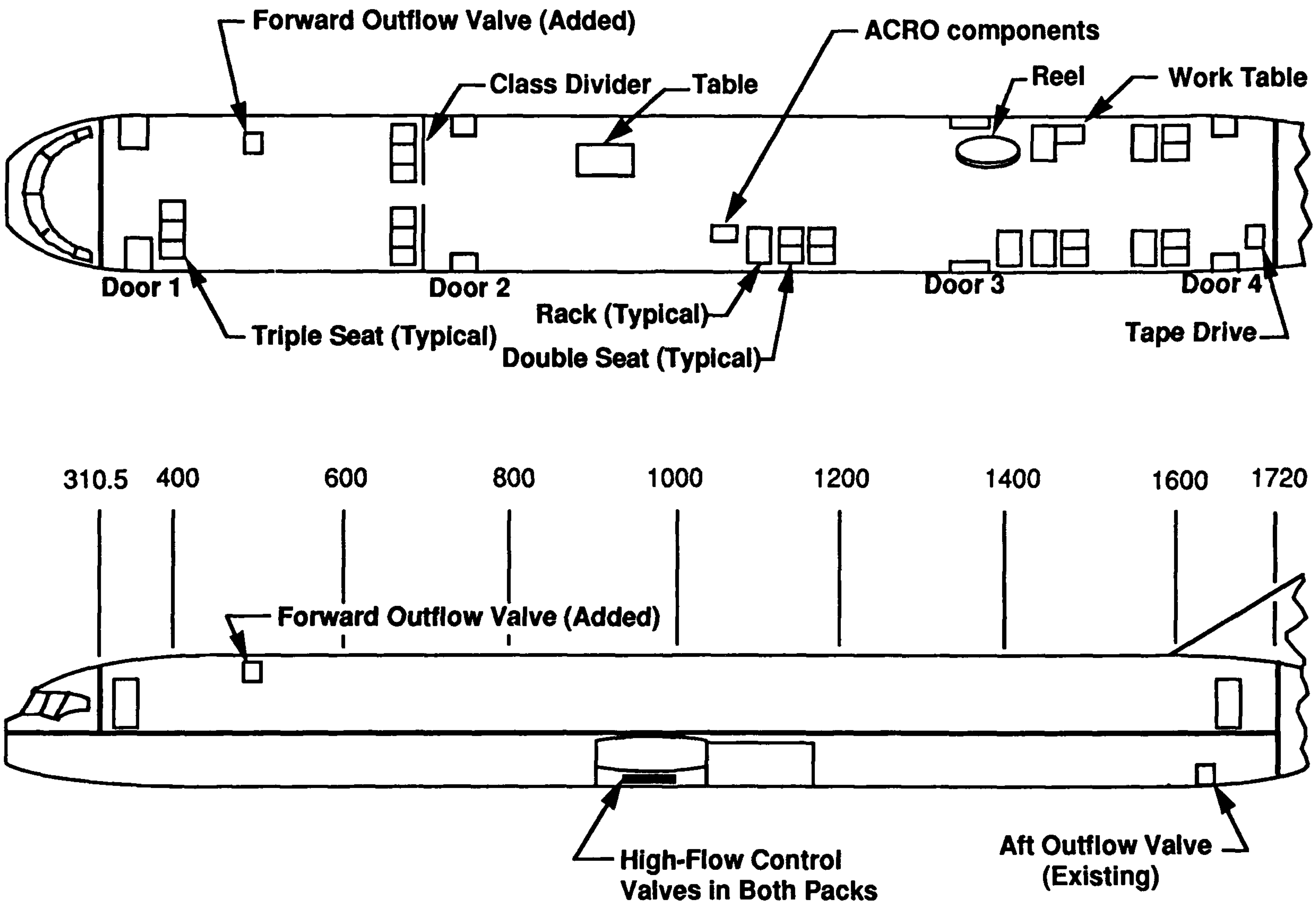

FIGURE 2.1.2-1 AIRPLANE MODIFICATIONS

FIGURE 2.1.2-2. ADDED FORWARD OUTFLOW VALVE

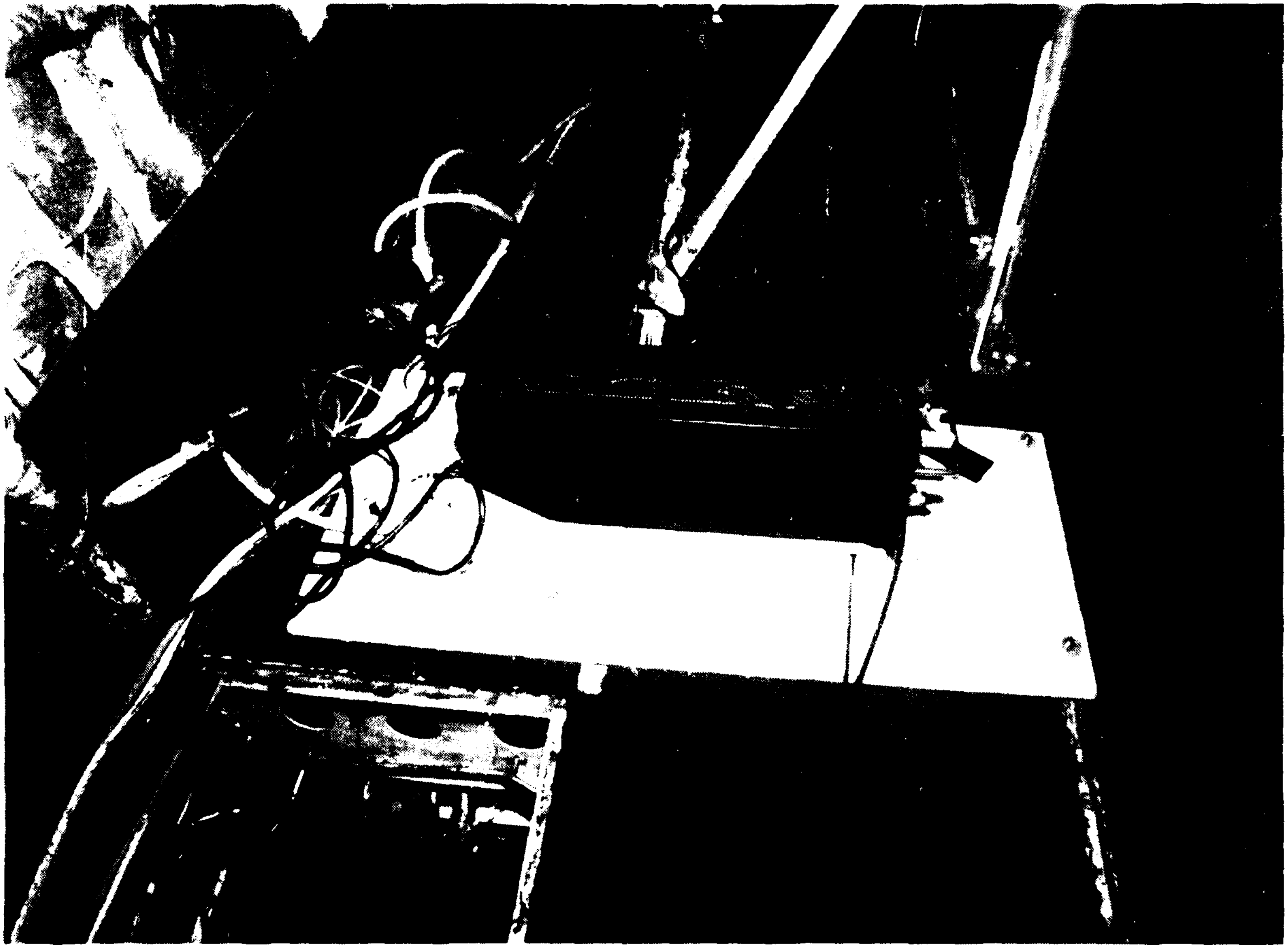

FIGURE 2.1.2-3. CABIN PRESSURE CONTROLLER (ON CABIN FLOOR)

2.2 TEST EQUIPMENT

2.2.1 SMOKE GENERATION

A Roscoe smoke machine (Model Pro 1500) was used as the smoke source in all tests. The machine was used on a stand-alone basis in all flight tests and also in the equipment checkout tests on the ground. The machine has a variable generation rate capability, and the relatively low setting of 2 on the unit was employed in all tests. The motivation for the low setting was to provide adequate cabin visibility so that the overall movement of smoke could be documented both by the video cameras and by observations by test personnel.

The balance of the tests consisted of six conditions on the ground wherein helium was employed to give the smoke buoyancy so that it would behave more like hot fire smoke. This was accomplished by passing the smoke through and FAA-provided mixing device (see Figure 2.2.1-1). This device was set to generate a mixture of 50 percent helium and 50 percent air on a volumetric basis to give an overall density equivalent to 475 F air alone. The FAA established this mixture ratio in an attempt for consistency with enclosure fire te[illegible] recently conducted for the FAA outside of this contract. The overall helium/air volumetric flow was set at approximately 200 cubic feet per minute. This rate was selected for consistency with the generation rates used in the fire scenarios developed in the previous study phase (FAA Report No. DOT/FAA/CT-88/22). In these helium assisted tests, the helium source was external to the aircraft and the air source was cabin air forced into the mixing device by electric powered fans. It should be noted that the smoke generation points in all conditions except .106 and .206 were selected to be consistent with the previous study phase.

2.2.2 HELIUM SOURCE

The external helium source consisted of 20 bottles of helium manifolded together, each with its own shutoff valve, and then one master valve to control total flow. A flexible line was run from the master valve into the aircraft through the external E/E bay access hatch (see Figure 2.2.2-1), then up into the cabin to the helium mixing chamber. Total line length was approximately 275 feet.

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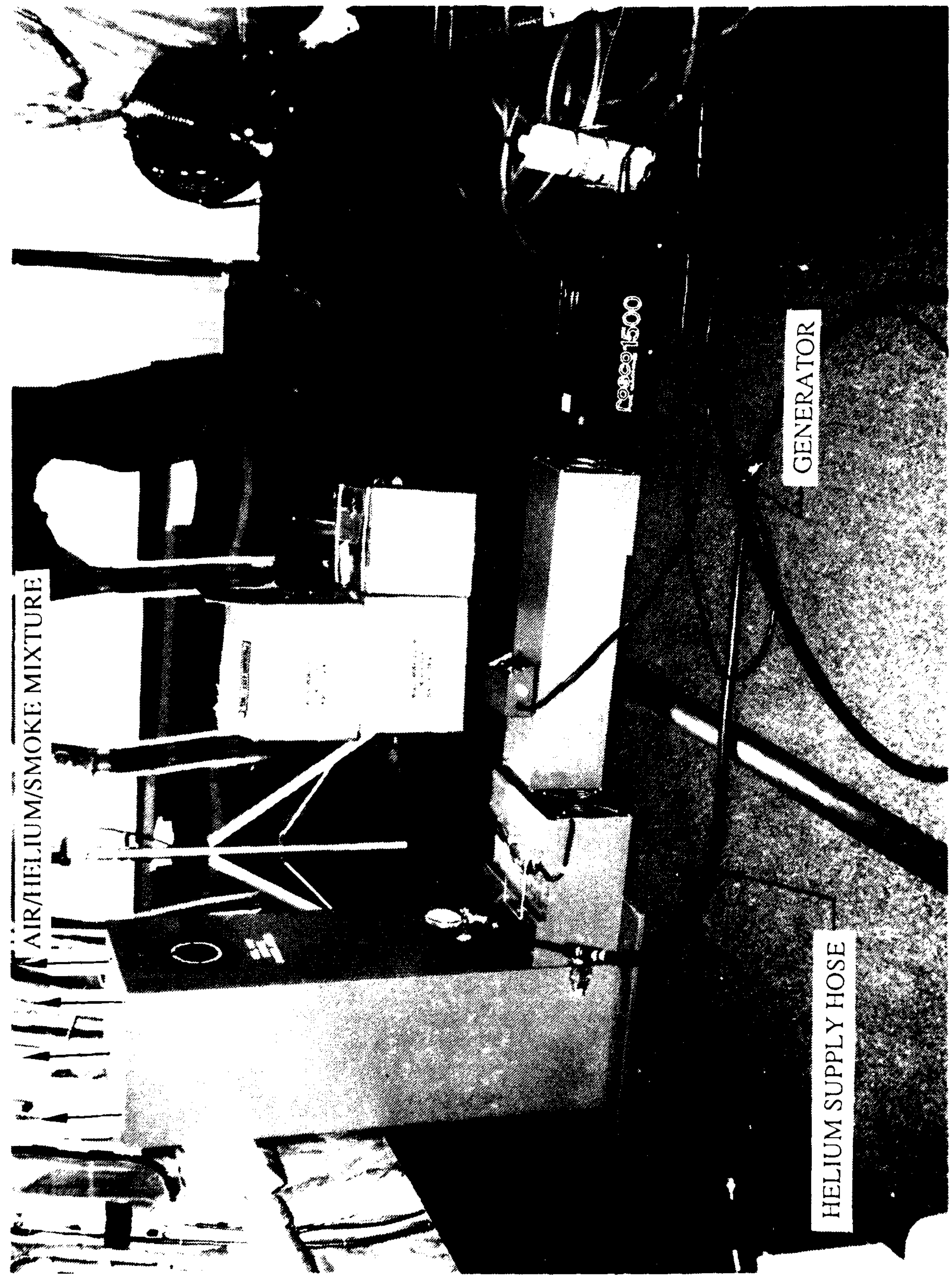

FIGURE 2.2.1-1 HELIUM/SMOKE MIXING CHAMBER

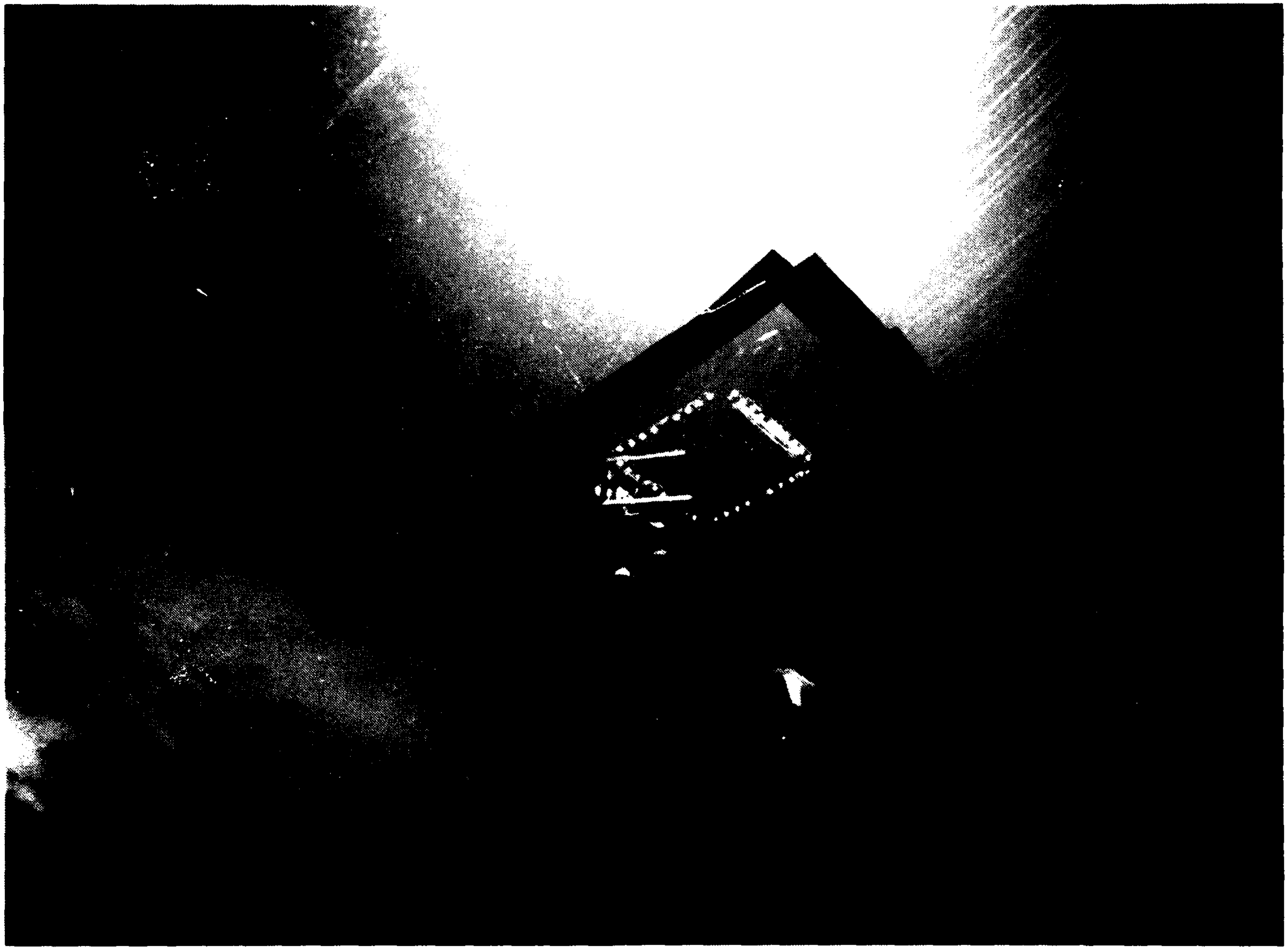

FIGURE 2.2.2-1 HELIUM HOSE AT ACCESS HATCH

2.3 INSTRUMENTATION

2.3.1 VIDEO CAMERAS AND RECORDERS

Three video cameras, each with real time-of-day recording, were used to document smoke movement. One camera was mounted on the counter on the flight deck aft bulkhead and provided a fixed view looking aft (see Figure 2.3.1-1). Another camera was mounted in the aft end of the cabin near the ceiling and provided a fixed view looking forward (see Figure 2.3.1-2). The third camera was mobile but tripod mounted (see Figure 2.3.1-3). Each camera had its own recorder and monitor. A 75-inch long pallet containing the three video recorders and three small TV monitors was mounted lengthwise on the left side with its forward edge at Station 920 (see Figure 2.3.1-4).

2.3.2 SMOKE MEASUREMENT

The FAA provided and operated a smoke density data acquisition system for these tests. Five sets of smoke meters were evenly spaced along the length of the cabin. Each set had one meter mounted with its centerline approximately 43 inches above floor level (just above typical seat back height) and the other mounted with its centerline approximately 66 inches above floor level (standing head height). They were all mounted approximately 18 inches to the right of the aircraft centerline. There was a set at each of Stations 560, 800, 1030, 1270, and 1530 (see Figures 2.3.2-1 and 2.3.2-2). The smoke meter details are shown on Figure 2.3.2-3. The smoke meters included a photocell attached to one end of a cylindrical light trap and a light source at the opposite end of the meter provided by a "Mini-Mag" flashlight modified to operate *on a DC power supply. The light path was set at 10 centimeters.*

The signals from the photocells were sent to an Acrosystems data acquisition and control system (Model ACRO 900). This unit had power supply modules that allowed it to operate on 12 or 28 volts DC or on 115 volts AC, 60 to 400 Hertz. The data from the ACRO 900 system was recorded on a ZENITH 181 lap-top computer which stores test data on a 3.5 inch disc.

2.3.3 MIX MANIFOLD PRESSURE

The cabin air distribution mix manifold was instrumented to provide a rough indication of ventilation flow rates by measuring the differential between mix manifold pressure and cabin pressure. A static port was installed in the mix bay and a pressure line was run from this port up to a round dial differential pressure gauge mounted at the instrumentation rack containing the FAA's ACRO system and laptop computer (see Figure 2.1.1-3).

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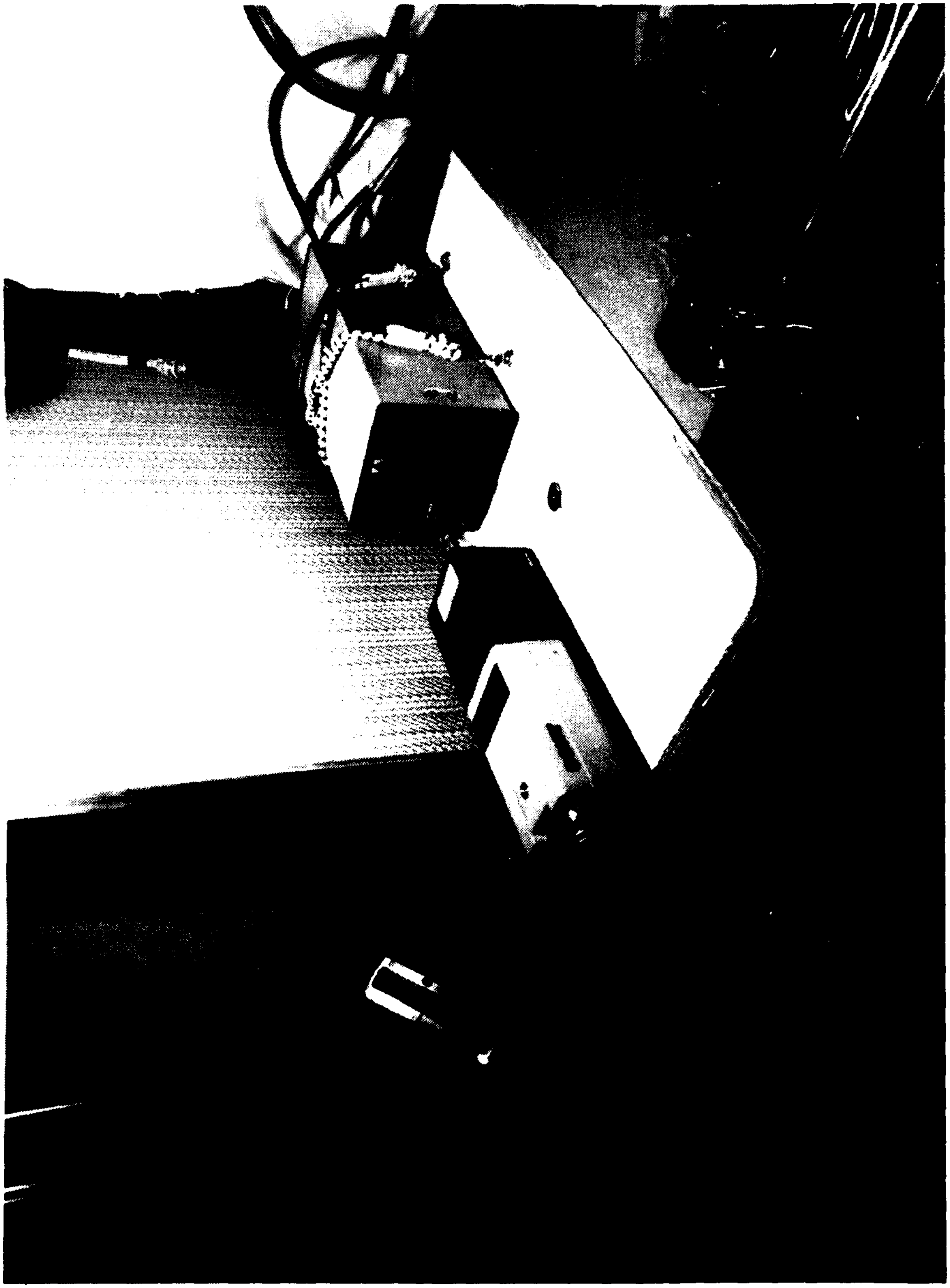


FIGURE 2.3.1-1 FORWARD VIDEO CAMERA

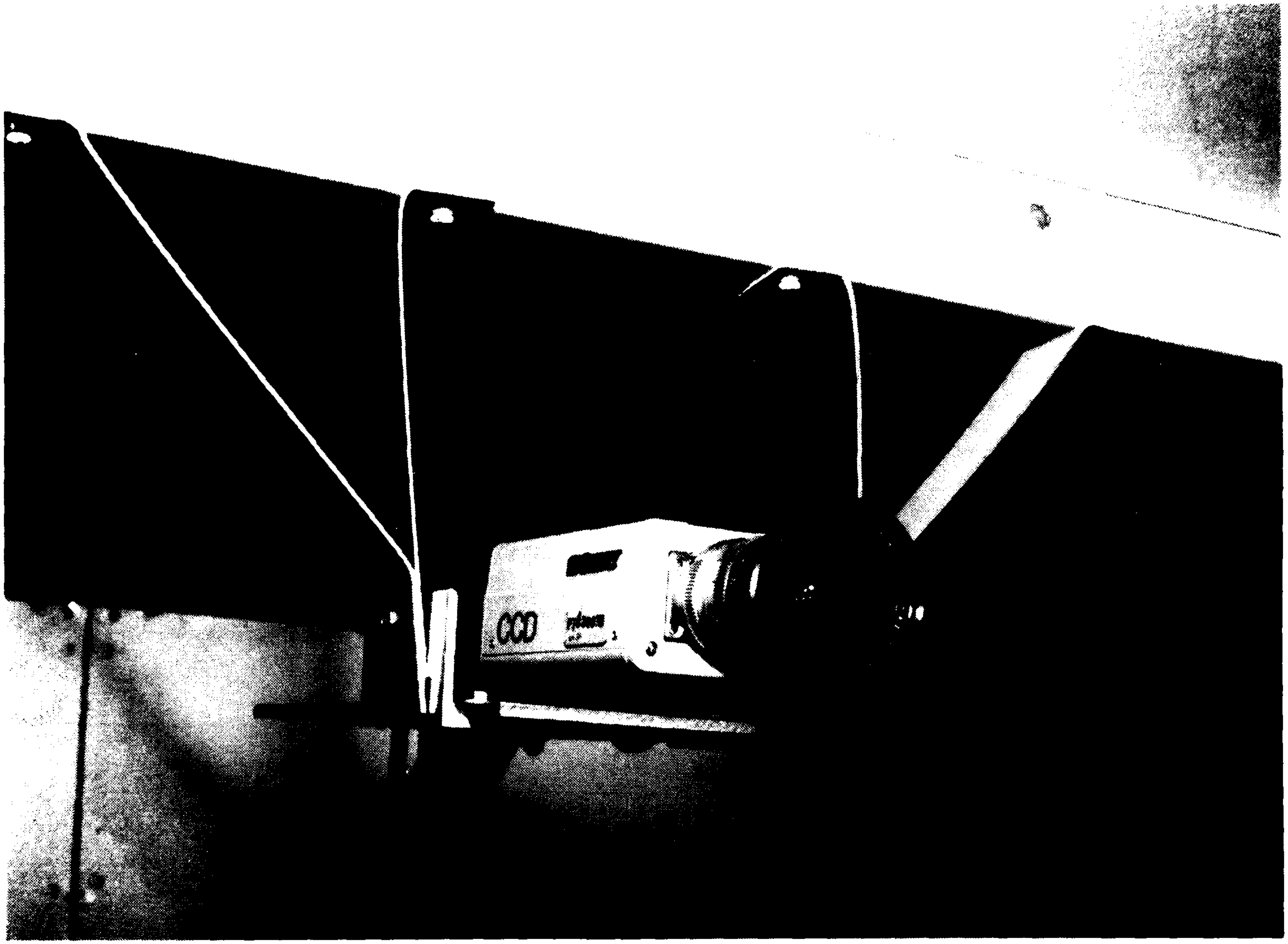


FIGURE 2.3.1-2 AFT VIDEO CAMERA

FIGURE 2.3.1-3 MOBILE VIDEO CAMERA

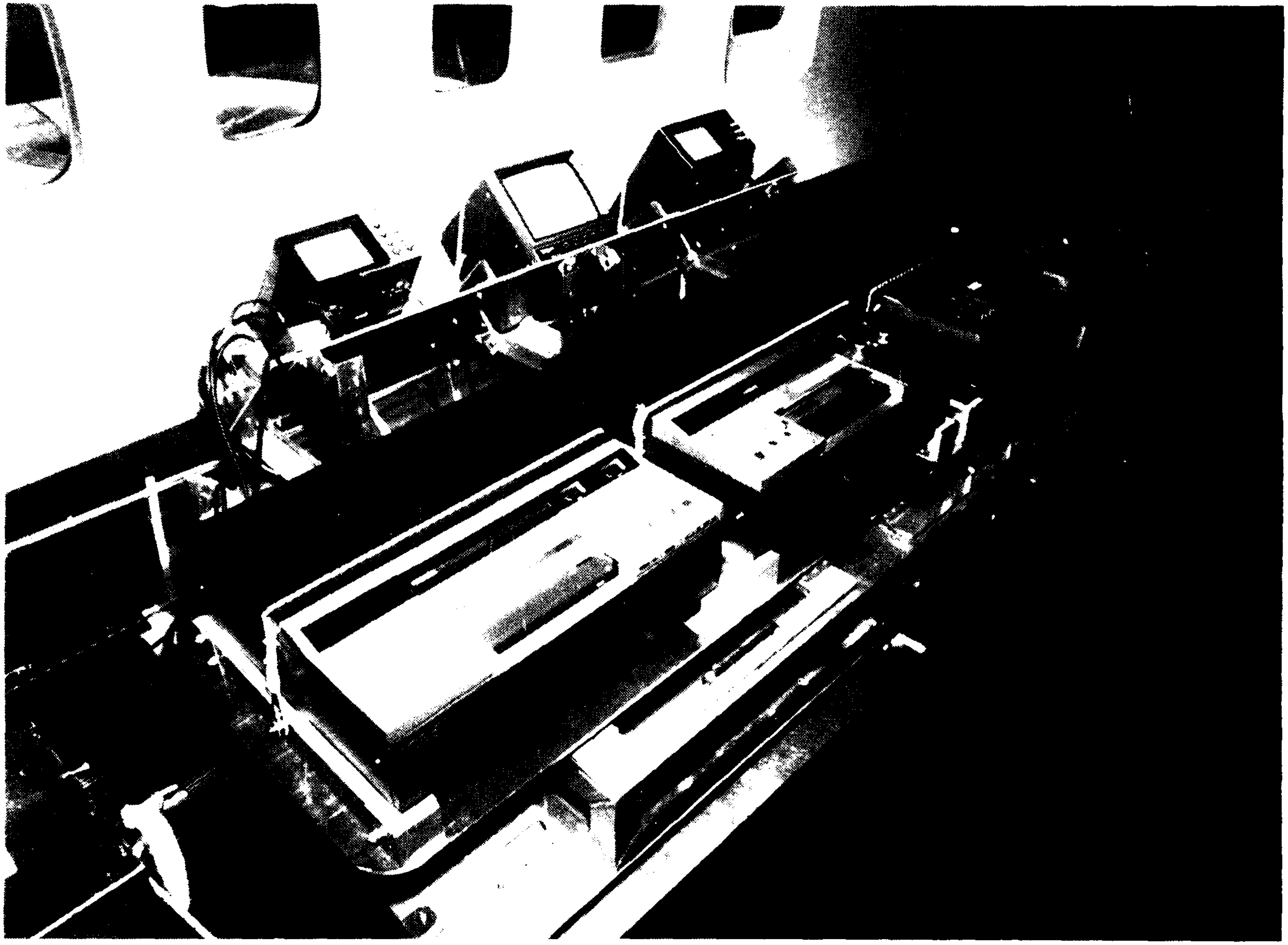


FIGURE 2.3.1-4 VIDEO RECORDERS AND MONITORS

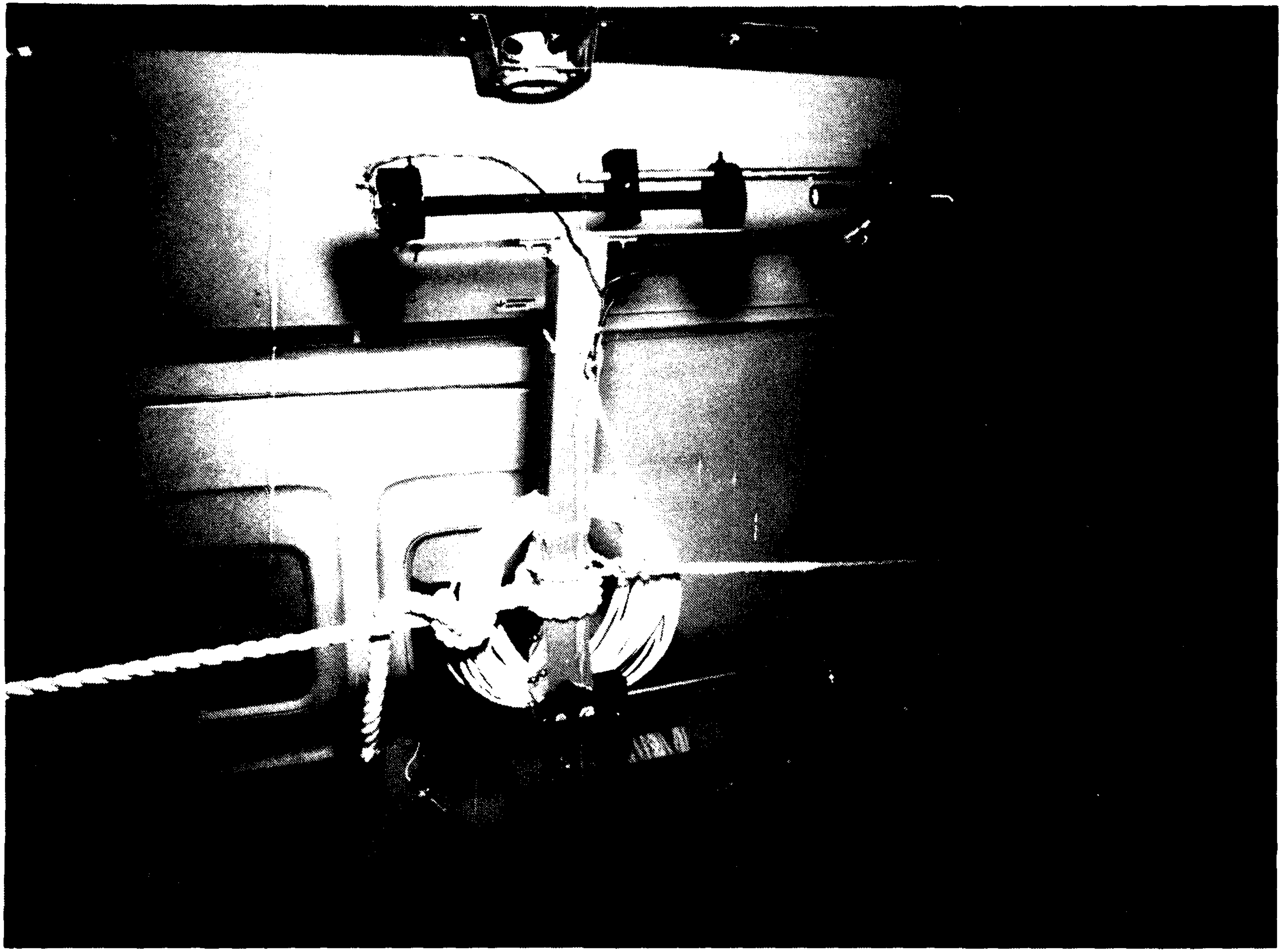


FIGURE 2.3.2-1. SMOKE METERS, TYPICAL FOR STATIONS 560, 800, 1030 AND 1270

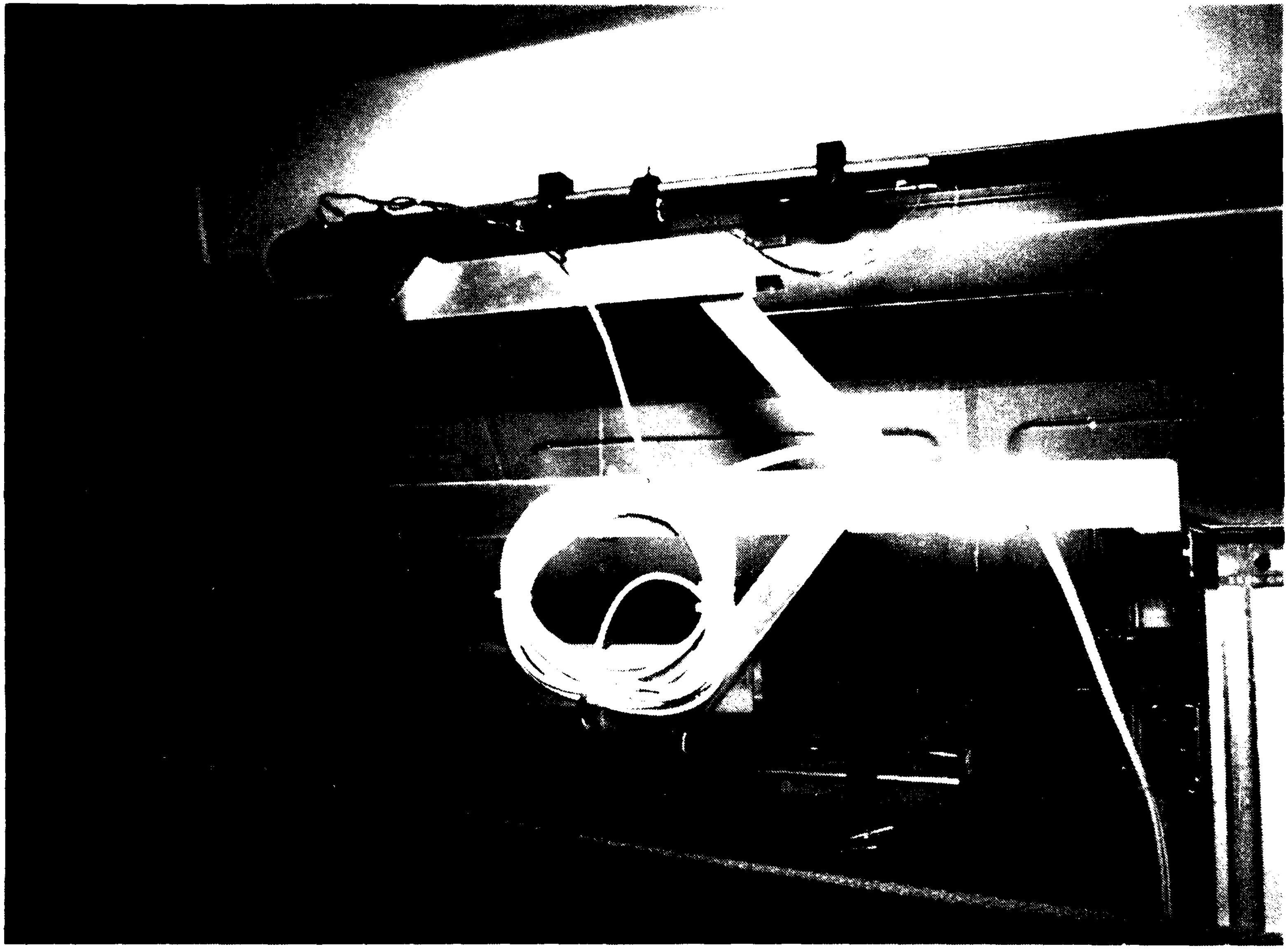
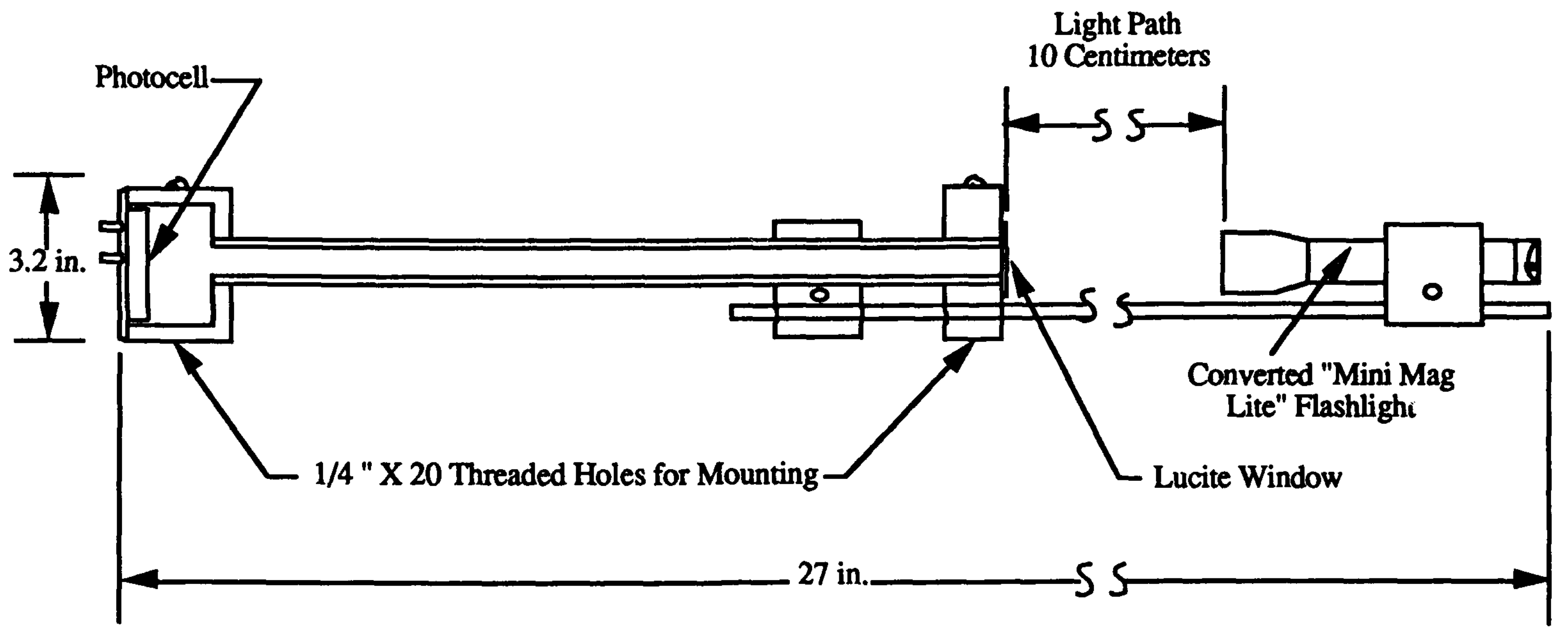


FIGURE 2.3.2-2 SMOKE METERS, STATION 1530



Weight 2.7 lbs

FIGURE 2.3.2-3 SMOKE METER DETAILS

3. TEST PROCEDURES

3.1 GENERAL

The test conditions and procedures were conducted in accordance with the contract and the deletions and additions approved by the FAA during the test period. Figure 3.1-1 shows the test conditions actually conducted and relates each condition to the test numbers in the contract. The ground checkouts and tests were done at Boeing Field International (BFI), elevation 20 feet, in Seattle, Washington and at the Moses Lake Airport (MWH), elevation 1160 feet, in Moses Lake, Washington. Flight tests were done at altitudes up to 20,000 feet above Eastern Washington.

3.2 GROUND CHECKOUTS

Test conditions .001 through .004 were for checkout of the smoke meter locations and the operation of equipment and instrumentation. After parking the airplane and closing all doors, the engines and air conditioning packs were turned on. The smoke generation was started and continued until the smoke cloud position and density stabilized in the passenger cabin. The resulting smoke conditions were recorded by manual notes, video tapes and the smoke meter recording system.

3.3 GROUND TESTS WITH BUOYANT SMOKE

Test conditions .014.1 through .019 were for evaluation of buoyancy effects on venting smoke from the passenger cabin. After parking the airplane and connecting the hose from the external helium source to the smoke chimney inside the passenger cabin, the engines and air conditioning packs were started. The smoke generation was started and continued until the smoke cloud position and density stabilized in the passenger cabin. After stabilization, the smoke generation was continued while certain doors were opened simulating a 2-minute period of passenger evacuation. The results were recorded by the same means as for the ground checkout tests, above.

3.4 FLIGHT AND GROUND TESTS WITH NEUTRAL SMOKE

Test conditions .005 through .012, .106 and .206 were for evaluation of neutral smoke venting during cruise, descent, landing and passenger evacuation. Each condition started with the airplane in level cruise at 20,000 ft and with the cabin pressurized to 1,000 ft below sea level to give the maximum normal cabin pressure differential. The smoke generation was started and continued for the rest of the test. After about 2 minutes the smoke cloud position and density stabilized in the passenger cabin and descent was initiated. When the cabin test coordinator determined that the smoke was stable, the test director in the cockpit informed the pilot that he could then use his own discretion to land the aircraft as soon as possible subject to Air Traffic Control and airplane performance constraints. This resulted in an average descent time of 12.9 minutes for these tests which was comparable to the descent times reported in past fire accidents on the Saudi L-1011 and Air Canada DC-9 (about 14.5 and 11.0 minutes, respectively). When the test airplane was landed and parked, the doors at the cabin end opposite the smoke generator were opened for a 2-minute period of simulated passenger evacuation. The results were recorded by the same means as for the ground checkout tests, above.

								Test to evaluate . . .					
Test Cond	Smoke Gen Station	Helium	% Pack Flow(s)	Outflow Valve	Altitudes (ft) Cruise/Land	Doors Opened (Packs on?)	Contract Test Number	Check-out	Current Config	Concept A	Concept B	With Upper Lobe Outflow Valve	Buoyancy Effects
.001	1030	No	100+RC*	Aft	-/20	-	1	X					
.002	1030	No	100+RC	Fwd	-/20	-	2	X					
.003	1030	No	215	Aft	-/20	-	3	X					
.004	1030	No	215	Fwd	-/20	-	4	X					
.005	465	No	165	Aft	20K/1160	Aft(No)	5-1 & -2		X				
.006	465	No	215	Fwd	20K/1160	Aft(No)	6-1 & -2			X		X	
.007	465	No	165/215	Fwd	20K,3K/-	-	7-1, -2 & -3				X	X	
.007.1	465	No	215	Fwd	-/1160	Aft(Yes)	7-4				X	X	
.008	1664	No	165	Aft	20K/1160	Fwd(No)	8-1 & -2		X				
.009	1664	No	215	Aft	20K/1160	Fwd(Yes)	9-1 & -2			X	X		
.011	1030	No	165	Aft	20K/1160	Fwd(No)	11-1 & -2		X				
.012	1030	No	215	Aft	20K/1160	Fwd(No)	12-1 & -2			X			
.014.1	465	Yes	165	Aft	-/20	Aft(No)	14-1 & -2		X				X
.015	465	Yes	215	Fwd	-/20	Aft(Yes)	15-1, -2 & -3			X	X	X	X
.016	1664	Yes	165	Aft	-/20	Fwd(No)	16-1 & -2		X				X
.017	1664	Yes	215	Aft	-/20	Fwd(Yes)	17-1, -2 & -3			X	X		X
.018	1030	Yes	165	Aft	-/20	Fwd(No)	18-1 & -2		X				X
.019	1030	Yes	215	Aft	-/20	Fwd(Yes)	19-1, -2 & -3			X	X		X
.106	750	No	165	Fwd	20K/1160	Aft(No)	Added		X			X	
.206	750	No	215	Fwd	20K/1160	Aft(No)	Added			X		X	
							(Note: Tests 10 and 13 deleted)						

* RC means recirculation fans ON

FIGURE 3.1-1 TEST CONDITIONS

4. TEST RESULTS AND DISCUSSIONS

4.1 RESULTS

The tests were conducted on November 29 through December 1, 1988.

Figure 4.1-1 shows the test data locations. Appendix A presents the plan of test, test log and manual notes from the test conditions conducted during test 90-1 on November 29. Appendixes B and C present the same data for tests 90-2 and 90-3 conducted on November 30 and December 1, respectively. Appendix D presents the smoke meter data from all test conditions. The video tapes recorded during these tests are contained in 23 cassettes. The originals are filed by the Boeing Flight Test organization at Seattle, Washington and copies have been provided to the FAA Technical Center at Atlantic City Airport, New Jersey.[1] As shown on Figure 4.1-1, some video recorders were inoperative during conditions .001, .002, .017, .018 and .019. All other equipment and instruments operated satisfactorily.

The results of all the ground tests and the cruise/descend/land tests are given on Figure 4.1-2 (8 sheets). The results given are composites of the manual notes in the Appendixes and the video tapes. The "TIME" column gives the real time-of-day and corresponds to the time readout on the video tapes. The time given for opening cabin doors was taken from the video tapes by noting when the lighting change indicated that a door had been opened. The times for smoke ON and OFF were taken from the manual notes by the smoke generator operator. All other times are from the test director's manual notes. The "ACTUAL FLOW" column gives the approximate air conditioning pack flow which were calculated from the readings of the manifold differential pressure gauge using the following equation:

$$\%Wact = \%Wsel\ (Wact)/Wsel$$
$$= \%Wsel\ (sDP/Z)^{0.5}/Wsel$$

Where:

% Wact	=	Actual percent weight flow (%)
%Wsel	=	Selected percent weight flow (%)
Wact	=	Actual weight flow for 2 packs (lb/min)
Wsel	=	Selected weight flow for 2 packs (lb/min) which depends on % Wsel and airplane altitude:

Airplane Altitude (ft)	Wsel (lb/min) %Wsel =165%	Wsel (lb/min) %Wsel =215%
20,000	220.	286.
10,000	228.	298.
0	234.	307.

[1]Boeing Letter 6-1171-DEH-352, "Shipment of Videos and Photos, FAA Contract DTFA03-88-C-00056", dated 12-21-88.

s	=	Pc/Po (Equals density ratio since temperatures are equal)
Pc	=	Cabin pressure (psia)
Po	=	Sea level pressure=14.70 psia
DP	=	Differential pressure between the mix manifold and the passenger cabin (inches of water)
Z	=	A constant to relate total two-pack flow to the resistance from the mix manifold to the passenger cabin = 0.0000875 (inches of water)/(lb/min)^2

Text continued on page 44

Test Cond	Manual Notes in Appendix	Video Tape XTV No. (VCR Counts: Start/End) Fwd Camera Look Aft	Mobile Camera Look Smoke Gen	Aft Camera Look Fwd
.001	A	3130(160/480)	3128(0/1020)	Note
.002	A	3129(60/270)	Note	Note
.003	A	3126(0/450)	3127(0/450)	3125(0/450)
.004	A	3126(460/750)	3127(460/750)	3125(460/750)
.005	B	3134(0/1000)	3135(0/1000)	3133(0/1000)
.006	B	3134(1000/1720)	3135(1000/1720)	3133(1000/1720)
.007	B	3137(0/640)	3138(0/640)	3136(0/640)
.007.1	C	3123(1650/2060)	3124(830/1080)	3122(830/1080)
.008	B	3137(710/1430)	3138(710/1430)	3136(710/1430)
.009	B	3140(0/900)	3141(0/900)	3139(0/900)
.011	B	3140(920/1640)	3141(920/1640)	3139(920/1640)
.012	C	3119(0/1230)	3121(0/600)	3120(0/1230)
.014.1	A	3126(930/1260)	3127(930/1260)	3125(930/1260)
.015	A	3126(1280/1580)	3127(1280/1580)	3125(1280/1580)
.016	A	3126(1590/1910)	3127(1590/1910)	3125(1590/1910)
.017	A	3132(0/950)	Note	3131(0/950)
.018	A	3132(1120/1800)	Note	3131(1120/1800)
.019	A	3132(1820/2460)	Note	3131(1820/2460)
.106	C	3119(1410/2400)	3121(700/1400)	3120(1410/2580)
.206	C	3123(0/1500)	3124(0/740)	3122(0/740)

Note: Recorder(s) inoperative.

FIGURE 4.1-1 TEST DATA LOCATIONS

Test Condition No: .005
Smoke Generator Station: 465 Helium: No
Outflow Valve: Aft Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	CABIN	FLOW-BOTH PACKS SELECTED	ACTUAL	DOORS	RESULTS
9:47:19	20,000	-1,000	165%	151%	Closed	Smoke ON. Smoke moving aft throughout the cabin. Thick fwd, medium to thin aft and hugs floor.
9:49:20	20,000	-1,000	165%	151%	Closed	Start descent. During descent smoke was approx the same with increasing thickness.
10:08:23	1,160	1,160	165%	Varies	Closed	Touchdown.
10:10:10	1,160	1,160	0	0	Aft open	Stopped. Smoke drifting and thickening.
10:12:48	1,160	1,160	0	0	Aft open	Smoke OFF.

Test Condition No: .006
Smoke Generator Station: 465 Helium: No
Outflow Valve: Fwd Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	CABIN	FLOW-BOTH PACKS SELECTED	ACTUAL	DOORS	RESULTS
10:37:10	20,000	-1,000	215%	220%	Closed	Smoke ON. Smoke thick and staying fwd of about Sta 700
10:39:44	20,000	-1,000	215%	220%	Closed	Start descent. During descent smoke was approx the same.
10:53:01	1,160	1,160	215%	Varies	Closed	Touchdown.
10:55:00	1,160	1,160	0	0	Aft open	Stopped. Smoke thickening and drifting aft to about Sta 1000 by end of condition.
10:57:10	1,160	1,160	0	0	Aft open	Smoke OFF.

FIGURE 4.1-2 (SHEET 1 OF 8) TEST RESULTS

Test Condition No:. .007
Smoke Generator Station: 465 Helium: No
Outflow Valve: Fwd Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	CABIN	FLOW-BOTH PACKS SELECTED	ACTUAL	DOORS	RESULTS
11:18:40	20,000	-1,000	165%	169%	Closed	Smoke ON Smoke thick and staying fwd of about Sta 700.
11:20:42	20,000	-1,000	165%	169%	Closed	Start descent.
11:22:00	11,000	1,000	165%	Varies	Closed	During descent smoke
11:25:30	10,000	9,000	165%	157%	Closed	was approx the same.
11:26:00	10,000	10,000	215%	219%	Closed	Smoke approx the same with more motion.
11:28:11	10,000	10,000	215%	219%	Closed	Start descent. During descent smoke was approx the same.
11:34:00	approx 3,000	approx 3,000	215%	Varies	Closed	Stopped test due to sinus problem of one of the test personnel.

Test Condition No: .007.1*
Smoke Generator Station: 465 Helium: No
Outflow Valve: Fwd Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	CABIN	FLOW-BOTH PACKS SELECTED	ACTUAL	DOORS	RESULTS
10:47:01	1,160	1,160	215%	234%	Closed	Smoke ON. Smoke thick and staying fwd of about Sta 700.
10:49:42	1,160	1,160	215%	234%	Aft Open	Smoke thickening and moving aft; thin smoke exiting doors about 2.5 minutes after doors open.
10:52:33	1,160	1,160	215%	234%	Aft Open	Smoke OFF.

* Ground test to complete the doors-open portion of interrupted test .007.

FIGURE 4.1-2 (SHEET 2 OF 8) TEST RESULTS

Test Condition No: .008
Smoke Generator Station: 1664 Helium: No
Outflow Valve: Aft Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	ALTITUDE (ft) CABIN	FLOW-BOTH PACKS SELECTED	FLOW-BOTH PACKS ACTUAL	DOORS	RESULTS
13:05:42	20,000	-1,000	165%	165%	Closed	Smoke ON. Smoke medium and staying aft of about Sta 1400.
13:07:50	20,000	-1,000	165%	165%	Closed	Start descent. During descent smoke was approx the same.
13:19:50	1,160	1,160	165%	Varies	Closed	Touchdown.
13:22:35	1,160	1,160	0	0	Fwd Open	Stopped. Smoke thickening & drifting fwd with thin smoke to about Sta 1350 by end of condition.
13:24:30	1,160	1,160	0	0	Fwd Open	Smoke OFF.

Test Condition No: .009
Smoke Generator Station: 1664 Helium: No
Outflow Valve: Aft Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	ALTITUDE (ft) CABIN	FLOW-BOTH PACKS SELECTED	FLOW-BOTH PACKS ACTUAL	DOORS	RESULTS
13:46:40	20,000	-1,000	215%	229%	Closed	Smoke OFF. Smoke medium & staying aft of about Sta 1500.
13:48:50	20,000	-1,000	215%	229%	Closed	Start descent. During descent smoke was about the same and staying aft of about Sta 1400.
14:04:16	1,160	1,160	215%	Varies	Closed	Touchdown.
14:06:45	1,160	1,160	215%	222%	Fwd Open	Stopped. Smoke medium and moving fwd; thin to about Sta 1120 by end of condition.
14:08:54	1,160	1,160	215%	222%	Fwd Open	Smoke OFF.

FIGURE 4.1-2 (SHEET 3 OF 8) TEST RESULTS

Test Condition No: .011
Smoke Generator Station: 1030
Outflow Valve: Aft

Helium: No
Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	ALTITUDE (ft) CABIN	FLOW-BOTH PACKS SELECTED	FLOW-BOTH PACKS ACTUAL	DOORS	RESULTS
14:38:00	20,000	-1,000	165%	167%	Closed	Smoke ON. Smoke thick and staying aft of about Sta 970.
14:40:30	20,000	-1,000	165%	167%	Closed	Start descent. During descent smoke was approx the same and staying aft of about Sta 870 with thin smoke in aft cabin.
14:52:16	1,160	1,160	165%	Varies	Closed	Touchdown.
14:54:52	1,160	1,160	0	0	Fwd Open	Stopped. Smoke drifting fwd mostly along ceiling with thin smoke to doors 130 seconds after doors opened.
14:57:31	1,160	1,160	0	0	Fwd Open	Smoke OFF.

Test Condition No: .012
Smoke Generator Station: 1030
Outflow Valve: Aft

Helium: No
Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	ALTITUDE (ft) CABIN	FLOW-BOTH PACKS SELECTED	FLOW-BOTH PACKS ACTUAL	DOORS	RESULTS
9:09:50	20,000	-1,000	215%	233%	Closed	Smoke ON Smoke medium and staying aft of about Sta 1000.
9:12:10	20,000	-1,000	215%	233%	Closed	Start descent. During descent smoke was medium and staying aft of about Sta 1000.
9:20:00	1,160	1,160	215%	Varies	Closed	Touchdown.
9:22:20	1,160	1,160	0	0	Fwd Open	Stopped. Smoke drifting fwd mostly along ceiling with thin smoke to doors 70 sec after doors opened.
9:24:24	1,160	1,160	0	0	Fwd Open	Smoke OFF.

FIGURE 4.1-2 (SHEET 4 OF 8) TEST RESULTS

Test Condition No: .014.1
Smoke Generator Station: 465 Helium: Yes
Outflow Valve: Aft Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	ALTITUDE (ft) CABIN	FLOW-BOTH PACKS SELECTED	FLOW-BOTH PACKS ACTUAL	DOORS	RESULTS
13:14:19	20	20	165%	147%	Closed	Smoke ON. Smoke thick at fwd ceiling and moving aft. At mid-cabin, medium from ceiling down to knee level. Medium in aft cabin.
13:19:36	20	20	0	0	Aft Open	Smoke approx the same and thicker exiting doors.
13:21:35	20	20	0	0	Aft Open	Smoke OFF.

Test Condition No: .015
Smoke Generator Station: 465 Helium: Yes
Outflow Valve: Fwd Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	ALTITUDE (ft) CABIN	FLOW-BOTH PACKS SELECTED	FLOW-BOTH PACKS ACTUAL	DOORS	RESULTS
13:31:37	20	20	215%	213%	Closed	Smoke ON. Smoke thick and staying fwd of about Sta 680.
13:34:43	20	20	215%	213%	Aft Open	Smoke moving aft with thin to doors 80 sec after doors opened.
13:36:55	20	20	0	0	Aft Open	Smoke thickening and drifting out doors.
13:38:53	20	20	0	0	Aft Open	Smoke OFF.

FIGURE 4.1-2 (SHEET 5 OF 8) TEST RESULTS

Test Condition No: .016
Smoke Generator Station: 1664
Outflow Valve: Aft

Helium: Yes
Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	ALTITUDE (ft) CABIN	FLOW-BOTH PACKS SELECTED	FLOW-BOTH PACKS ACTUAL	DOORS	RESULTS
14:03:08	20	20	165%	162%	Closed	Smoke ON. Smoke thick at ceiling and moving fwd with gradual spreading toward floor. Thin to fwd doors in 4 minutes with thin flow aftward along floor.
14:09:32	20	20	0	0	Fwd Open	Smoke thickening and drifting out doors.
14:11:34	20	20	0	0	Fwd Open	Smoke OFF.

Test Condition No: .017
Smoke Generator Station: 1664
Outflow Valve: Aft

Helium: Yes
Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	ALTITUDE (ft) CABIN	FLOW-BOTH PACKS SELECTED	FLOW-BOTH PACKS ACTUAL	DOORS	RESULTS
14:25:06	20	20	215%	214%	Closed	Smoke ON. Smoke thick at ceiling and moving fwd with gradual spreading toward floor. Very thin to fwd cabin in 5 minutes with thin flow aftward along floor.
14:31:03	20	20	215%	214%	Fwd Open	Smoke moving fwd and thickening in fwd cabin and flowing out doors.
14:33:00	20	20	0	0	Fwd Open	Smoke thickening and drifting out doors.
14:35:01	20	20	0	0	Fwd Open	Smoke OFF.

FIGURE 4.1-2 (SHEET 6 OF 8) TEST RESULTS

Test Condition No: .018
Smoke Generator Station: 1030
Outflow Valve: Aft

Helium: Yes
Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	ALTITUDE (ft) CABIN	FLOW-BOTH PACKS SELECTED	FLOW-BOTH PACKS ACTUAL	DOORS	RESULTS
16:03:25	20	20	165%	156%	Closed	Smoke ON. Smoke thick at ceiling and moving both fwd and aft with gradual spreading toward floor. Thin to fwd doors in 70 seconds with medium flow aftward along floor.
16:09:51	20	20	0	0	Fwd Open	Smoke thickening and drifting out doors.
16:11:55	20	20	0	0	Fwd Open	Smoke OFF.

Test Condition No: .019
Smoke Generator Station: 1030
Outflow Valve: Aft

Helium: Yes
Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	ALTITUDE (ft) CABIN	FLOW-BOTH PACKS SELECTED	FLOW-BOTH PACKS ACTUAL	DOORS	RESULTS
16:31:15	20	20	215%	220%	Closed	Smoke ON. Smoke thick at ceiling and moving both fwd and aft with gradual spreading toward floor. Thin to fwd doors in 60 seconds with medium flow aftward along floor.
16:36:50	20	20	215%	220%	Fwd Open	Smoke moving fwd and thickening in fwd cabin and flowing out doors.
16:38:45	20	20	0	0	Fwd Open	Smoke thickening and drifting out doors.
16:40:45	20	20	0	0	Fwd Open	Smoke OFF.

FIGURE 4.1-2 (SHEET 7 OF 8) TEST RESULTS

Test Condition No: .106
Smoke Generator Station: 750 Helium: No
Outflow Valve: Fwd Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	CABIN	FLOW-BOTH PACKS SELECTED	ACTUAL	DOORS	RESULTS
9:38:57	20,000	-1,000	165%	167%	Closed	Smoke ON. Smoke thick and staying fwd of about Sta 800.
9:41:20	20,000	-1,000	165%	167%	Closed	Start descent. During descent smoke was approx the same.
9:53:34	1,160	1,160	165%	Varies	Closed	Touchdown.
9:56:13	1,160	1,160	0	0	Aft Open	Stopped. Smoke thickening and drifting aft to doors 90 sec after doors opened.
9:58:24	1,160	1,160	0	0	Aft Open	Smoke OFF.

Test Condition No: .206
Smoke Generator Station: 750 Helium: No
Outflow Valve: Fwd Recirculation: Off

TIME (HR:MIN:SEC)	ALTITUDE (ft) A/P	CABIN	FLOW-BOTH PACKS SELECTED	ACTUAL	DOORS	RESULTS
10:16:51	20,000	-1,000	215%	233%	Closed	Smoke ON. Smoke medium thick and staying fwd of about Sta 770.
10:18:58	20,000	20,000	215%	233%	Closed	Start descent. During descent smoke was approx the same and staying fwd of about Sta 800.
10:31:00	1,160	1,160	215%	Varies	Closed	Touchdown.
10:33:14	1,160	1,160	0	0	Aft Open	Stopped. Smoke thickening and drifting aft to doors by 105 sec after doors opened.
10:35:24	1.160	1,160	0	0	Aft Open	Smoke OFF.

FIGURE 4.1-2 (SHEET 8 OF 8) TEST RESULTS

4.2 DISCUSSIONS

4.2.1 SMOKE METER DATA

4.2.1.1 INCONSISTENT REPRESENTATION OF CABIN SMOKE

The attempt to characterize the cabin smoke environment with the smoke meters yielded mixed results. In the tests that used helium, the smoke meters provided good data on the smoke throughout the cabin on a time-resolved basis due to two factors. Firstly, the helium caused a buoyancy that brought the smoke to the cabin upper levels where the smoke meters were installed. Secondly, the flow dynamics resulted in the smoke layer spreading forward and aft along the ceiling to cause signals to be generated in all ten smoke meters. Furthermore, this stratified layer was distributed across the width of the aircraft. Despite the fact that the smoke generator and smoke meters were on opposite sides of the aircraft, the width-wise smoke distribution enabled the smoke meters to provide data that was truly representative of conditions in the upper half of the cabin. The one exception to these observations was test condition .015 where use of the upper lobe outflow valve resulted in confinement of the ceiling smoke layer to the front of the aircraft until the rear doors were opened. Even in this test, the zero smoke indication of the aft four smoke meter sets was an accurate representation of the cabin conditions.

A contrasting situation was found with many of the tests that used the smoke generator alone without the helium smoke simulator. Because the smoke has minimal buoyant behavior, it tends to move in the direction of localized cabin air currents. In tests where the generator was in the aft location, the smoke remained aft of the rearmost smoke meters and was not detected at that point until after aircraft touchdown. In tests where the smoke generation was at the middle location, the smoke generally favored the left hand side of the cabin. Since the smoke meters were to the right of the cabin centerline, their outputs were not representative of conditions of points several feet away. A third example would be test conditions .006, .007, .007.1, .106, and .206. All of these employed the upper lobe outflow valve. In these tests, there were strong and clear three-dimensional effects in the cabin air flow in the front part of the aircraft. Visibility conditions were generally substantially worse on the left side than on the right hand side. Again, the data from the smoke meters, which were to the right of the centerline, do not provide data that gives the true overall situation in the front part of the aircraft.

The above contrasts reinforce the visual observations on the striking difference between the behaviors of buoyant and non-buoyant smoke. They further show that when non-buoyant smoke is used, additional care in the placement of smoke meters is required if useful, representative information on cabin smoke distribution is to be provided. Finally, the smoke meter data for the most part in these tests evidenced less than optimal light obscuration for data analysis. The smoke meters were originally developed for airplane tests that involved much larger smoke generation rates that resulted in peak smoke densities such that the light transmission was in the 10% to 30% range. In the tests reported herein, the smoke densities were much lower with the result that the transmissions were around 90%. At these values, instrumentation "noise" begins to be large enough (in proportion to signal) such that data analysis becomes more difficult. This shows the need for better balancing between the smoke generator setting best suited for video documentation (low smoke rate) and that best suited for optical smoke meters (high smoke rate). Another way of handling this would be increasing the distance between the light source and the detector from the current 10 centimeters to 0.5 meter.

4.2.1.2 RECIRCULATION EFFECTS

All of the above inconsistent representations notwithstanding, some valuable information can be developed from the smoke meter data. Figures 4.2.1-1 and 4.2.1-2 show the data from the upper smoke meters at stations 1030 and 1270 for test conditions .001 and .011, respectively. These tests both employed neutral smoke generation (no helium) at the mid-cabin location. Condition .001 involved 100% pack flow with recirculation. Condition .011 involved 165% pack flow and no recirculation. Condition .001 resulted in containment of the smoke to the middle of the aircraft (between about stations 850 and 1300), while Condition .011 involved movement of smoke all the way to the aft doors. Figure 4.2.1-1 shows transmission traces for condition .001 until approximately 30 seconds after the smoke generator was turned off. The meter at station 1030, which was at the same station as the smoke generator, shows a gradual and modest decrease on transmission. The smoke meter at station 1270 shows the same type of gradual change but the transmission loss was noticeably less. A contrasting situation is shown in Figure 4.2.1-2 for condition .011. Although this condition involved a total test time of over 20 minutes, only the first ten minutes are shown for easier comparison with condition .001. At approximately seven minutes into the test, the smoke distribution in the cabin stabilized. In the second half of this ten minute time frame, the light obscuration at station 1270 was greater than that at the smoke generation point. The differences in the light transmission data between conditions .001 and .011 can be attributed to the cabin flow balancing effected by the 165% pack flow rate and the recirculation fans which are in the forward part of the aircraft. Use of the fans results in a negligible axial flow at the mid-cabin smoke generation point. Use of the 165% pack flow rate without recirculation results in a situation where much of the air supplied to the forward half of the cabin will move axially to the rear. This causes the smoke at station 1030 to be more diluted and transported to the rear of the cabin.

Thus, the analytic predictions of the preceding study (FAA Report No. DOT/FAA/CT-88/22) will be affected not only if the test smoke is buoyant, but also by whether the recirculation fans are ON or OFF.

4.2.1.3 SMOKE MOVEMENT RATE

Figure 4.2.1-3 shows the data from the upper smoke meters at stations 800 and 1530 for condition .016 which involved the helium smoke generator being located in the aft cabin. The data shows a time interval of about 62 seconds between the start of light transmission reduction at the two meters. These meter locations were approximately 61 feet apart. Dividing this distance by the time interval of 62 seconds results in a smoke cloud movement rate of approximately one foot per second along the length of the fuselage. A similar exercise on the smoke data from condition .014.1 shows the buoyant smoke ceiling layer moving aft at three feet per second. These movement rates indicate that the smoke cloud moves independently at about two feet per second. Using the aft outflow valve and 165% flow, the average aft moving cabin axial flow is about one foot per second. With smoke generation in the rear, this slows the overall cloud movement forward from two to one foot per second. With smoke generation forward, the axial cabin flow is additive to yield the three feet per second rate of smoke movement.

4.2.1.4 OUTFLOW VALVE LOCATION EFFECTS

Figures 4.2.1-4 and 4.2.1-5 show the data from the upper smoke meters at the location closest to the smoke generator and at station 1030 for conditions .015 and .017 respectively. Both conditions involved the use of helium and also the high ventilation flow rate. In condition .015, the smoke generator was located in the forward cabin location and the upper lobe forward outflow valve was used. In condition .017, the smoke generator was in the aft cabin and the lower lobe aft outflow valve was used. It is evident from these figures that using an upper rather than lower lobe outflow in the vicinity of the smoke generation results in lesser smoke locally. Furthermore, the upper lobe test resulted in no measurable smoke at all at the middle of the aircraft until the doors of the aircraft were opened. This is clearly different from the situation with a lower lobe outflow valve in the vicinity of the smoke generation.

4.2.1.5 PACK FLOW EFFECT WITH DOORS OPEN

In all tests other than conditions .001 through .004, smoke generation was continued after the doors were open with either the aircraft ventilation system (air packs) left on or off. In all cases, the smoke would migrate toward the open doors. With packs on, this movement was assisted by the axial cabin air flow which flowed towards the open doors. With the packs off, this movement occurred because the continued smoke generation kept filling the enclosure with no pack flow to remove it or balance the cabin air. An example of this is shown in Figure 4.2.1-6 which shows the lower smoke meters for condition .206 at stations 1030 and 1270. The mid and aft cabin were free of smoke until the doors were opened. Then the smoke migrated towards the rear in spite of the fact that the air packs were turned off when the rear doors were opened.

4.2.2 FORWARD VS AFT OUTFLOW VALVE

The discussion in this Section is based on the manual notes and video tapes as given in Figure 4.1-2. Comparison of tests .005 and .007 shows a very significant difference due to the forward or aft position of the outflow valve. In test .005, which used the aft outflow valve, the smoke generated at the forward station 465 spread throughout the entire length of the passenger cabin whereas in test .007, which used the forward outflow valve, smoke generated at the the same location was contained forward of station 700.

Similarly, a comparison of tests .014.1 and .015 (both with helium) shows a significant difference due to buoyant smoke. Test .014.1 used the aft outflow valve and resulted in smoke spreading throughout the cabin whereas test .015 used the forward outflow valve and showed that the smoke was contained forward of station 680.

The results show that an outflow valve operating at the same end of the passenger cabin as the source of neutral smoke will maintain about 73% of the passenger cabin free of smoke. When the operating outflow valve and the smoke source are at opposite ends of the passenger cabin, none of the cabin length will be free of smoke. There was no data to indicate that these results varied with upper or lower lobe outflow valve positions.

4.2.3 UPPER VS. LOWER LOBE OUTFLOW VALVE

Comparison of the results from Figure 4.1-2 for tests .006 and .009 with neutral smoke shows virtually no difference between the upper and lower lobe positions of the outflow valve. In test .006 which used the upper lobe outflow valve, the smoke generated at Station 465 was contained forward of Station 700. Test .009 used the lower lobe outflow valve and the smoke generated at Station 1664 was contained aft of Station 1500.

Comparison of tests .015 and .017 with helium shows that buoyant smoke spreads differently depending on upper or lower lobe position of the outflow valve. In test .015, using the upper lobe outflow valve, the buoyant smoke generated at Station 465 was contained forward of Station 680. This differs from test .017 which used the lower lobe outflow valve with buoyant smoke generated at Station 1664; in this test the smoke spread forward along the ceiling until a thin cloud reached the forward doors in about 5 minutes.

Text continued on page 53

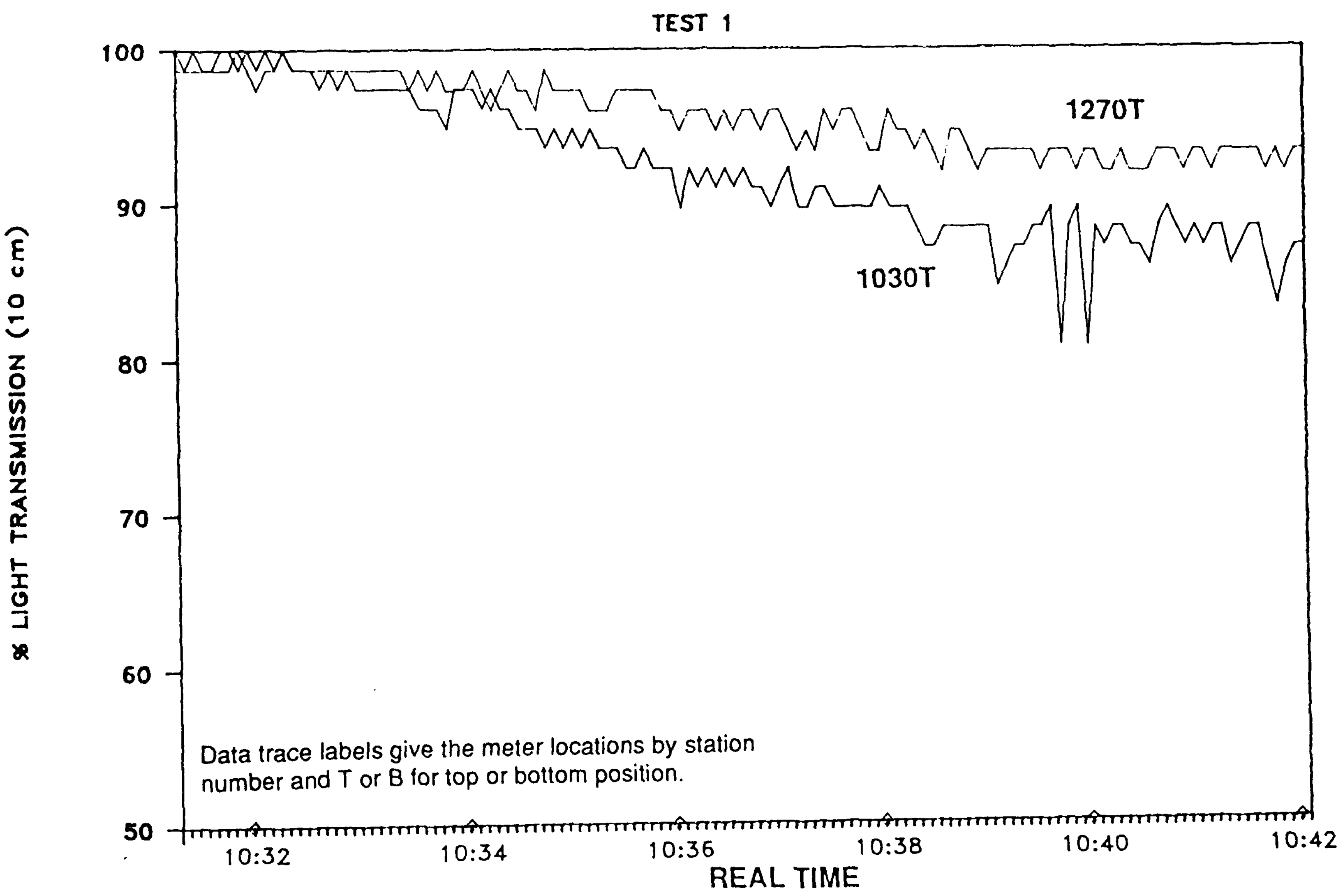


FIGURE 4.2.1-1 SMOKE METER DATA, TEST .001

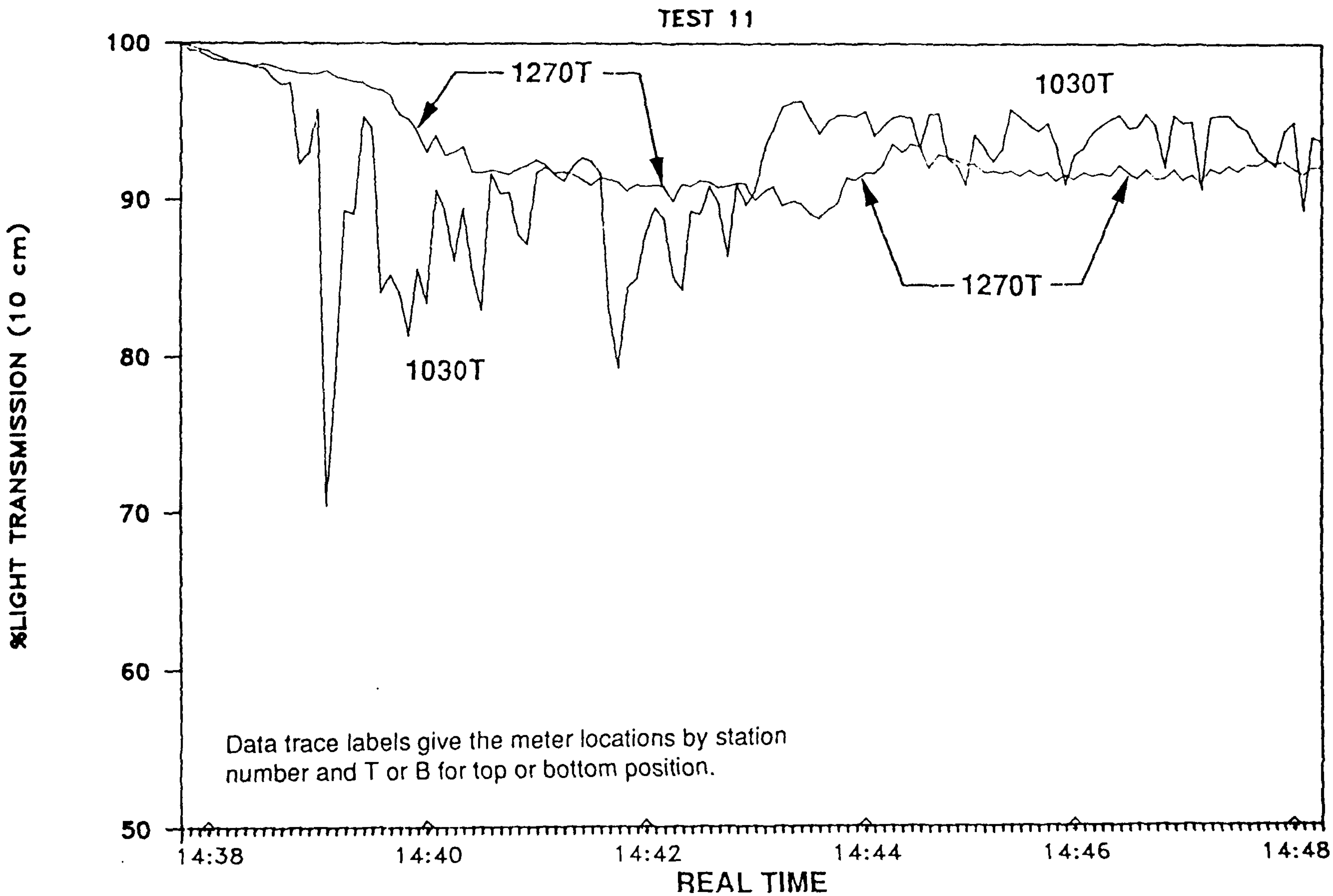


FIGURE 4.2.1-2 SMOKE METER DATA, TEST .011

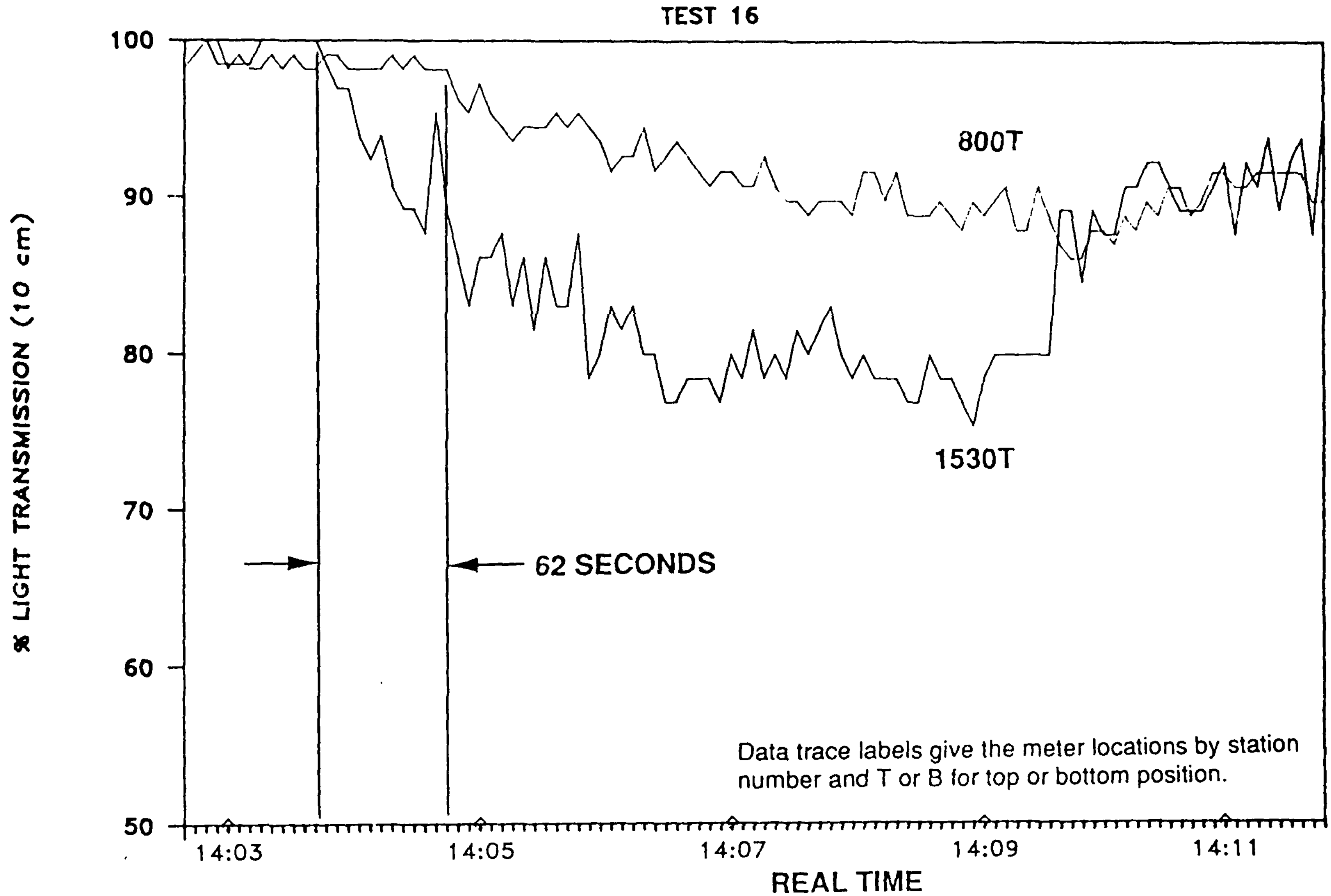


FIGURE 4.2.1-3 SMOKE METER DATA, TEST .016

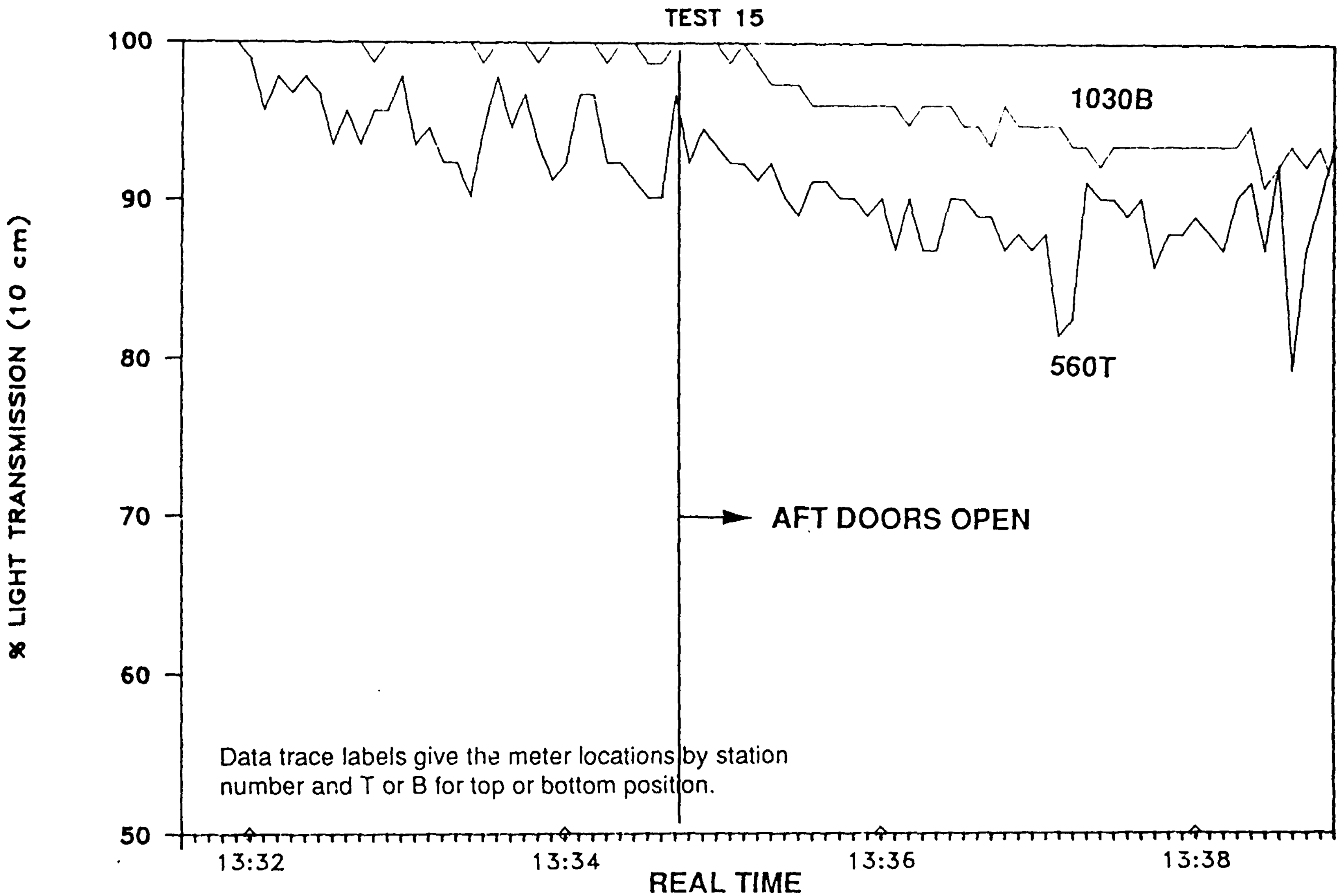


FIGURE 4.2.1-4 SMOKE METER DATA, TEST .015

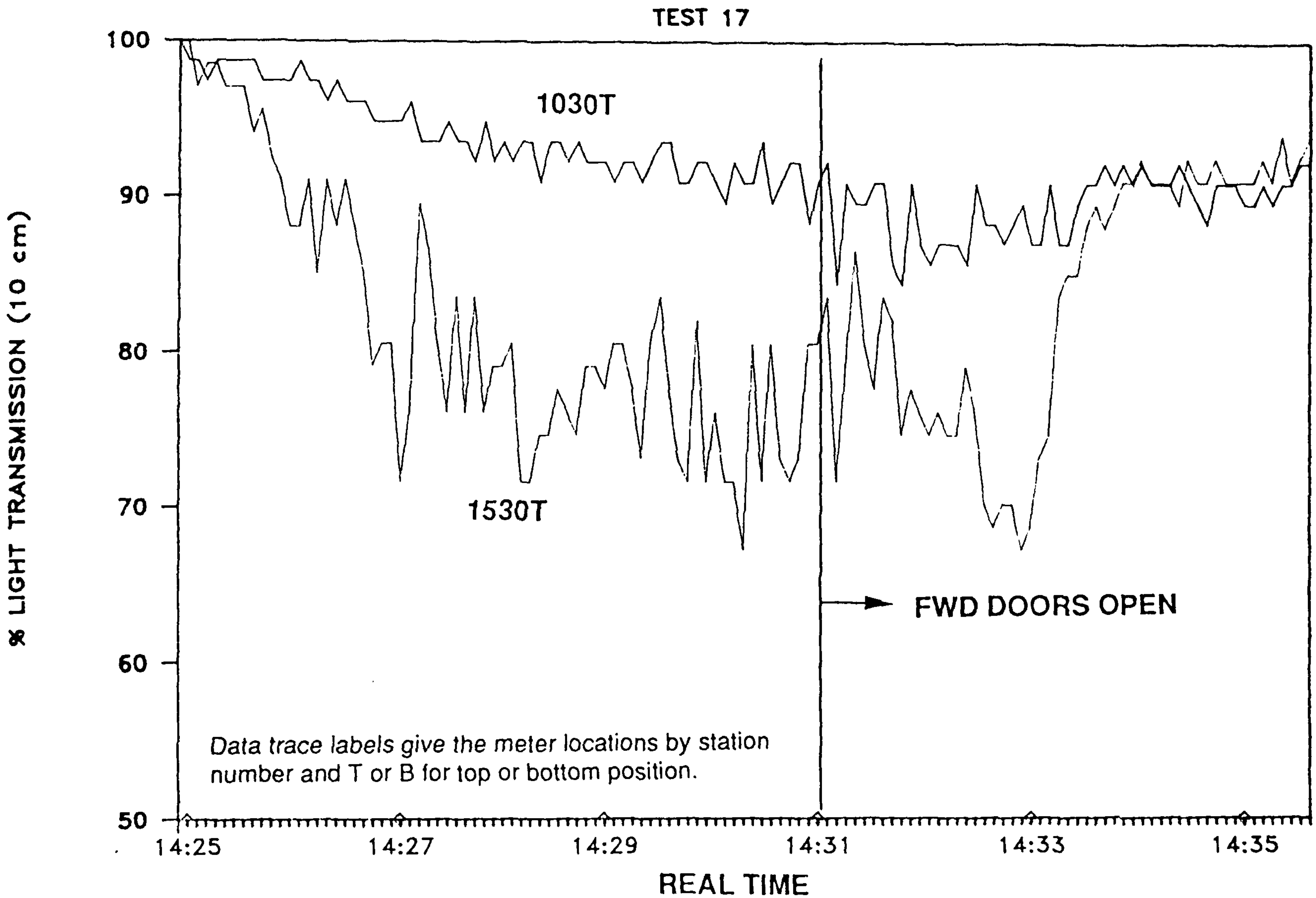


FIGURE 4.2.1-5 SMOKE METER DATA, TEST .017

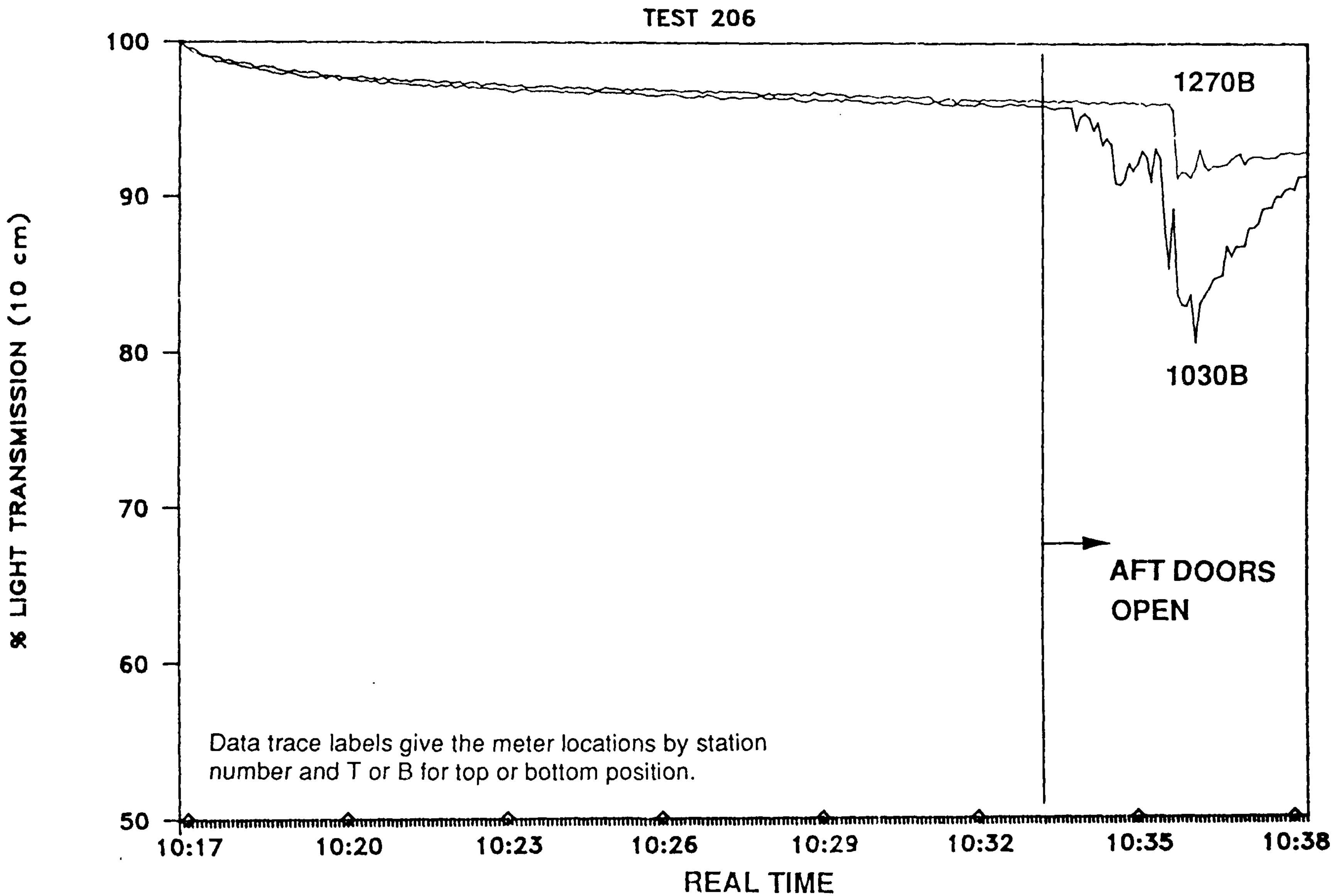


FIGURE 4.2.1-6 SMOKE METER DATA, TEST .206

The results show that for buoyant smoke an upper lobe outflow valve is better than a lower lobe valve since the upper valve maintained 74% of the passenger cabin length free of smoke while the lower lobe valve allowed thin smoke to spread throughout the passenger cabin.

For neutral smoke, the results show that upper and lower lobe outflow valves are nearly equal since they maintained between 72% and 84% of the passenger cabin length free of smoke.

4.2.4 HIGH FLOW MODE

Comparisons of the results from Figure 4.1-2 for six pairs of tests show very little difference between the high (215%) and the current (165%) pack flow rates. Tests .006 and .007 used 215% and 165% flows with neutral smoke generated at Station 465 during cruise at 20,000 feet; both tests showed that the smoke was contained forward of Station 700. Tests .206 and .106 were the same as tests .006 and .007 except the smoke was generated at Station 750; the results showed that the smoke was contained forward of Stations 770 and 800, respectively. Tests .009 and .008 were conducted with the smoke generated at station 1664 and showed that the smoke was contained aft of Stations 1500 and 1400, respectively. Similarly, tests .012 and .011 were conducted with the smoke generated at Station 1030 and showed that the smoke was contained aft of Stations 1000 and 970, respectively.

Tests .017 and .016 used 215% and 165% flows with buoyant smoke generated at Station 1664 during ground operation; the results showed that the smoke spread forward along the ceiling until a thin cloud reached the forward doors in 5 and 4 minutes, respectively. Similarly, tests .019 and .018 were conducted with the smoke generated at Station 1030 and showed that the smoke spread to the forward doors in 60 and 70 seconds, respectively.

The results show that a 30% increase of the high flow mode (from the current 165% to 215%) will not provide any significant change in maintaining the passenger cabin free of smoke.

4.2.5 SMOKE BUOYANCY

Six pairs of test results as given on Figure 4.1-2 provide comparisons of neutral versus buoyant smoke.

In four of the six comparisons, the smoke buoyancy caused significant differences compared to neutral smoke. Comparison (1): tests .008 and .016 used neutral and buoyant smoke, respectively, with the smoke generated at Station 1664 and the packs on 165% flow; the results showed the smoke contained aft of Station 1400 with neutral smoke and thin smoke spreading along the ceiling to the forward doors with buoyant smoke. Comparison (2): tests .009 and .017 were conducted at the same conditions as tests .008 and .016 except that pack flow was 215%; the results were similar with the smoke contained aft of Station 1500 with neutral smoke and smoke spreading to the forward doors with buoyant smoke. Comparison (3): tests .011 and .018 used neutral and buoyant smoke, respectively, with the smoke generated at Station 1030 and the packs on 165% flow; the results showed the smoke contained aft of Station 970 with neutral smoke and smoke spreading to the forward doors with buoyant smoke. Comparison (4): tests .012 and .019 were conducted at the same conditions as tests .011 and .018 except that pack flow was 215%; the results were similar with the smoke contained aft of Station 1000 with neutral smoke and smoke spreading to the forward doors with buoyant smoke.

In the last two of the six comparisons, the smoke buoyancy caused minimal differences. Comparison (5): tests .005 and .014.1 used neutral and buoyant smoke, respectively, with the smoke generated at Station 460, the packs on 165% flow and the aft outflow valve operating; the results in both tests showed the smoke spreading throughout the entire length of the passenger cabin. Comparison (6): tests .006 and .015 used neutral and buoyant smoke, respectively, with the smoke generated at Station 460, the packs on 215% flow and the forward outflow valve operating; the results showed that the smoke was contained forward of Stations 700 and 680 for neutral and buoyant smoke, respectively.

The results show that the as-tested buoyant smoke will spread a cloud varying from thick to thin at the ceiling along the length of the passenger cabin when the lower lobe outflow valve is used with either current or 30% increased pack flow. It was also shown that an upper lobe outflow valve was able to control buoyant smoke and maintain a majority of the passenger cabin free of smoke.

4.2.6 PACK FLOW WITH DOORS OPEN

Comparison of the results from Figure 4.1-2 for tests .006 and .007.1 shows the impact of maintaining pack flow while doors are open for passenger evacuation. In test .006 the packs were stopped when the aft doors were opened while smoke generation continued at Station 465; the result was that the smoke cloud drifted about 300 inches aft in the next 130 seconds. In test .007.1 the conditions were the same as test .006 except the packs were on 215% flow during the door open period; the result was that the smoke cloud moved aft about 964 inches (to the aft doors) in the next 150 seconds.

Tests .008 and .009 were like tests .006 and .007.1 except that the smoke was generated at Station 1664 and the forward doors were opened. These tests showed that the smoke drifted about 50 inches in 115 seconds with the packs stopped compared to moving about 280 inches in 129 seconds with the packs on 215% flow.

The results show that maintaining inflow to the passenger cabin while doors at the cabin end opposite the smoke generator are opened for passenger evacuation causes undesirable increases in the rate of smoke spreading into the smoke free portions of the cabin.