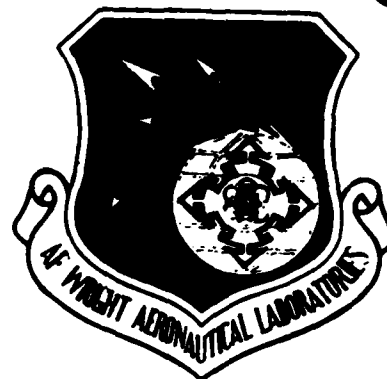AFWAL-TR-88-2022

FIRE EXTINGUISHING AGENT EVALUATION IN THE
AIRCRAFT ENGINE NACELLE FIRE TEST SIMULATOR

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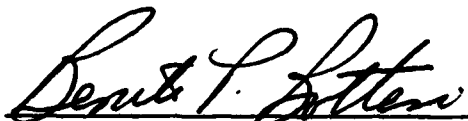| 1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED		1b. RESTRICTIVE MARKINGS			
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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Fire tests and extinguishant concentration tests were conducted using a simulated portion of the F-16 aircraft engine compartment in the Aircraft Engine Nacelle Fire Test Simulator (AENFTS) at Wright-Patterson Air Force Base. Engine compartment ventilation airflow pressure and temperature were varied to simulate a variation in altitude and ram air pressure. Combat damage simulation included inflow with ambient temperature, simulating outer compartment wall penetration and inflow at elevated temperature simulating fan case perforation or engine bleed air line damage.

The length of time between ignition and agent release was found critical, particularly when ventilation air pressure greater than sea level ambient was simulated. The existing Halon 1301 specifications were found to be adequate but a revision is proposed to encourage actual agent release tests with high realism for all planned flight conditions, discourage the use of Halon 1202 and include survivability/vulnerability considerations.

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Block 11 (continued)

TITLE: Fire Extinguishing Agent Evaluation in the Aircraft Engine Nacelle Fire
Test Simulator.

PREFACE

This is a final report of work conducted under F33615-84-C-2431 and submitted by Boeing Advanced Systems, Seattle, Washington for the period January 1985 through March 1987.

Program sponsorship and guidance were provided by the Fire Protection Branch of the Aero Propulsion Laboratory (AFWAL/POSF), Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, Under Project 3048, Task 07, and Work Unit 94. Robert G. Clodfelter was the Project Engineer. The Joint Technical Coordination Group on Aircraft Survivability (JTCG/AS) also provided funds to support this effort.

The work partially satisfies the requirements of Task III of the contract, AEN (Aircraft Engine Nacelle) Test Requirements. In general, the task requires utilization of the AEN fire test simulator to establish the fire initiation, propagation, and damage effects exhibited by aircraft combustible fluids under representative dynamic operational environmental conditions, followed by the evaluation and development of protection measures. This is the third report submitted to date under Task III. The other reports under this task include the following:

Document Number	Title
AFWAL-TR-87-2004	Effects of Aircraft Engine Bleed Air Duct Failures on Surrounding Aircraft Structure
AFWAL-TR-87-2089	Optical Fire Detector Testing in the Aircraft Engine Nacelle Fire Test Simulator
AFWAL-TR-88-2031	Advanced Air Separation Module Performance Evaluation
AFWAL-TR-88-(tbd)	Hot Surface Ignition Testing in the Aircraft Engine Nacelle Fire Test Simulator (this document to be released about 1 Oct. 1988)

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1.0 INTRODUCTION

Because an aircraft engine compartment contains a variety of combustible fluids, air and numerous ignition sources, fire can be a major hazard. The variables affecting the threat of engine compartment fires are complex. They include the type of fuel and its temperature, pressure, and method of introduction; the direction, velocity, temperature and density of the ventilation airflow; the temperature, shape, size material and surface conditions of hot surfaces within the compartment; and the nature and location of potential electrical arcs.

1.1 Background

The current approach to fire protection in the engine compartments of Air Force multi-engined aircraft is the use of a Halon 1301 system designed to comply with MIL-F-87168 (USAF) which is based on MIL-E-22285. This specification defines the quantity of agent based on compartment size, roughness and ventilation airflow rate and specifies that at least a 6-percent concentration (by volume) must exist for 0.5-second in all parts of the compartment following agent release.

The chemical reactions involved in engine compartment fires and their interaction with extinguishants are complex and extremely difficult to model analytically. The number of chemical reactions possible is very large and the combustion process is influenced by the combustibles involved, the temperature field, local airflow velocities, engine compartment materials and a variety of other factors. Combat damage can further complicate the situation by changing airflow patterns and providing additional ignition sources. The Aircraft Engine Nacelle Fire Test Simulator (AENFTS or AEN) was designed and constructed at Wright-Patterson Air Force Base to allow realistic testing of these complex variables.

Earlier testing in the AENFTS (Ref. 1) conducted under contract F33615-78-C-2063 included fire and extinguishant concentration tests conducted using a simulated portion of the F-16 aircraft engine compartment. Combat damage simulation included outer compartment wall penetration allowing either inflow or outflow of ventilation airflow through an external wound and perforation of the fan case or engine bleed air line damage. "Standard" fire and agent concentration test techniques were developed.

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We found that MIL-E-22285 was generally adequate in terms of quantity of extinguishing agent. Results also indicated that more rapid agent release resulted in more effective use of the agent. Halon 1301 performed better than Halon 1202 in these tests, contrary to what the available literature indicated. Fires with simulated combat damage inflow were the most difficult to extinguish because hot surface ignition sources were created soon after the test fire was ignited. For these, the quantity of agent specified would have been adequate only if the agent reached the fire within a few seconds after ignition.

1.2 Objective and Approach

Tests conducted in the current study addressed four questions which arose during the analysis of the data acquired during earlier AENFTS testing:

Would the extension of flight conditions into high altitude and high Mach number regimes cause engine compartment fires to be more difficult to extinguish?

Why was the performance of Halon 1202 inferior to that of Halon 1301?

Would the storage of agent at low temperatures, as in sustained high altitude flight, have influenced performance?

Would changes in agent discharge dynamics have provided different results?

Prior to testing, damage to the F-16 nacelle simulator, which had occurred during the previous fire tests, was repaired so that comparable test results might be obtained. In addition, an improved Halon fill and dump system was developed to allow more precise agent measurement and better control over agent fill ratio and temperature.

1.3 Summary of Test Results

During earlier AENFTS tests, we found that the requirements of MIL-E-22285 were conservative in most situations. However, during the current program a number of additional situations were identified where agent quantities, as specified by MIL-E-22285, were inadequate. These generally resulted from hot surface

reignition and included flight conditions with elevated ventilation air pressure and temperature. In the majority of these cases, the agent appeared to extinguish the fire, but reignition occurred usually before the fuel injection was terminated.

Fire and agent concentration tests revealed that Halon 1202 was less effective than Halon 1301 because of poor distribution characteristics resulting from the low vapor pressure of Halon 1202. This was particularly true when Halon 1202 was discharged into low temperature ventilation air.

2.0 TEST FACILITIES

2.1 AENFTS Facility

The AENFTS is a ground test facility designed to simulate the fire hazards which exist in the annular compartment around an aircraft engine. The AENFTS is installed in I-Bay of Building 71-B, Area B, Wright-Patterson Air Force Base, Ohio. This facility includes air delivery and conditioning equipment designed to simulate engine compartment ventilation airflow, a test section within which fire testing can safely be conducted, and an exhaust system which can cool the combustion products and scrub them sufficiently to allow their release into the atmosphere. In addition, it includes a gas fired heating system to provide simulated engine bleed air to the test section (Figure 1).

The test section of the AENFTS (Figure 2) is a two-radian (114 degree) segment of the annulus between a 15-inch-radius duct, which simulates an engine case, and a 24-inch-radius duct, which simulates the engine compartment outer wall. The test section is approximately 14 feet long and is equipped with access ports and viewing windows that are provided for access to test equipment and instrumentation and for observation of the test activities taking place within.

As shown in Figure 1, the AENFTS ventilation airflow conditioning systems include a blower that provides air at atmospheric pressure (to simulate low speed sea level flight conditions), a high pressure compressor and air storage bottle farm to provide ventilation airflow simulating ram pressure in low altitude supersonic flight conditions and an air driven ejector (to evacuate the test section to simulate high altitude flight conditions). The shorter curved test section wall, which simulates the case of a turbojet or turbofan engine, can be heated with radiant heaters.

Simulation of the hazards associated with hot engine bleed ducts and the leakage that might result from damage to bleed ducts or the engine case is provided by the AENFTS bleed air heating system. A natural gas fired heater, mounted on the roof over the AENFTS test cell, heats incoming high-pressure air from the bottle farm and provides automatic control over flowrate and temperature. Temperatures from ambient up to 1500°F can be simulated at flowrates up to 1-pound per second. An insulated flex duct delivers this heated simulated engine bleed to the AENFTS test section.

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BLEED AIR HEATING

SCRUBBING

AIR STORAGE BOTTLE FARM

COMPRESSOR

DRYER

HIGH PRESS. MEAS'M'T & CONTROL

GLYCOL COOLING

ATMOSPHERIC BLOWER

RADIANT HEATERS

DUCT HEATERS

TEST SECTION

EJECTOR

QUENCH
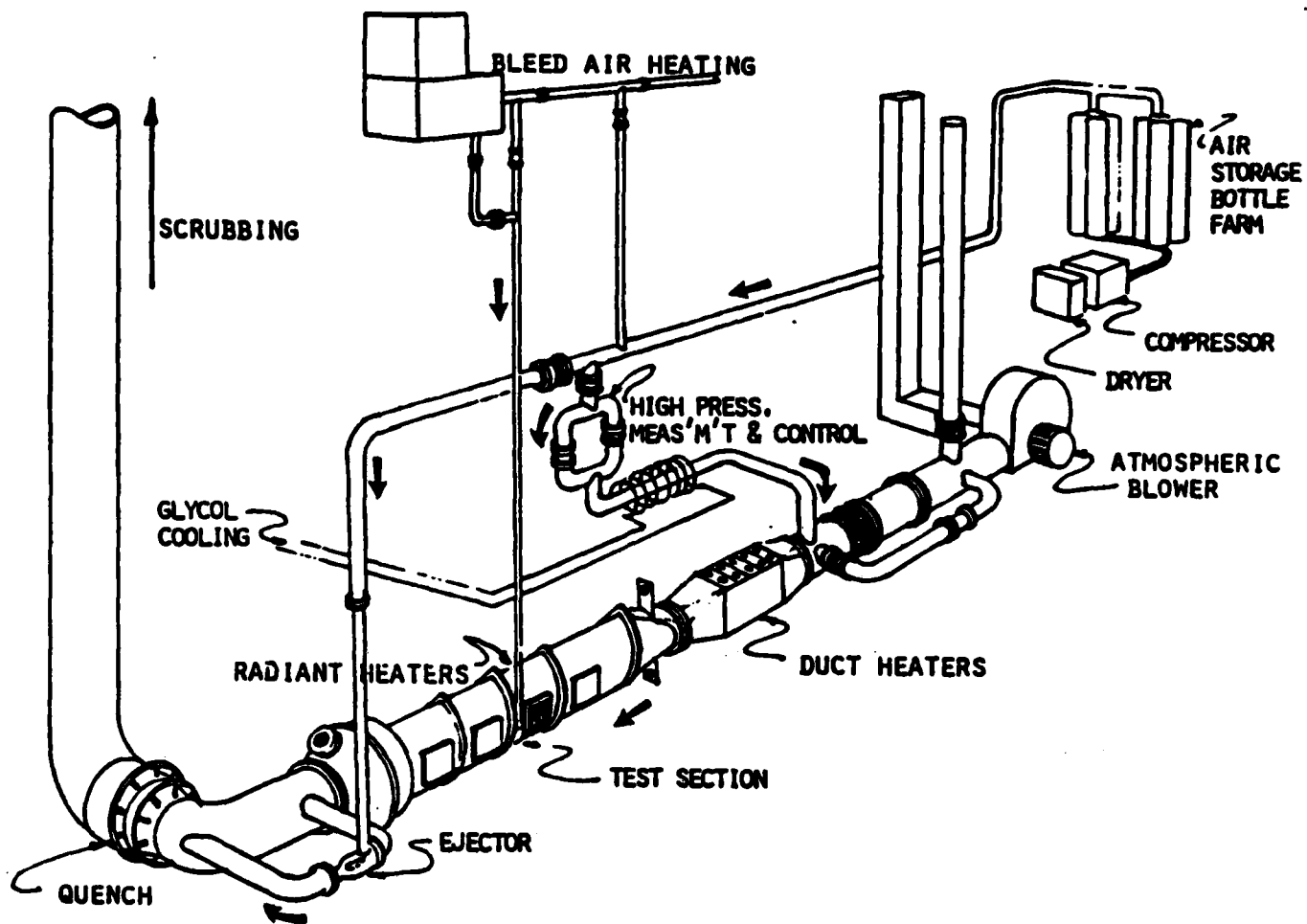
(ARROWS INDICATE AIRFLOW DIRECTION)

Figure 1. Components of the AENFTS

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VENTILATION

AIRFLOW IN THE TEST SECTION SIMULATES NACELLE VENTILATION. PRESSURE, TEMPERATURE AND VELOCITY CAN BE ADJUSTED TO SIMULATE VARIOUS FLIGHT CONDITIONS.

ENGINE HEAT

RADIANT HEATERS SIMULATE HEATING FROM FAN CASE

ALTITUDE

EJECTOR DOWNSTREAM OF TEST SECTION CAN BE USED TO REDUCE STATIC PRESSURE IN TEST SECTION TO SIMULATE ALTITUDE.

37" TYP 3 PLCS.

ACCESS PORT TYP 4 PLCS.

Figure . 2. AENFTS Test Section

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2.2 Instrumentation

Basic AENFTS instrumentation consisted of the sensors employed to measure the various flowrates, the test section temperatures and pressure and the fuel reservoir and nozzle pressures (Figure 3). Twenty-two pressure transducers were used to acquire AENFTS pressure data. Their calibration was periodically checked using a dead weight tester. Details of the transducer ranges, sensitivities and accuracies are included in Table 1. Thermocouples were employed to measure air temperatures at the various flowmeters and air and surface temperatures in the AENFTS test section. They are identified by type, location and parameter name in Table 2.

To measure the agent concentration, six stainless steel probes were installed in the test section connected to six channels of Beckman model LB-2 Medical Gas Analyzers. As shown schematically (Figure 4), each of these six units consisted of a pickup head and a console containing a vacuum pump. These units were calibrated to directly measure halon volumetric concentration in the AENFTS test section.

The pickup head contained a dual beam NonDispersive InfraRed (NDIR) analyzer, a sample cell, a reference cell, a mechanical chopper and a variable capacitance pneumatic detector. A gas sample drawn through the sample cell and the detector responded to the difference between an InfraRed (IR) beam projected through the sample cell and a similar beam projected through the reference cell. The IR absorption of the gas sample determined the gas concentration. Signal conditioning in the pickup head converted the detector output to a voltage signal which was sent to the console unit.

The console unit contained a vacuum pump along with a visible flow meter and flow adjustment control. It also contained signal conditioning to convert the pickup head preamplifier output voltage to a voltage representative of the actual Halon concentration.

System response time, as installed, was about 150 milliseconds. Accuracy was determined through repeated calibrations with a known "calibration" mixtures of Halon 1301 or Halon 1202, as required. These units reliably provided concentration data which was accurate to within ± 0.1-percent, by volume.

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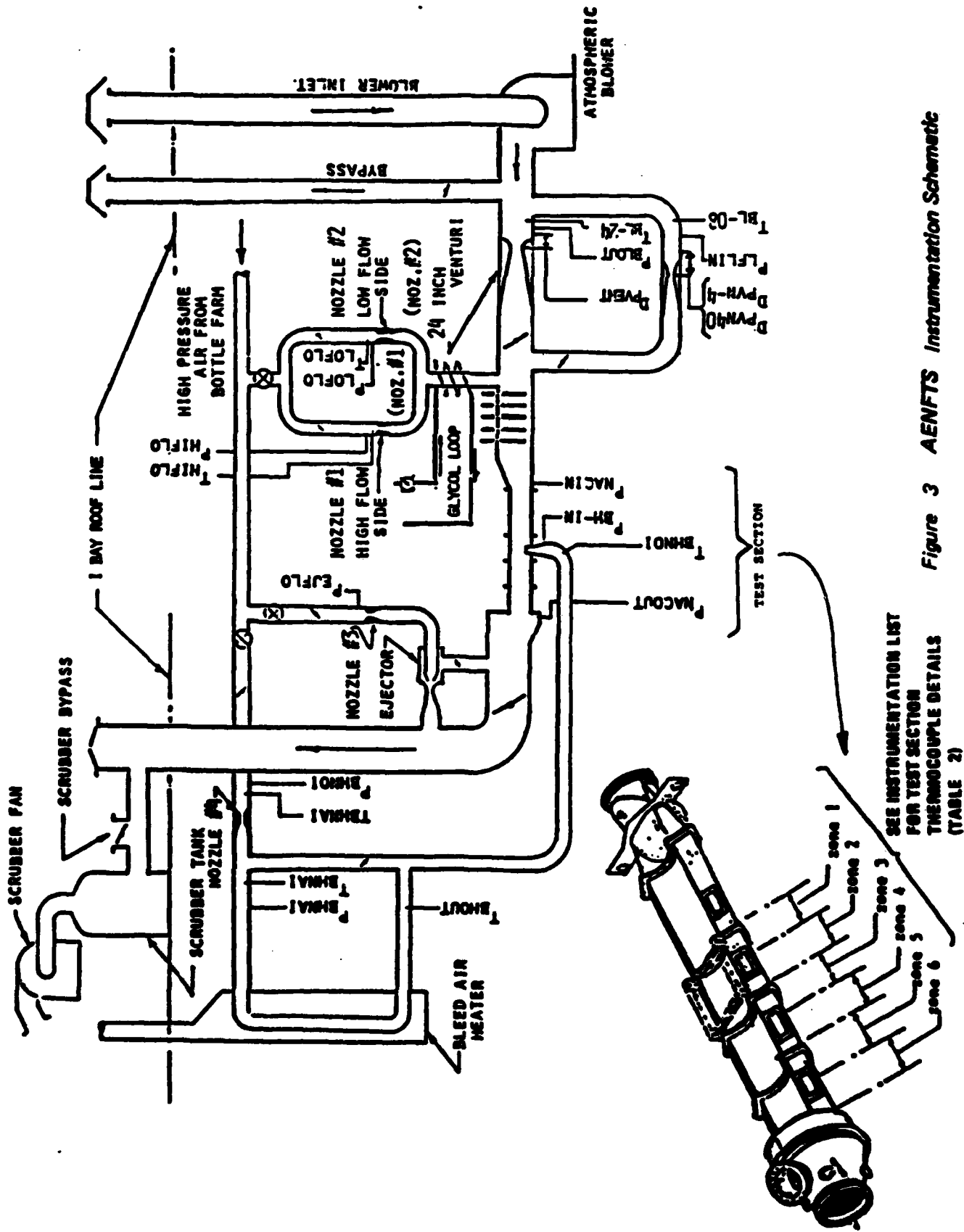
Figure 3 AENFTS Instrumentation Schematic

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Table 1. Details of AENFTS Pressure Measurement

PRESSURE NUMBER	MODCOMP CHANNEL	SOFTWARE SYMBOL	ITEM DESCRIPTION	MFG&S/N	RANGE	ACCURACY[a]
PT-1	57	PBLOUT	Blower outlet press	S-34212	0-50 in. H2O	+0.25
PT-2	69	DPVENT	24" venturi delta P	S-33659	0-60 in. H2O	+0.5
PT-4	59	PMACIN	AEM inlet press	S-34214	0-30 psia	+0.25
PT-5	60	PEXFAN	Scrubber inlet press	S-27984	0-16 in. H2O	+0.25
PT-6	61	PHIFLO	Hi press/hi flow nozzle press		0-1000 psia	+0.25
PT-7	62	PLOFLO	Hi press/lo flow nozzle press		0-643 psia	+0.25
PT-8	63	PEJPLO	Ejector nozzle press		0-500 psia	+0.25
PT-9	64	PMCOUT	AEM outlet press		0-30 psig	+0.25
PT-10	65	P-STOR	High press line press		0-2500 psig	+0.25
PT-11	66	P-FUEL	Fuel reservoir press	S-34218	0-420 psig	+0.5
PT-12	67	P-HYD	Hydraulic reservoir		0-5000 psig	+0.25
PT-13	68	PBAROM	Barometric press	S-40737	26-32 in.Hg	+0.25
PT-14	78	PNSFUL	Fuel nozzle press	S-48291	0-500 psig	+0.25
PT-15	77	PNSHYD	Hydraulic fluid nozzle press		0-5000 psig	+0.25
PT-16	79	PLFLIN	8" venturi inlet press	S-50823	0-5000 psig	+0.25
PT-17	51	DPVN-4	8" venturi delta P	M-21784-1	0-4 in. H2O	+0.15
PT-18	50	DPVN40	8" venturi delta P	M-21784-2	0-40 in. H2O	+0.15

Manufacturers: S: Sensotec
M: MKS
ST: Setra

[a]Percent of full scale reading

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Table 2. Details of AENFTS Temperature Measurement

| THERMO-COUPLE NUMBER	MODCOMP CHANNEL	SOFTWARE SYMBOL	DESCRIPTION	TYPE	ACCURACY
TC-28	1	TENG1A	Engine side skin temp zone 1	K	+4 degrees F.
TC-29	2	TENG1B	Engine side skin temp zone 1		
TC-30	3	TENG2A	Engine side skin temp zone 2		
TC-31	4	TENG2B	Engine side skin temp zone 2		
TC-32	5	TENG3A	Engine side skin temp zone 3		
TC-33	6	TENG3B	Engine side skin temp zone 3		
TC-34	7	TENG4A	Engine side skin temp zone 4		
TC-35	8	TENG4B	Engine side skin temp zone 4		
TC-36	9	TENG5A	Engine side skin temp zone 5		
TC-37	10	TENG5B	Engine side skin temp zone 5		
TC-38	11	TENG6A	Engine side skin temp zone 6		
TC-39	12	TENG6B	Engine side skin temp zone 6		
TC-40	13	TAIR-1	Nacelle air temp zone 1		
TC-41	14	TAIR-2	Nacelle air temp zone 2		
TC-42	15	TAIR-3	Nacelle air temp zone 3		
TC-43	16	TAIR-4	Nacelle air temp zone 4		
TC-44	17	TAIR-5	Nacelle air temp zone 5		
TC-45	18	TAIR-6	Nacelle air temp zone 6		
TC-46	19	TNAC1A	Nacelle side skin temp zone 1		
TC-47	20	TNAC1B	Nacelle side skin temp zone 1		
TC-48	21	TNAC2A	Nacelle side skin temp zone 2		
TC-49	22	TNAC2B	Nacelle side skin temp zone 2		
TC-50	23	TNAC3A	Nacelle side skin temp zone 3		
TC-51	24	TNAC3B	Nacelle side skin temp zone 3		
TC-52	105	TF16-1	Test article temp #1		
TC-53	106	TF16-2	Test article temp #2		
TC-54	107	TF16-3	Test article temp #3		
TC-55	108	TF16-4	Test article temp #4		
TC-56	109	TF16-5	Test article temp #5		
TC-57	110	TF16-6	Test article temp #6		
TC-58	111	TF16-7	Test article temp #7		
TC-58	31	TOUTLG	Nacelle outlet air temp (long)		
TC-59	32	TOUTSH	Nacelle outlet air temp (short)		
TC-60	33	TNACIN	Nacelle inlet air temp	K	
TC-61	34	TBL-08	Low flow venturi temp	T	
TC-62	35	TBL-24	Blower outlet temp	K	
TC-63	35	T-NIFL	Hi flo/Hi press temp		
TC-64	37	TSTKLO	Lower exhaust stack temp		
TC-65	38	TSTKUP	Upper exhaust stack temp		
TC-70	39	OATPAD	Pad outside air temp		
	40	OAT-RF	Roof outside air temp		
	41	TNACRM	Nacelle room air temp		
	43	T-NPAD	North pad temp	K	
	44	RTDREF	Reference room temp	T	
TC-72	45	TGLYCO	Cold glycol temp	J	
TC-74	47	T--HYD	Hyd. reservoir temp	J	
TC-75	46	T-FUEL	Fuel injection reservoir temp	J	
TC-91	94	TLOFLO	Lo-flo/Hi-press temp	T	+4 degrees F

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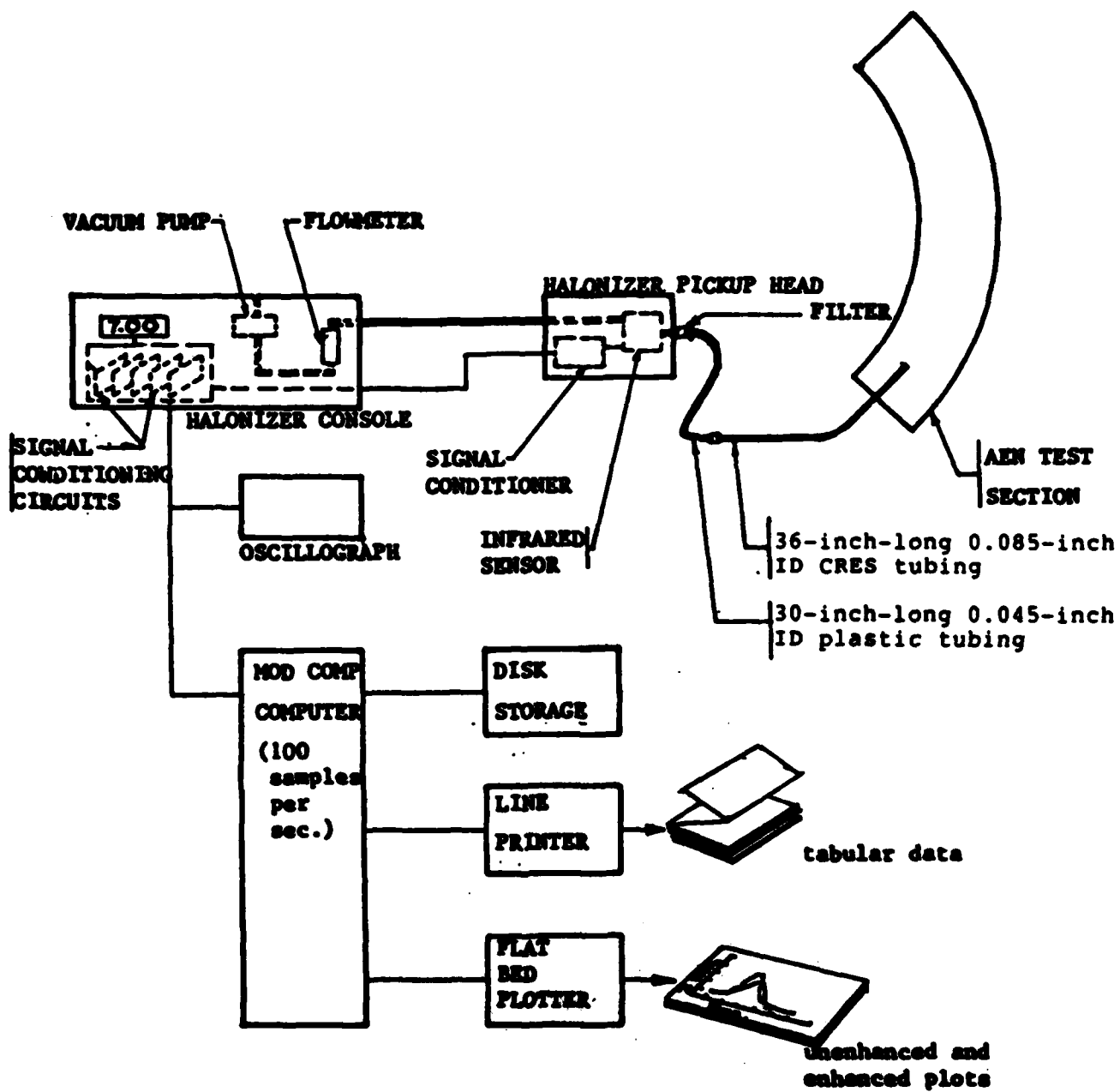
Figure 4. Schematic Diagram of Beckman Halonizer Equipment

A closed circuit TV camera with a zoom lens was mounted on a tilt and pan mechanism on the top of the fuel cart. During fire tests, the camera was focused on the viewing window in the test section adjacent to the test fire zone. Its output signal was observed on a TV monitor on the AENFTS control panel to allow the test operator to observe fire tests, assure safe conduct of the test and evaluate the effectiveness of the extinguishant. A Video Cassette Recorder (VCR) received and recorded the signal from the TV camera.

2.3 Data Acquisition and Reduction

AENFTS test data consisted of temperatures, pressures and agent concentrations which were measured by sensors in the test cell and sampled, digitized, averaged, and calibrated by the facility computer system, a 16-bit, general purpose, digital computer manufactured by Modular Computer Systems Inc. (ModComp) of Ft. Lauderdale, Florida. These data included flowrates calculated by the computer, the test run and condition number information used to identify each test event, and the manually recorded information concerning the effectiveness of the various extinguishants. In addition, video cassette records were made of the fire tests.

Each time the data acquisition switch on the AENFTS console was operated, the ModComp acquired digital millivolt data 100 times during a 3.2-second period for all AENFTS channels. These 100-millivolt values were first averaged and then converted to engineering unit data using appropriate pressure and thermocouple calibration information. This information was immediately used to update the AENFTS operating console terminals as well as being sent to the line printer and logged onto the data disk.

When Halon concentration data were acquired, operation of the Halon dump valve switch on the control panel caused the computer to acquire a 2-second record, at approximately 100 samples per second, for each of the six analog channels of Halon concentration information coming from the Beckman Halonizers. These data were digitized and converted to concentrations using appropriate calibrations for Halon 1202 and Halon 1301. These 200 concentration values for each of the six channels were then stored on the data disk for off-line use as well as being printed on the line printer. Quick-look analog agent concentration data were also recorded using a Honeywell Visicorder.

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Subsequent to the completion of the test work documented herein, comparison of agent concentrations obtained with similar quantities of Halon 1201 and Halon 1301 led to the conclusion that the agent concentrations measured with Halon 1202 were often too high and that the duration of these concentrations was probably too long. Details of this analysis are included in paragraph 5.5.1 and Appendix E. It was deduced that liquid droplets of Halon 1202 were accumulating in the sample lines, a problem not experienced with Halon 1301 because of its higher vapor pressure. Even with this bias toward indicating higher concentrations than actually existed, most of the test results obtained with Halon 1202 indicated that inadequate concentrations existed at some locations or that adequate concentrations existed in some locations for too brief a time.

Once the ModComp computer had calculated engineering unit data for the thermocouples and pressure transducers at the flowmeters in the AEN, these data were used to calculate airflows and velocities in the test section. The actual data reduction equations employed are included in Appendix A. The airflow equations for the venturiis are based on the handbook (Ref. 2) and those for the sonic nozzles are based on data from their manufacturer.

The most important information acquired during all of the fire tests was whether or not the selected charge of Halon agent successfully extinguished the test fire without reignition. This information was obtained by observing the TV monitor in the control room and was hand logged on the test log sheets along with identification of volume of agent, the dump tank nitrogen pressure, ventilation flow conditions and additional observations concerning the test. Identification of the specific test video record and the video cassette used was also recorded on the test log sheets.

2.4 Fire Test Concept

For the AENFTS fire tests, the test concept employed was to model "worst case" situations in aircraft engine compartments by igniting JP-4 fuel and allowing it to burn for a predetermined period before releasing a measured agent charge into

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the compartment. Where an engine compartment extinguishing system is available on an aircraft, the timing is determined by the pilot:

o   Combustible fluid present due to leakage (a tank punctured or a line severed by combat damage, a loose fitting, a line damaged during maintenance, etc.) is ignited by a hot surface, an electrical arc, incendiary explosion, etc.) and a fire begins to burn within the engine compartment.

o   Fire detectors in the engine compartment alert the pilot by illuminating a "fire" light on the aircraft control panel. Response time varies from fractions of a second for optical detection equipment to the minutes that it might take for "fire wire" based systems to be heated by a small fire several feet from the sensor.

o   With current fire detection system reliability, the pilot would probably first attempt to determine whether the "fire" light was due to fire or was a false alarm.

o   Once convinced that the fire was real, the pilot would shut off the fuel to the affected engine and discharge agent into the affected engine compartment.

The fuel shut off provision available in most aircraft does not preclude the presence of combustible fluids in the engine compartment following its use. Hydraulic fluids, lubricating oil and fuel puddled in the bottom of the compartment and/or the residual fuel accumulated beyond the shut off valve could continue to support combustion for an extended period.

Hence it was decided to allow the fires to burn for a predetermined period prior to agent release and to continue to inject fuel for an additional 5 seconds after the agent was released into the compartment.

2.5 Test Procedure

2.5.1 <u>Fire Tests</u>

During AENFTS fire tests, a standardized procedure was followed once the pretest procedures and checklist had been completed:

1. Atmospheric blower airflow and temperature were adjusted to the desired flow conditions at the control console.

2. The technician entered the test cell, adjusted the agent dump tank volume, filled the agent sight gauge to an appropriate level and transferred the desired amount of agent into the agent dump tank. He then backcharged the remaining volume in the tank to 600 psig with nitrogen and exited from the test cell.

3. If the high pressure air system was to be employed for simulated altitude tests, high pressure tests, or combat damage inflow tests, blower flow was terminated at this time. The desired high-pressure airflow conditions were set.

4. Tabular data was recorded, the VCR was started and manual notes were logged.

5. The fuel flow and igniter were operated simultaneously, starting the test fire and the TI programmer which was employed to control the preburn period before the agent was discharged and to terminate the fuel flow after another 5-seconds had elapsed.

6. If high pressure airflow was in use, it was terminated at this time. Blower airflow was set to at least 6-lbs/sec for at least 2-minutes to cool the test article.

7. The procedure was repeated.

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2.5.2 Agent Concentration Tests

The procedure followed for agent concentration tests consisted of:

1. If the atmospheric blower was to be used, its airflow and temperature were set to match the fire test conditions being duplicated.

2. The test technician filled the agent dump tank in the same manner as for fire tests. Since there were no fires in this phase of testing, the technician remained in the AENFTS room during testing.

3. If the high pressure air system was to be employed the desired airflow conditions were set at this time.

4. Tabular data were recorded, manual notes were logged and the visicorder was started.

5. The agent dump switch was operated releasing the agent and starting the acquisition of ModComp agent concentration data.

6. If high pressure airflow was in use it was terminated at this time.

7. The procedure was repeated.

3.0 F-16 NACELLE SIMULATOR

In an actual aircraft engine compartment, the ventilation airflow does not flow uniformly as in the clean AENFTS test section. Regions of reverse flow and flow stagnation have been seen in the F-111 being tested by the Federal Aviation Administration's Technical Center (FAA/TC) and the F-111 engine compartment is cleaner and designed for higher ventilation airflow rates than the F-15 and F-16 engine compartments. To simulate a more realistic environment, having the complex of tubes, ribs, clamps, wires, and other flow disturbances of a real aircraft engine compartment, a portion of the F-16 nacelle was selected for simulation in the AENFTS during 1984.

The forward right side of the F-100 engine, as it exists in the portion of the F-16 engine compartment selected for simulation, is shown in Figure 5. A scrap early prototype F-100 engine was obtained and the components in this region were removed and installed on a 5-foot-long simulated engine side stainless steel base plate constructed to fit the engine side of the AENFTS test section (Figure 6). Intrusion into this region of the F-16's glove tank and structural ribs was simulated in sheet metal (Figures 7, 8 and 9) and fitted into the AENFTS test section over the engine side base plate. The final assembly represents one-third of the engine compartment annulus (Figure 10). The remaining AENFTS test section length, approximately 60 inches, simulated the less cluttered annulus around the afterburner.

Fused quartz viewing windows were provided in the 15-inch-square access ports on the nacelle side of the AEN. One of these opened onto the forward "arch" of the F-16 bleed duct which was the planned fire zone.

In the F-16, ventilation air enters the engine compartment through a scoop inlet on each side adjacent to the fan face of the engine and in some operating conditions, through spring loaded fire doors near the base of the engine compartment, about 18-inches aft of the scoops. These were simulated with an inlet baffle plate at the fan face location with slotted openings approximating one-third of the area of the aircraft nacelle ventilation inlets and fire doors. A baffle plate was also placed at the exit end of the last AENFTS test section to simulate the flow area in the F-16 engine compartment as the ventilation flow exits around the afterburner.
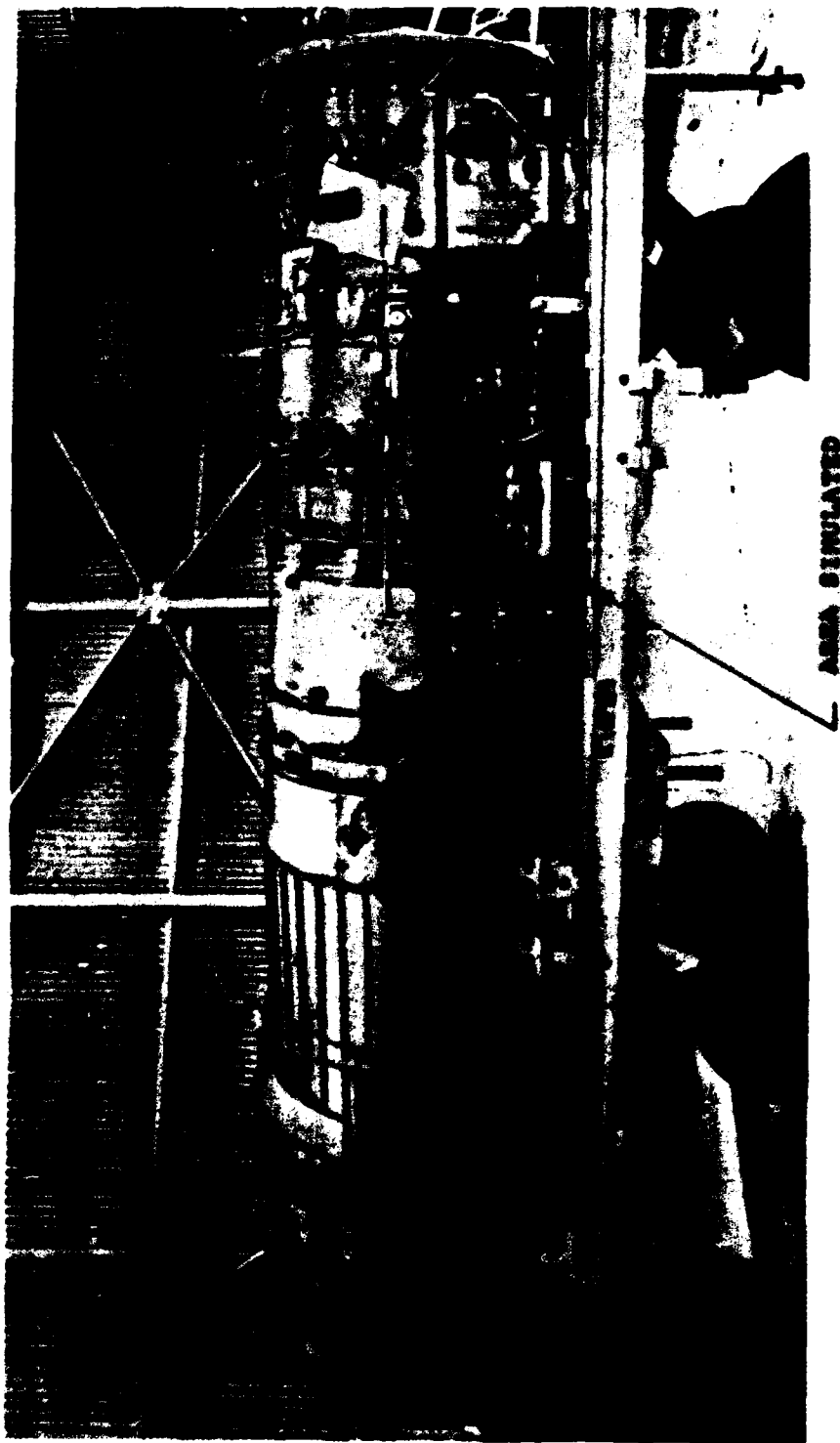
17

Figure 5. F—100 Engine Showing Accessories for F—16 Simulator

Figure 6. F-16 Simulator Engine Side

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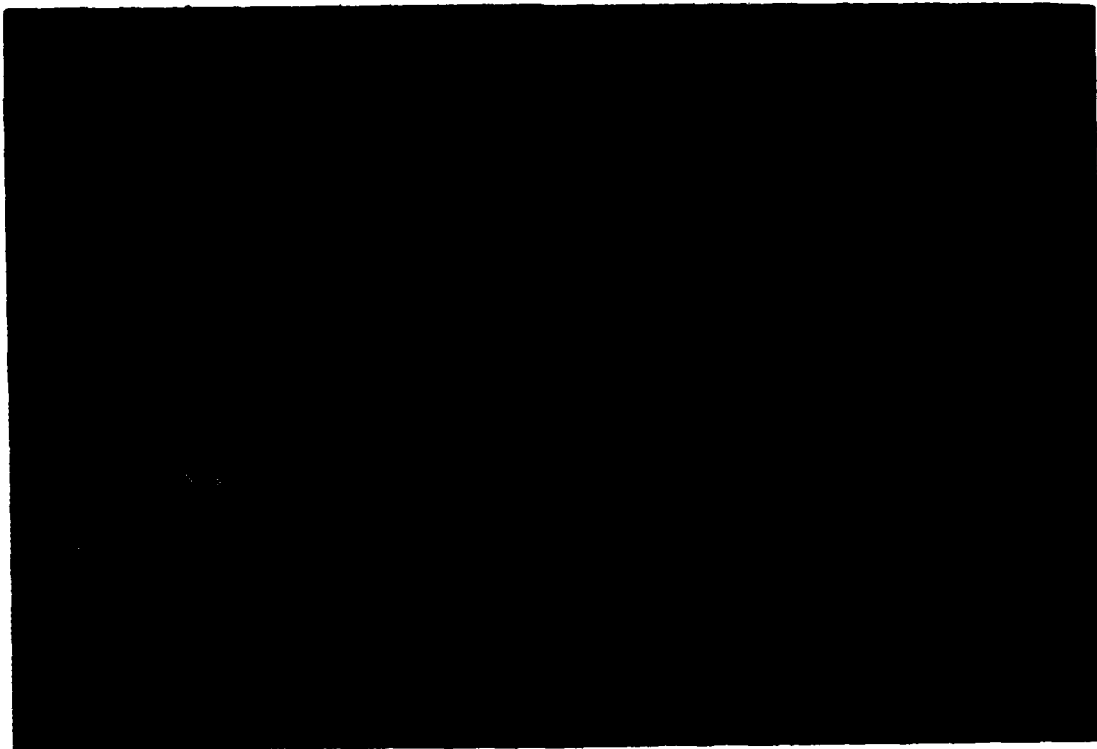Figure 7. Rear View of F-16 Simulator Prior to Installation

Figure 8. Front View of F-16 Simulator Prior to Installation
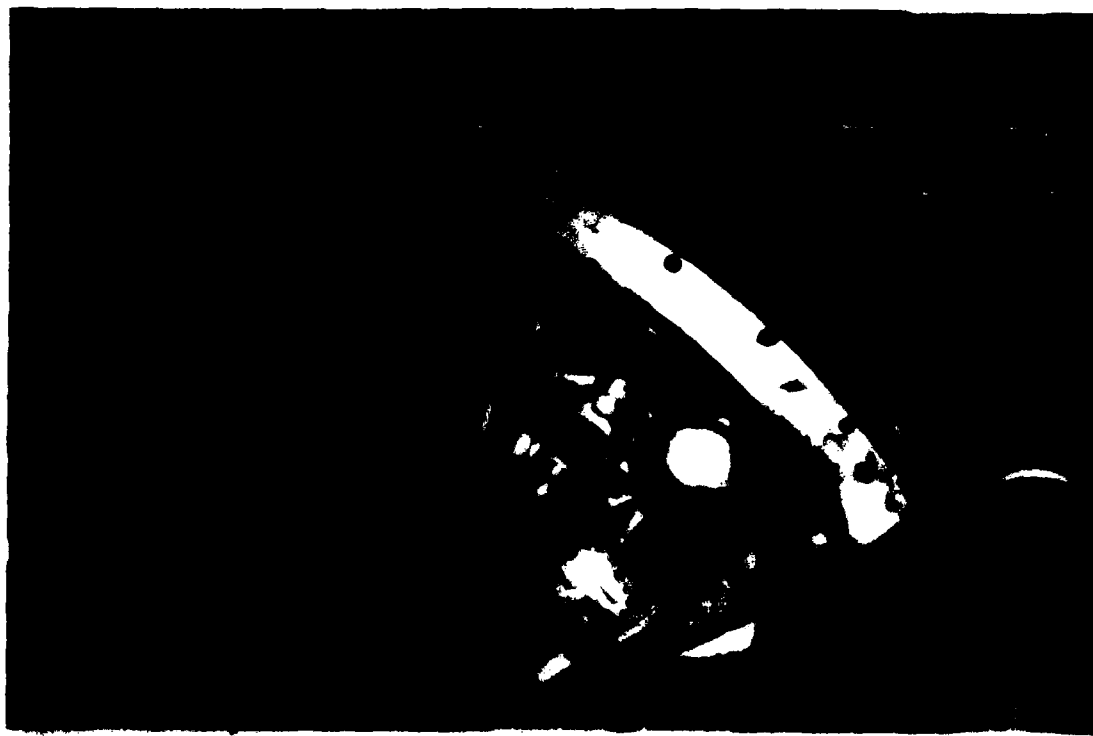
Figure 10. F-16 Nacelle Simulator Installed in AEN Test Section

Figure 9. Closeup of Fire Zone of F-16 Nacelle Simulator

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During an earlier AENFTS test program (Ref. 1), a pitot probe was employed to establish the relationship between test section airflow and lateral velocity in the vicinity of the flame holder and igniter employed in this test. The probe was traversed from the outer test section wall where the viewing window is installed to the surface of the "engine-side" of the F-16 nacelle simulator at a point approximately in the middle of the window. The velocities that were measured during this traverse (Fig. 11) varied as the probe passed behind the F-16 bleed duct and behind the rib simulating the F-16 engine compartment outer structure. Virtually no velocity was measure behind the rib and velocities as high as 160 ft/second were observed near the edge of the bleed duct. Substantial vertical components were encountered, particularly behind the rib, that could not be measured without a more sophisticated probe.

The test article had been purposely designed to provide the complex, multi-directional airflow patterns of the engine compartment. In analyzing the extinguishment of the test fires, no single velocity measurement was found which seemed appropriate in this analysis. The fires tended to extend throughout the simulator into regions with high velocity as well as those with virtual stagnation. Hence airflow, rather than velocity, was employed as the more meaningful engine compartment ventilation variable.

These earlier AENFTS tests in the F-16 simulator included fuel flow rates from 0.13- to 1-GPM and included the use of JP-4 fuel, and MIL-H-5606 and MIL-H-83282 hydraulic fluids. The current program employed only JP-4 at 0.52-GPM because these fires had consistently required the most agent for extinguishment in previous tests. The fuel injection nozzle was located in the shelter of the simulated aircraft rib structure, adjacent to the leading edge of the viewing window. A "vee-channel" flameholder was installed around the fuel nozzle.

When the agent evaluation tests were begun in August of 1985, the test fires were ignited using a high-voltage spark between electrodes placed near the fuel injection nozzle. This igniter had also been employed during the Reference 1 tests. Agent evaluation testing was interrupted in late 1985 so that the optical fire detection program reported in Reference 3 could be conducted. The spark gap igniter was found to interfere with the operation of several of the optical fire detection systems being tested. The remedy was a remote igniter consisting of a 0.75-inch diameter tube, perpendicular to and below the main viewing window, within which a propane-air mixture could be ignited by an
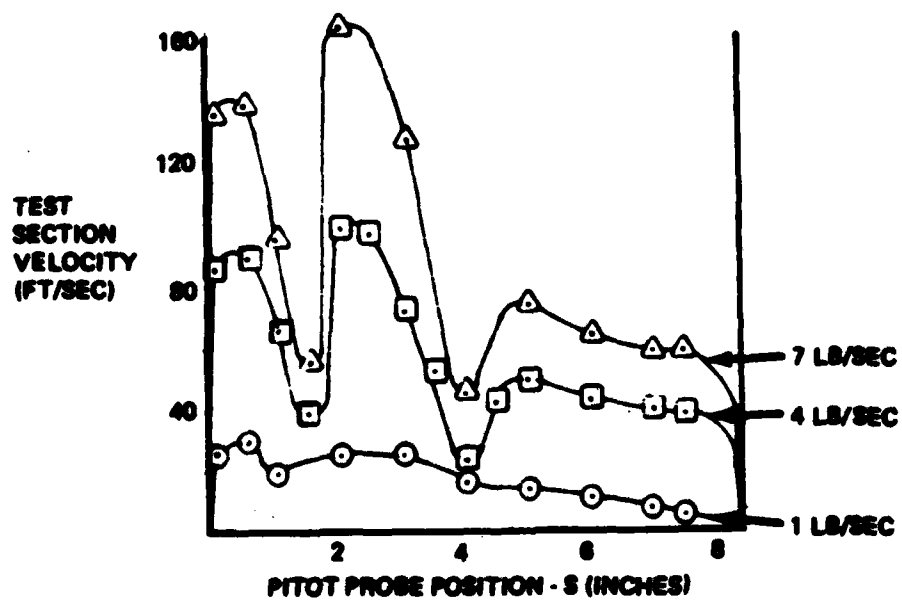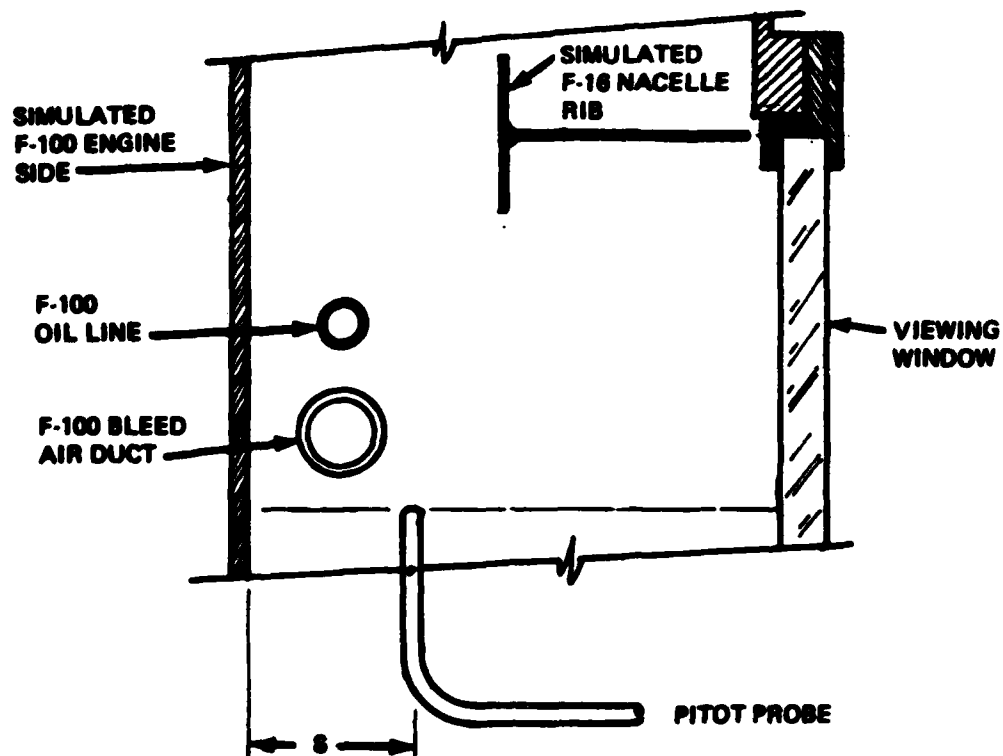
22

Figure 11. Pitot Probe Traverse of F-16 Nacelle Simulator

automotive spark plug. The burning propane was pulsed into the AENFTS test
section for a fraction of a second, once JP-4 injection was initiated. Because
no affect on the extinguishment process was anticipated, agent evaluation tests
were continued in early 1986 using the propane igniter.

Aircraft engine compartment extinguishing agent tanks are generally sized to
contain a charge of agent at least equal to that specified by MIL-E-22285:

$$W = 3 (0.02 \ V + 0.25 \ Wa) \qquad \text{For rough nacelles with high airflow}$$

<div align="center">or</div>

$$W = 0.05 \ V \qquad \qquad \text{Whichever is greater for smooth}$$
$$W = 0.02 \ V + 0.25 \ Wa \qquad \text{nacelles with any airflow, or}$$
<div align="center">rough nacelles with low airflow</div>
<div align="center">(Wa < 1-lb/sec)</div>

Where,

W = weight of Halon 1301 (pounds)

Wa = nacelle airflow (lbs/sec)

V = compartment volume (ft^3)

The compartment volume for the AENFTS with the F-16 nacelle simulator was
21.2-ft^3 (Ref. 1).

Since varying the agent charge size to find how much agent was actually required
for knockdown of the fires was employed as a means of defining the severity of
the test fires, a variable volume agent tank was developed. It employed a
piston operated by a jack screw to vary the tank size and an high-speed air-
operated ball valve to simulate the dynamics of the squib firing in a normal
tank. The tank volume was adjusted to twice that of the planned agent charge.
The agent was measured in a sight gage prior to being moved into the tank. The
tank was then backcharged with nitrogen to 600-psig. The tank and the sight-
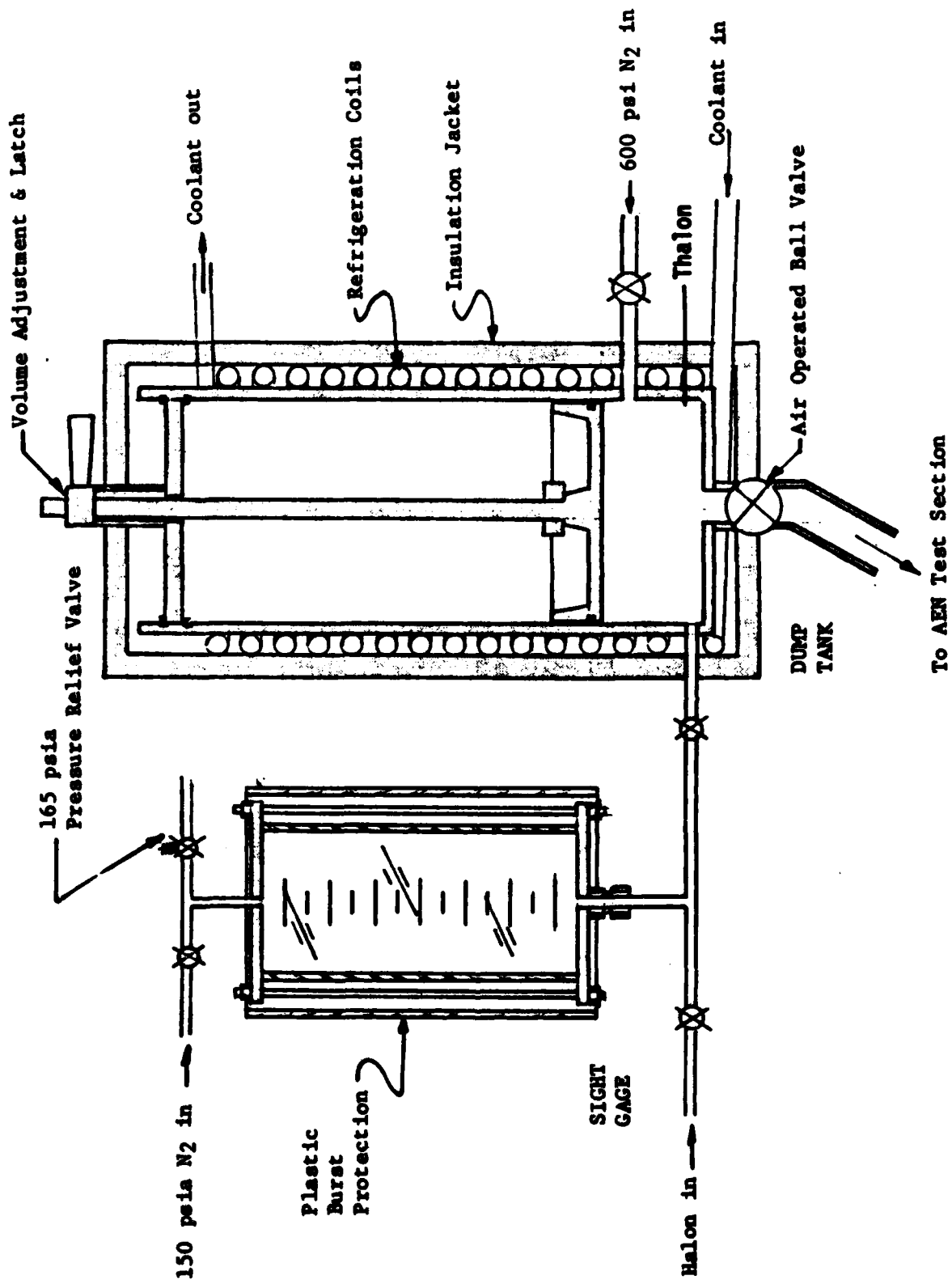gage employed in this program are shown in Figure 12.

Figure 12. Variable Volume Dump Tank for AEN Testing

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4.0 TEST RESULTS

4.1 Baseline JP-4 Fire Tests

Initially, baseline fire tests were undertaken using Halon 1301 on the 0.52 GPM JP-4 fires which had been used as the baseline in the earlier (Ref. 1) testing under contract F33615-78-C-2063. As before, a preburn period of 20-seconds was allowed before the agent was released and the fuel injection was continued for 5-seconds after the agent was released. As the test article had been completely refurbished following the Ref. 1 tests, it was anticipated that there would be some minor differences in local airflow patterns and that the amount of agent required to extinguish these fires might have changed.

However, major changes were observed (Figure 13). Where the test fires throughout the entire airflow range of 1- to 6-lbs/sec had required 0.16-pound of agent (or less) during the earlier tests, at airflows between 1.5- and 3.5-lbs/sec the fires could not be extinguished with the 2.47-pound maximum charges available with the new variable volume dump tank. These maximum charges were twice the agent quantity specified by MIL-E-22285 for this nacelle (rough nacelle with low airflow).

All of these fires appeared to be knocked down briefly but were nearly always reignited before the fuel injection was terminated. A second video camera was installed below the test section directed at a viewing window installed at the bottom of the AENFTS test section, just aft of the end of the F-16 simulator. The reignition phenomenon was studied and it was discovered that the reignition took place in the vicinity of a thermocouple lead which was "white hot" at the time that the agent was released.

When the 0.52 GPM JP-4 test fires were repeated using preburn periods of 15-seconds, we found that 0.085-pound of agent was sufficient for knockdown at all airflows, consistent with the earlier (20-second pre-burn) results (Figure 13).

4.2 Altitude and Ram Air Flow Simulations

The pumping capacity of the AENFTS ejector system (Figure 14) was reduced when 0.52 GPM JP-4 test fires were ignited. Hence, the simulated altitude tests were
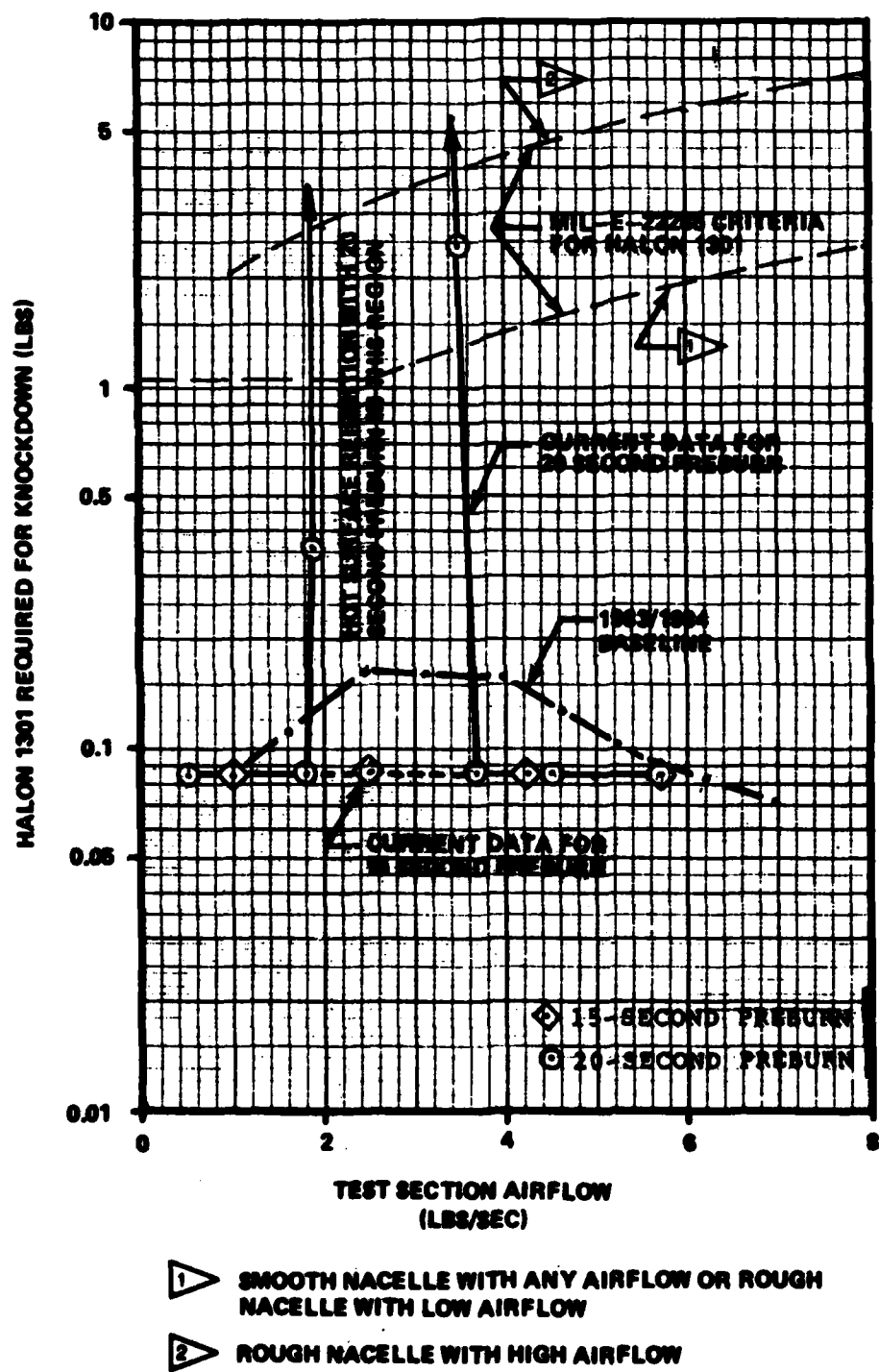
Figure 13. Quantity of Halon 1301 Required for Knockdown
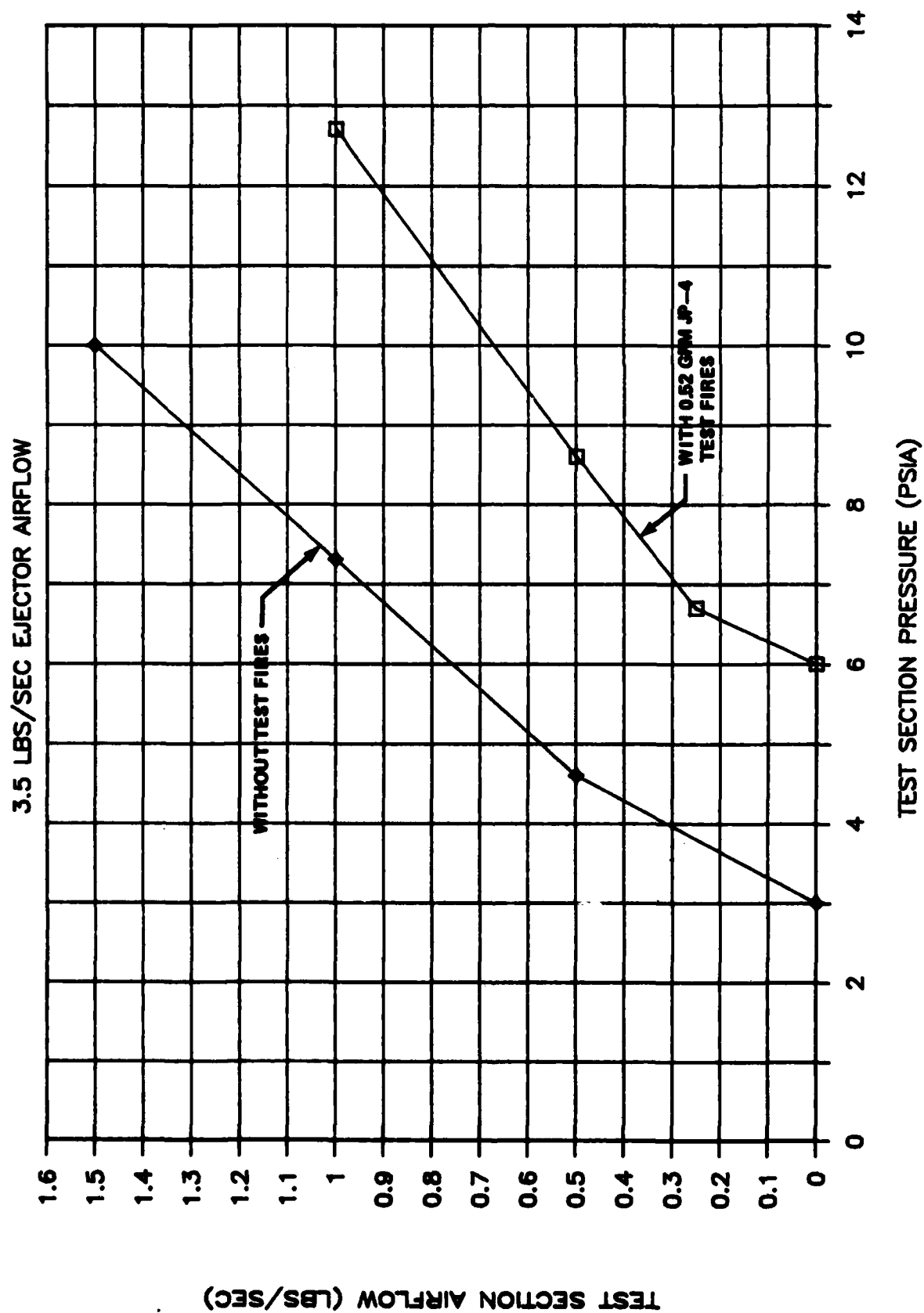of 0.52 GPM JP—4 Fires

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Figure 14. Pumping Capacity of AEN Ejector System

limited to very low airflows, 1-lb/sec and less. No combinations of airflow and reduced test section pressure were found which required more than 0.18-pound of Halon 1301, one-fifth of the agent quantity specified by MIL-E-22285 at these airflows (Figure 15). The hot surface reignition phenomena were not experienced during these tests.

When elevated test section pressures were investigated, the hot surface reignition phenomena became more pronounced than with the ambient pressure tests. Even with the preburn period reduced to 15-seconds, a region where the maximum agent charges were insufficient was again experienced. The preburn period was reduced to 12-seconds and again a minimal charge of 0.18-pound of agent was sufficient to extinguish all the test fires.

Three three-dimensional plots (Figure 16) show the amount of agent required as airflow and test section pressure were varied with preburn periods of 20-, 15- and 12-seconds. They illustrate the large region where: The fires could not be extinguished with the maximum charges available with 20 seconds of preburn; the reduction in the size of that region with 15 seconds of preburn; and its elimination with 12 seconds of preburn.

4.3 Combat Damage Simulation Tests

Additional airflow introduction due to combat damage was simulated using the AEN's bleed air system. This flow was introduced into the test section at the point where the F-16 bleed air duct would normally be clamped to the augmentor fuel pump. These tests included ambient inflow simulating inflow through a damaged skin panel, inflow heated to 424°F simulating fan case perforation and inflow heated to 1200°F simulating leakage from a damaged bleed air duct. These tests were all run with JP-4 at 0.52 GPM and with a 15-second preburn period. The results are difficult to present in terms of quantity of agent required for extinguishment as many of the test fires could not be extinguished with the maximum agent quantities available. Hence the results are tabulated in Table 3.

With the ambient temperature inflow at both 0.5- and 1.0-lbs/sec, the fires were no more difficult to extinguish than the baseline fires, and 0.085-pound of agent was sufficient in all cases. In most tests, the JP-4 fire could not be ignited with the additional airflow discharged so close to the fuel nozzle. Therefore the bleed air system was not started until the fire was ignited.
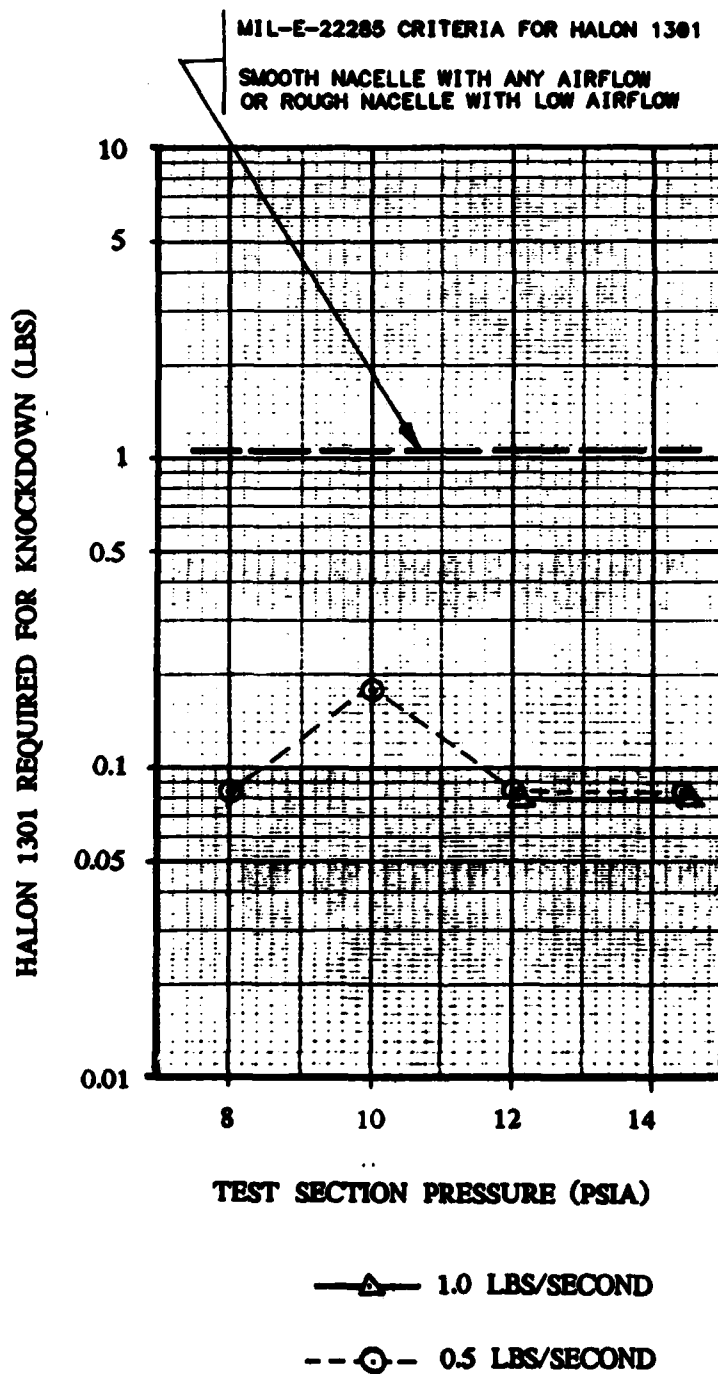
Figure 15. *Effect of Altitude on Quantity of Halon 1301 Required to Extinguish 0.52 GPM JP-4 Fires*
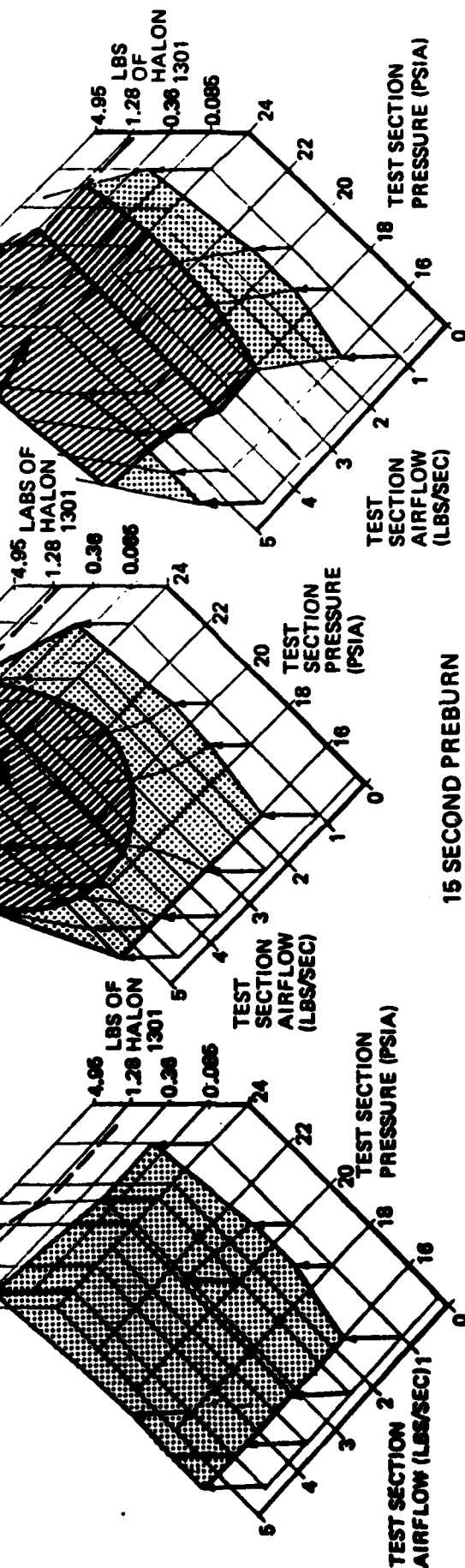
EFFECT OF PREBURN DURATION

.52 GPM JP-4 FIRES NACELLE SIMULATOR
50% HALON FILL RATIO & 600 PSIG BACK CHARGE

MIL-E22285 "SPEC" CHARGE
FOR ROUGH NACELLE WITH
LOW AIRFLOW OR SMOOTH
NACELLE WITH ANY AIRFLOW

MIL-E22285 "SPEC" CHARGE
FOR ROUGH NACELLE WITH
LOW AIRFLOW OR SMOOTH
NACELLE WITH ANY AIRFLOW

UNPROTECTED
REGIONS

MIL-E22285 "SPEC" CHARGE
FOR ROUGH NACELLE WITH
LOW AIRFLOW OR SMOOTH
NACELLE WITH ANY AIRFLOW

20 SECOND PREBURN

LARGE REGION WITHIN WHICH HOT SURFACE
REIGNITION OCCURS AND "SPEC" CHARGES
CAUSE BRIEF EXTINGUISHMENT BUT NOT
PERMANENT KNOCKDOWN

15 SECOND PREBURN

HOT SURFACE REIGNITION REGION
IS SMALLER THAN FOR 20 SECOND
PREBURN – KNOCKDOWN STILL
IMPOSSIBLE WITH "SPEC"
CHARGES ATE HIGHER PRESSURES
AND INTERMEDIATE AIRFLOWS

12 SECOND PREBURN

SMALLER THAN "SPEC" CHARGES
OF HALON 1301 SUFFICIENT TO
ACHIEVE KNOCKDOWN AT ALL
AIRFLOWS AND PRESSURE

Figure 16. High Pressure Hot Surface Reignition in F–16 Nacelle Simulator

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TABLE 3. SUMMARY OF RESULTS: COMBAT DAMAGE INFLOW FIRE TESTS

RUN/COND	DATE	AGENT (LBS)	AIRFLOW (LBS)	INFLOW (LBS/SEC)	INFLOW TEMP (°F)	KNOCKDOWN (YES/NO)
99/1	12/03/86	0.36	1	1	AMB	Y
99/2	12/03/86	0.18	1	1	AMB	Y
99/3	12/03/86	0.085	1	1	AMB	Y
99/4	12/03/86	0.085	1	1	AMB	Y
99/5	12/03/86	0.085	4	1	AMB	Y
99/6	12/03/86	0.085	6	1	AMB	Y
99/7	12/03/86	0.085	6	1	AMB	Y
99/8	12/03/86	0.085	6	1	AMB	Y
103/1	12/18/86	0.36	6.5	1	AMB	Y
103/2	12/18/86	0.36	6.5	1	AMB	Y
103/3	12/18/86	0.36	4	1	AMB	Y
103/4	12/18/86	0.36	4	1	AMB	Y
103/5	12/18/86	0.36	6.5	0.5	AMB	Y
103/6	12/18/86	0.18	6.5	0.5	AMB	Y
103/7	12/18/86	0.085	6.5	0.5	AMB	Y
103/8	12/18/86	0.085	6.5	0.5	AMB	Y
103/9	12/18/86	0.085	4	0.5	AMB	Y
103/10	12/18/86	0.36	4	0.5	AMB	Y
103/11	12/18/86	0.18	4	0.5	AMB	Y
103/12	12/18/86	0.18	4	0.5	AMB	Y
103/13	12/18/86	0.085	4	0.5	AMB	Y
103/14	12/18/86	0.085	4	0.5	AMB	Y
103/15	12/18/86	0.085	1	0.5	AMB	Y
103/16	12/18/86	0.085	1	0.5	AMB	N
103/17	12/18/86	0.085	1	0.5	424	N
103/18	12/18/86	0.18	1	0.5	424	N
103/19	12/18/86	0.69	1	0.5	424	Y
103/20	12/18/86	2.47	1	0.5	424	Y
103/21	12/18/86	2.47	4	0.5	424	Y
103/22	12/18/86	2.47	6.5	0.5	424	Y
103/23	12/18/86	2.47	6.5	0.5	424	Y

RUN/COND	DATE	AGENT (LBS)	AIRFLOW (LBS)	INFLOW (LBS/SEC)	INFLOW TEMP (°F)	INFLOW KNOCKDOWN (YES/NO)
104/1	12/19/86	2.47	6.5	0.5	424	Y
104/2	12/19/86	1.28	6.5	0.5	424	Y
104/3	12/19/86	0.18	6.5	0.5	424	N
104/4	12/19/86	0.36	6.5	0.5	424	Y
104/5	12/19/86	0.36	6.5	0.5	424	Y
104/6	12/19/86	0	1	1	424	Y
104/7	12/19/86	0.36	1	1	424	Y
104/8	12/19/86	0.085	1	1	424	Y
104/9	12/19/86	0.085	1	1	424	Y
104/10	12/19/86	0	4	1	424	Y
104/11	12/19/86	0.085	4	1	424	Y
104/12	12/19/86	0.085	4	1	424	Y
104/13	12/19/86	0.085	6.5	1	1200	Y
104/14	12/19/86	0.085	6.5	1	1200	Y
104/15	12/19/86	0.085	1	1	1200	N
104/16	12/19/86	0.69	1	1	1200	N
104/17	12/19/86	1.28	1	1	1200	N
104/18	12/19/86	2.47	1	1	1200	Y
104/19	12/19/86	2.47	1	1	1200	N
104/20	12/19/86	2.47	4	0.5	1200	Y
104/21	12/19/86	1.28	6.5	0.5	1200	Y
104/22	12/19/86	1.28	6.5	0.5	1200	Y
104/23	12/19/86	0.69	4	0.5	1200	Y
104/24	12/19/86	0.69	4	0.5	1200	Y
104/25	12/19/86	0.36	6.5	0.5	1200	Y
104/26	12/19/86	0.36	6.5	0.5	1200	N
104/27	12/19/86	0.36	4	0.5	1200	Y
104/28	12/19/86	0.36	4	0.5	1200	Y
104/29	12/19/86	0.18	6.5	0.5	1200	N
104/30	12/19/86	0.18	6.5	0.5	1200	N

ALL TESTS WITH 0.52 GPM JP-4 FIRES AND 15 SECOND PREBURN PERIOD
AEN TEST SECTION AIRFLOW AT AMBIENT TEMPERATURE AND PRESSURE
AMB = AMBIENT TEMPERATURE; THESE TESTS WERE RUN AT 100°F ±2°F

With 424°F inflow at 0.5-lb/second, simulating fan case perforation, maximum (2.47-pounds) Halon 1301 charges were inadequate at 1- and 4-lbs/sec test section airflow. The fires appeared to be knocked down but reignited within 1 to 2-seconds of the agent release, while the fuel was still being injected into the test section. With the test section airflow at 6.5-lbs/sec, 0.36-pound of agent was required with 0.5-lb/sec of 424°F inflow, twice what had been required without the inflow but still much less than the 2-pounds that MIL-E-22285 specifies at this airflow.

When the 424°F inflow was increased to 1.0-lb/sec, the test fires at 1- and 4-lb/sec were extinguished with the 0.085-pound agent charges that were required without the inflow. At 6.5-lb/sec test section airflow, the 1-lb/sec inflow extinguished the test fire without agent.

With 1200°F inflow at 0.5-lb/sec (simulating a leaking bleed air duct) 2.47-pounds of Halon 1301 were inadequate to extinguish the test fires at 1-lb/sec test section airflow but 0.36-pound was sufficient at 4- and 6.5-lb/sec. When the inflow was increased to 1-lb/sec, 2.47-pounds of agent were adequate at 1-lb/sec test section airflow, whereas the baseline 0.085-pound charge was adequate at 6.5-lb/sec.

4.4 High Temperature Ventilation Air Tests

Advanced aircraft may have engine compartment ventilating air temperatures higher than in present practice because of ram air heating in high-Mach number operation and greater heat transfer from the engine cases of turbojet and low-bypass turbofan engines. To simulate this, fire tests were undertaken in the F-16 nacelle simulator with ventilating air heated to the maximum available with the AEN's duct heaters of 500°F.

The results of these tests are illustrated in Figure 17. When the preburn period was limited to 12-seconds, the same 0.085-pound agent charge was adequate to extinguish the 0.52 GPM JP-4 fires at 1- and 5.5-lb/sec. At 4-lb/sec, 0.36-pound of agent was required, still less than one-third of that specified by MIL-E-22285.
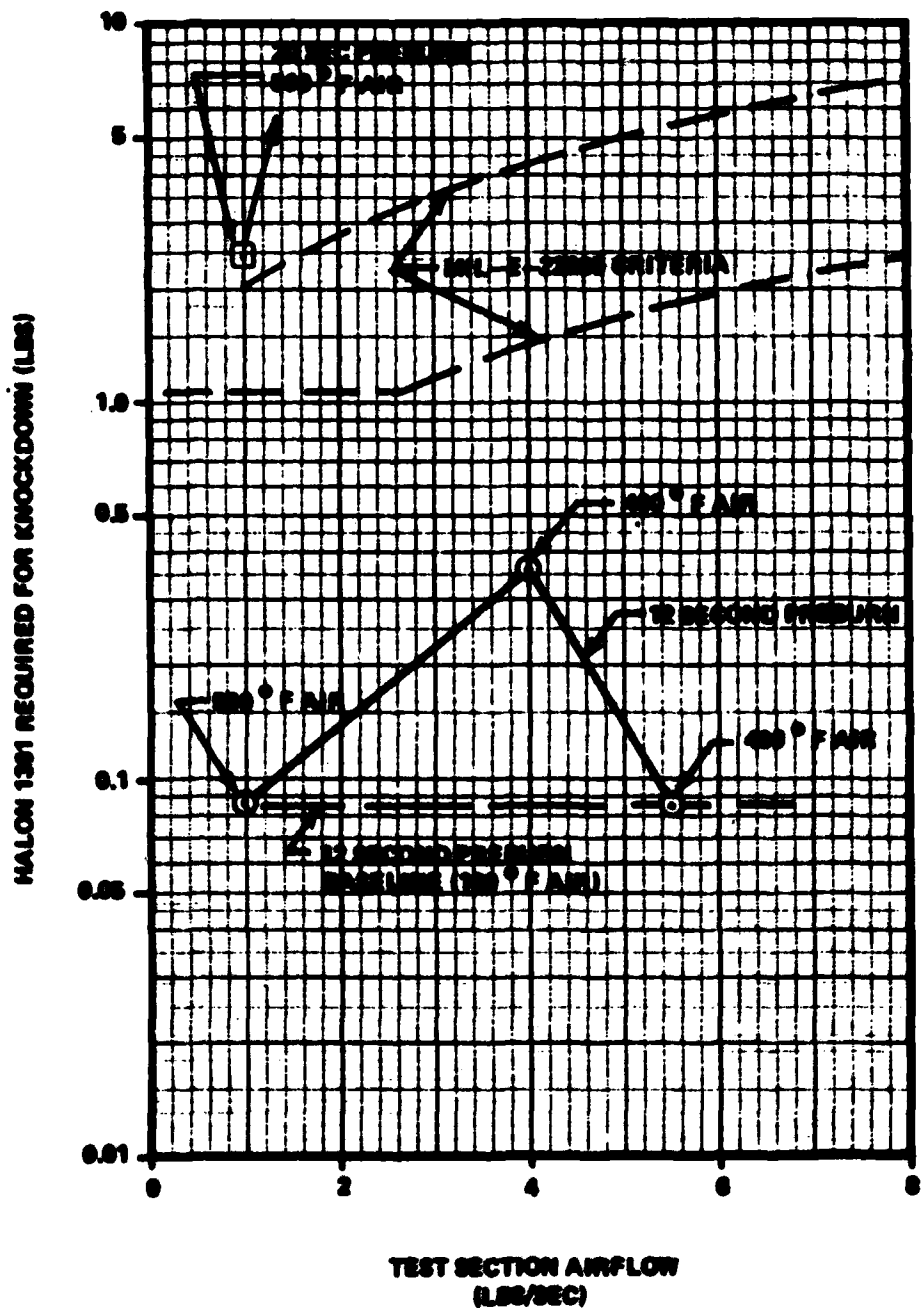
Figure 17. Effect of Ventilating Air Temperature on Quantity of Halon 1301 Required for Knockdown of 0.52 GPM JP-4 Fires

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When the preburn period was increased to 20-seconds, the maximum available 2.47-pound charge of Halon 1301 was just adequate to extinguish the fires at 1-lb/sec, while at higher airflows it was inadequate. With 100°F airflow, 0.085-pound of agent had been adequate at 1-lb/sec though at higher airflows the maximum 2.47-pound charge had also been inadequate.

4.5 Agent Distribution Dynamics Tests

4.5.1 Low Temperature Agent Tests

Agent concentration tests were run with both Halon 1301 and Halon 1202 to investigate the effect of low temperatures on agent performance. These included refrigerating the agent in the dump tank prior to agent release and using the AEN's glycol heat exchanger loop to refrigerate the test section airflow. The agent was refrigerated to about -65°F to simulate a cold soak during an extended high altitude mission. Because of the limitations of the glycol refrigeration system, the air temperature could only be reduced to -20°F.

These tests were run at test section airflows of 1, 3.5 and 6.5-lbs/sec. The quantity of Halon 1301 chosen for these tests was 0.36-pounds (5.7 cubic inches), the maximum amount which had been required to extinguish the 12-second preburn JP-4 fire tests. The same 5.7-in^3 volume was used with Halon 1202 (that amount weighing 0.4-pound).

Results of these tests are shown for Halon 1301 (Figure 18) and for Halon 1202 (Figure 19). Refrigerating the agent diminished the measured concentrations slightly for both agents. Refrigerating both the agent and the test section airflow had little additional effect on the Halon 1301 concentrations but greatly reduced the Halon 1202 concentrations.

As noted in paragraphs 2.3 and 5.5.1, there is doubt about the validity of the Halon 1202 agent concentration data because of evidence that droplets were accumulating in the sample lines. This does not decrease confidence in the above conclusion that Halon 1202 does not vaporize as well as Halon 1301 when discharged into cold ventilating air as the actual concentrations would have been even lower than indicated when droplets were present.
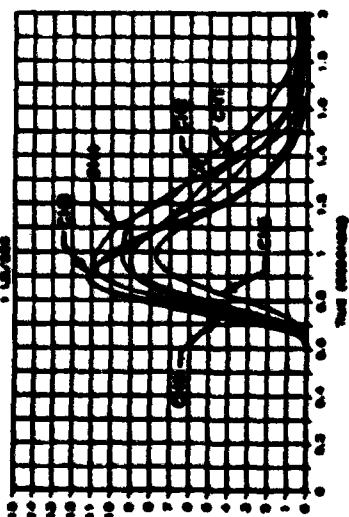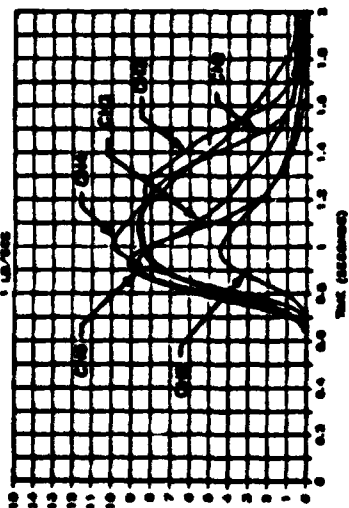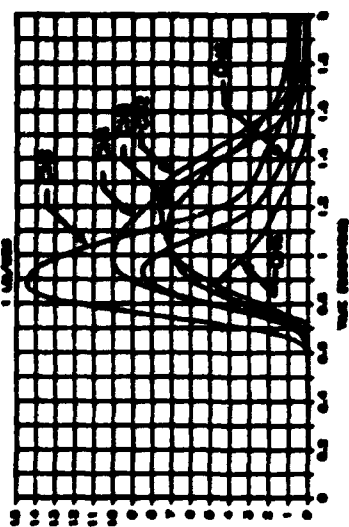
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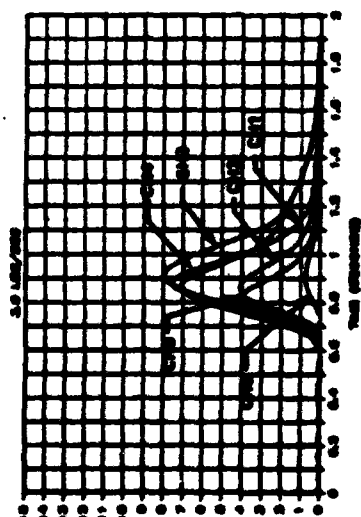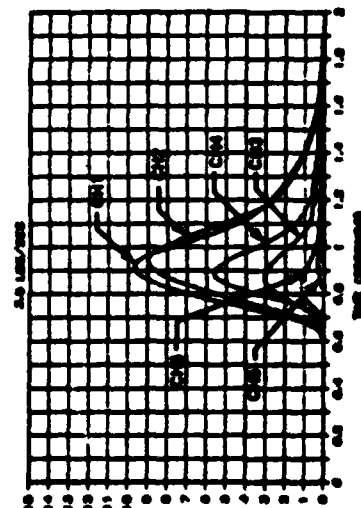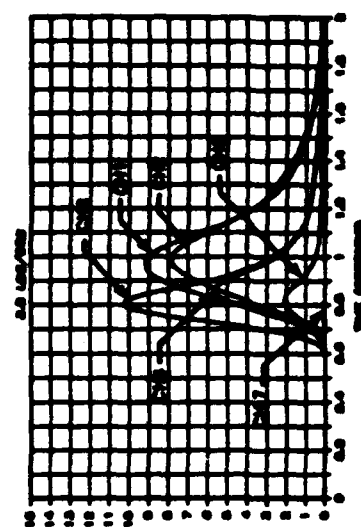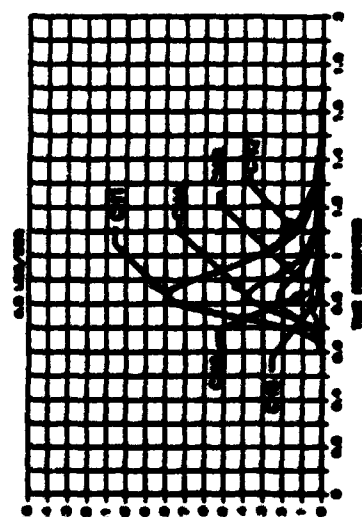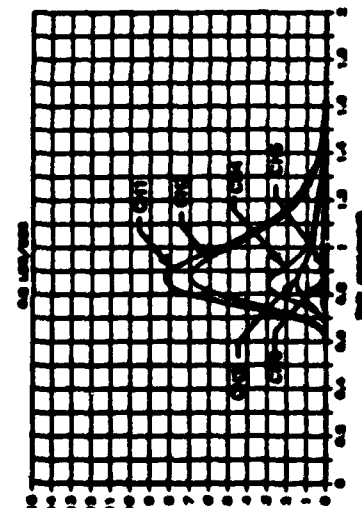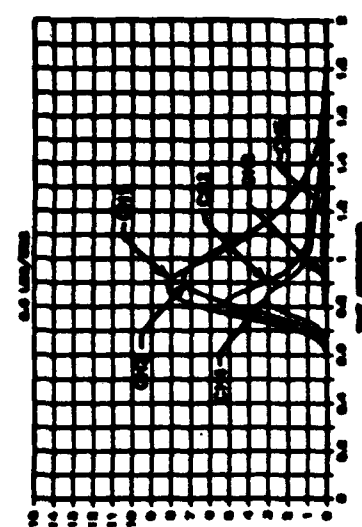
Figure 18. Effect of Tank and Air Temperature on Halon 1301 Distribution

Figure 19. Effect of Tank and Air Temperature on Halon 1202 Distribution
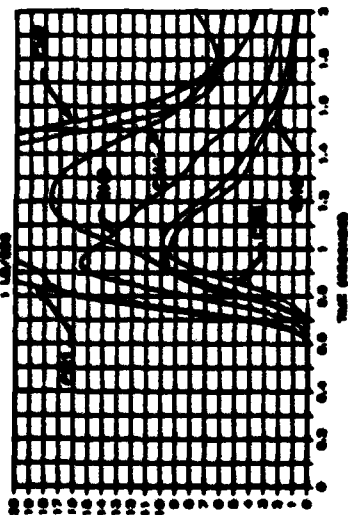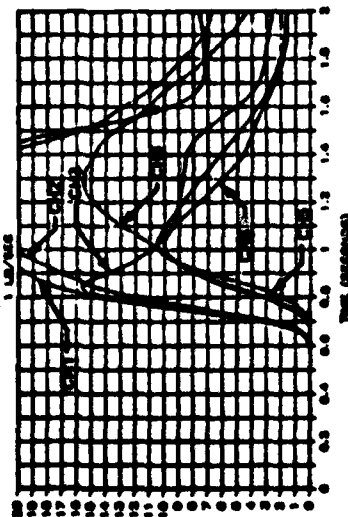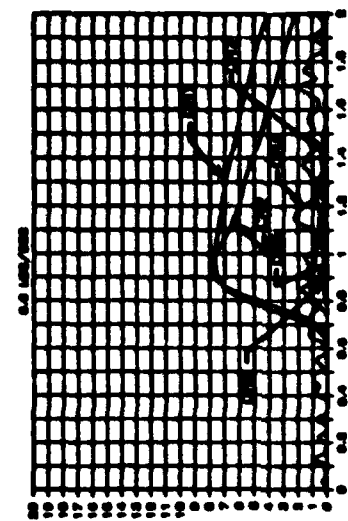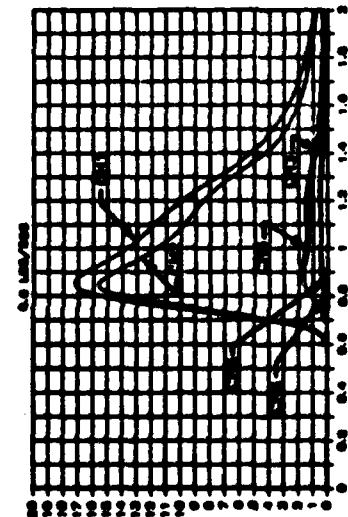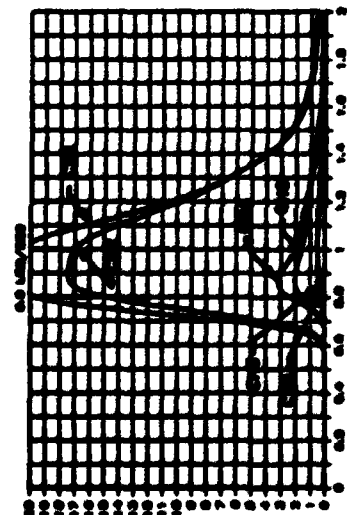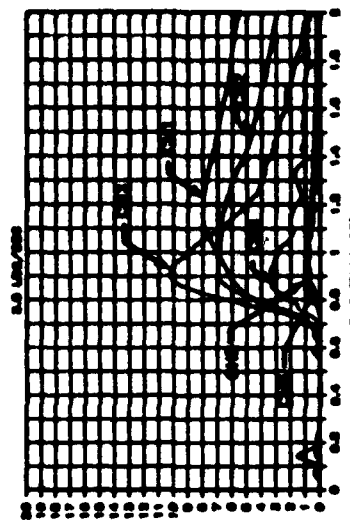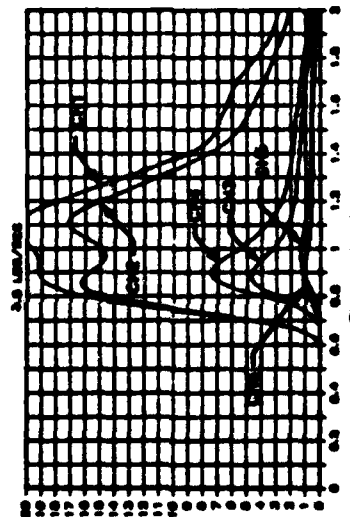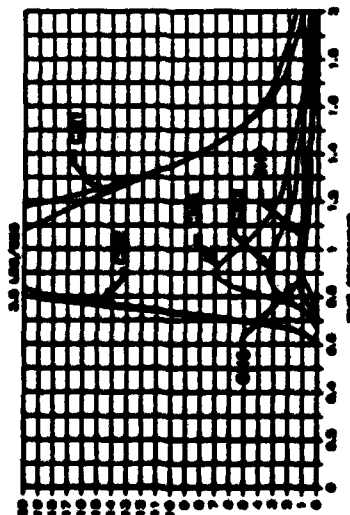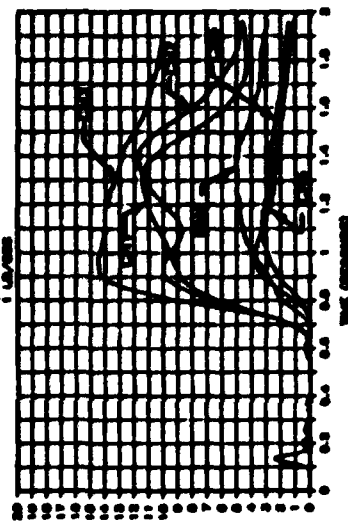
NOTE: 0.7 CU. IN. BATTLES OF HALON 1202 RELEASED IN ALL TESTS

4.5.2 Dump Line Restriction Tests

A series of tests was undertaken to investigate whether the agent might be more effectively used if it was released more slowly. In particular, it was thought that the reignition phenomena observed earlier was unaffected by the rapid agent pulses being employed and might be eliminated with longer duration pulses even though these would have a lower agent concentration.

The dump line leading from the AENFTS variable volume dump tank was restricted with interchangeable orifices of various sizes. Halonizer tests were run in the F-16 simulator at various airflow rates with these restrictions, employing various size agent charges. The Halon concentration measured by Halonizer probe number 4 (Figure 20) during the 2-seconds following release of the agent with unrestricted flow and with two orifice sizes, with three agent charge sizes and with the three different test section airflows. This particular probe was selected as it was closest to the most intense part of the test fires, about eight inches aft of the fuel injection nozzle.

Following these tests, JP-4 fire tests were run using the baseline 0.52 GPM JP-4 fires with the same agent flow restrictions at the same test section airflows of 1-, 4- and 6.8-lb/sec. The results of these tests are shown in Figure 21. In no case was less agent required using the orifice to restrict the flow than with the unrestricted baseline. In fact, the use of restrictions seemed generally to increase the amount of agent required.

4.5.3 F-111 Tests at Atlantic City

In July of 1986 and again in January and February of 1987, the AENFTS test crew took the Beckman Halonizer equipment to the FAA/TC at Atlantic City, New Jersey, to assist in the conduct of an agent concentration test program conducted using the FAA's F-111 test article. While the FAA is responsible for overall documentation of that effort, minimal documentation of the Boeing/Air Force contribution was prepared and is included as Appendices B and C of this report.

The F-111 has a high ventilation airflow engine compartment and is equipped with a Halon 1202 extinguishing system that was originally demonstrated at General Dynamics in 1969. While MIL-E-22285 does not apply directly to the use of Halon 1202 (similar guidelines developed for that agent are contained in Ref. 4).
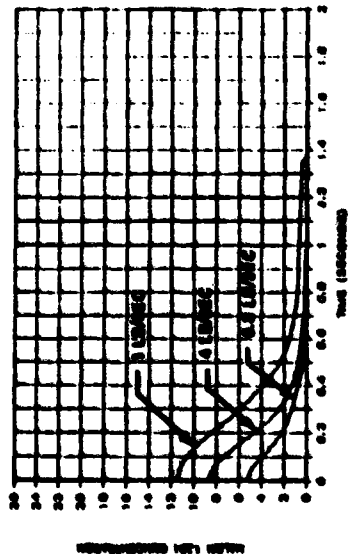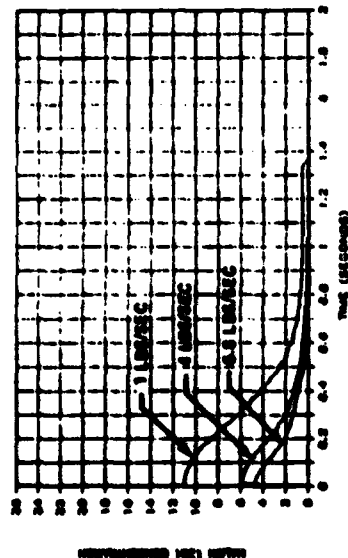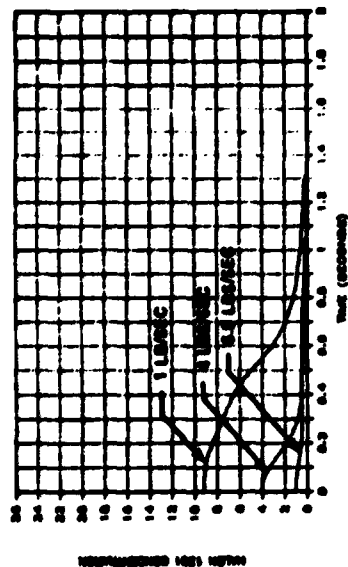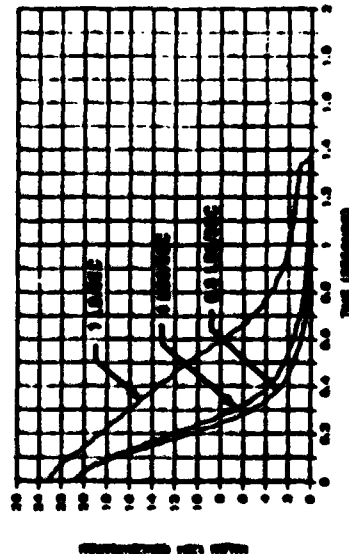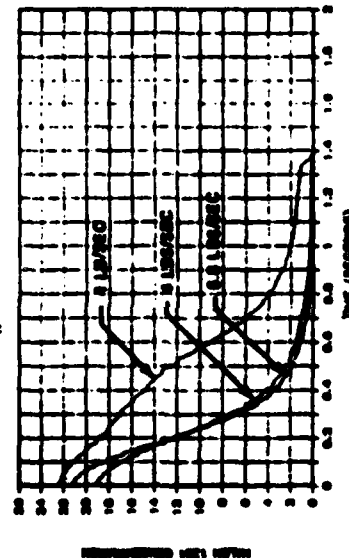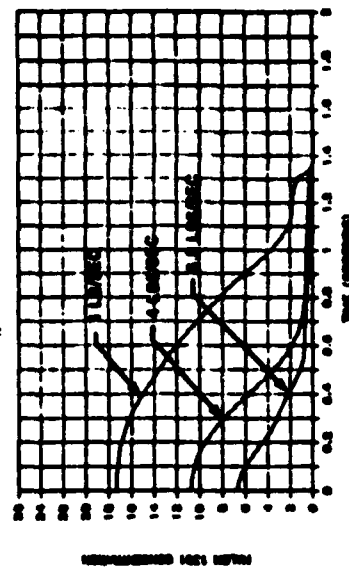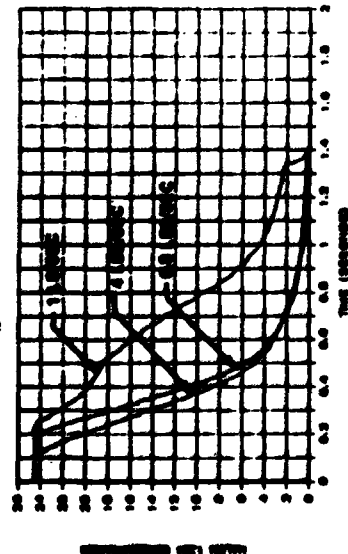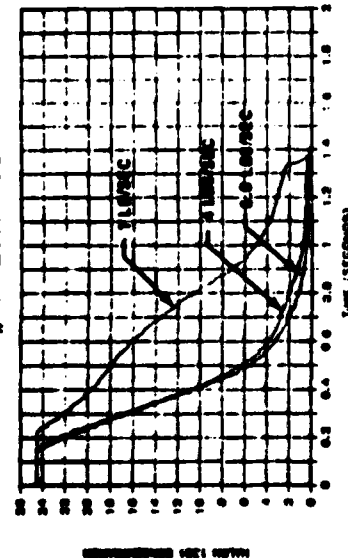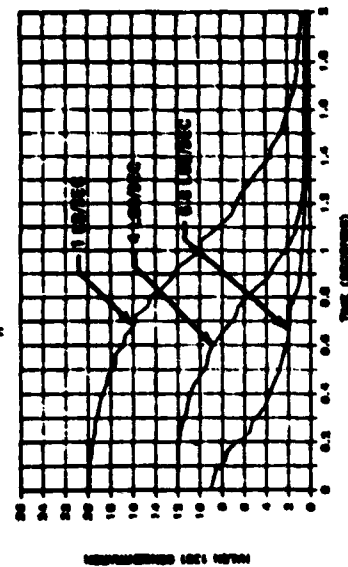
Figure 20. Effect of Dump Line Restriction on Duration of Agent Concentration in Fire Zone

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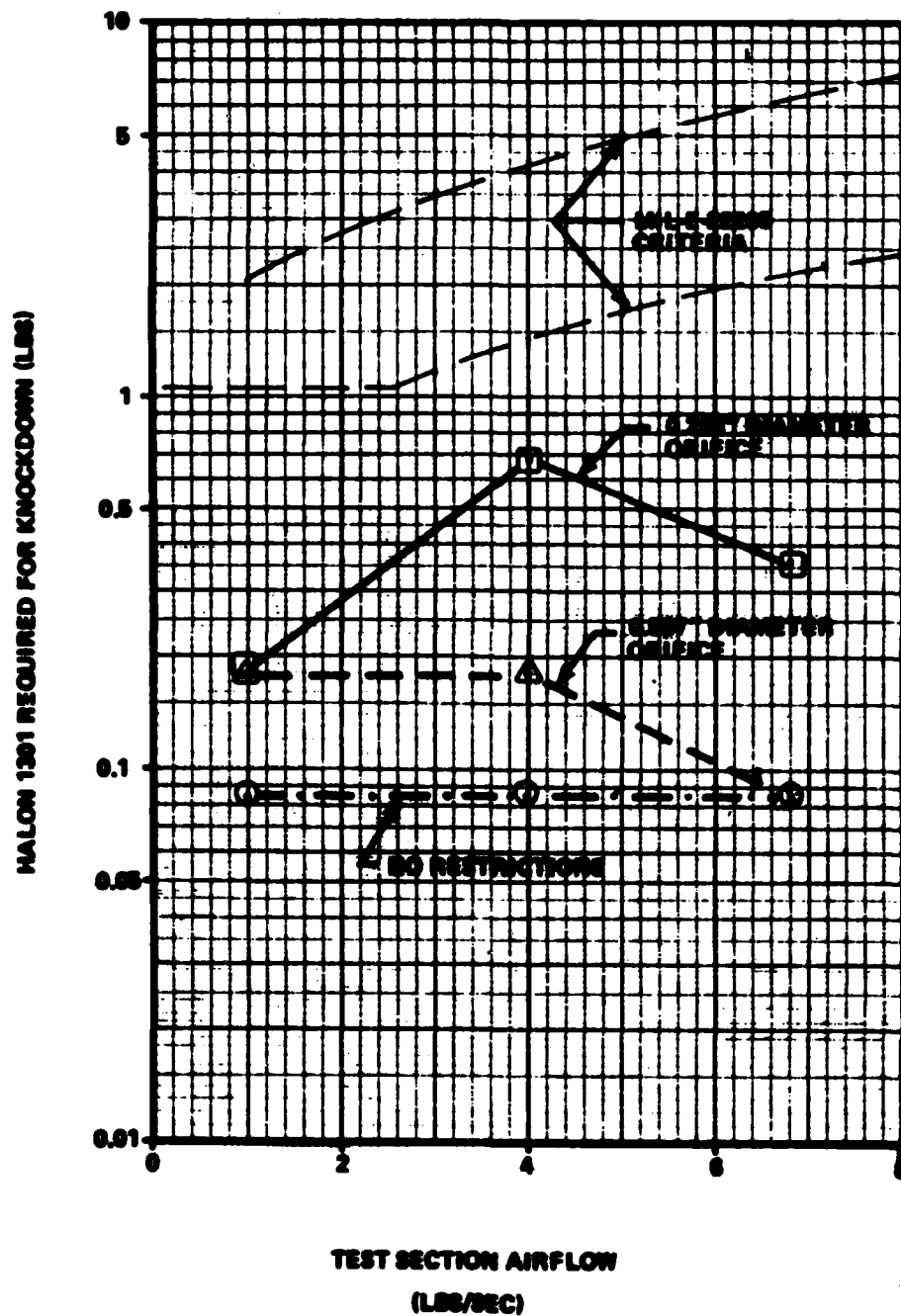
Figure 21. Effect of Flow Restriction on Agent Quantity Required
to Extinguish 0.52 GPM JP—4 Fires

These also require that a 6-percent concentration be maintained for a minimum of one-half second simultaneously at all measurement locations. The July 1986 testing was intended to establish whether or not the addition of an oil cooler for the Integrated Drive Generator (IDG) would adversely effect the agent distribution in the EF-111A's engine compartment.

The FAA's F-111 test article (Figure 22) is an aircraft fuselage with an operable TF-30 engine in its right side engine bay. Engine compartment ventilation airflow is supplied from the fan airflow of a remotely located TF-33 engine and is ducted into the engine compartment ventilation inlet. The F-111 engine compartment is currently equipped with an extinguishing system consisting of a single 390-cubic-inch container holding 12.65-pounds of Halon 1202.

The agent concentration time histories obtained for the ground operation case (where the compartment airflow was minimal) agreed well with the 1969 data as contained in Ref. 4 (Figure 23). More than the 6-percent concentration of agent for the required half-second at all measurement locations was demonstrated in both tests. However, at all other flight conditions investigated, there was inadequate agent concentration and/or duration to comply with the specification. The presence or absence of the IDG oil cooler had little effect on the agent distribution, but the compartment airflow did. The data acquired at four simulated flight conditions with airflows ranging from 5.98- to 30-lb/sec are shown in Figure 24. Again with these test results, the probable presence of liquid droplets in the sample lines may mean that actual concentrations of Halon 1202 were even lower than indicated.

The second test period, early in 1987, was intended to be a preliminary investigation of how the problem identified in the 1986 tests might be resolved. Failure of the F-111's TF-30 engine required that this testing be conducted without an operating aircraft engine but compartment ventilation airflow was provided as in the July testing. This change was of secondary importance, since proper ventilation airflow was the primary concern.

Initially Halon 1301 was substituted for Halon 1202 in the original F-111 bottles and the superior vaporization characteristics of Halon 1301 did improve the situation (Figure 25). Use of larger agent charges in larger storage bottles was also tried, and it was found that an 18-pound charge of Halon 1301 would provide compliance with MIL-E-22285 at all airflows tested other than the 30-lb/sec anticipated at Mach 1.2 sea level dash (Figure 26).

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Figure 22. FAA/TC's F-111 Test Setup at Atlantic City

GRD. OPS W/EJ; 1986 FAA TEST
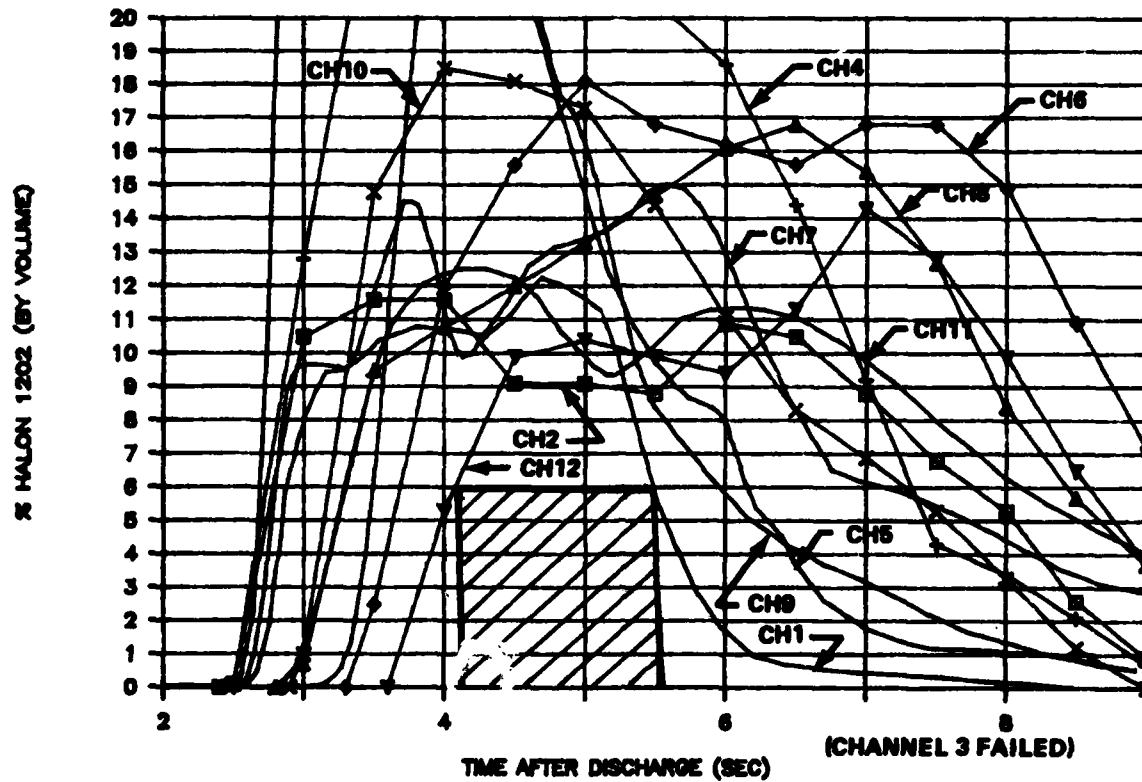
GRD. OPS W/EJ; 1969 GEN'L DYNAMICS TEST
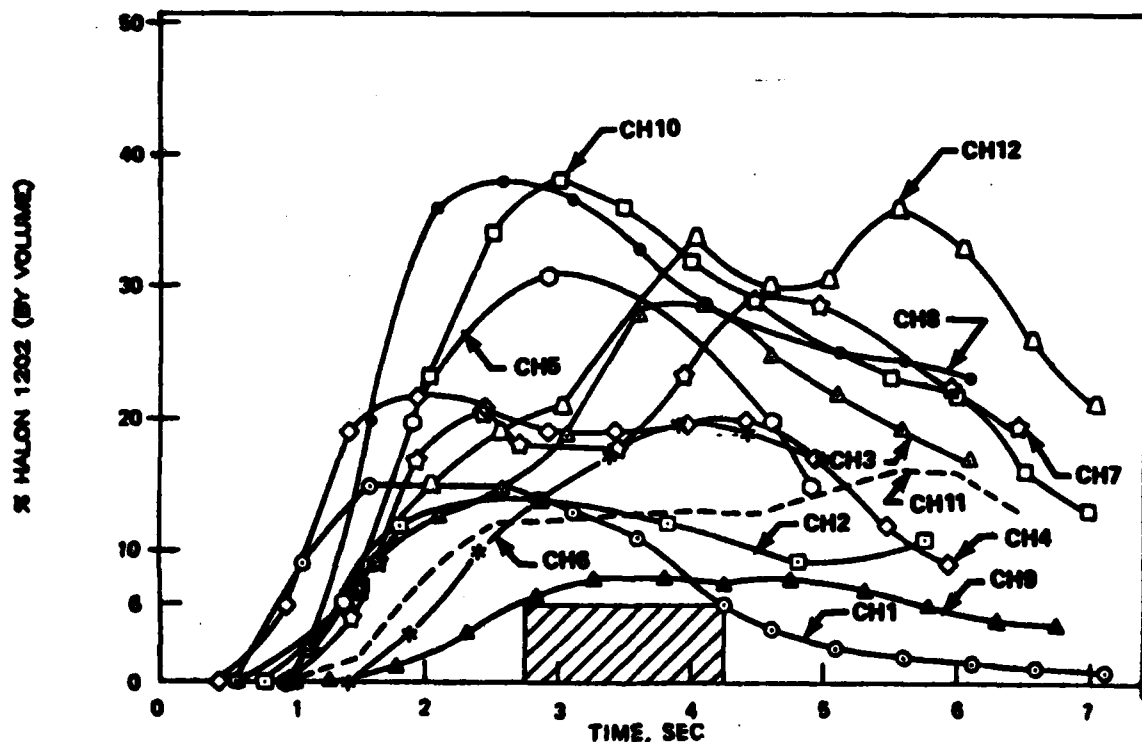
Figure 23.   Comparison of General Dynamics and FAA/TC Agent Concentration Data

43
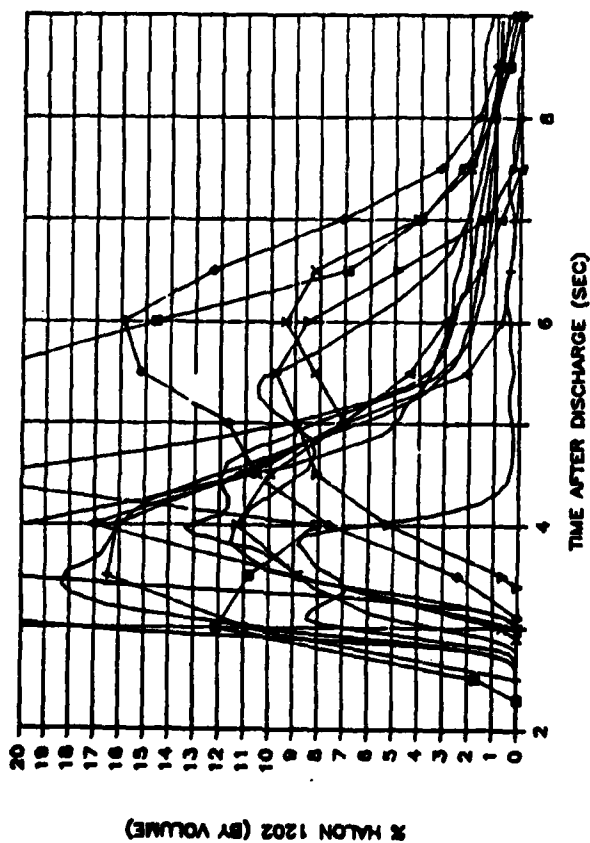
78% HOLDING; 9.67 LBS/SECOND

% HALON 1202 (BY VOLUME)

TIME AFTER DISCHARGE (SEC)
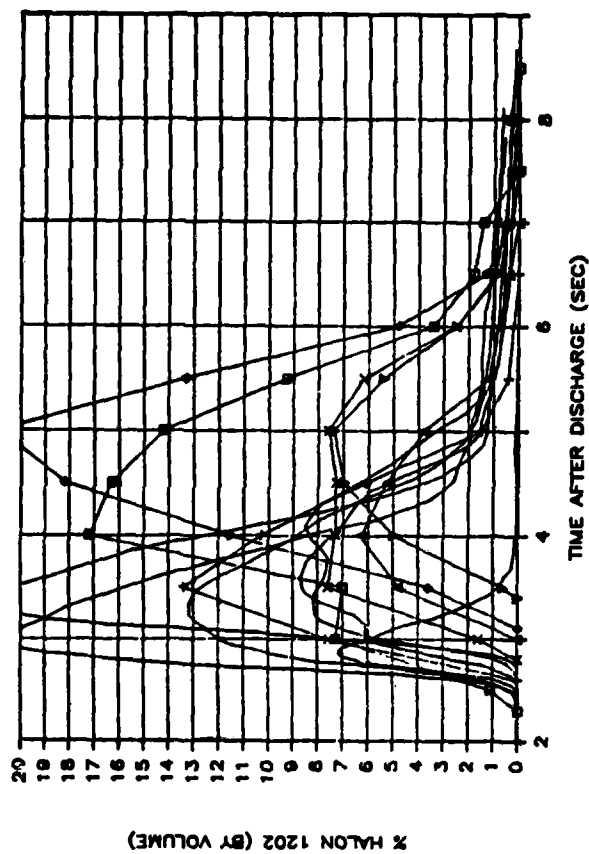
NOTE: SEE APPENDIX B FOR IDENTIFICATION OF PROBES
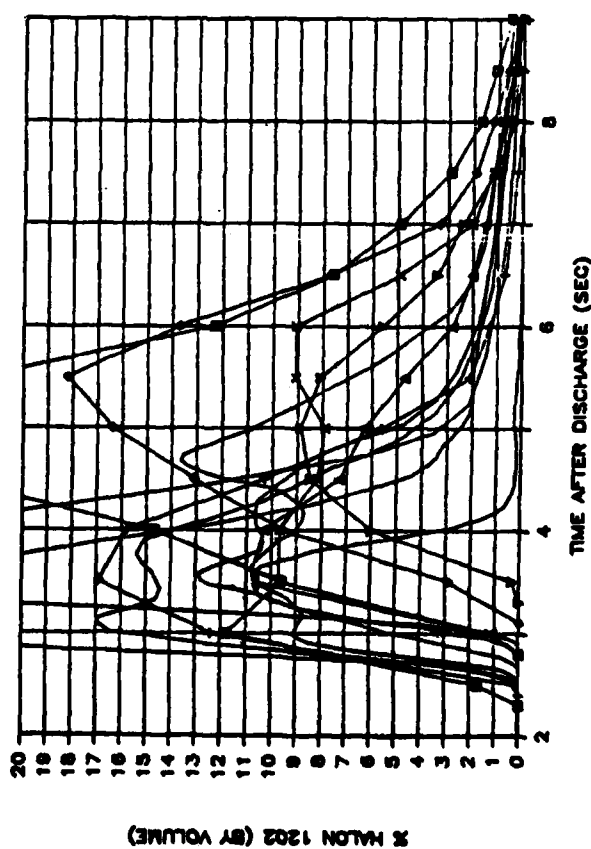
S/L DASH, Z1 A/B; 30 LBS/SECOND

% HALON 1202 (BY VOLUME)

TIME AFTER DISCHARGE (SEC)

82% CRUISE; 5.98 LBS/SECOND

% HALON 1202 (BY VOLUME)

TIME AFTER DISCHARGE (SEC)

90% T/O; 7.5 LBS/SECOND

% HALON 1202 (BY VOLUME)

TIME AFTER DISCHARGE (SEC)
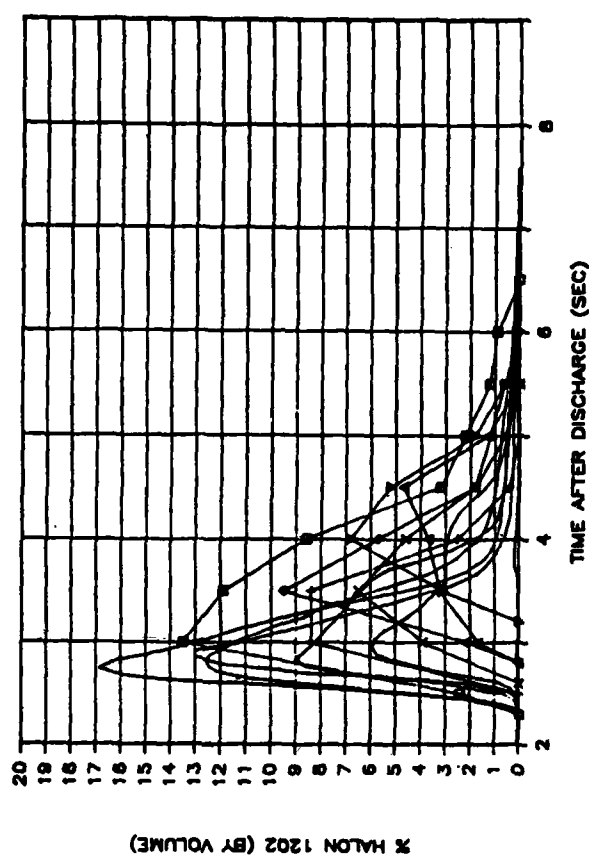
Figure 24. Halon 1202 Concentration at Four F—111 Flight Conditions

JANUARY '87 TEST WITH HALON 1301

11 LBS HALON 1301 IN F-111 BOTTLE

TEST 2A & 2B: TF-33
AIRFLOW AT 10 LB/SEC;
NO TF-30 OPERATION

CH10, CH5, CH9, CH2, CH11, CH10, CH6, CH12, CH3, CH7, CH8, CH1

% HALON 1301 BY VOLUME

TIME (SECONDS)
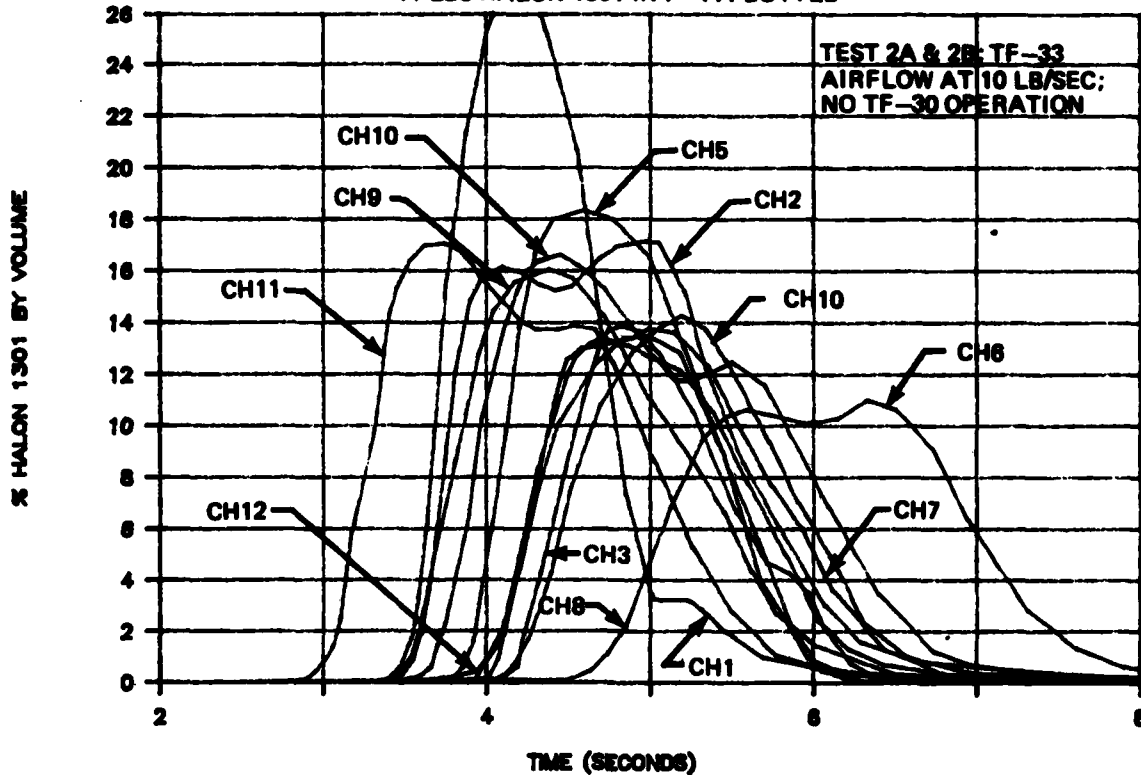
JULY '86 TEST WITH HALON 1202

12.65 LBS HALON 1202 IN F-111 BOTTLE

TEST 4; TF-33 AIRFLOW
AT 10 LBS/SEC; TF-30
THROTTLE CHOP FROM
78% HOLDING

CH9, CH5, CH6, CH4, CH2, CH7, CH8, CH10, CH11, CH3, CH12, CH1

% HALON 1202 BY VOLUME

TIME (SECONDS)
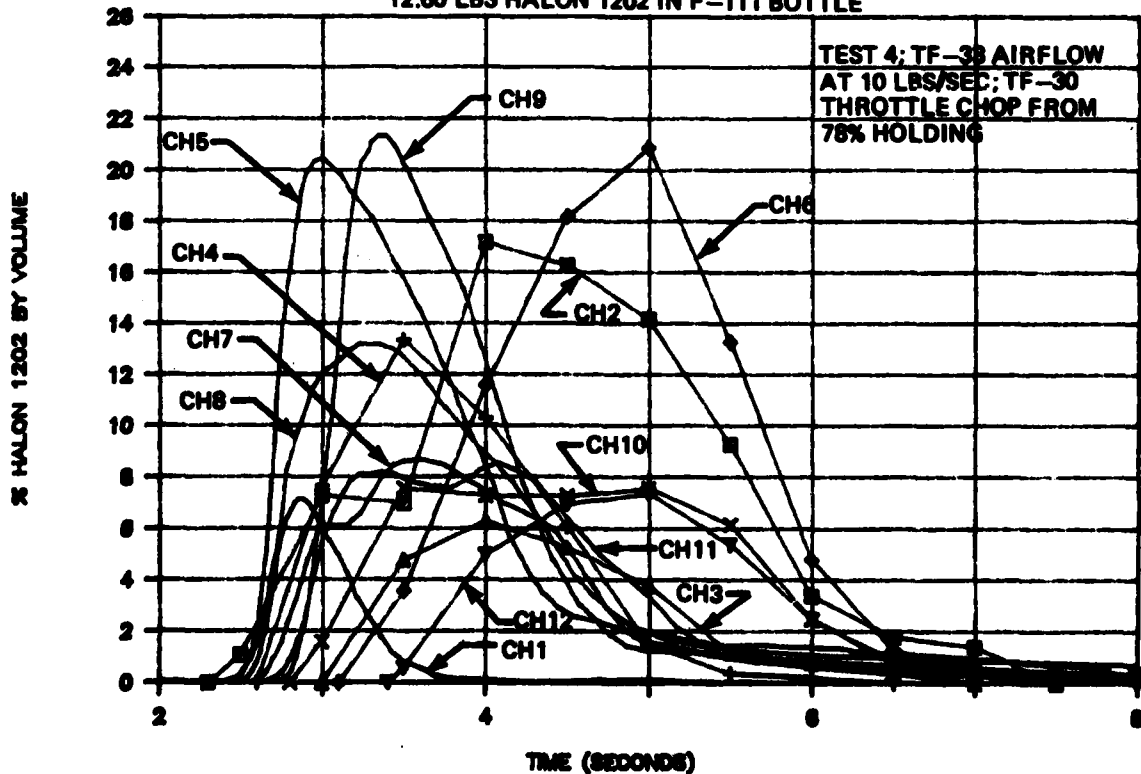
Figure 25. Comparison of Halon 1301 and 1202 in F-111 Bottle

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HALON 1301 TEST IN F-111 AT FAA/TC

MIN AGENT CONCENTRATION FOR 1/2 SEC (%)

ENGINE COMPARTMENT AIRFLOW (LBS/SEC)

28.5 LBS OF HALON 1301
IN 1050 CU. IN. BOTTLE

18 LBS OF HALON 1301
IN 630 CU. IN. BOTTLE

11 LBS OF HALON 1301
IN 390 CU. IN. F-111 BOTTLE
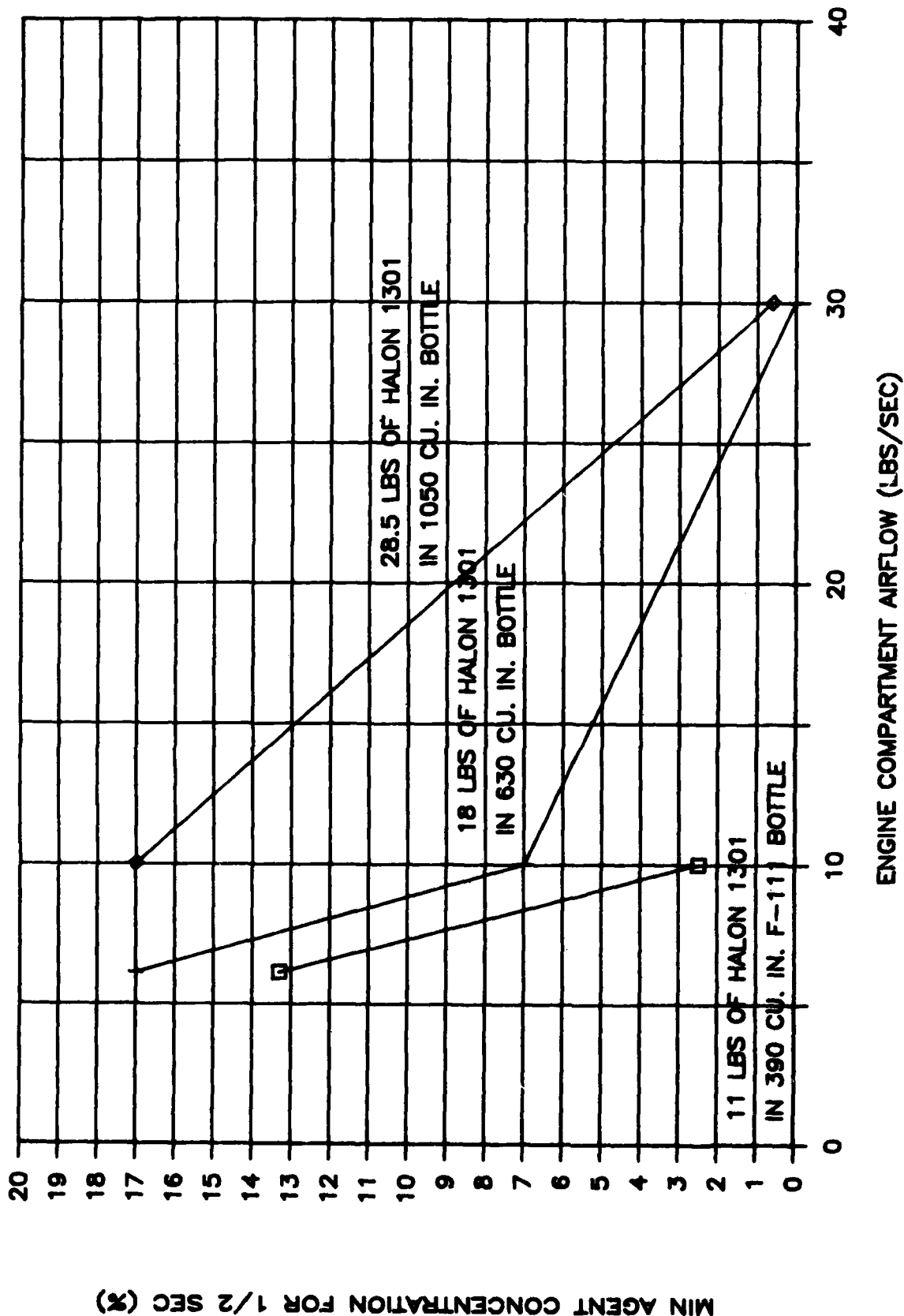
Figure 26. Quantity of Halon 1301 Required to Provide Compliance with MIL-E-22285 in F-111

4.6 Airflow Reduction Tests

It had been theorized that airflow reduction might be employed to handle engine compartment fires which could not otherwise be extinguished. In an aircraft, this would involve equipping the engine compartment ventilation system with an inlet door (or doors) which could be closed prior to agent release.

To check the effectiveness of this concept a series of AENFTS fire tests was run with 0.52 GPM JP-4 fires and 3-lb/sec of ventilation airflow heated to 400°F. The baseline tests were run with the specified ventilation airflow held constant during ignition, the 20-second preburn period, and during 5-seconds of continued fuel injection following the release of the agent. The airflow reduction tests were also run with 0.52 GPM JP-4 fires and 3-lb/sec of ventilation airflow heated to 400°F for the first 19-seconds of the 20-second preburn period. They differed in that the airflow was terminated during the last second of the preburn period, just prior to the release of the agent, using the high-flow/low-flow switch.

During the baseline tests these fires could not be extinguished, even with a maximum 2.47-pound charge of Halon 1301, comparable to that specified by MIL-E-22285 for 3-lb/sec airflow. When the airflow was reduced to zero just prior to agent release, the fires initially appeared to be extinguished. However, they did reignite about 7-seconds after they appeared to be extinguished and just after the fuel injection was terminated. The test was repeated with an additional video camera installed in several different positions below the rig. From the video tapes we concluded that the fires probably had been completely extinguished by the agent and were again reignited by a hot component of the F-16 simulator.

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5.0 ANALYSIS OF RESULTS

5.1 Baseline JP-4 Fire Tests

During the 1983 and 1984 tests (Ref. 1), nearly all test fires were extinguished with agent charges smaller than required by MIL-E-22285. The only exception were fires where a jet of air simulating a leaking bleed duct had been introduced.

Between the completion of that work and the start of the test work documented herein, the F-16 simulator was removed from the AENFTS and components severely damaged by the earlier fire tests were repaired or replaced. This included replacement of damaged thermocouple wires and fabrication of a new aircraft structure section. While some change in the amount of agent required to extinguish the baseline fires of the current program was anticipated the fact that many of the baseline fires could not be extinguished by "spec. Halon charges" was a surprise. The changes in baseline performance were analysed using an additional video camera and it was concluded that they were probably caused by hot surface ignition, probably by a hot section of thermocouple wire.

While the flow rate and pressure of the fuel being injected into the AENFTS test section were monitored, the quantity of air consumed in its combustion could not be measured. The test fires employed a 0.52-GPM JP-4 spray.

JP-4 density at $68^{O}F$ = 6.34 lbs/gallon

$$\frac{0.52 \text{ gpm} \times 6.34 \text{ lbs/gallon}}{60 \text{ sec/min}} = 0.056 \text{ lb/sec fuel flow}$$

Hence, if all the test section airflow were used burning the JP-4, the air to fuel ratios at 1-, 3- and 6-lbs/second would have been 17.9, 53.6 and 107.

There was no instrumentation employed to monitor products of combustion and the airflow through the simulator was entirely too complicated to conclude, even approximately, how much of the air was actually employed in combustion. For JP-4, a stoichiometric air-fuel ratio would be about 15:1. The construction of the F-16 Nacelle Simulator is such that about half of the airflow might be

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expected to flow through the "glove tank" region and not be employed to burn the fuel. Hence, the region shown on Figure 12 where the baseline fires could not be extinguished, between ventilation flowrates of 2 and 3.5 lbs/second is probably that where the air-fuel ratio was closest to stoichiometric, provided the hottest fires, and was most likely to lead to the hot surface ignition phenomenon noted above.

The test apparatus was configured to define agent requirements rather than to explore ignition mechanisms. A hot surface ignition test program was planned for the AENFTS and is underway at the time of this report's preparation. While it was concluded, after viewing video tape records of some of the test fires, that reignition of some of the test fires was due to hot surfaces in the simulator, the limited view of the aft portion of the simulator during fire tests prevented determination of just which component was hot enough to cause the reignition.

At the start of the test program, a test was conducted where a 0.52 gpm JP-4 fire at 4-lbs/second airflow was allowed to burn for about 40 seconds and thermocouple data was acquired about once every 10 seconds for the air temperature thermocouples along the centerline of the AENFTS (Fig. 27). As noted in Table 2 and Figure 3, the air temperature thermocouples, TAIR-1 through TAIR-6 are uniformly spaced through the AENFTS test section. As the F-16 simulator was placed in the test section, TAIR-1 was upstream of the test fires, and TAIR-4, TAIR-5 and TAIR-6 were aft of the simulator. TAIR-2 and TAIR-3 were located between the flameholder and the aft end of the simulator.

Temperature data were also acquired during this test for the 6 thermocouples located along the simulated aircraft rib structure at the aft end of the F-16 nacelle simulator (Fig. 28). While the maximum temperatures measured were less than $1900^{\circ}F$, the inconel sheathed leads for the thermocouples on the rib structure were burned off within the next several months, however, indicating that there were probably local temperatures in excess of $2200^{\circ}F$.

Hence it not surprising that the test results were complicated occasionally by hot surface reignition of the fuel following initial extinguishment of the fires. Since there was insufficient instrumentation to understand the specific location, temperatures, materials, and the nature of the fuel delivery on the hot surface (spray, stream, drip, etc.), analysis of these phenomenon will be left to the hot surface ignition test program where these issues were addressed.

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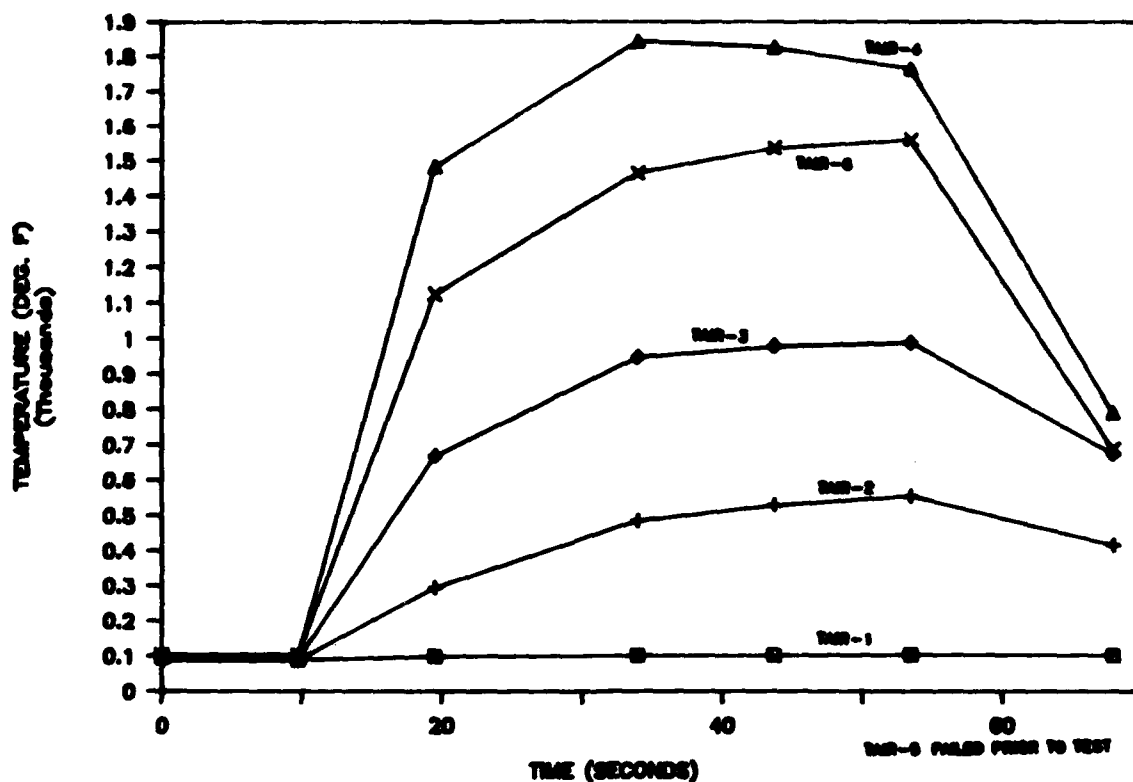
Figure 27. Air Temperature on AENFTS Centerline
During 0.52 gpm JP-4 Fire
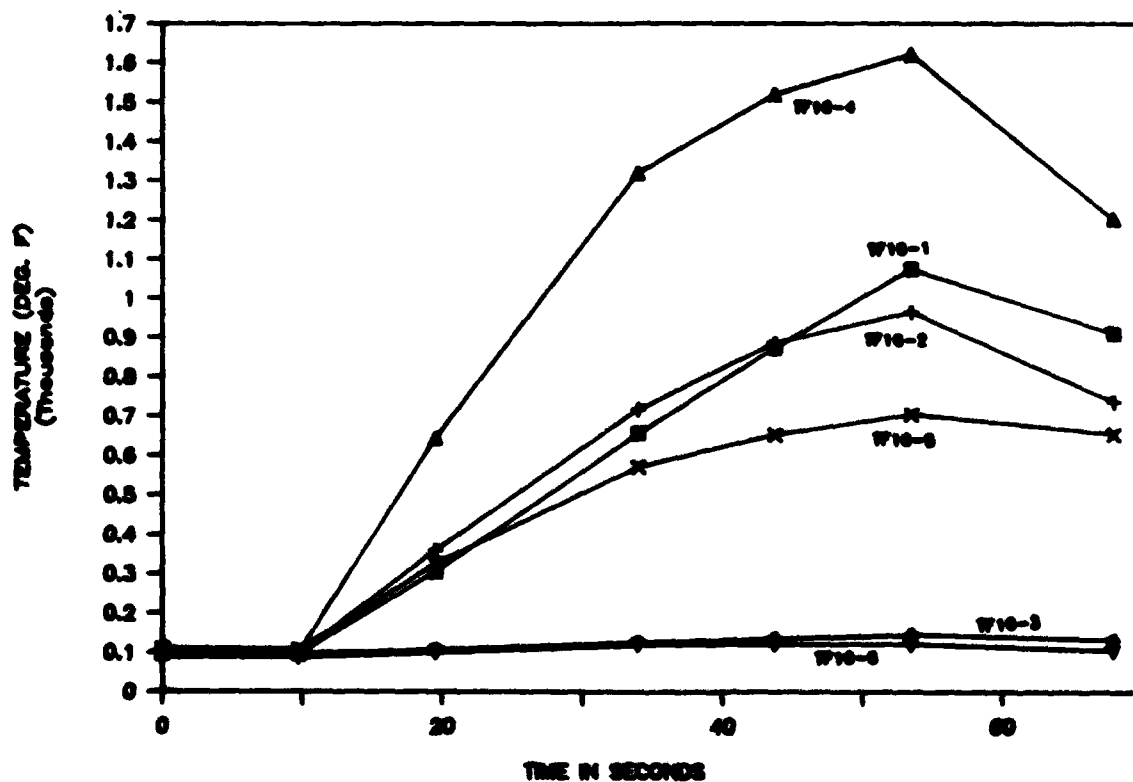
Figure 28. Surface Temperatures on Ribs of F-16 Nacelle
Simulator During 0.52 gpm JP-4 Fire

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Of greatest concern, however, was the fact that the tests revealed that there was much less conservatism in MIL-E-22285 than had been concluded earlier. Unlike other parts of the F-16 simulator, when bathed in the test fires the thermocouple wires were evidently heated to higher temperatures than during the earlier work. Since wires and tubes cannot be totally eliminated from potential fire zones, a means of extinguishing such fires more rapidly is needed.

5.2 Altitude and Ram Conditions

Analysis indicates that engine compartment fires occurring during high altitude flight conditions would be less severe than those experienced at sea level. Low air density would lead to fuel rich fires for all but very low fuel flows and the low air temperatures would further reduce the extent of the threat. This seemed to be demonstrated in the AENFTS because the testing did not identify additional situations where MIL-E-22285 was inadequate. Caution is advised in applying this finding to aircraft design, however, because the altitude simulations were limited to low airflow conditions (the maximum ejector system capability of the AEN).

The ram air flow conditions of low altitude supersonic flight could provide the opposite of the above. If high ventilation air inlet recoveries were experienced during low altitude, high Mach number flight conditions, the most severe engine compartment fires might be expected because of high temperatures and high air density. AENFTS testing corroborated this. As the test section air temperature and pressure were increased the amount of agent required increased and many of these test fires could not be extinguished with the maximum available agent charges. Hence high absolute pressures (i.e., above 14.7 psia) should be avoided in aircraft engine compartments, if possible.

5.3 Combat Damage Simulation Tests

Analysis of airflow and pressure recovery associated with a damaged engine compartment skin panel (included in Ref. 1) revealed that pressure recovery of air coming through a damaged skin panel would be lower than that of the air entering through the inlet scoop. Hence, while combat damage caused inflow could increase the air velocity in the compartment, any resulting fires would not necessarily be more difficult to extinguish.

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Additional airflow simulating inflow caused by skin panel damage did not result in greater difficulty in extinguishing the test fires. These fires were harder to ignite, often requiring that the inflow not be initiated until the test fire had been ignited. This was probably due to the inflow discharge point being within inches of the fuel-nozzle flame-holder assembly.

Outflow through damaged skin panels was not included in this program because it would not lead to greater air density or elevated ventilation air temperatures. AENFTS testing during 1983 and 1984 (Ref. 1) indicated similar results to those without the outflow. Outflow could increase fire damage threats, however, in situations where such damage allowed the agent to escape from the engine compartment without getting to the fire location.

When the temperature of the simulated combat damage inflow was elevated to represent fan case perforation or bleed duct leakage (Table 3) some of the test fires again became more difficult to extinguish. This was particularly noticeable with low ventilation airflow fires where the fires were probably initially fuel rich and became hotter as the inflow caused them to become leaner. This often led to hot surface reignition following agent discharge.

During some of the higher airflow tests the addition of the simulated inflow extinguished the fires without agent. The higher airflow fires probably were already quite lean without the airflow and became too lean to burn once the inflow was added.

5.4 High Temperature Ventilation Air Tests

Most often, when the maximum sized agent charges were inadequate, the fire appeared to be knocked down by the agent for a fraction of a second but reignited after the agent had dissipated. These extinguishment failures seemed always to be caused by hot surface reignition though the hot target was not actually observed.

Testing with elevated ventilation air temperature would be expected to cause the target to get hotter before and during the fires. The test results seemed to indicate that. When the preburn period was limited to 12-seconds, the fires at 1- and 6-lbs/second airflow were no harder to extinguish than the baseline,

although the test fire at 4-lbs/second required somewhat more agent. As noted in paragraph 5.1, the hottest fires seemed to exist at air-fuel ratios close to stoichiometric, although there was insufficient instrumentation to determine this with certainty. Probably, the 4-lbs/second fires produced hotter surfaces in the simulator hence requiring somewhat more agent for their extinguishment. When the preburn period was increased to 20-seconds the test fire at 1-lb/second required more than 10 times as much agent for extinguishment; the test fires at greater airflows could not be extinguished.

5.5 Agent Distribution Dynamics Tests

5.5.1 Halon 1202 Concentration Data Anomalies

The Halon concentration data from this test program agreed quite well with data obtained by General Dynamics for the F-111 airplane (Ref. 4). Furthermore, the joint FAA/Boeing F-111 tests at Atlantic City indicated very close agreement between the agent concentration data acquired with Boeing's (Beckman) Halonizer equipment and that acquired with FAA's traditional Statham equipment (Appendices B and C). However, analysis of Halon 1202 concentration data yielded anomalous results, such as:

o for similar size agent charges, substantially higher concentrations were produced with Halon 1202 than with Halon 1301 (comparing Figures 18 and 19)

o a simplified theoretical analysis (included as Appendix E) of quantity of agent required to produce indicated agent concentrations shown in the upper left-hand plots on Figures 18 and 19 indicates that the quantity of Halon 1301 calculated was consistent with that employed but the quantity of Halon 1202 calculated was about 2.5 times greater than actually employed

Because of these observations, we concluded that the problem was probably due to Halon 1202's low vapor pressure and that droplets were being trapped in the sample tubes, in those cases where fairly high concentrations were experienced. Therefore, the Halonizers indicated agent was present long after it was no longer present in the ventilation airflow. Also, presence of fluid droplets in the sample lines probably resulted in concentration measurements much higher than actual concentration in the airflow. Since there was excellent agreement

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between the Boeing Beckman and FAA Statham data, it seems likely that this problem is not limited to this test but had occurred whenever fairly high concentrations of Halon 1202 had been measured.

Because Halon 1202 is not currently employed commonly there is probably insufficient demand for concentration instrumentation to resolve this difficulty and develop a technique which is not sensitive to this problem. For the same reasons, there is probably no need to attempt to repeat these tests or develop a means of correcting the data.

<u>Caution is advised, however, that Halon 1202 probably does not produce substantially higher concentrations than Halon 1301 as much of the test data contained herein suggests.</u>

5.5.2 Low Temperature Agent Tests

Lower agent concentrations were measured when Halon 1202 was discharged into airflow refrigerated to -20°F than into 66°F air (Figure 29). While this temperature was the minimum available with the AENFTS glycol coolers, engine compartment ventilation air temperature could be much lower (-80°F for a Mach 0.8 cruise in a cold atmosphere at 60,000 feet, for example). Refrigerating the airflow did not have as great an effect on Halon 1301 concentrations as on Halon 1202 concentrations.

This difference probably is largely due to the high boiling point of Halon 1202 (73°F at atmospheric pressure compared to -72°F for Halon 1301). Even at room temperature, Halon 1202 tends to remain a liquid, if spilled, while Halon 1301 immediately vaporizes. Hence much of the Halon 1202 probably was blown downstream as liquid with diminished effect on the measured agent concentrations.

5.5.3 Dump Line Restriction Tests

Previous agent concentration tests run in the AENFTS indicated that the existing agent release and distribution system did not meet the requirement in MIL-E-22285 that a 6-percent concentration of agent be present in all parts of the engine compartment for 0.5-second. The agent flow restriction tests reported in Paragraph 4.5.2 were run to examine the importance of that part of the specification. Figure 18 indicates that, with 0.36-pound charges, 6-percent

5.7 CU. IN. OF HALON 1301 (0.36 LBS)

HALON 1301

AVERAGE HALON 1301 CONCENTRATION

TIME (SECONDS)

5.7 CU. IN. OF HALON 1202 (0.4 LBS)

HALON 1202

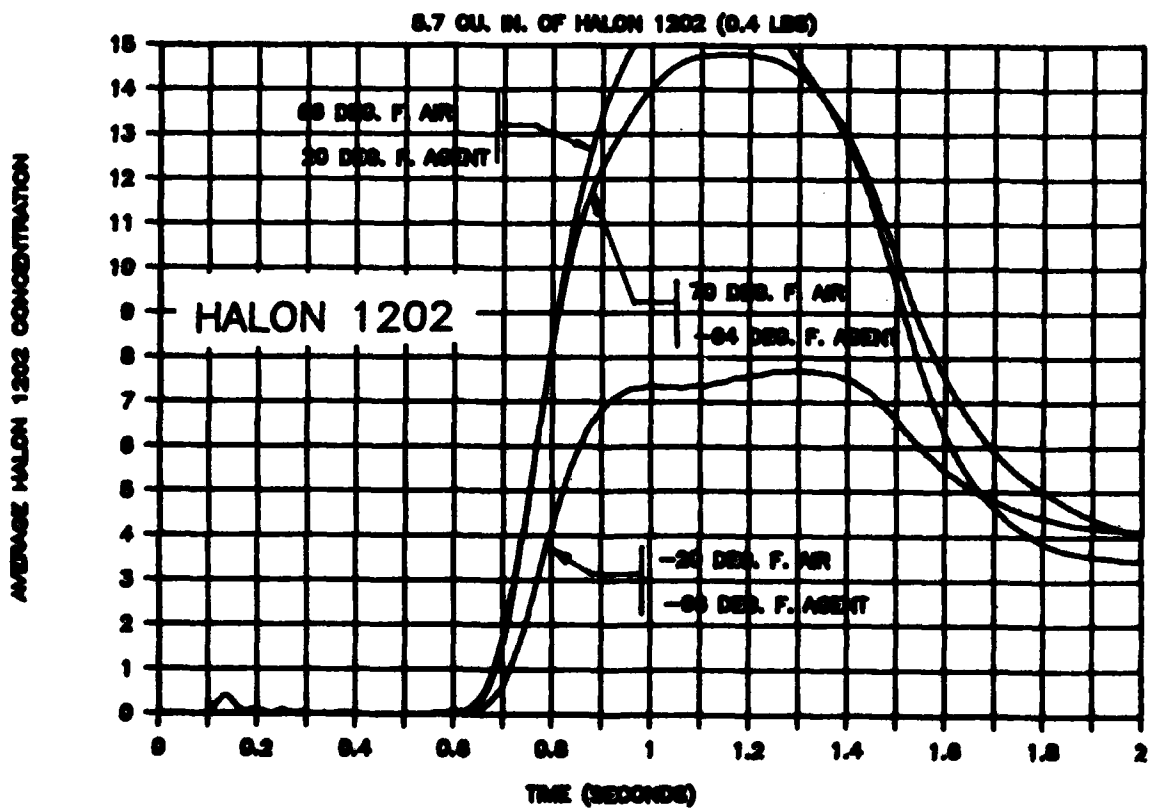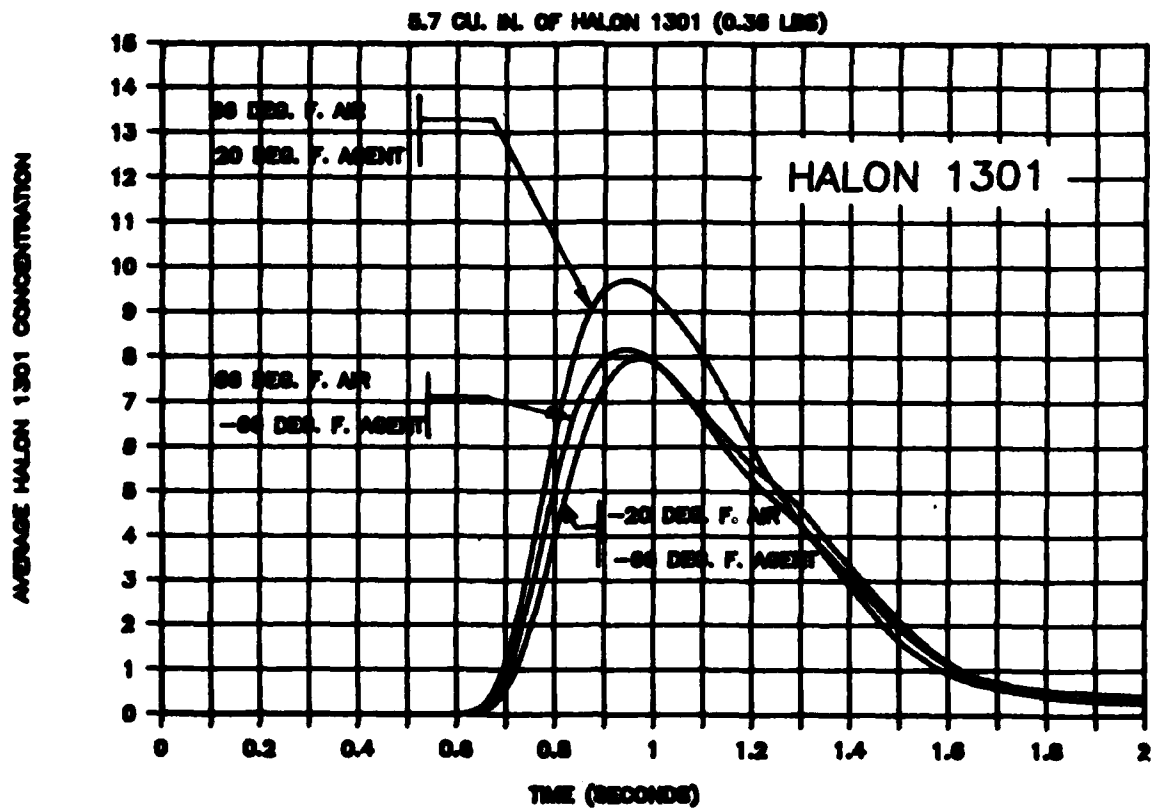AVERAGE HALON 1202 CONCENTRATION

TIME (SECONDS)

Figure 29. Effect of Dump Tank and Air Temperature on Halon 1301 and 1202 Distribution

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Halon concentrations were obtained in the fire zone (probe 4) only at 1-lb/sec airflow and that the duration of these varied from 0.3-second with no restriction in the dump line to almost the 0.5-second required by MIL-E-22285 with the 0.298-inch orifice in the dump line. Conversely, the maximum concentration measured at this location varied from about 11-percent with no restriction to 9-percent with the 0.298 orifice. When the 1.28-pound and 2.47-pound agent charges were used, 6-percent charges were measured at all airflows. The 2.47-pound charge provided the required 0.5-second durations at 4- and 6.8-lbs/sec except with the 0.298-inch orifice at 6.85-lbs/sec.

During the corresponding fire tests, including those where the fire appeared to be extinguished but reignition occurred, no advantage was found in the use of the restrictions. Since it also seems likely that the agent cooled the hot surfaces in the simulator as well as extinguishing the fires, the conclusions from the 1983 and 1984 AENFTS testing (Ref. 1) that the 0.5-second duration requirement is less important than the actual amount of agent dumped into the fire are confirmed.

5.6 Airflow Reduction Tests

In the cases where the test fires had not been extinguished with the largest available agent charges, a hot component within the F-16 nacelle simulator probably caused reignition after the agent had been released. It had been theorized that terminating the airflow prior to agent release would maintain a high agent concentration in the test section for a significantly longer time and allow more time for hot surfaces to cool below ignition temperatures. The tests conditions chosen were particularly severe; with a 20-second preburn period and 3.5-lbs/sec airflow, the maximum agent charges had not been able to extinguish the test fires during the baseline tests due to reignition. With the airflow heated to 400°F, the hot surface or surfaces which were causing reignition would be even hotter than during the baseline tests.

As noted in Section 4.6, terminating the airflow prior to agent release greatly reduced the severity of these fires but they continued to reignite. The reignition delay was also increased. Hot surface reignition probably again was the cause. With the reduced airflow, the continued fuel injection during the 5-seconds following agent release probably helped cool the hot targets while

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providing too much fuel for reignition to occur with the minimal air available. Once the fuel injection was terminated the fuel air ratio was evidently reduced, and there evidently remained some surfaces which were still hot enough to ignite the mixture.

When these fires did reignite they were not visible on the TV monitor and were no more than a "flicker," about the size of a candle flame. While there clearly was an adequate agent concentration in most of the test section to prevent these fires from becoming larger, there evidently was insufficient concentration in some of the stagnation regions at the bottom of the simulator to totally extinguish the fires.

5.7 Test Article Contamination

The F-16 nacelle simulator was not removed from the AENFTS test section during the entire period that agent evaluation tests were being conducted. When it was removed, prior to the beginning of the follow-on hot surface ignition tests, it was found to be coated with soot. In addition, the simulated aircraft ribs were distorted from the hundreds of fire tests that had been performed. The structural deformation probably had little effect on airflow within the simulator. While the soot accumulations increased steadily during the test period, and could have influence the hot surface reignition phenomenon which were encountered, the amount of agent required to extinguish the fires remained consistent. These deposits were similar to, if more extreme, than the deposits normally found in the engine compartment of an aircraft which had been in service for a number of years. We concluded that this was consistent with our attempt to model "worst case" situations in aircraft engine compartments.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

While the use of a "high realism" test article led to some test anomalies and complicated the interpretation of the test results, much information was obtained that would be unavailable from analysis or from a more carefully controlled but less realistic laboratory experiment. The AENFTS with the F-16 nacelle simulator was again found to be effective experimental tools.

Compared to the AENFTS tests run during 1983 and 1984, the most important and disturbing conclusion is that MIL-E-22285 does not specify large enough agent quantities to provide adequate protection when components within the engine compartment are bathed in flame and become hot enough to reignite flammables after the agent charge has been dissipated.

Increasing the size of the agent charge alone does not seem to be the answer, however. As shown in Figure 12 an order of magnitude increase in the agent quantity was not sufficient to prevent reignition. Instead, the test results suggest:

1.   A reduction in the length of time that the fire is allowed to burn prior to agent release is the best method of eliminating the chance of hot surface reignition. The 20-second preburn period was employed in these tests because it is common practice for a pilot to distrust his fire detection equipment and await independent confirmation that he has a fire before shutting the engine down and releasing the agent. As shown in Figure 14, reducing the preburn period to 15-seconds greatly improved the situation and reducing it further to 12-seconds eliminated the problem in those tests that did not employ combat damage simulation.

2.   Termination of ventilation airflow in the event of a fire would be very beneficial. The required technology is currently available because this provision is required for other ventilated aircraft compartments. MIL-F-87168 currently exempts engine compartments from this requirement because agent concentration testing is employed to demonstrate the effectiveness of the agent quantity and distribution system. AENFTS test results indicate that ventilation termination would be advantageous in engine compartments also.

The AENFTS has definite advantages when compared to agent demonstration testing in an actual aircraft. These include:

o   Minimum manpower required to conduct tests

o   A multi-million dollar flight-test aircraft is not required

o   Fuel costs are minimal

o   Ventilation airflow temperature and pressure can be simulated without flight

o   Complex instrumentation can be provided which is accessible and inexpensive compared to flight test equipment

o   Agent effectiveness can be assessed with representative fires. Actual aircraft tests could not simulate worst-case fires without risk of aircraft loss

There are limitations in the AENFTS simulator:

o   Without a 180° annulus, the exact airflow pattern within the engine compartment of an aircraft cannot be simulated in the AENFTS.

o   At present, the AENFTS ejector system provides very limited altitude simulation.

6.2 Recommendations

6.2.1. Engine Compartment Design Considerations

Since we found that preburn duration has a strong effect on the difficulty of extinguishing test fires in the AENFTS tests, we have a need for rapid detection of engine compartment fires and for rapid deployment of extinguishing agents. Faster reacting and more reliable fire detection systems and the use of automatic agent release systems should be considered as a means of getting the agent to a fire sooner.

The high engine compartment pressures which could result from recovery of r[
air pressure at high Mach numbers should be avoided, as they also contribute [
the severity of many of the fires which might be encountered in an engi[
compartment. This could be accomplished by employing low recovery ventilati[
air inlets and minimizing the resultant aircraft drag by minimizing t[
ventilation flowrates.

The use of Halon 1202 should be avoided because of its poor vaporizati[
characteristics. Where its use is required because of Halon 1301's high[
critical pressure, its distribution within the compartment should [
demonstrated in all anticipated missions, particularly those where it will [
refrigerated in its storage tank during high altitude flight and/or it will [
discharged into low temperature airflow.

A ventilation airflow shutoff system should be considered as an additional mea[
of engine compartment fire protection. Such a system would be operated prior
agent release.

6.2.2. Changes in Engine Compartment Fire Protection Specifications

A draft revision to that portion of MIL-F-87168 which deals with engi[
compartment fire extinguishing was prepared and is included as Appendix D [
this report. Changes implemented by this revision include:

1. Actual agent release tests with high realism will be required at a
   planned flight conditions. If these are not flight tests, they should
   tests where the compartment ventilation flow rate and temperature and age
   storage temperatures are realistically simulated.

2. Use of Halon 1202 is discouraged except in cases where Halon 1301 is not
   acceptable alternative. Potential problems with Halon 1202 are discussed

3. Survivability/vulnerability (combat conditions) considerations have been included in the overall approach to engine compartment fire protection. These include:

    o A requirement for a means of shutting off the engine compartment ventilation airflow prior to agent release has been included as part of the engine compartment fire protection system.

    o A recommendation that additional agent be included to provide protection when combat damage caused perforation of compartment outer walls, fan case or bleed air lines introduces additional airflow into the engine compartment.

    o A recommendation that rapid detection, fuel shutoff and extinguishant deployment be included in the engine compartment fire protection system design to minimize the probability that hot surfaces can reignite combustible fluids following agent release.

    o A recommendation that elevated engine compartment ventilation air pressures be avoided.

REFERENCES

1. Johnson, A. M. and A. P. Grenich, "Vulnerability Methodology and Protective Measure for Aircraft Fire and Explosion Hazards, Volume II - Aircraft Engine Nacelle Fire Test Program; Part I - Fire Detection, Fire Extinguishment and Surface Ignition Studies," AFWAL-TR-85-2060, January 1986.

2. Kunkle,J. S., et al, "Compressed Gas Handbook," NASA GSP-3045, 1969.

3. Johnson, A. M., "Optical Fire Detector Testing in the Aircraft Engine Nacelle Fire test Simulator," AFWAL-TR-87-2089, March 1988.

4. McClure, J. D. and R.J. Springer, "Environmental and Operating Requirements for Fire Extinguishing Systems on Advanced Aircraft," JTCG/AS Report 74-T-002, November 1974.

APPENDIX A - AWTS DATA REDUCTION EQUATIONS

The following three sections provide the equations which were used to calculate airflows and velocities for the 8- and 24-inch venturi meters, the high pressure air supply system and for the sonic nozzles used to measure simulated bleed airflow, ejector flow and high pressure flow.

1.0 Calculation of 8-Inch Venturi Mass Flow and Velocity:

Per the Reference 3, Compressed Gas Handbook, the mass flow through a venturi meter in lbs/sec. is equal to:

$$W = C_d * A2 \sqrt{\frac{(2 * g * rho * DP)}{1 - beta^4}} \sqrt{\frac{r^{2/k}(k)(1-r^{(k-1)k})(1-beta^4)}{(k-1)(1-r)[1-(r^{2/k})(beta^4)]}}$$

Where the first radical term is the incompressible flow equation and the second radical term is the compressibility correction, and:

V - mass flow in lbs/sec

C_d - discharge coefficient

g - gravitational constant

rho - upstream density

DP - differential pressure across venturi

beta - ratio of throat diameter to upstream pipe diameter, D2/D1

k - specific heat ratio

r - ratio of upstream to downstream pressure, P2/P1

For air (k - 1.4) this simplifies to:

$$W = 0.525\ C_d * D2^2 \sqrt{\frac{rho * DP}{1 - beta^4}} * \sqrt{\frac{r^{1.429}(3.5)(1-r^{0.2857})(1-beta^4)}{(1-r)[(1-(r^{1.429} * beta^4)]}}$$

Hence, substituting AEN parameters:

P1 = PFLIN   (venturi upstream static pressure in psia)

DP = DPVN40 *0.03606   (venturi differential pressure from high
                       range transducer when differential pressure
  or   greater than 4 inches of water)

DP = DPVN-4 *0.03606   (venturi differential pressure from low
                       range transducer when differential pressure
                       less than 4 inches of water)

$$RHO = \frac{P1 * 144}{(53.35) * (TBL-08 + 460)}$$

(Where TBL-08 is 8 Inch Venturi Temperature)

$$R = \frac{P1 - DP}{P1}$$ or, if R < 0.6, or R > 1.0, substitute R = 1.0

For the 8-inch venturi, C_d = 0.985, D2 = 4.1768, beta = 0.4968

$$K = 0.525 * 0.985 * (4.1768)^2 * \sqrt{3.5} = 16.877842$$

The test section mass flow in lbs/second becomes:

$$WBL-08 = K * \sqrt{\frac{RHO * DP * (R^{1.429}) * (1 - R^{0.2857})}{(1 - R) * [1 - (R^{1.429}) * 0.0609153]}}$$

The clean test section velocity in ft/second becomes:

$$VNAC-8 = \frac{(0.152 * WBL-08) * (TNACIN + 460)}{PNCOUT}$$

Where TNACIN is the test section inlet temperature in degrees F and PNCOUT is the
in test section pressure in psia.

2.0 Calculation of 24-Inch Venturi Mass Flow and Velocity:

Using the same equation as for the 8-inch venturi, but with:

C_d = 0.9895, D2 = 10.158, beta = 0.4277

$K = 0.525 * 0.98975 * (10.158)^2 * \sqrt{3.5} = 100.307926$

P1 = PBLOUT   (venturi upstream static pressure in psia)

DP = DPVENT *0.03606   (venturi differential pressure)

   If DP < 0, DP = 0

$$RHO1 = \frac{P1 * 144}{(53.35) * (TBL\text{-}24 + 460)}$$ (Where TBL-24 is 24-Inch Venturi Temperature)

$$R = \frac{P1 - DP}{P1}$$ or, if R < 0.6, or R > 1.0, substitute R = 1.0

K = 100.307926

The test section mass flow in lbs/second becomes:

$$VBL\text{-}24 = K * \sqrt{\frac{RHO1 * DP * (R^{1.429}) * (1 - R^{0.2857})}{(1 - R) * [1 - (R^{1.429}) * 0.0334624]}}$$

The clean test section velocity in ft/second becomes:

$$VNAC24 = \frac{(0.152 * VBL\text{-}24) * (TNACIN + 460)}{PNCOUT}$$

where TNACIN is the test section inlet temperature in degrees F. and PNCOUT is the test section temperature in psia.

A-3

3.0 CALCULATION OF AIRFLOW FOR SONIC NOZZLES

The manufacturer of the sonic nozzles installed in the AEN, Flow Measurement Systems, Inc., provides the following equation for calculation of sonic nozzle airflow:

$$V = \frac{Po * A * C^* * C_d}{\sqrt{T + 460}}$$

Where:
- V = Airflow in lbs/second
- Po = Nozzle inlet stagnation pressure
- C^* = Critical flow function for air
- A = Nozzle throat area in square inches
- C_d = Nozzle discharge coefficient
- T = Nozzle inlet temperature, degrees Rankine

They further state that the ratio of nozzle stagnation to measured static pressure is a function of the approach Mach number and hence of the ratio of nozzle throat to pipe diameter. Thus it is a constant for each nozzle. They also provide diameters, areas, and stagnation to static pressure ratios for the nozzles:

Nozzle No.	Location	Diameter (inches)	Area (in^2)	Po/P
1	Hi flow/Hi pressure	0.9264	0.6740	1.0019
2	Lo flow/Hi pressure	0.3712	0.1082	1.0003
3	Ejector	0.8075	0.5121	1.0011
4	Bleed air heater	0.2964	0.0690	1.0001

C^* is obtained from NASA TN D-2565 and is relatively constant within the range of temperatures and pressures anticipated. It is equal to 0.5351 at 520°F and 200 psia.

C_d is calculated based on Reynolds number and is obtained using:

$$N_R = (4 * V)/(3.14159 * d * mu)$$

and

$$C_d = 0.99738 - \frac{3.3058}{\sqrt{N_R}}$$

In the range of Reynolds numbers anticipated, C_d varies only from 0.993 to 0.996, however, so a constant 0.995 is employed in all these calculations.

Hence:

$$VHIFLO = \frac{1.0019\ (0.6740)\ (0.5351)\ (0.995)\ (PHIFLO)}{\sqrt{THIFLO + 460}} = \frac{0.3595(PHIFLO)}{\sqrt{THIFLO + 460}}$$

$$VLOFLO = \frac{1.0003\ (0.1082)\ (0.5351)\ (0.995)\ (PLOFLO)}{\sqrt{TLOFLO + 460}} = \frac{0.0576(PLOFLO)}{\sqrt{TLOFLO + 460}}$$

Since no temperature is measured at the ejector and the ejector airflow is not employed in subsequent data reduction, being only an indicator in setting test section pressure, a constant temperature of 60°F. is assumed.

$$VEJFLO = \frac{1.0011(0.5121)(0.5351)(0.995)(PEJFLO)}{\sqrt{60 + 460}} = 0.001197(PEJFLO)$$

$$VBLHTR = \frac{1.0001(0.0690)(0.5351)(0.995)(PBHNOI)}{\sqrt{TBHNOI + 460}} = \frac{0.03674(PBHNOI)}{\sqrt{TBHNOI + 460}}$$

AIR FORCE PARTICIPATION IN
THE F-111 HALON 1202 AGENT
DISTRIBUTION TEST AT THE
FAA'S TECHNICAL CENTER,
ATLANTIC CITY, N.J.

Boeing Advanced Systems Company
P. O. Box 3707
Seattle, Washington, 98124

September 1986

An informal summary of test activities
performed during July of 1986 at the
Federal Aviation Administration's
Technical Center at Atlantic City as
part of Contract F33615-84-C-2431

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EF-111A AGENT DISTRIBUTION TEST AT THE
FEDERAL AVIATION ADMINISTRATION TECHNICAL CENTER (FAA/TC)

OBJECTIVE

The objective of the subject test program was to provide a single pass/fail test of existing baseline F-111 Halon 1202 engine compartment fire extinguishing system at simulated flight conditions after modifying the FAA's F-111 test article to approximate internal aerodynamics of EF-111A aircraft.

TEST SETUP

To this end, 12 channels of halon concentration instrumentation were installed with sample tubes located in the same locations used for the original F-111 engine fire extinguishing system demonstration tests in 1969. Because the FAA/TC's Statham equipment is no longer maintainable, they recorded data for only six of these channels and the WPAFB/Boeing Beckman equipment was used for the other six. The firing of the agent release squib was recorded on the oscillograph charts for both sets of data to provide time correlation. The FAA/TC equipment was also used to monitor one of the WPAFB/Boeing channels to further facilitate time correlation of the two sets of data.

The F-111 engine compartment aerodynamics were modified by the installation of the Integrated Drive Generator (IDG) oil cooler (Figure B-1). The flapper doors at the entrance to the engine compartment had been removed as they have been in all operational F-111's.

Boeing provided six channels of Beckman Halonizer equipment. This equipment, while intended for use with medical halothane, has been successfully employed for several years at WPAFB to determine Halon

Figure B-1.   IDG Oil Cooler Installation in
F-111 Engine Compartment

1202 and 1301 concentrations.   Each channel is a stand-alone unit consisting of a detector head containing the sample cell, chopper and IR detector and a rack mounted unit housing a vacuum pump, flow controller, signal conditioning and a digital display of the measured concentration.   Analog output from all six channels was recorded using a Honeywell Visicorder.   This equipment is shown in Figure B-2.

The halonizer equipment and an IBM PC based data reduction system were housed in a 16-foot air conditioned trailer. The data system included a graphics tablet and mouse to allow the oscillograph charts to be manually digitized, a dot matrix printer, and a Hewlett Packard plotter. The trailer was located adjacent to the F-111 test article, just forward of the engine compressor face (Figures B-3 and B-4).
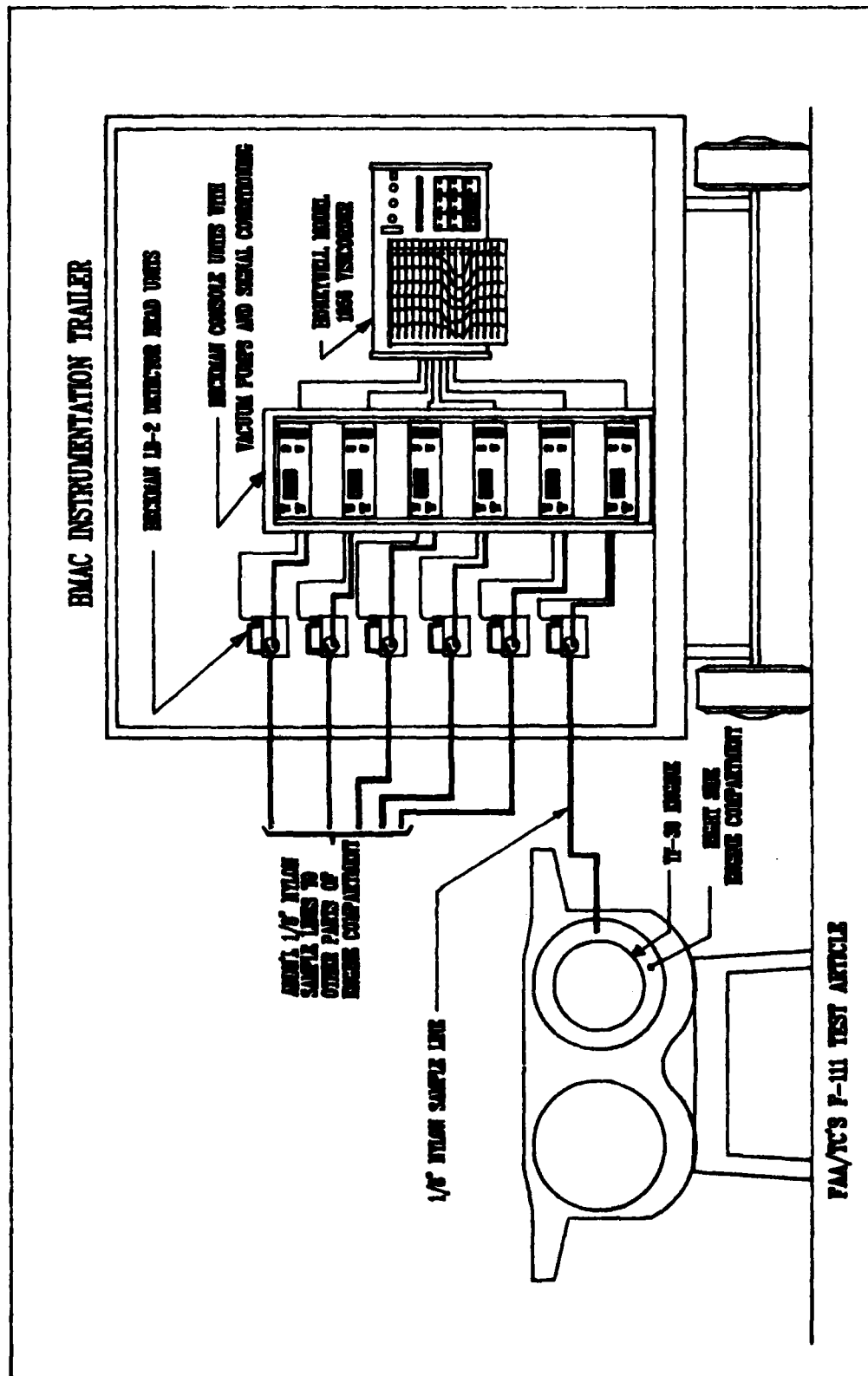
Figure B-2. Boeing Halon Concentration Instrumentation Installed on F-111 Engine Compartment
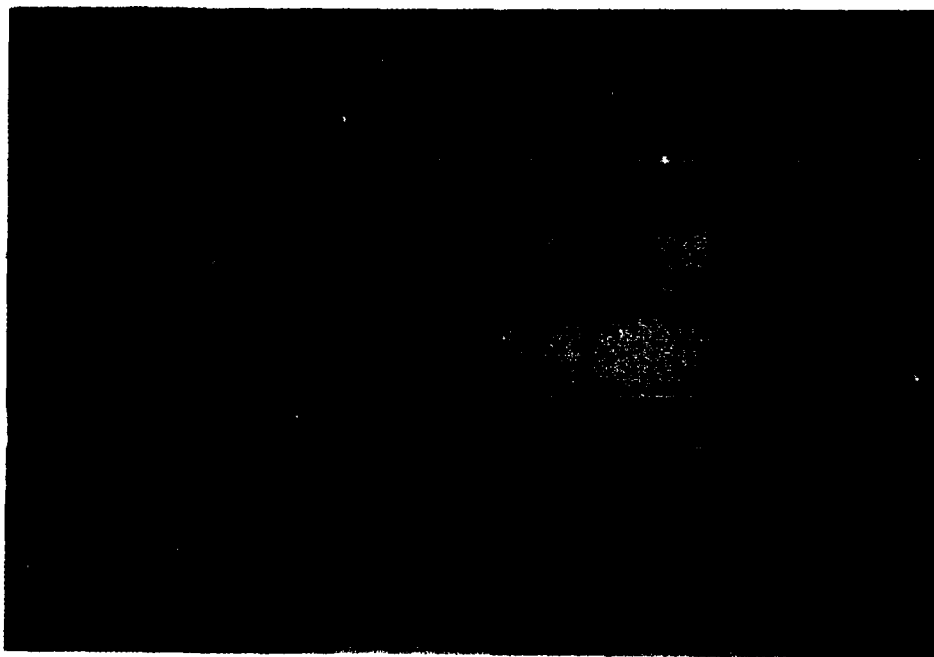
Figure B-3.   Boeing Test Trailer Adjacent to F-111 Test Article
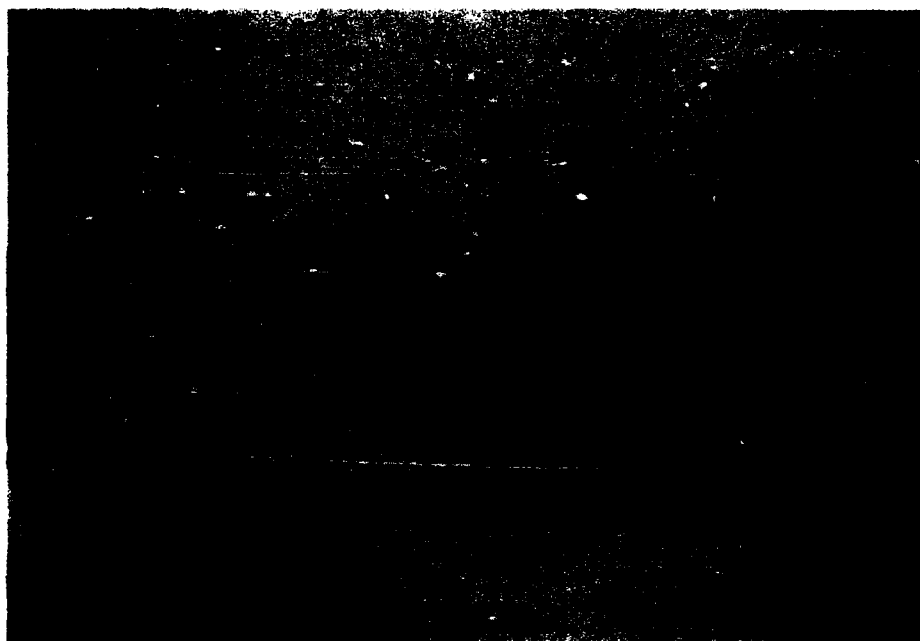

Figure B-4.   FAA/TC's F-111 Test Article Showing Engine
Compartment Ventilation Air Duct from Remotely
Located TF-33 Engine

Boeing provided 0.070-inch ID sample tubes, 40-feet long. Most were entirely 1/8 inch nylon but the four to be installed in the aft portion of the engine compartment were 0.070-inch ID stainless steel for the 4-foot portion to be installed inside the airplane. FAA/TC installed the sample lines parallel with their own sample lines (Figure B-5) in the engine compartment so that they terminated where the Boeing trailer was to be located.

The FAA/TC was responsible for overall plan and conduct of test program, for installation of all agent sample tubes, and for the acquisition and reduction of data from all but those six channels of agent concentration being acquired and reduced by Boeing. They were also solely responsible for final documentation of the test program. Boeing agreed to prepare final plots of all halon concentration data, including data from the six channels measured by the FAA, once they had been provided with complete tabular data.

Figure B-5.   Installation of Boeing and FAA Sample Lines

CALIBRATION

Boeing provided Halon 1202 calibration mixtures to allow daily adjustment of its instrumentation and to allow correlation of Boeing and FAA/TC data. These consisted of two 9-gallon containers of a calibration mixture which had been mixed to a volumetric concentration of approximately 6-percent Halon 1202 using the mass spectrometer in I-Bay at WPAFB and a cylinder of certified 6.02-percent Halon 1202 mixture purchased from the Matheson Company in Dayton.

The Boeing instrumentation was adjusted each day using the calibration mixtures during the subject testing and was checked with the certified mixture three times during the period. On 22 July 1986, all channels of the FAA/TC Statham equipment were exposed to the calibration mixture with one channel being checked against the certified mixture. Preliminary FAA/TC data indicated the Statham readings varied only from 6.02- to 6.29-percent.

TRANSPORT TIME

During June 1986, preliminary tests were run at WPAFB to define the response time for the Beckman equipment as it would be installed at the FAA/TC. From these tests, 0.070-inch ID tubing was selected for the Boeing sample lines. Figure B-6 shows the effect of sample line length on the transit time for this tubing, the transit time being the delay measured from the time the sample tube was initially exposed to a known halon concentration until the Halonizers indicated 95-percent of the known value. For the 40-foot sample tubes used at the FAA/TC the transit time was expected to be 3.5 seconds. These preliminary tests are informally documented in Section II of this Appendix.

The solenoid operated halon step function generating rig used during the WPAFB tests, as described in Section II of this Appendix, was transported to Atlantic City and used to check transport time of the Boeing equipment as it was set up for this test. The transport time of the system, as installed, was 3.2 seconds.
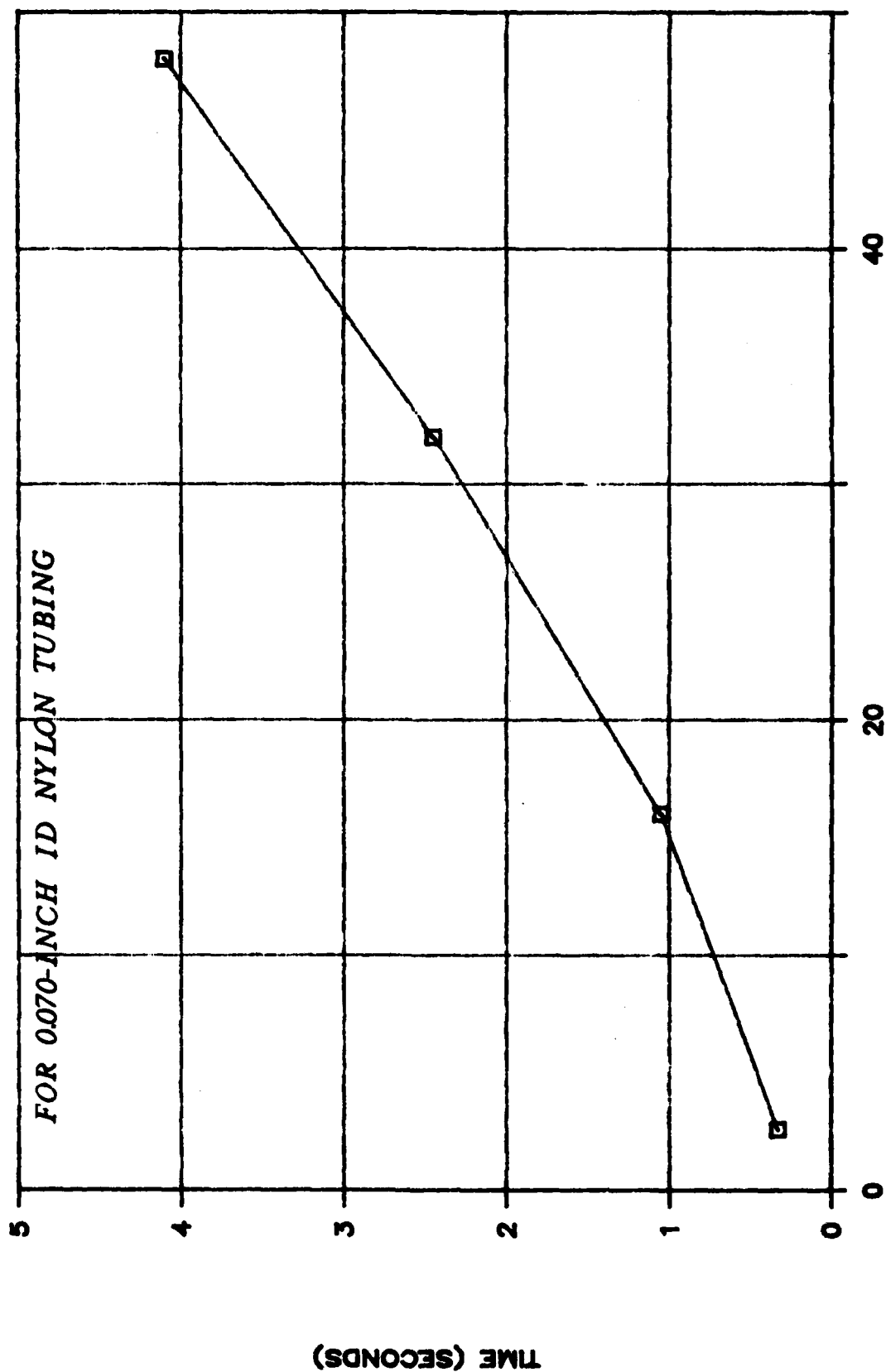
TUBING LENGTH (FEET)

TIME (SECONDS)

FOR 0.070-INCH ID NYLON TUBING

Figure B-6. Effect of sample Tube Length on Halonizer
Transit Time

PROCEDURE

The test procedure employed was consistent throughout the test
program and consisted of the following steps:

1. The Statham equipment was warmed up to operating temperature
   using a 28-volt dc power cart.

2. The TF-33 engine (which provided the ventilation airflow to
   the F-111 engine compartment) was started and run up to the
   desired operating condition. The gate valve controlling the
   ventilation airflow was adjusted as required and the engine
   was allowed to stabilize for several minutes. On the ground
   operation tests this step was omitted.

3. The TF-30 engine in the F-111 was started, run up to its
   desired operating condition and allowed to stabilize for a
   minute or two.

4. The Statham operator checked that the Boeing crew was ready
   and initiated a 10-second countdown. At this time final
   adjustments of zero and dither were made on the Beckman
   equipment. At a count of seven the operator and the Boeing
   crew started their oscillographs. At the count of two the
   engine operator chopped the TF-30 throttle. At the count of
   zero the squib was fired releasing the agent. Once both
   crews indicated that data acquisition was over, the engine
   operator adjusted both engines to appropriate cool off
   settings and ran them briefly before shutdown.

5. The agent bottle was changed, deficiencies noted during the
   previous run were corrected and the cycle was repeated.

CORRELATION WITH FAA/TC DATA

Time correlation of the two data sets was to be based on the squib firing event marker on Boeing and FAA oscillograph charts and on examination of agent distribution data for aircraft channel 1, which had been acquired on data both systems.

While both sets of data were digitized so the elapsed time started with the firing of the agent release squib, differences in the pneumatic tubing and vacuum pumps caused the Boeing data to consistently lag behind the FAA data by 0.75 second. Hence the Boeing elapsed time data was adjusted by this amount prior to plotting. The time correlation data for channel 1 is shown in Figures B-7, B-8 and B-9. These figures show acceptable agreement between the two data systems, differences being due to:

1. The FAA data was digitized once every half second while as many as 20 points per second were digitized near points of inflection with the Boeing data.

2. Calibration equations for both types of sensors were optimized for the 6-percent concentration presumed to be required. At significantly higher concentrations differences are anticipated.
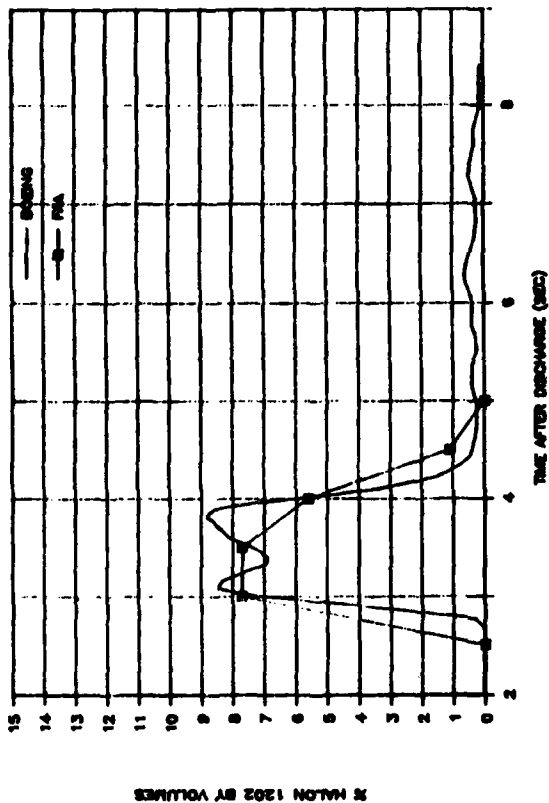
Channel 1 correlation plots are not presented for Tests 5, 10, 11 or 14 because the channel 1 halon concentrations were negligible during these high airflow test conditions.

Combined plots for all twelve agent concentration sampling locations for the 14 tests which were performed are included as Section III of this Appendix.
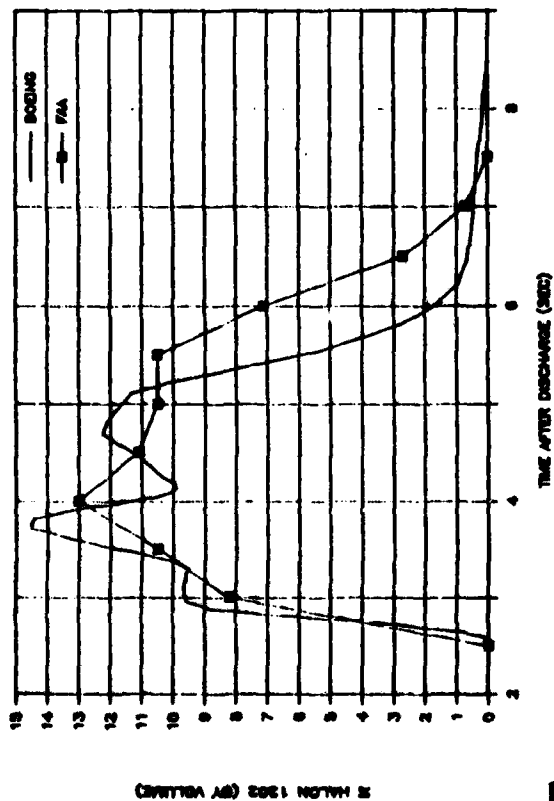
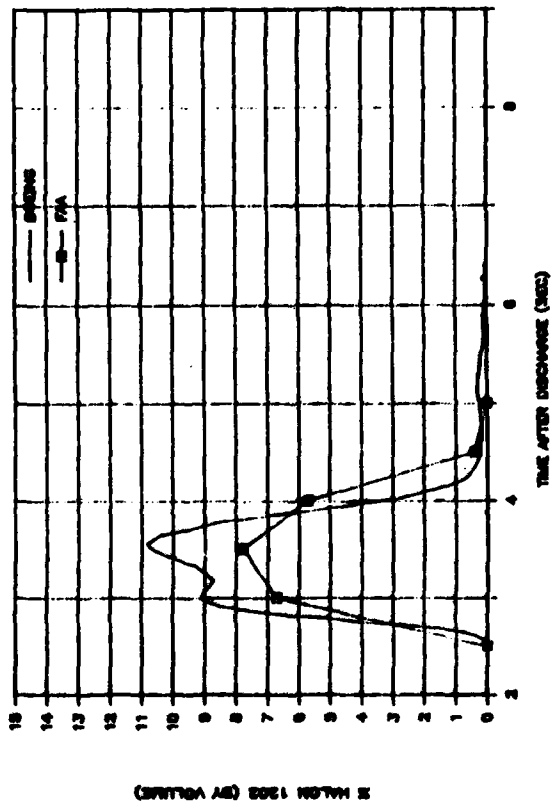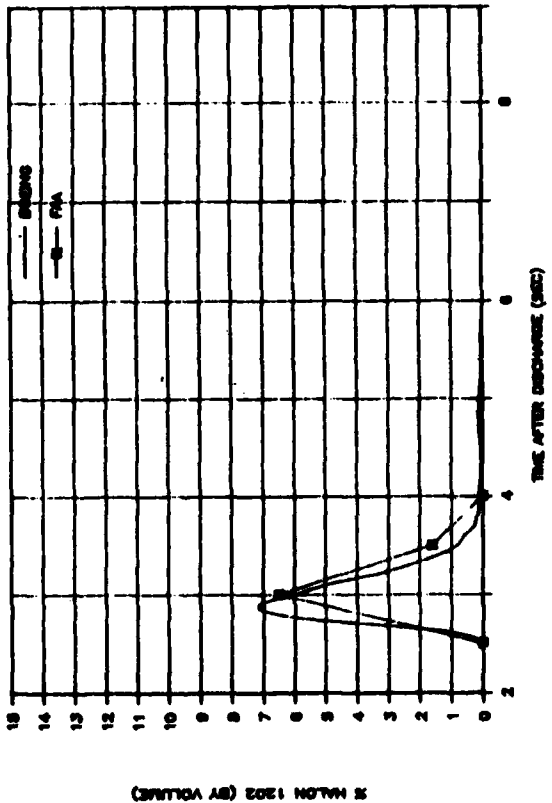Figure B-7. Time Correlation of Boeing and FAA Data
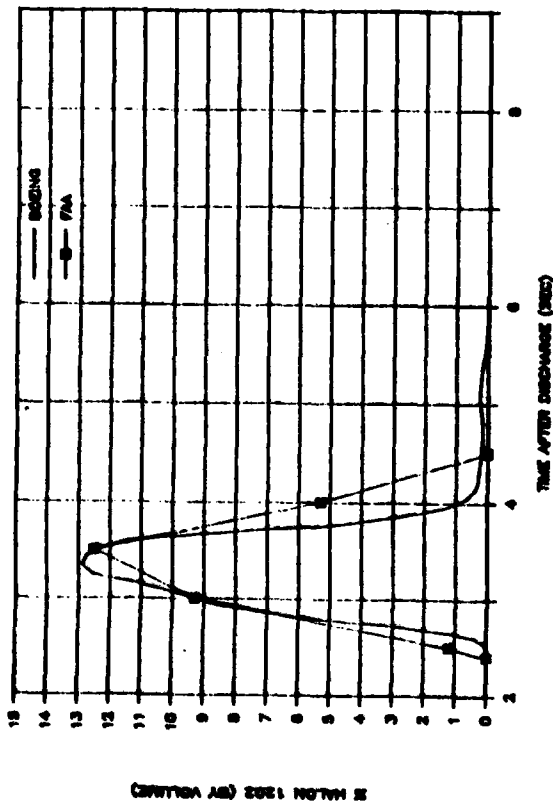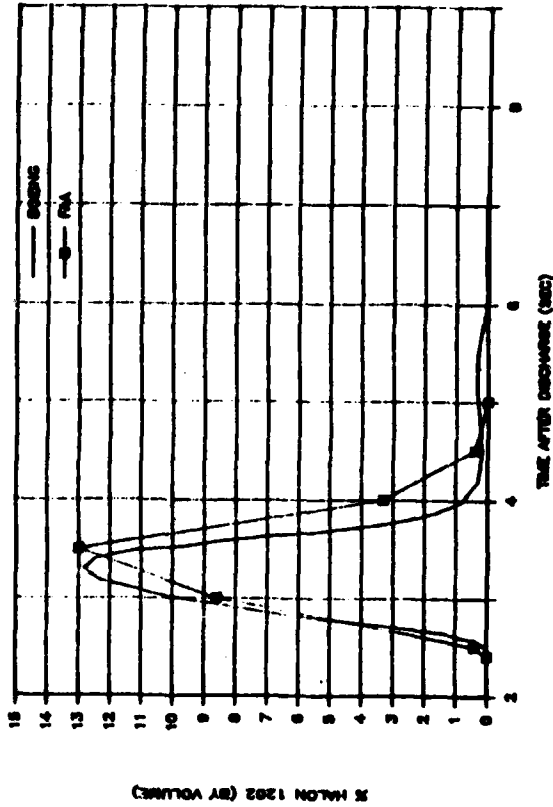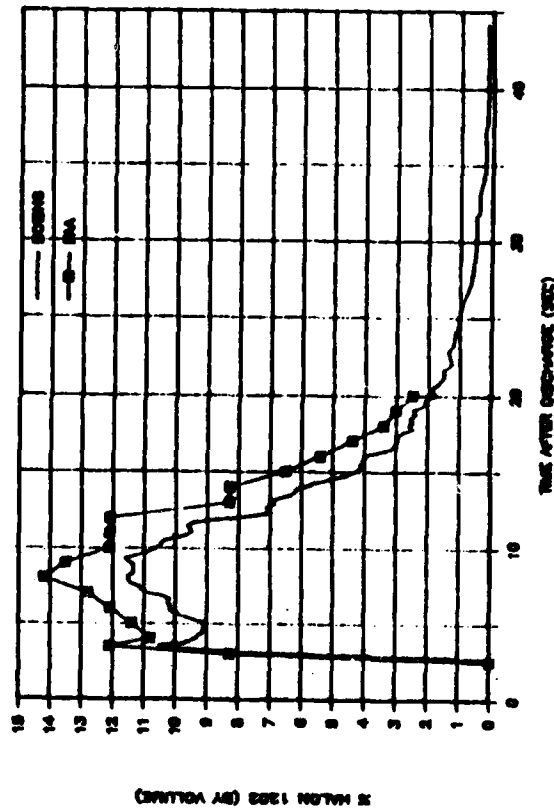
Figure B-8. Time Correlation of Boeing and FAA Data

TEST #12 (F-1), GRD. OPS W/EJ

TEST #9 (OC-1), GRD. OPS W/EJ
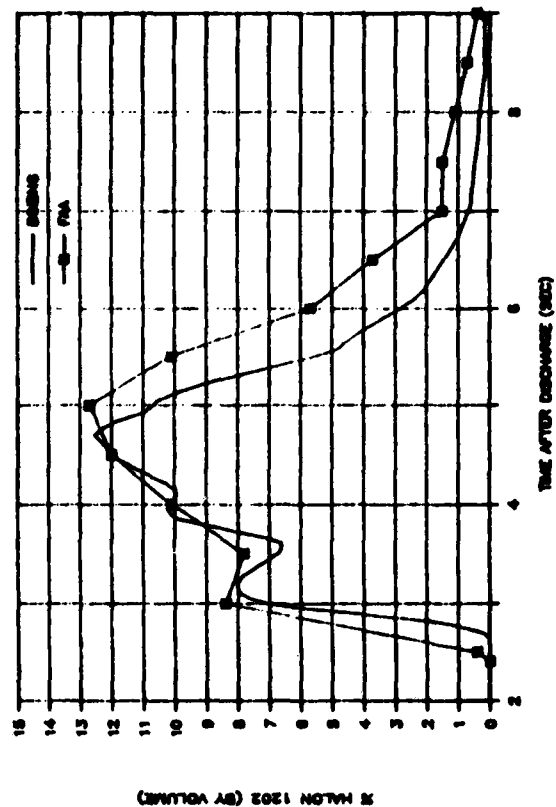
TEST #13 (F-2), 78% HOLDING
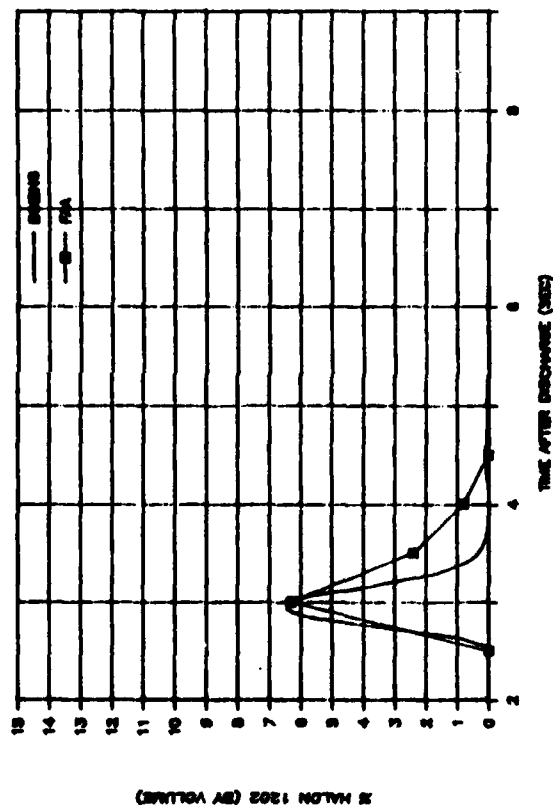
Figure B-9. Time Correlation of Boeing and FAA Data

BOEING TEST RESULTS

As noted previously, Boeing agreed to plot the FAA portion of the
test data along with its own on a single set of plots once the FAA
had completed digitizing their data and had transmitted it to WPAFB.
A total of 14 agent release tests were run at a variety of flight
conditions.   Table B-1 is a summary of the Boeing run log and
identifies the test number, the flight condition and the presence or
absence of the IDG oil cooler.   Plots of the Boeing and FAA test
results are included in Section III of this Appendix.

The locations of the halon concentration probes, within the F-111
engine compartment, are specified in Figures B-10 and B-11.   The
"FOC" and "F" configurations (as identified in Table B-1) used the
probe positions shown in Figure B-10 while "OC" test conditions
employed the probe positions shown in Figure B-11.

Table B-1. Boeing Test Lab - Summary of Test Runs

| TEST	CONFIG.	DATE	TIME	FLIGHT CONDITION AND COMMENTS
1	FOC-1	7/17/86	5:50 PM	GROUND OPERATION W/EJECTOR (NO TF-33 AIRFLOW)
Line to Boeing channel #2, F-111 probe #3 (1/8" nylon) plugged or melted during first try for this data condition				
2	FOC-2	7/18/86	12:08 PM	82 % CRUISE (5.98 LB/SEC VENTILATION)
Swapped Boeing channel #2 assignm't from F-111 #3 to #8 w/ FAA taking #3 on FAA equipm't to avoid pulling engine				
3	FOC-4	7/19/86	2:47 PM	90% TAKE OFF (7.5 LBS/SEC VENTILATION)
4	FOC-5	7/18/86	3:44 PM	78 % HOLDING (9.67 LB/SEC VENTILATION)
5	FOC-6	7/21/86	11:00 AM	S/L DASH WITH ZONE 1 AFTERBURNING
6	FOC-7	7/21/86	2:00 PM	80% CRUISE, MACH 0.6 AT 30,000 FT.
7	FOC-8	7/21/86	2:45 PM	Identical to FOC-4 except TF-30 at idle during countdown
8	FOC-9	7/22/86	11:30 AM	Neither TF-30 nor TF-33 going; STATIC AGENT DUMP
9	OC-1	7/24/86	11:14 AM	GROUND OPERATION WITH EJECTOR; New probe assignments--see notes
10	OC-2	7/24/86	11:40 AM	90% TAKE OFF (as with test #3)
11	OC-3	7/24/86	12:17 PM	SEA LEVEL MACH 1.2 DASH WITH ZONE 1 AFTERBURNING
12	F-1	7/24/86	3:12 PM	GROUND OPERATION WITH EJECTOR; probe assignments returned to original (test #2 through #8) configuration.
13	F-2	7/24/86	3:45 PM	78% HOLDING 10.05 LBS/SECOND ("F" setting)
14	F-3	7/24/86	4:15 PM	SE/ LEVEL MACH 1.2 DASH WITH ZONE 1 A/B; ("F" setting with 30.4 lbs/sec.)
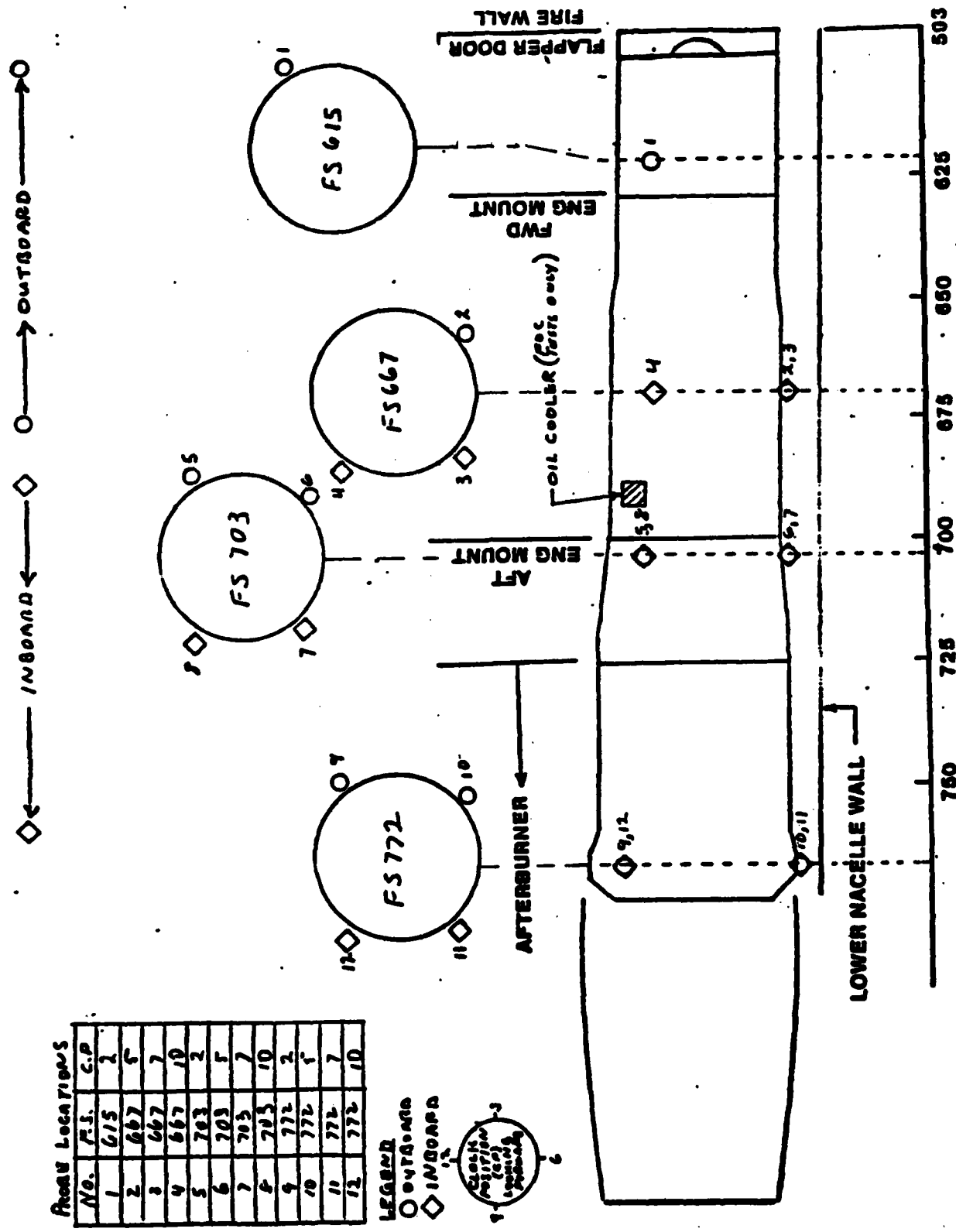
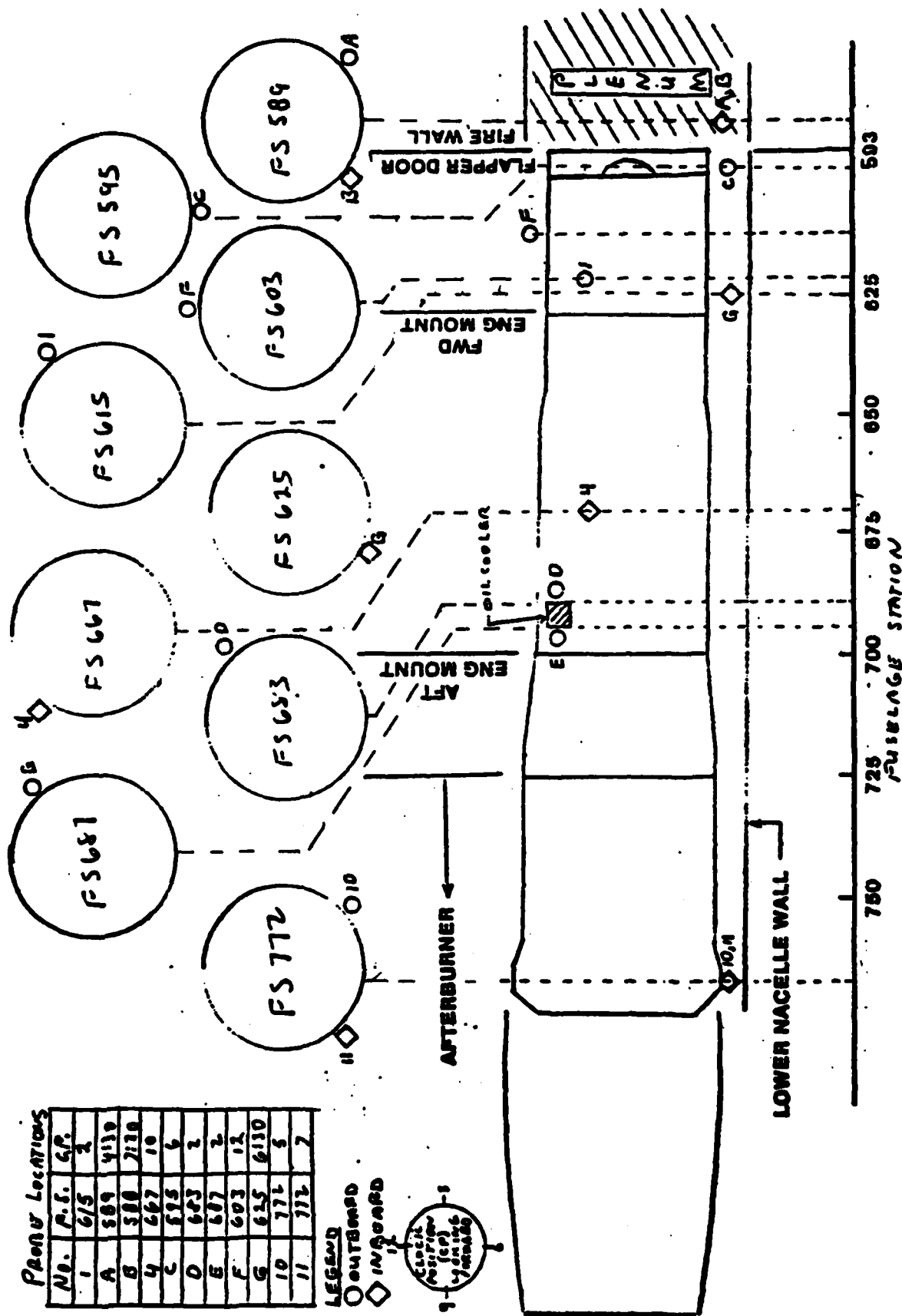Figure B-10. Sample Probe Locations for FOC and F Series Tests

Figure B-11. Sample Probe Locations for OC Series Tests

SECTION II - RESPONSE TIME INVESTIGATION FOR BECKMAN HALONIZERS

Prior work in the AEN using the Beckman Halonizers has employed pneumatic sample lines consisting of a 36-inch length of 0.085-inch ID CRES tubing coupled to the 30-inch-long 0.045-inch ID plastic tube (Beckman jumper) which attaches to the halonizer pickup head. Total response time with this arrangement was about 0.3 seconds, acceptable for normal halon pulses which ranged from about 0.5 to 2 seconds in duration.

The Beckman Halonizers will be used in July to assist the FAA/TC with the EF-111A testing at Atlantic City. Two potential problems with halonizer response time in that installation have been identified:

1.   The FAA/TC test setup currently employs 16-foot-long 1/4-inch (0.194-inch ID) copper tubing for sample lines, having a much larger volume to pull through the Beckman vacuum pumps than with the normal AEN installation. Initial calculations suggested transport time around 12 seconds. The degree to which the input data would be distorted is unknown.

2.   Earlier testing in the AEN suggested that the high airflow test points would produce very short halon pulses at the sample tubes, some less that half a second. Significant "smearing" due to response time problems might preclude accurate measurement of these.

BACKGROUND TESTS

General Dynamics (GD) testing of the F-111 with Statham analyzers in February of 1969, was limited to static conditions where the nacelle airflow was due entirely to the pumping of the nacelle ejectors. Figure B-12 shows the results of those tests as presented in JTCG/AS-74-T-002.

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F-111 NACELLE
GROUND OPERATION
12.65 POUNDS OF HALON 1202 & 2.6 LBS/SEC AIRFLOW
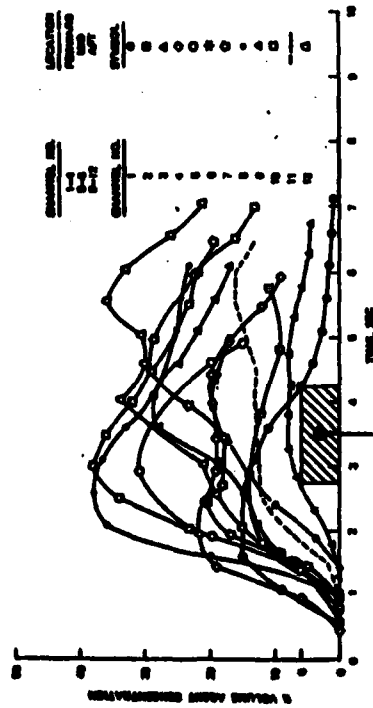
6% FOR 1.5 SECONDS

Figure B-12. F-111 Nacelle Fire Extinguishing Test Results

4 LBS HALON 1202 6.7 LBS/SEC AIRFLOW

OVER 30% FOR 2 SECONDS

% HALON 1202 (BY VOLUME)

TIME (SECONDS)
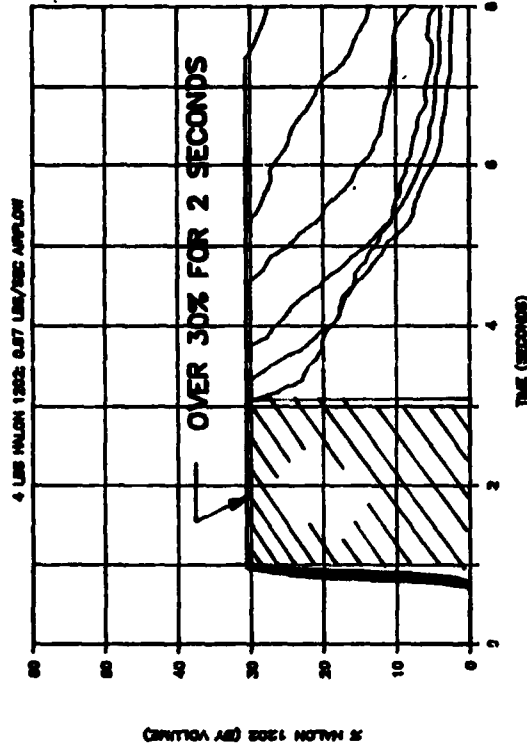
Figure B-13. AEN Ground Operation Simulation

F-16 NACELLE SIMULATOR IN AEN
4 LBS HALON 1202 7 LBS/SEC AIRFLOW

2% FOR 1/2 SECOND.

% HALON 1202 (BY VOLUME)

TIME (SECONDS)

Figure B-14. AEN Cruise Simulation

B-22

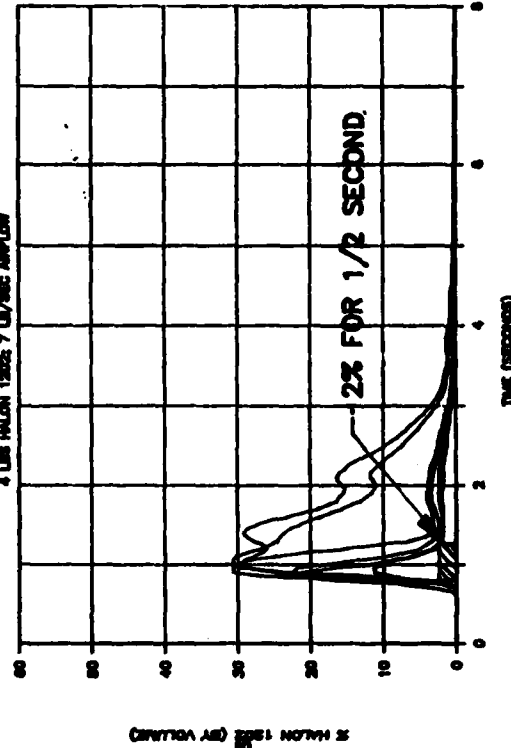Tests were run in the AEN to see if the GD halon concentration test results were duplicated at similar airflows and to examine what type of halon pulses might be experienced at higher airflows in the forthcoming EF-111A testing. The AEN F-16 Nacelle Simulator, a 1/3 annulus representing the nacelle flow areas and engine components of the F-16 engine compartment was used. An F-111 halon tank was filled with 4 lbs of Halon 1202, about 1/3 of the carried for the F-111 nacelle fire protection system and back charged with nitrogen to 600 psig. Halon 1202 concentration data were acquired at airflows of 0.87 and 7 lbs/second, representing 1/3 of F-111 airflow at ground idle and cruise conditions, respectively. Halon probes were left in the normal AEN locations, not matched to the F-111 locations used in the GD tests.

The data obtained are shown in Figures B-13 and B-14. The ground idle conditions (Figure B-13) roughly match the GD data in pulse strength and duration although the AEN data is truncated above 30-percent because the halonizers saturated. This saturation is not a problem as the halon specification, MIL-E-22285 is based on demonstrating that a concentration of 6-percent exists at all locations simultaneously for 1/2 second. The higher airflow case (Figure B-14) suggests that much shorter pulses will be measured for these tests. Hence it is unlikely that the F-111 system would have satisfied the specification requirements at cruise conditions. In addition, these data suggest that the halonizers' response time might be marginal for these tests and that it should be carefully examined.

APPROACH

Hence preliminary halonizer time response tests were run with a variety of tubing systems to describe the Beckman equipment's response time characteristic with tubing suitable for use at Atlantic City.

Because of Halon 1202's low vapor pressure it is not possible to contain large quantities at useful "calibrated" concentrations. A portion would liquefy and the concentrations would change. Hence the response time characteristics for measurement of 100-percent concentrations of Halon 1202 and 1301 were initially compared. Figure B-15 illustrates that the response time was the same for 100-percent concentrations of Halon 1202 and Halon 1301 except that the halonizers saturated at different levels. Thereafter, for convenience, all response time testing was performed with a 6.9-percent calibration mixture of Halon 1301 (6.9-percent Halon 1301 by volume, the remainder being nitrogen).

An input pulse was provided as a step function by passing the end of the sample tube from a jet of compressed air to a jet of 6.9-percent Halon 1301 and then back to the air jet. The tube location was changed rapidly with a solenoid so that transport time from one jet to the other was negligible. The test fixture is shown in Figure B-16. In some tests, an electronic timer was employed to return the tube to the air jet exactly one-half or two seconds later. The tube used for the data shown was 48 feet long. Its other end was plugged directly into the halonizer pickup head. Digital halon concentration data were acquired for this single halonizer channel for 10 or 20 seconds following the start of the pulse.

DEFINITION OF TERMS

Figure B-17 illustrates the components of pneumatic response time. Initially the halonizer shows no halon concentration while its vacuum pump is pulling the first of the halon through the length of the sample tube. This period is defined as "transport time." As the halonizer begins to respond it rises slowly, then rapidly and then slows again as it approaches its final value. "Smear" is defined as the time required for the output to rise from 5-percent to 95-percent of the input value. Hence the initial 5-percent of the rise is actually included in the transport time.
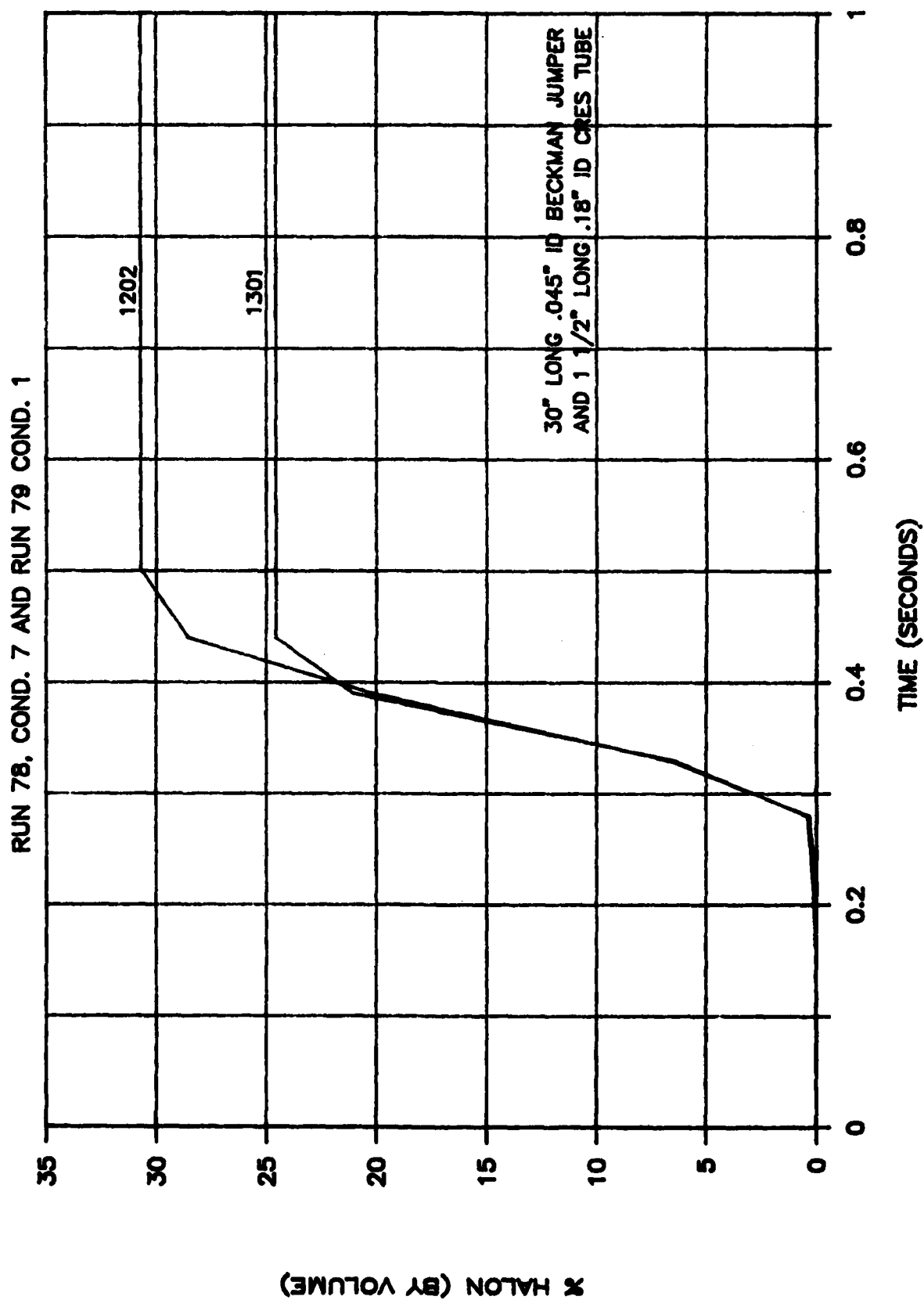
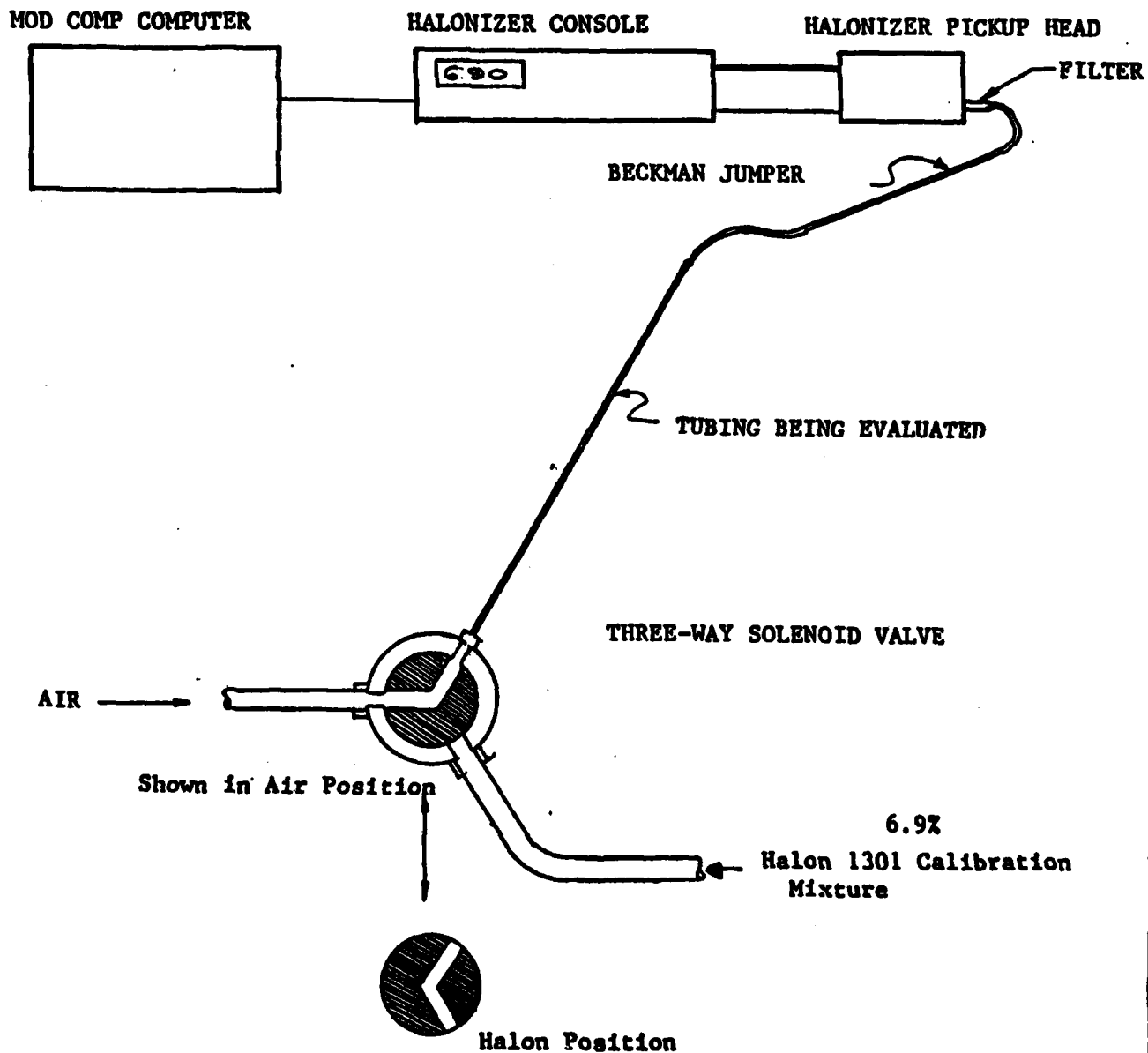Figure B-15. Response Times with 100% Halon 1202 and 1301

Figure B-16.   Halon Purge Simulator with Three-Way Solenoid
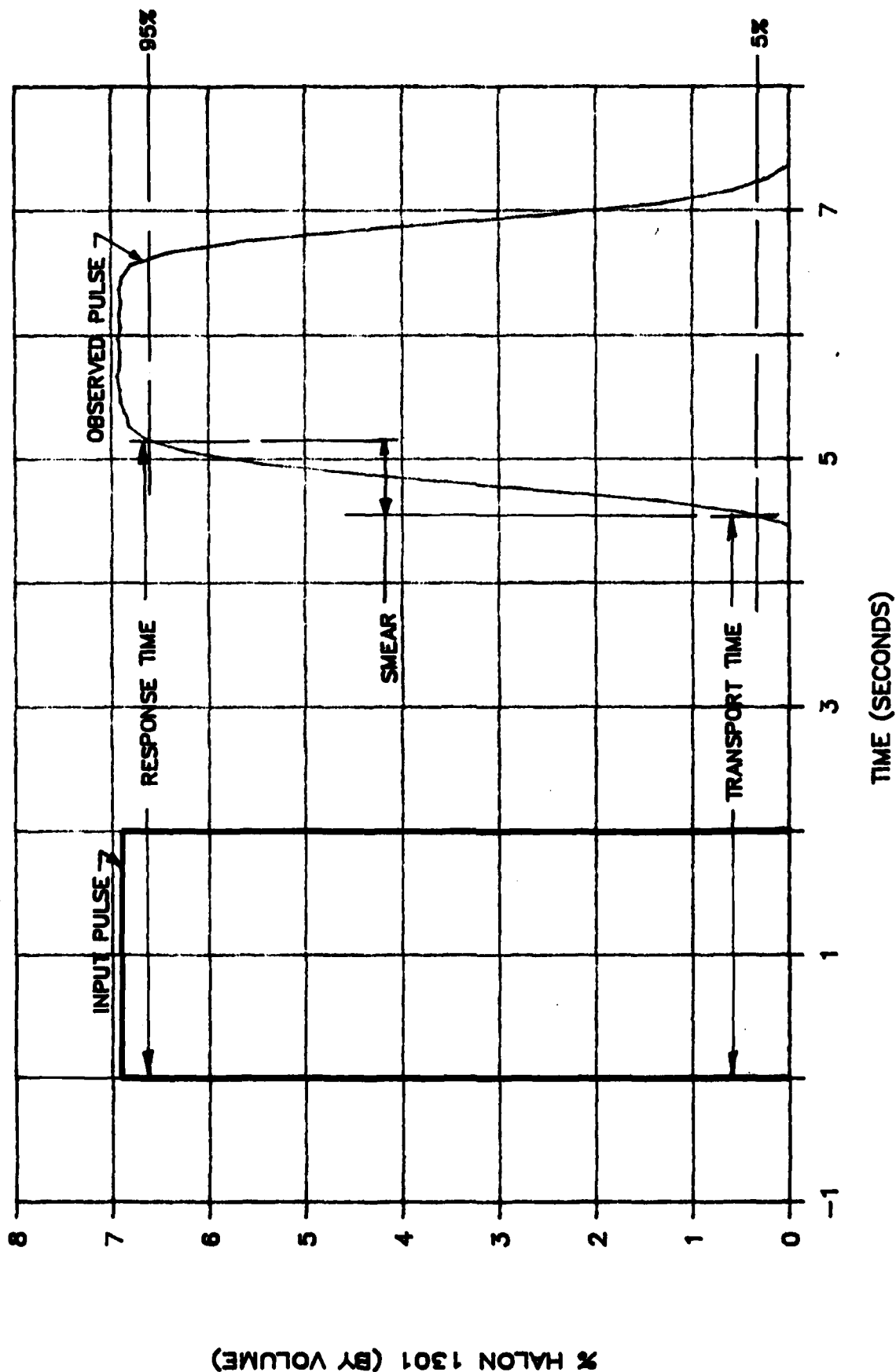
Figure B-17. Definition of Terms

B-27

Smear is most important for the anticipated EF-111A testing.
Transport time can be readily corrected as long as it is the same
for all channels. Smear can cause significant problems in data
quality.

ILLUSTRATION OF PROBLEM

Figure B-18 illustrates the extreme case of the difficulties which
would be encountered if the wrong tubing system were selected for
use with the Beckman equipment at Atlantic City in July. Different
tubing systems were coupled to the 0.045-inch ID Beckman jumper,
included 15 feet of 0.194-inch ID copper as will be used with the
Stathams at Atlantic City, 16 feet of 0.029-inch ID CRES tubing and
16 and 32 feet of 0.092-inch ID CRES tubing. The response times
recorded with these are contrasted to the response time with the
Beckman jumper with a minimum 1 1/2-inch length of 0.18-inch ID CRES
tubing fastened to the solenoid. The 1/2-second pulses of
6.9-percent Halon 1301 climb to less than 4-percent with both the
0.029-inch ID CRES and 0.194-inch ID copper tubing before the curves
starts to diminish. The curves for the two lengths of 0.092-inch ID
CRES tubing do not show a half second of width above 4-percent
concentration.

Because a half second pulse probably could not meet the simultaneity
criteria of the specification, a better guide for selecting the
tubing would be the 2-second duration pulses shown in Figure B-19.
In this case, using the original 30-inch Beckman 0.045-inch ID line
with the short connection to the solenoid, the observed pulse nearly
duplicates the original 6.9-percent square wave. The two different
lengths of 0.092-inch ID CRES tubing also duplicate the original
pulse adequately, having about 1.7-second width at the 6-percent
level for the 32-foot length and about 1.8-second width at the
6-percent level with the 16-foot length. Both the 0.029-inch ID
CRES tubing and the 0.194-inch ID copper tubing show lower peaks and
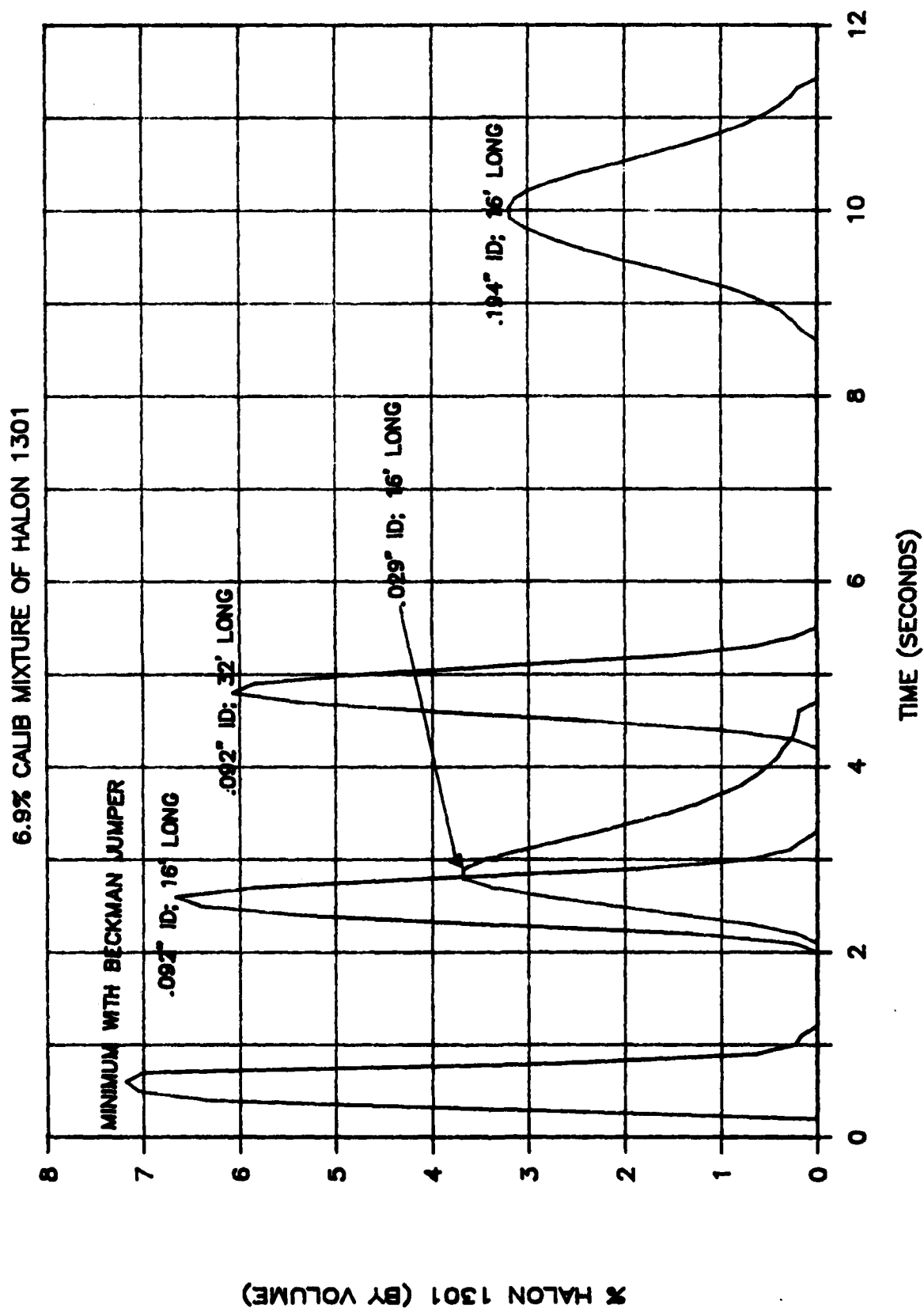significantly reduced duration at the 6-percent level, however.
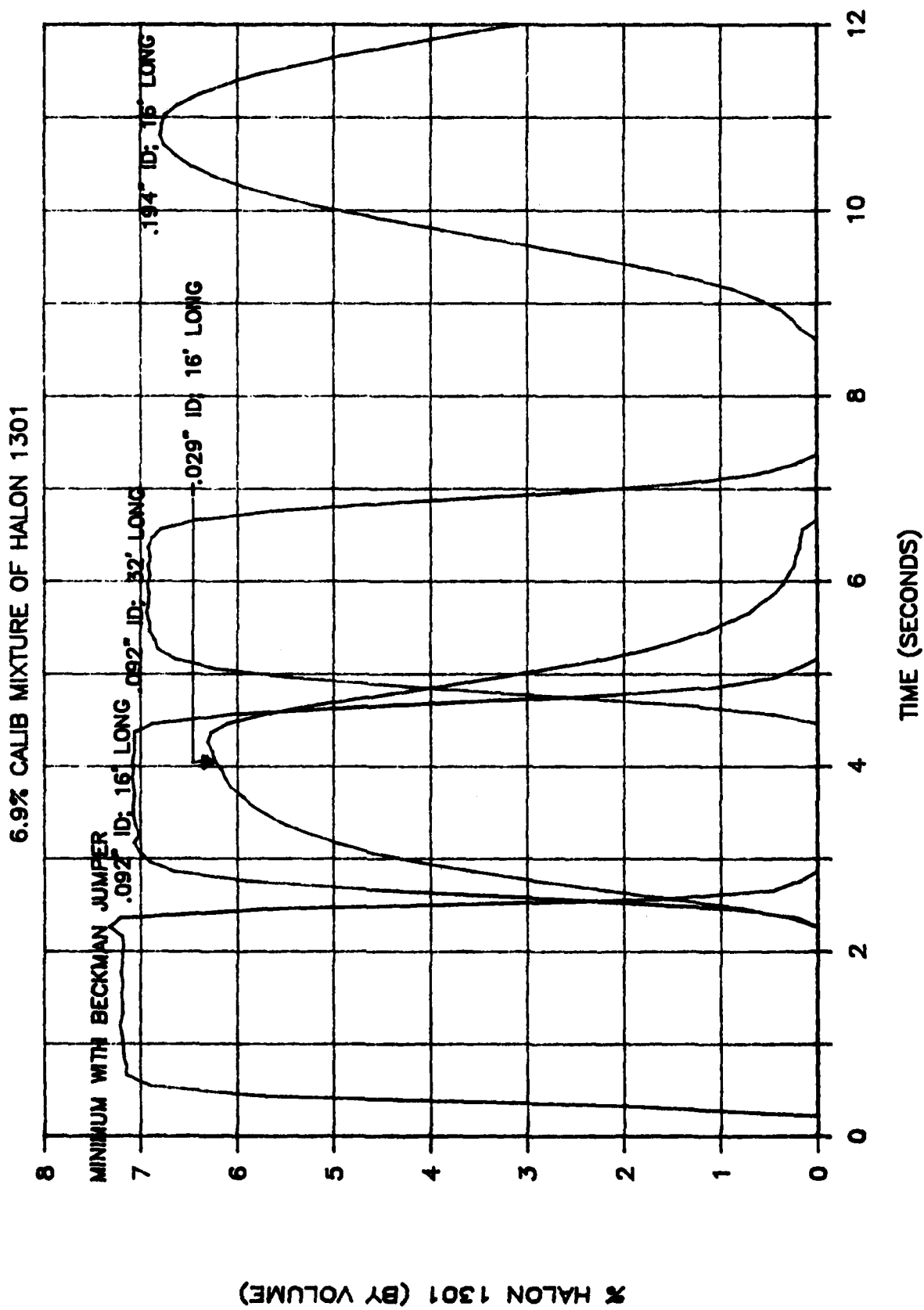
Figure B-18. Effect of Smear on Halon Concentration

Figure B-19. Effect of Smear on Halon Concentration Data; 2 sec pulses

Figure B-19 also illustrates that the diameter of the tubing effects both the transport time and the smear effect but that, for the 0.092-inch ID tubing, the length changes seem to effect transport time more than the smear.

At this point in the testing, a short length of 0.070-inch ID plastic line which could be attached directly to the Beckman pickup head without the 0.045-inch ID jumper was tried. It was noted that the Beckman rotameter setting rose to full scale indicating much less friction than with the other systems, all of which employed that 0.045 jumper.

Hence, 16-, 32- and 48-foot lengths of the 0.070-inch ID tubing were tried with the 1/2- and 2-second pulses of the 6.9-percent calibration mixture without the 0.045-inch ID restriction of the Beckman jumper. The results of these tests are shown in Figure B-20. Again the transport time increased as the tubing length was increased but the smear was relatively constant. The smear for the 0.070 and 0.092 tubing is compared in Figure B-21 with the time scale amplified. While we found that elimination of the 0.045-inch ID Beckman jumper allowed the rotameter settings to be increased with the 16- and 32-foot lengths of 0.070 inch ID tubing, this affected the transport time more than the smear.

The Beckman instruments could be installed at the end of 16-foot sample lines for the F-111 testing but this would compromise the installation in two ways: (1) The Beckman pickup heads would be adjacent to the F-111 engine and would probably be exposed to excessive vibration, particularly if used with the four sample tubes at the aft end of the nacelle. They have produced erratic signals unless protected from the vibration of the AEN. (2) Adjustments to the pickup head's optical balance would be easier with the pickup

B-31
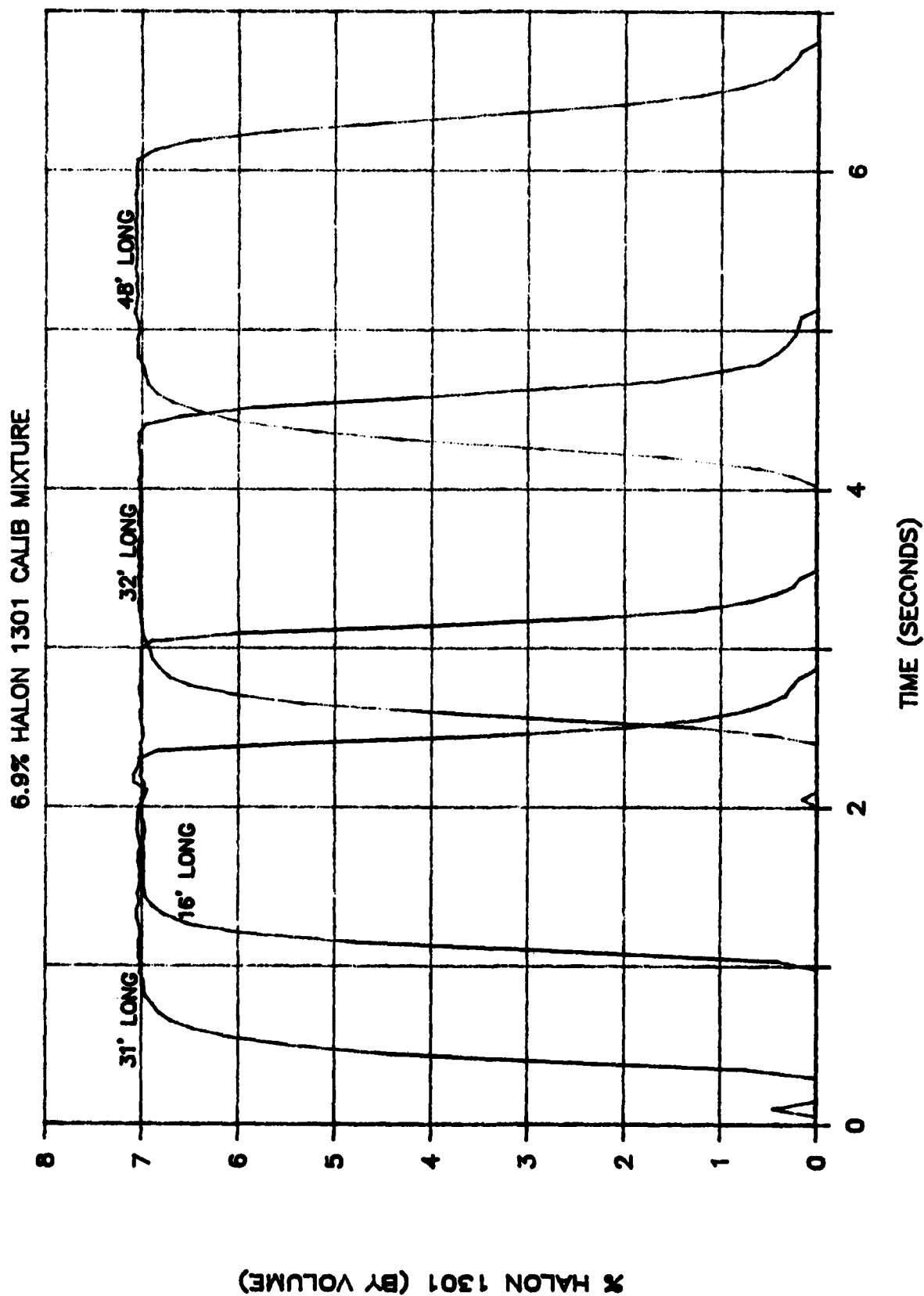
Figure B-20. Response Time for 0.070-inch ID Tubing without Beckman Jumper
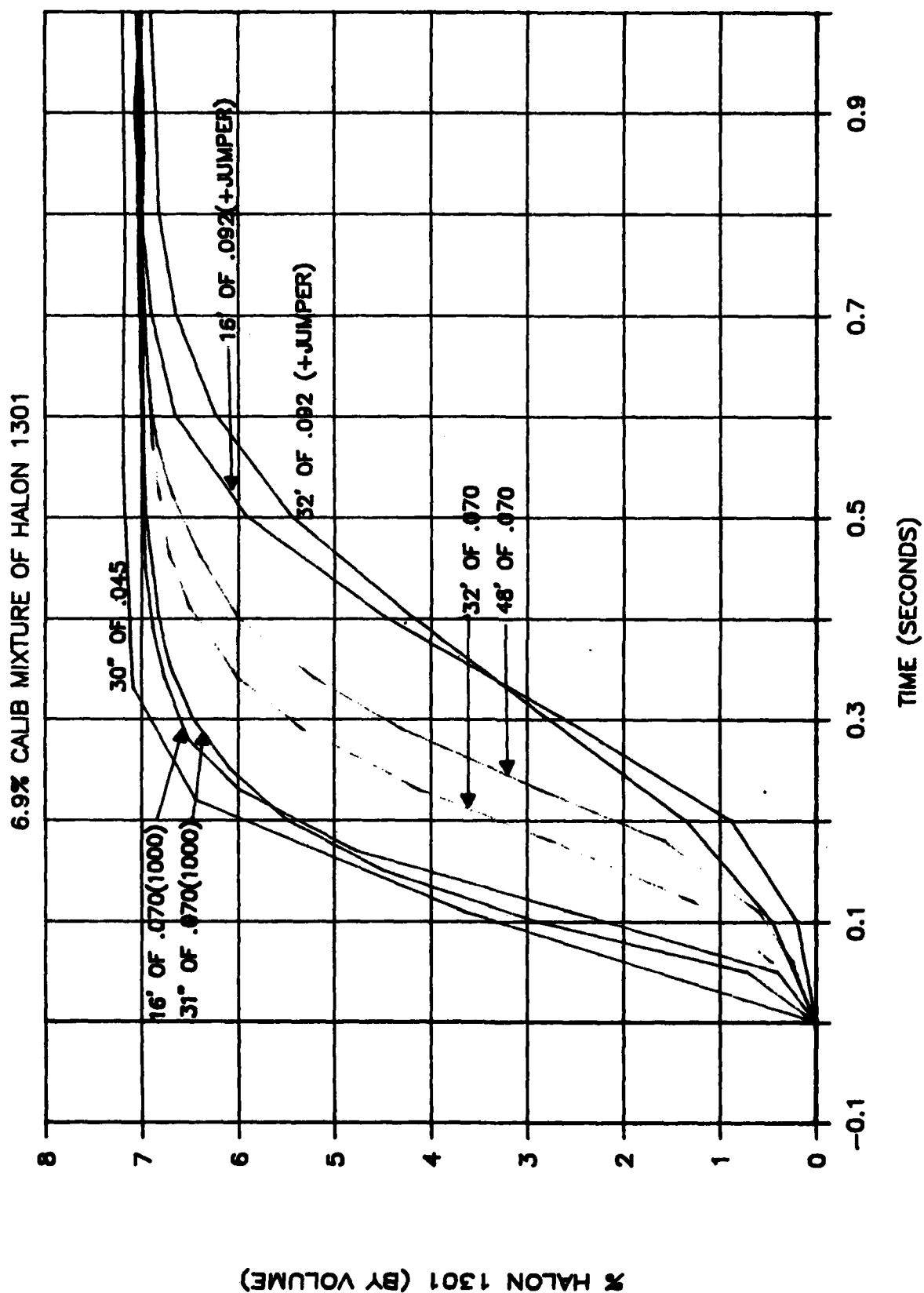
Figure B-21. Smear with 0.092- and 0.070-Inch ID Tubing

0.070 " ID NYLON TUBING

TRANSIT TIME

SMEAR

TIME (SECONDS)

TUBING LENGTH (FEET)
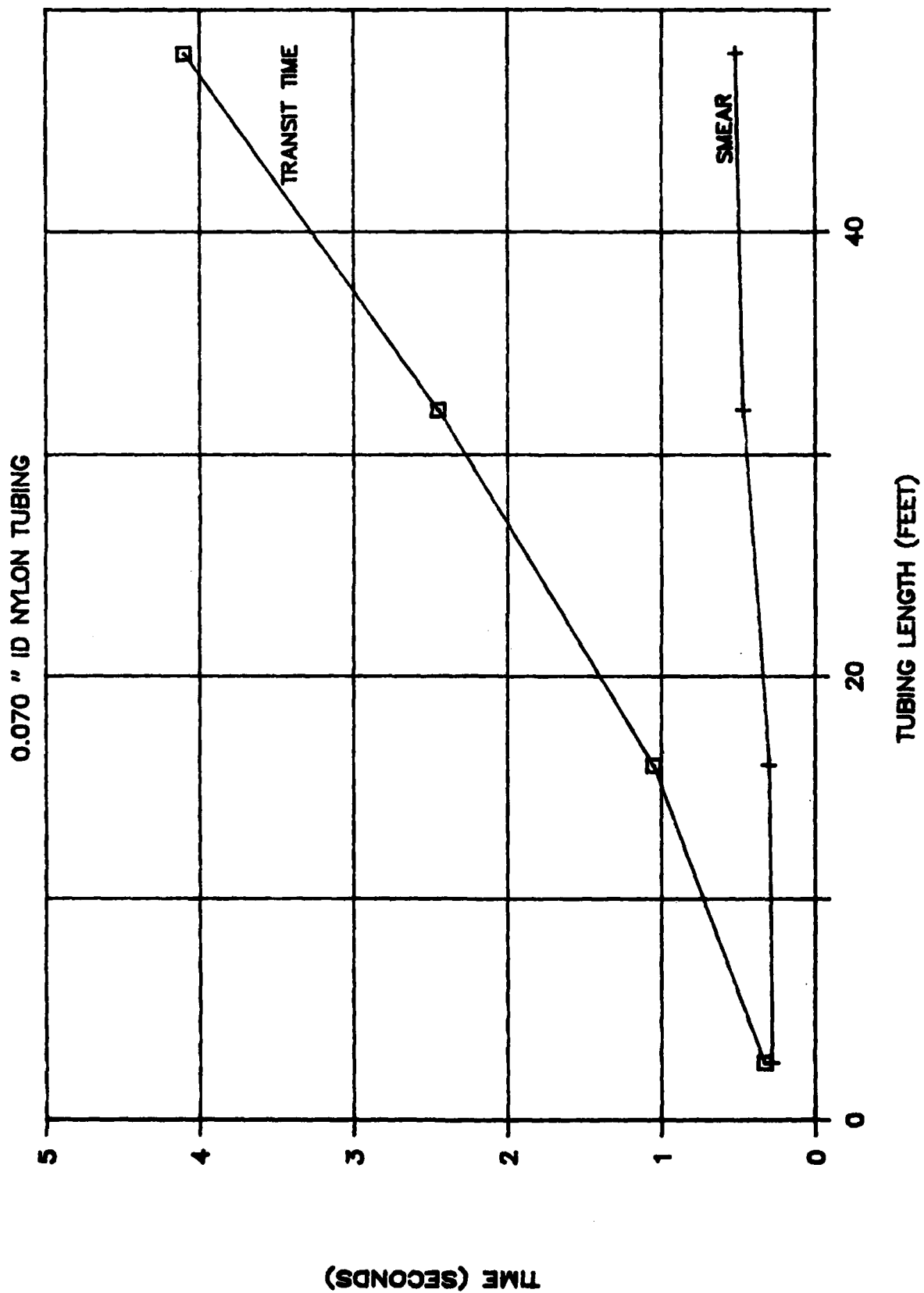
Figure B-22. Transit Time and Smear for Various Lengths of 0.070-Inch ID Tubing

B-34

heads near the console units in the instrumentation trailer. The
use of 40-foot sample tubes would allow the sample cells to be
located in the trailer and the tubes could still reach all planned
agent sampling locations including those at the aft end of the
nacelle.

Figure B-22 shows transport time and smear for the several lengths
of 0.070-inch ID tubing tested and suggests that transport time for
the 40-foot, 0.070-inch ID sample tubes will probably be about 3.3
seconds and smear, about 0.5 second. While pulses shorter than 1/2
second may occur during the higher airflow test conditions at some
of the sampling locations within the F-111 test article, it is
unlikely that these would satisfy Mil-E-22285 even without the
distortion caused by smear. With pulses long enough to satisfy the
specification requirement, the effect of the smear will be small.
Table B-2 lists all the tests that were conducted during this
investigation.

The solenoid operated calibration device used for these tests will
be taken to Atlantic City in July so that similar instrument
response time data can be acquired for the FAA's Statham equipment.
Transport time for the Beckman and Statham equipment will be defined
for the 6.9-percent Halon 1301 pulses and for the specific sample
tube configuration assembled for each device. These transport times
will be used to correct data from both devices so that simultaneity
of all halon concentration data can be assured.

Table B-2. Halonizer Time Response Testing in Preparation for FAA/TC EF-111A Agent Distribution Tests

RUN	COND	DATE	TUBING LENGTH	TUBING TYPE	TUBING ID	PULSE TYPE	PULSE DURATION	ROTOMETER SETTING	COMMENTS
78	1	6/3/86	16'	CRES	.032"	100% 1202	~2 SEC	500 CC/MIN	
78	2	6/3/86	16'	CRES	.032"	100% 1202	~2 SEC	500 CC/MIN	
78	3	6/3/86	16'	COPPER	.194"	100% 1202	~2 SEC	??	ROTOMETER HIGH - LESS FRICTION
78	4	6/3/86	16'	COPPER	.194"	100% 1202	~2 SEC	??	ROTOMETER HIGH - LESS FRICTION
78	5	6/3/86	16'	COPPER	.194"	100% 1202	~2 SEC	500 CC/MIN	
78	6	6/3/86	16'	COPPER	.194"	100% 1202	~2 SEC	500 CC/MIN	
78	7	6/3/86	1 1/2"	CRES	0.10"	100% 1202	~2 SEC	500 CC/MIN	
78	8	6/3/86	1 1/2"	CRES	0.10"	100% 1202	~2 SEC	500 CC/MIN	
79	1	6/3/86	1 1/2"	CRES	0.10"	100% 1301	~2 SEC	500 CC/MIN	
79	2	6/3/86	1 1/2"	CRES	0.10"	100% 1301	~2 SEC	500 CC/MIN	
79	3	6/3/86	1 1/2"	CRES	0.10"	6.9% 1301	~2 SEC	500 CC/MIN	
79	4	6/3/86	1 1/2"	CRES	0.10"	6.9% 1301	~2 SEC	500 CC/MIN	
79	5	6/3/86	16'	COPPER	.194"	6.9% 1301	~2 SEC	500 CC/MIN	
79	6	6/3/86	16'	COPPER	.194"	6.9% 1301	~2 SEC	500 CC/MIN	
79	7	6/3/86	16'	COPPER	.194"	6.9% 1301	~2 SEC	500 CC/MIN	
79	8	6/3/86	16'	CRES	.032"	6.9% 1301	~2 SEC	500 CC/MIN	
79	9	6/3/86	16'	CRES	.032"	6.9% 1301	~2 SEC	500 CC/MIN	
PRIOR TO THIS POINT PULSE LENGTH IS APPROXIMATE						FROM THIS POINT ON, T1 PROGRAMMER IN USE AND PULSES ARE AS NOTED			
80	1	6/4/86	32'	CRES	.032"	NONE			DATA SYSTEM CHECK
80	2	6/4/86	32'	CRES	.032"	6.9% 1301	1/2 SEC	500 CC/MIN	
80	3	6/4/86	32'	CRES	.032"	6.9% 1301	1/2 SEC	500 CC/MIN	
80	4	6/4/86	32'	CRES	.032"	6.9% 1301	2 SEC	500 CC/MIN	
80	5	6/4/86	32'	CRES	.032"	6.9% 1301	2 SEC	500 CC/MIN	
80	6	6/4/86	16'	CRES	.032"	6.9% 1301	2 SEC	500 CC/MIN	
80	7	6/4/86	16'	CRES	.032"	6.9% 1301	1/2 SEC	500 CC/MIN	
80	8	6/4/86	16'	CRES	.032"	6.9% 1301	1/2 SEC	500 CC/MIN	
80	9	6/4/86	16'	CRES	.029"	6.9% 1301	1/2 SEC	400 CC/MIN	VACUUM PUMP CAN'T PULL 500 CC/MIN
80	10	6/4/86	16'	CRES	.029"	6.9% 1301	1/2 SEC	400 CC/MIN	WITH 1/16
80	11	6/4/86	16'	CRES	.029"	6.9% 1301	2 SEC	400 CC/MIN	TUBING
80	12	6/4/86	16'	CRES	.029"	6.9% 1301	2 SEC	400 CC/MIN	
80	13	6/4/86	16'	COPPER	.194"	6.9% 1301	2 SEC	500 CC/MIN	
80	14	6/4/86	16'	COPPER	.194"	6.9% 1301	1/2 SEC	500 CC/MIN	
80	15	6/4/86	1 1/2"	CRES	.10"	6.9% 1301	1/2 SEC	500 CC/MIN	H2O COMP DIED, 9"GRAPH DATA ONLY
80	16	6/4/86	1 1/2"	CRES	.10"	6.9% 1301	1/2 SEC	500 CC/MIN	H2O COMP DIED, 9"GRAPH DATA ONLY
80	17	6/4/86	1 1/2"	CRES	.10"	6.9% 1301	1/2 SEC	500 CC/MIN	H2O TUBE FELL AWAY FROM HOLE
80	18	6/4/86	1 1/2"	CRES	.10"	6.9% 1301	1/2 SEC	500 CC/MIN	
80	19	6/4/86	1 1/2"	CRES	.10"	6.9% 1301	1/2 SEC	500 CC/MIN	
80	20	6/4/86	1 1/2"	CRES	.10"	6.9% 1301	2 SEC	500 CC/MIN	
80	21	6/4/86	1 1/2"	CRES	.10"	6.9% 1301	2 SEC	500 CC/MIN	
PRIOR TO THIS POINT ALL PNEUMATIC SYSTEMS INCLUDE SECHRON JUMPER. AFTER THIS POINT, TUBING PLUGGED DIRECTLY INTO PICKUP HEAD									READS 7.0%, NEED RECALIB'N
81	1	6/5/86	31'	NYLON	.070"	6.9% 1301	0.5 SEC	900	
81	2	6/5/86	31'	NYLON	.070"	6.9% 1301	0.5 SEC	900	
81	3	6/5/86	31'	NYLON	.070"	6.9% 1301	0.5 SEC	900	
81	4	6/5/86	31'	NYLON	.070"	6.9% 1301	2.0 SEC	900	
81	5	6/5/86	31'	NYLON	.070"	6.9% 1301	2.0 SEC	900	
81	6	6/5/86	31'	NYLON	.070"	6.9% 1301	2.0 SEC	1000	RECALIB'D -40 CHANGE
81	7	6/5/86	16'	NYLON	.070"	6.9% 1301	2.0 SEC	1000	
81	8	6/5/86	16'	NYLON	.070"	6.9% 1301	2.0 SEC	1000	RECALIB'D 16.6 TO 6.9%
81	9	6/5/86	16'	NYLON	.070"	6.9% 1301	2.0 SEC	1000	
81	10	6/5/86	16'	NYLON	.070"	6.9% 1301	0.5 SEC	1000	
81	11	6/5/86	16'	NYLON	.070"	6.9% 1301	0.5 SEC	1000	
81	12	6/5/86	40'	NYLON	.070"	6.9% 1301	0.5 SEC	900	RECALIB'D 16.5 TO 6.9%
81	13	6/5/86	40'	NYLON	.070"	6.9% 1301	0.5 SEC	900	
81	14	6/5/86	40'	NYLON	.070"	6.9% 1301	2.0 SEC	900	RECALIB'D
81	15	6/5/86	32'	NYLON	.070"	6.9% 1301	2.0 SEC	900	
81	16	6/5/86	32'	NYLON	.070"	6.9% 1301	2.0 SEC	730	
81	17	6/5/86	32'	NYLON	.070"	6.9% 1301	0.5 SEC	730	
81	18	6/5/86	32'	NYLON	.070"	6.9% 1301	0.5 SEC	730	

SECTION III – BOEING AND FAA AGENT CONCENTRATION MEASUREMENT PLOTS

EF-111A AGENT DISTRIBUTION TESTING
FAA/TC AIR BLAST TEST FACILITY/ATLANTIC CITY, N.J

17 JULY, 1986; 5:50 PM

% HALON 1202 (BY VOLUME)

TIME AFTER DISCHARGE (SEC)

Figure B-23. Test #1 (FOC-1), Ground Operation with Ejector B-37

18 JULY, 1986; 12:08 PM

TIME AFTER DISCHARGE (SEC)

% HALON 1202 (BY VOLUME)

Figure B-24. Test #2 (FOC-2), 82% Cruise

18 JULY, 1986; 2:47 PM

% HALON 1202 (BY VOLUME)

TIME AFTER DISCHARGE (SEC)
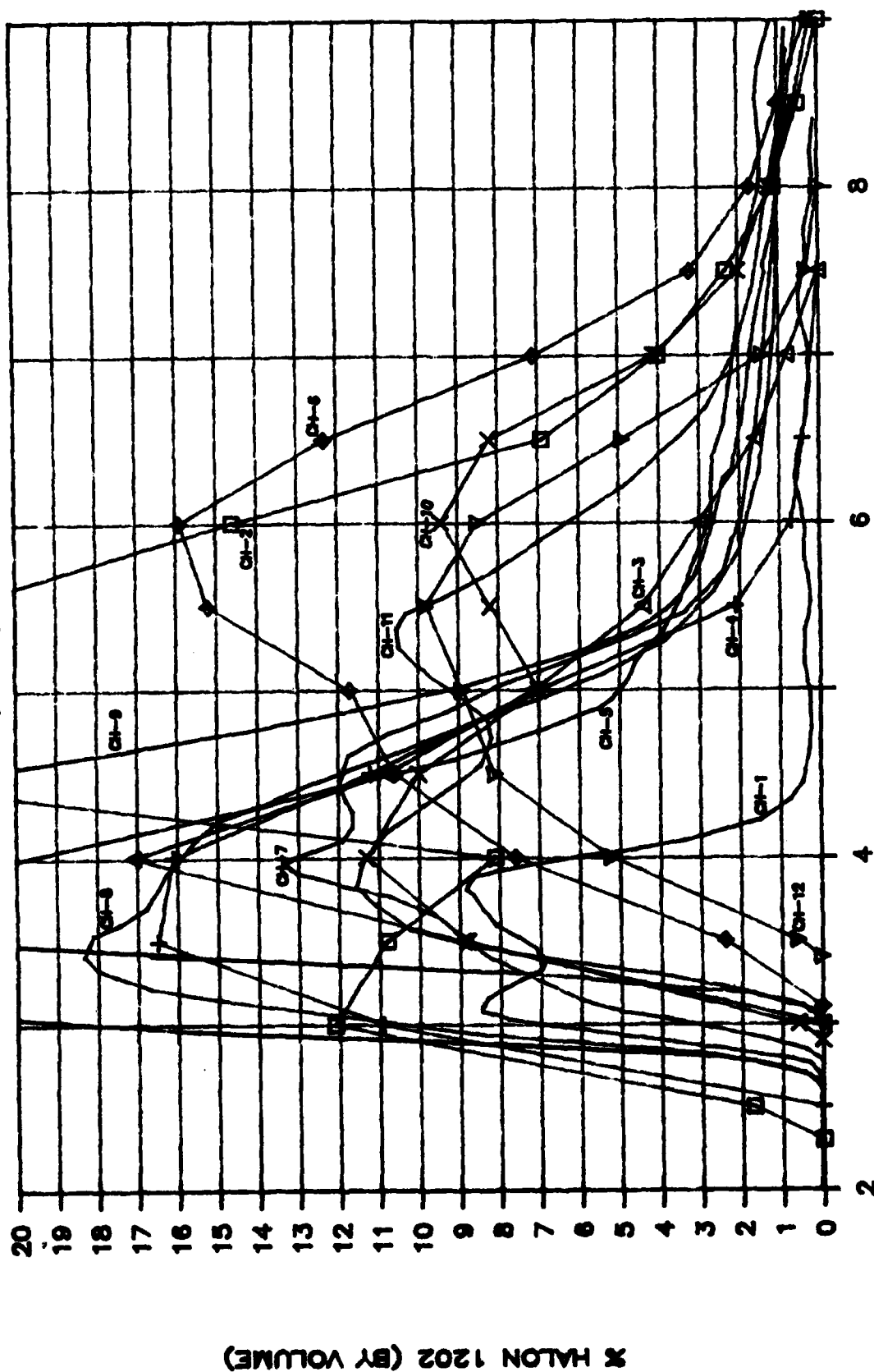
Figure B-25. Test #3 (FOC-4), 90% Take Off
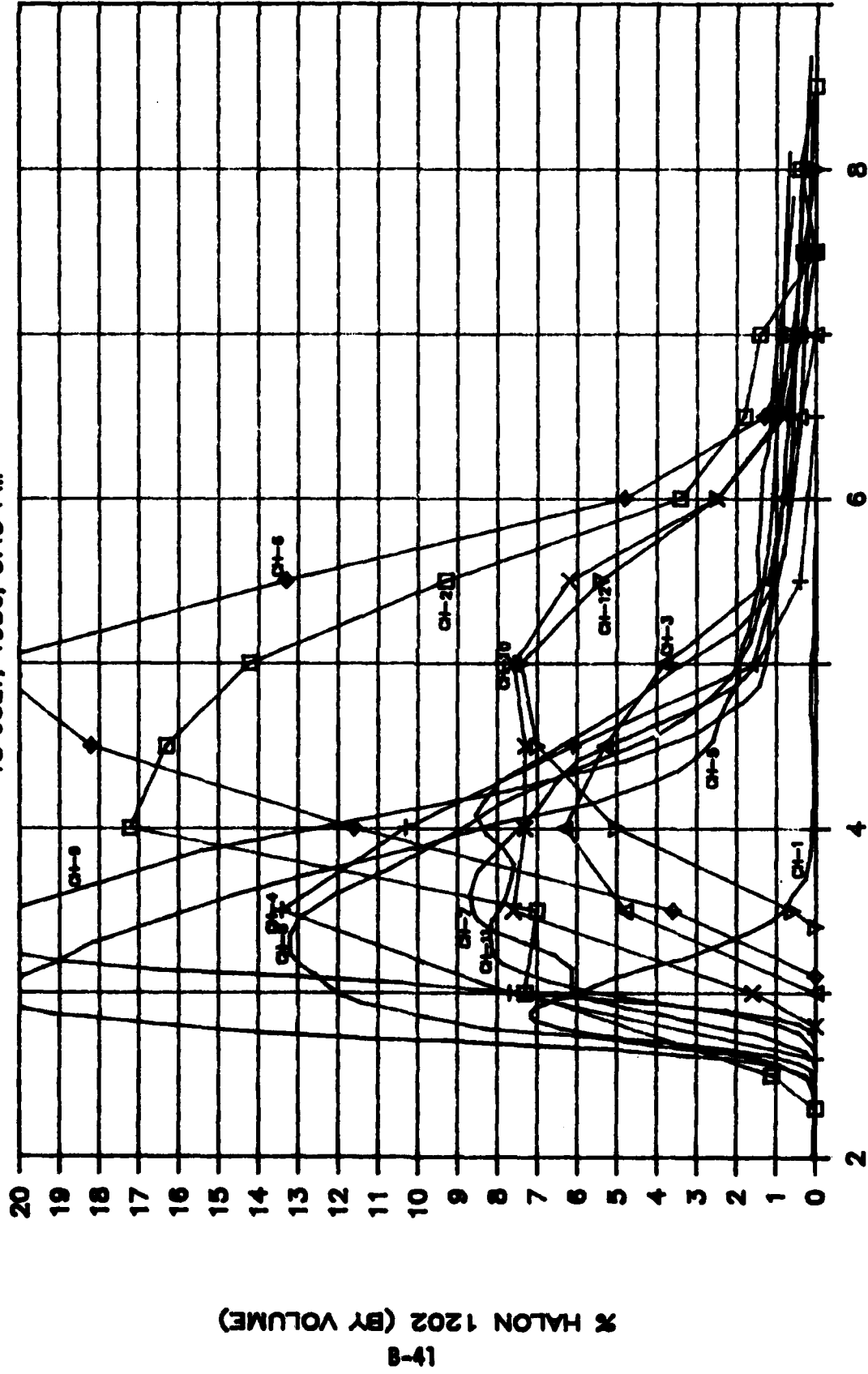
Figure B-26. Test #4 (FOC-5), 78% Holding

21 JULY, 1986; 11:00 AM
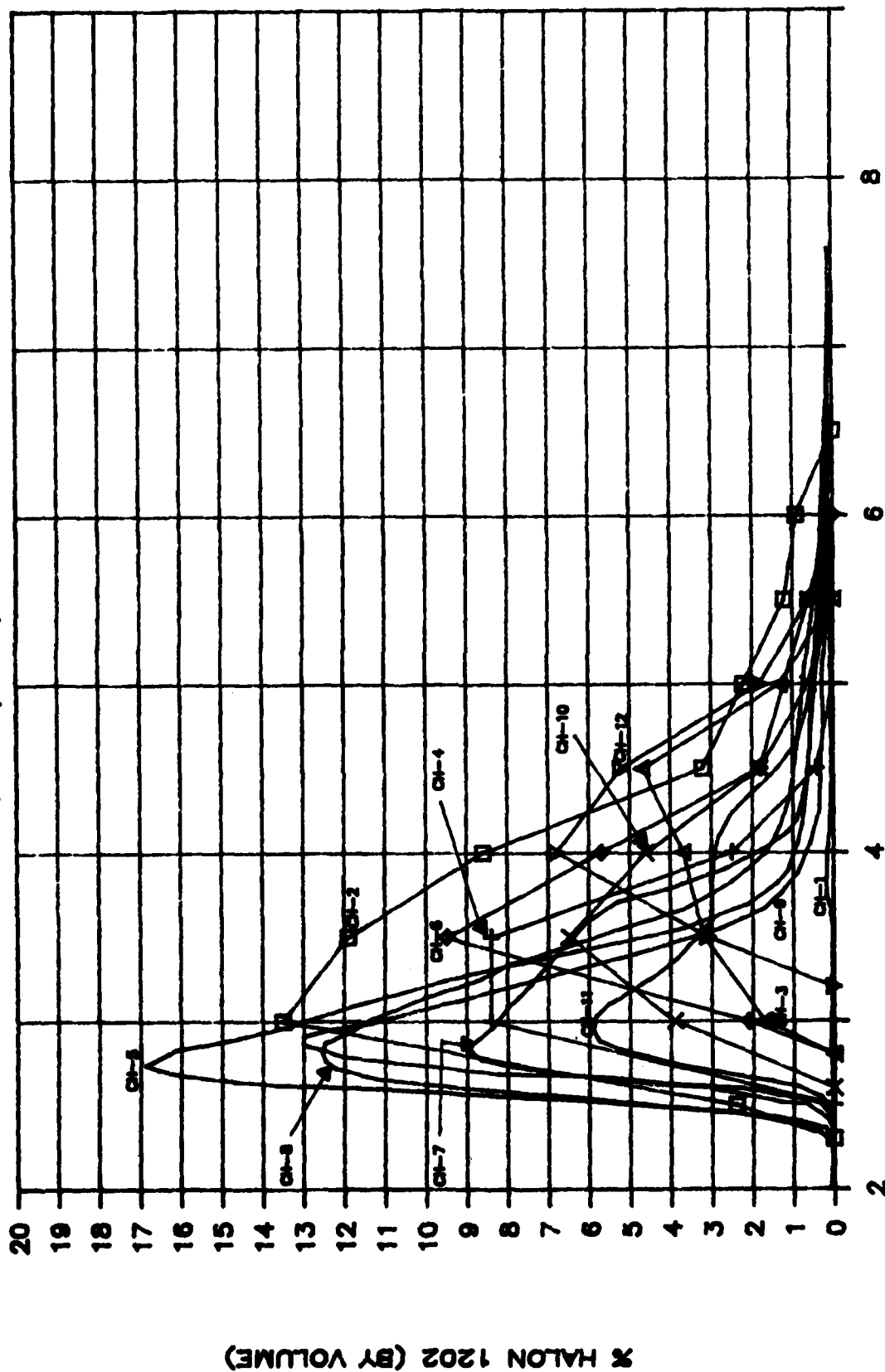
Figure B-27. Test #5 (FOC-6), S/L Dash, Zone 1 A/B

% HALON 1202 (BY VOLUME)

TIME AFTER DISCHARGE (SEC)
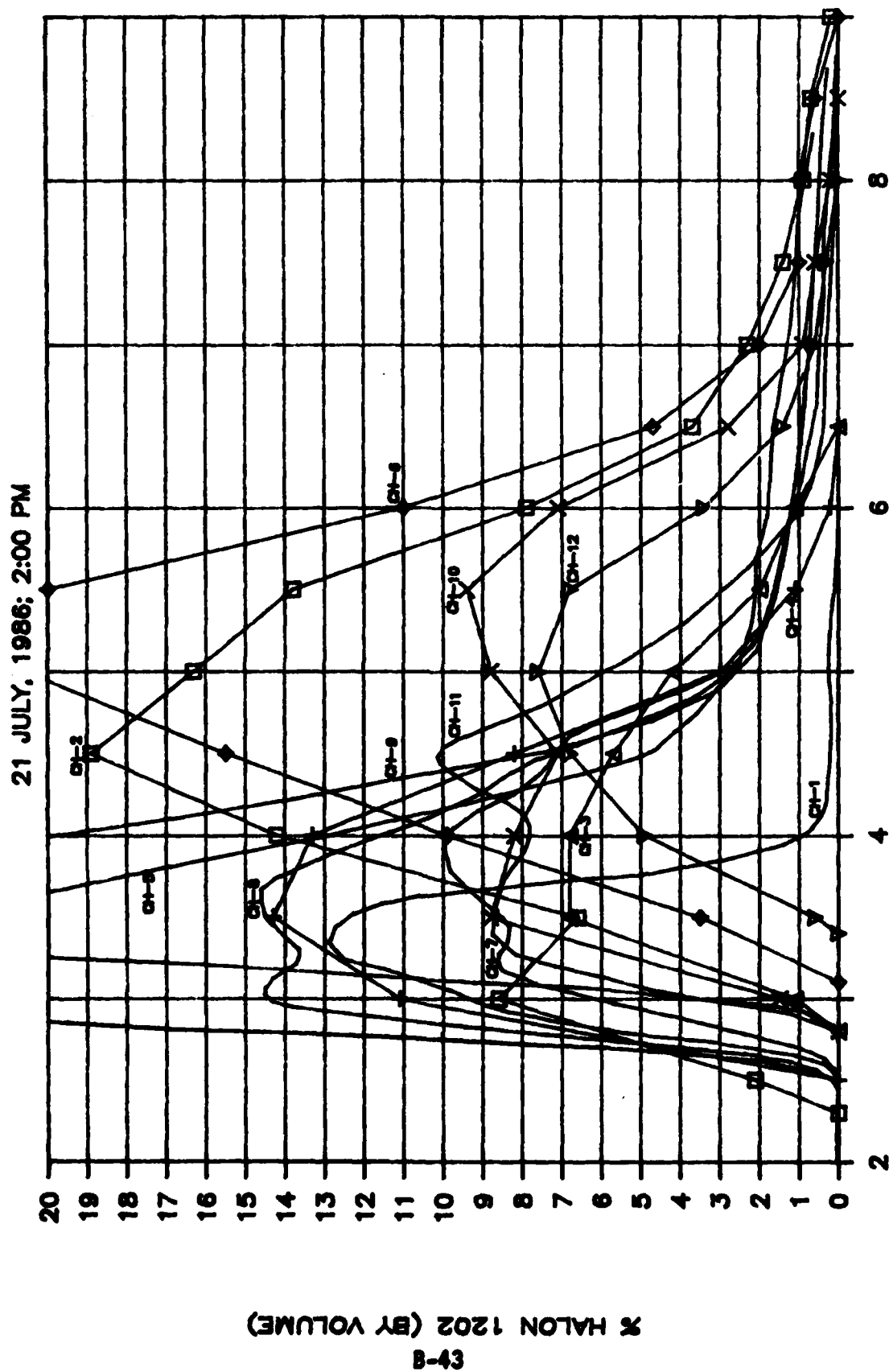
Figure B-28. Test #6 (FOC-7), 0.6 Mach @ 30K, 80% Cruise

B-43

21 JULY, 1986; 2:45 PM

% HALON 1202 (BY VOLUME)

TIME AFTER DISCHARGE (SEC)
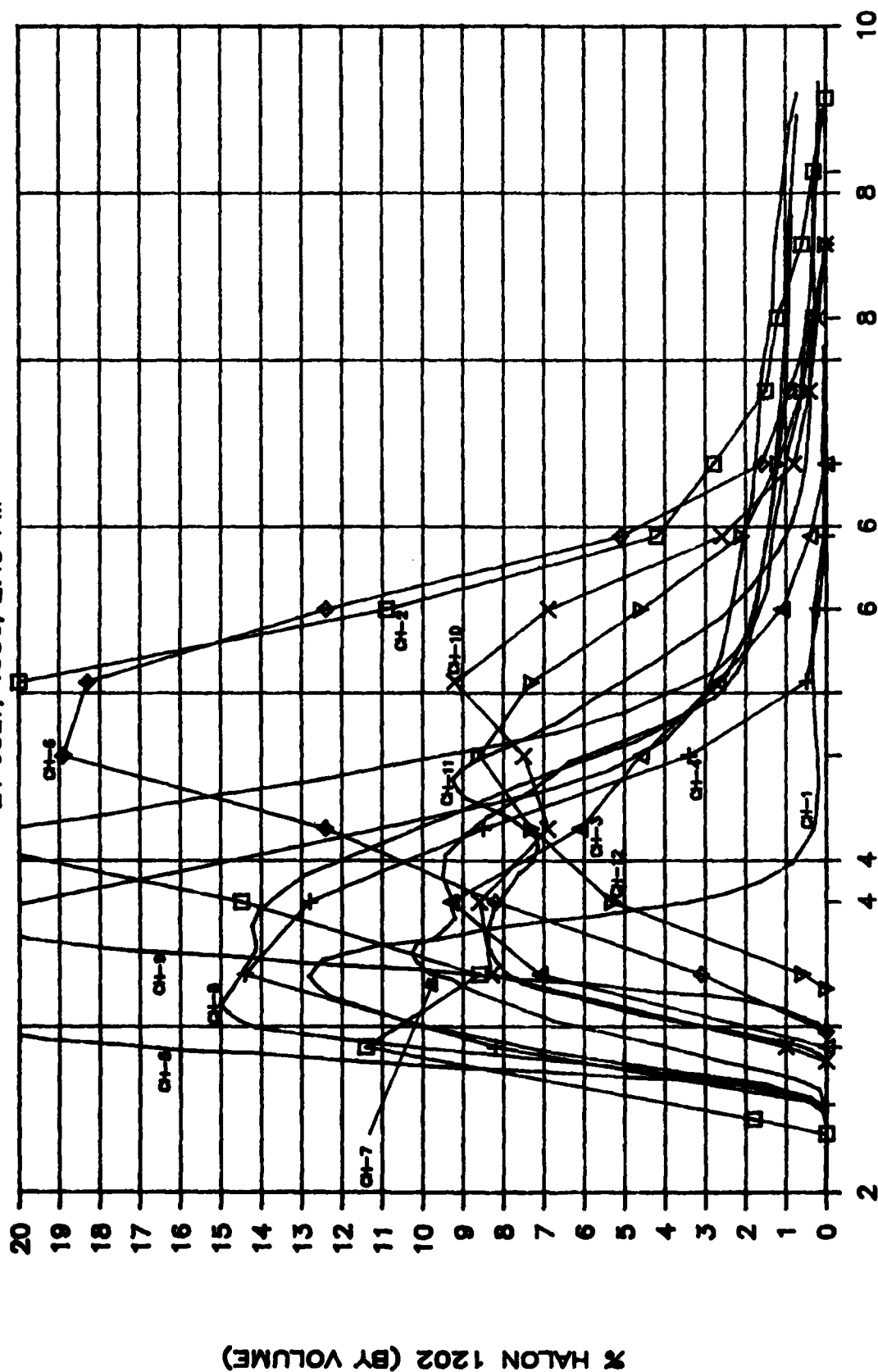
Figure B-29. Test #7 (FOC-8), 7.5 lbs/sec, TF-30 @ Idle
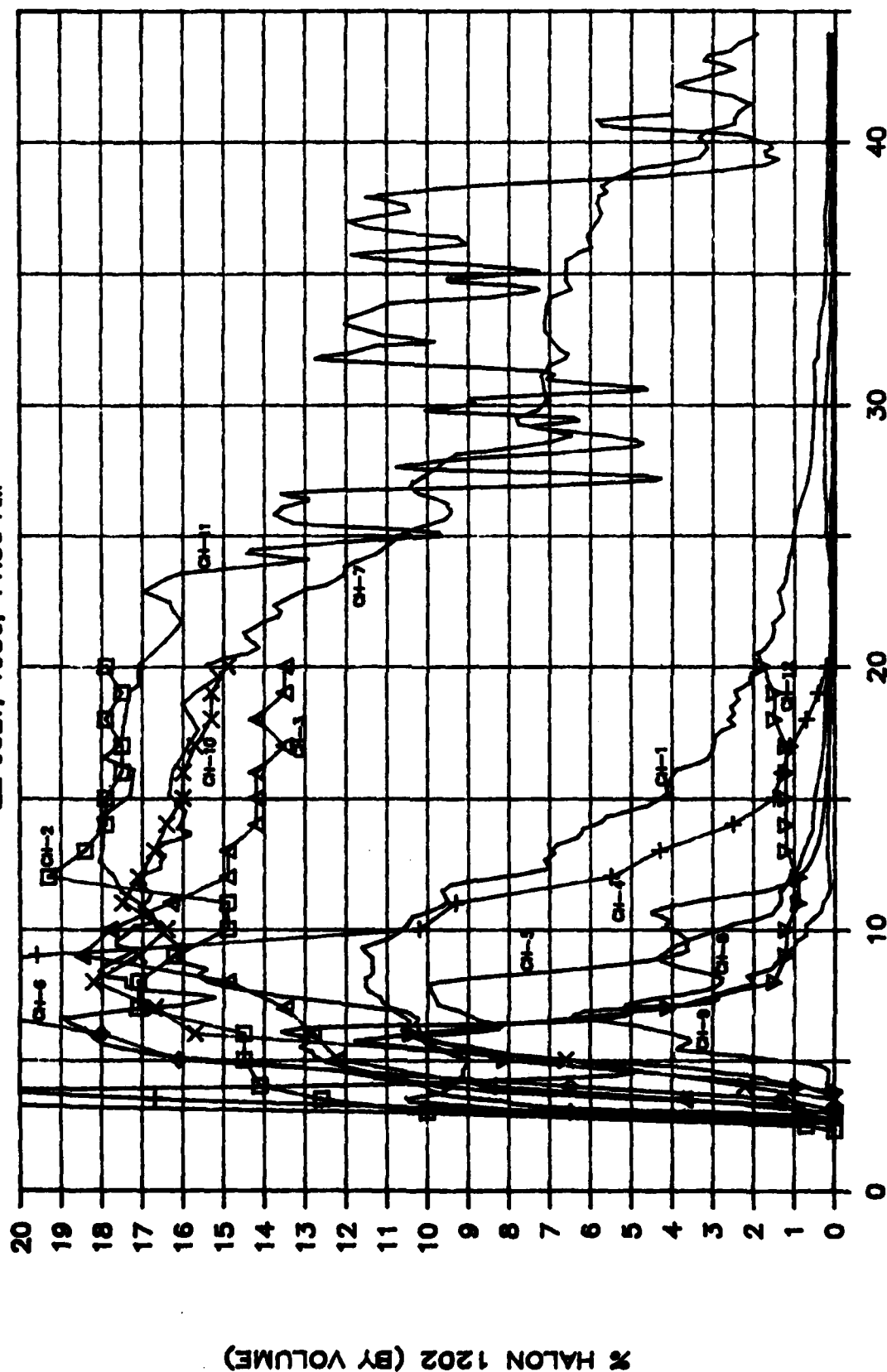
Figure B-30. Test #8 (FOC-9), Static Agent Dump

22 JULY, 1986; 11:30 AM

% HALON 1202 (BY VOLUME)

TIME AFTER DISCHARGE (SEC)

24 JULY, 1986, 11:14 AM

TIME AFTER DISCHARGE (SEC)

% HALON 1202 (BY VOLUME)
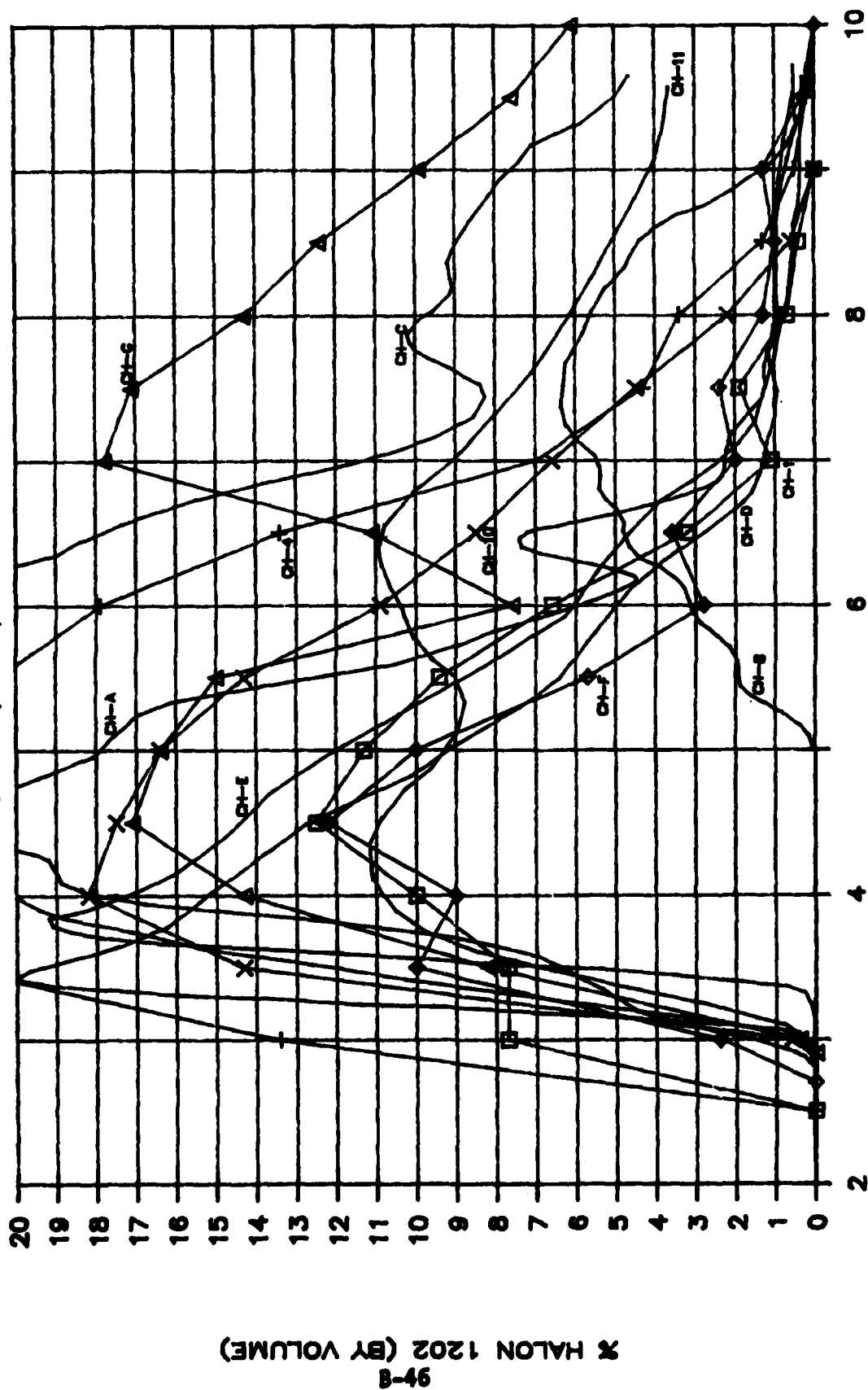
Figure B-31. Test #9 (OC-1), Ground Operation with Ejector

24 JULY, 1986; 11:40 AM

% HALON 1202 (BY VOLUME)

TIME AFTER DISCHARGE (SEC)
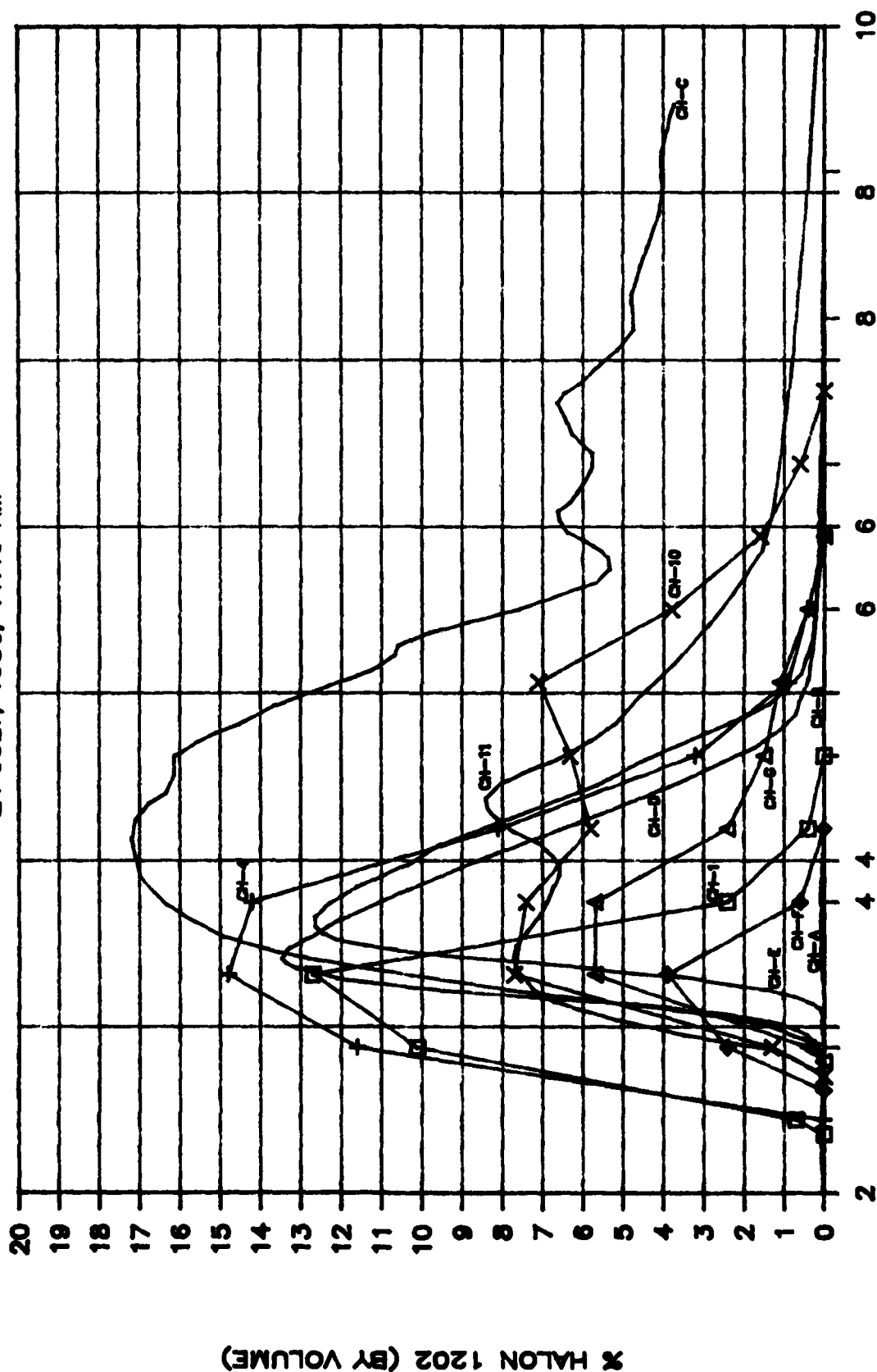
Figure B-32. Test #10 (OC-2), 90% Take Off

24 JULY, 1986: 12:17 PM
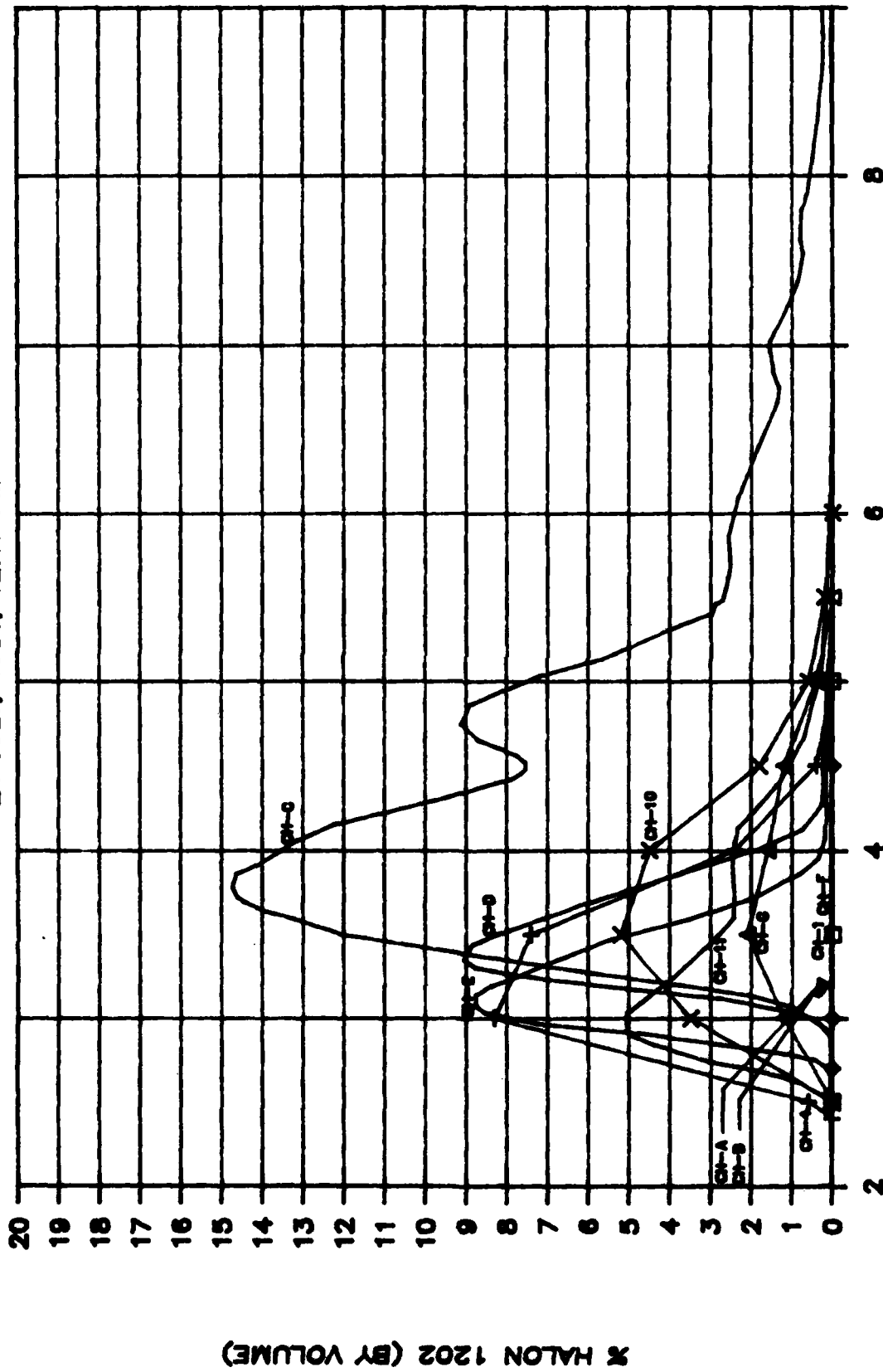
Figure B-33. Test #11 (OC-3), S/L Dash, Zone 1 A/B
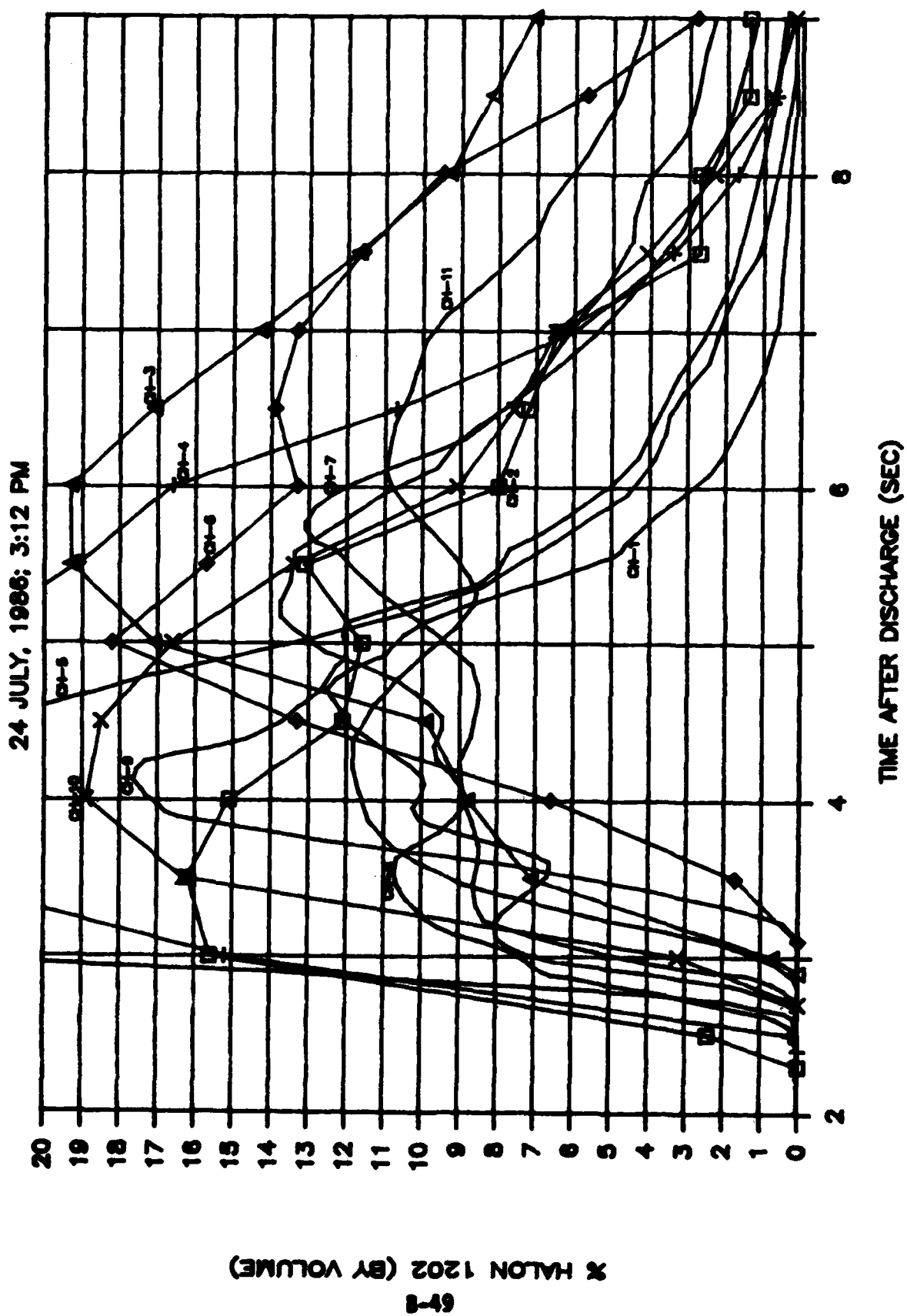
Figure B-34. Test #12 (P-1), Ground Operation with Ejector

24 JULY, 1986; 3:40 PM

% HALON 1202 (BY VOLUME)

TIME AFTER DISCHARGE (SEC)
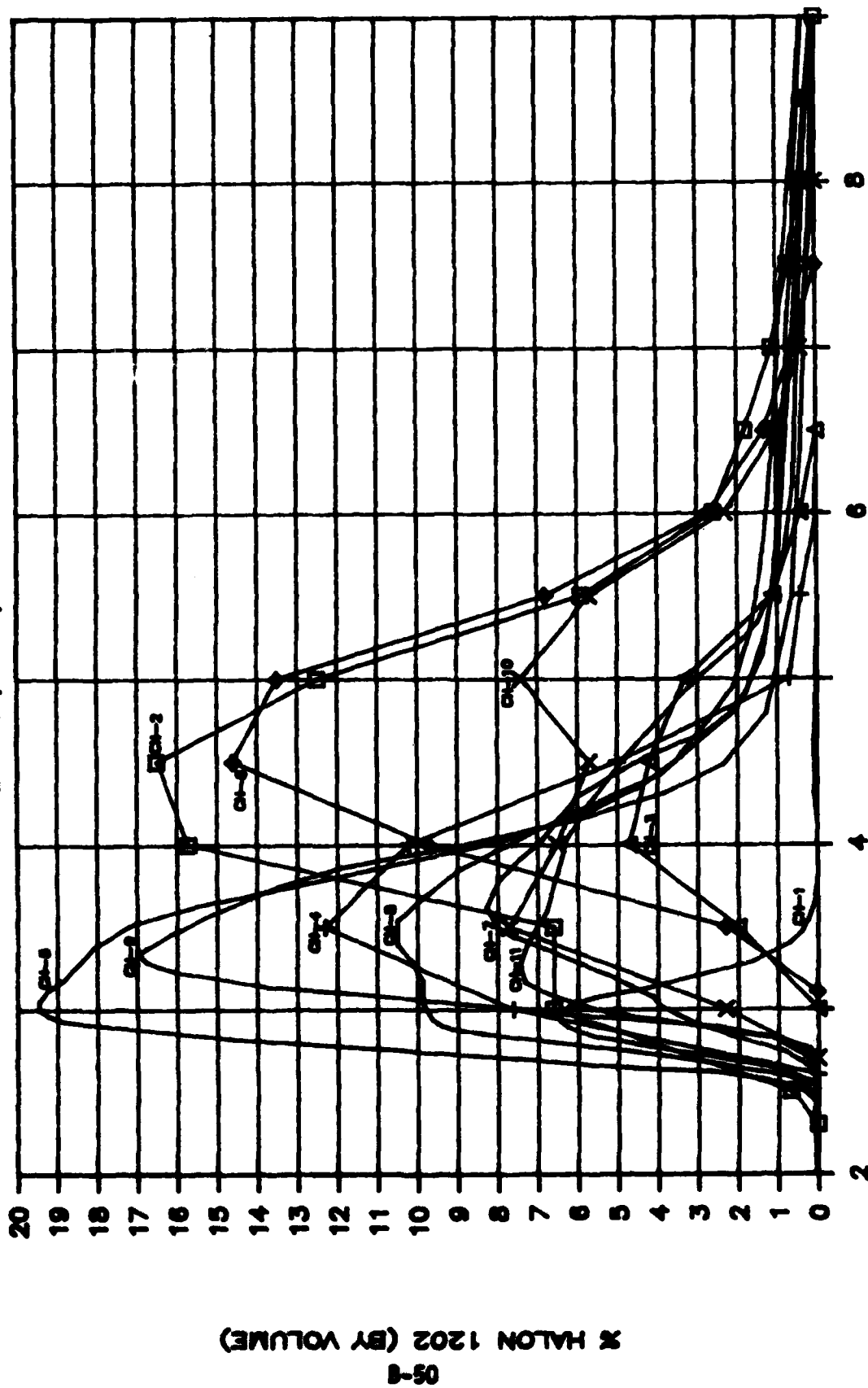
Figure B-35. Test #13 (F-2), 78% Holding

24 JULY, 1986; 4:15 PM
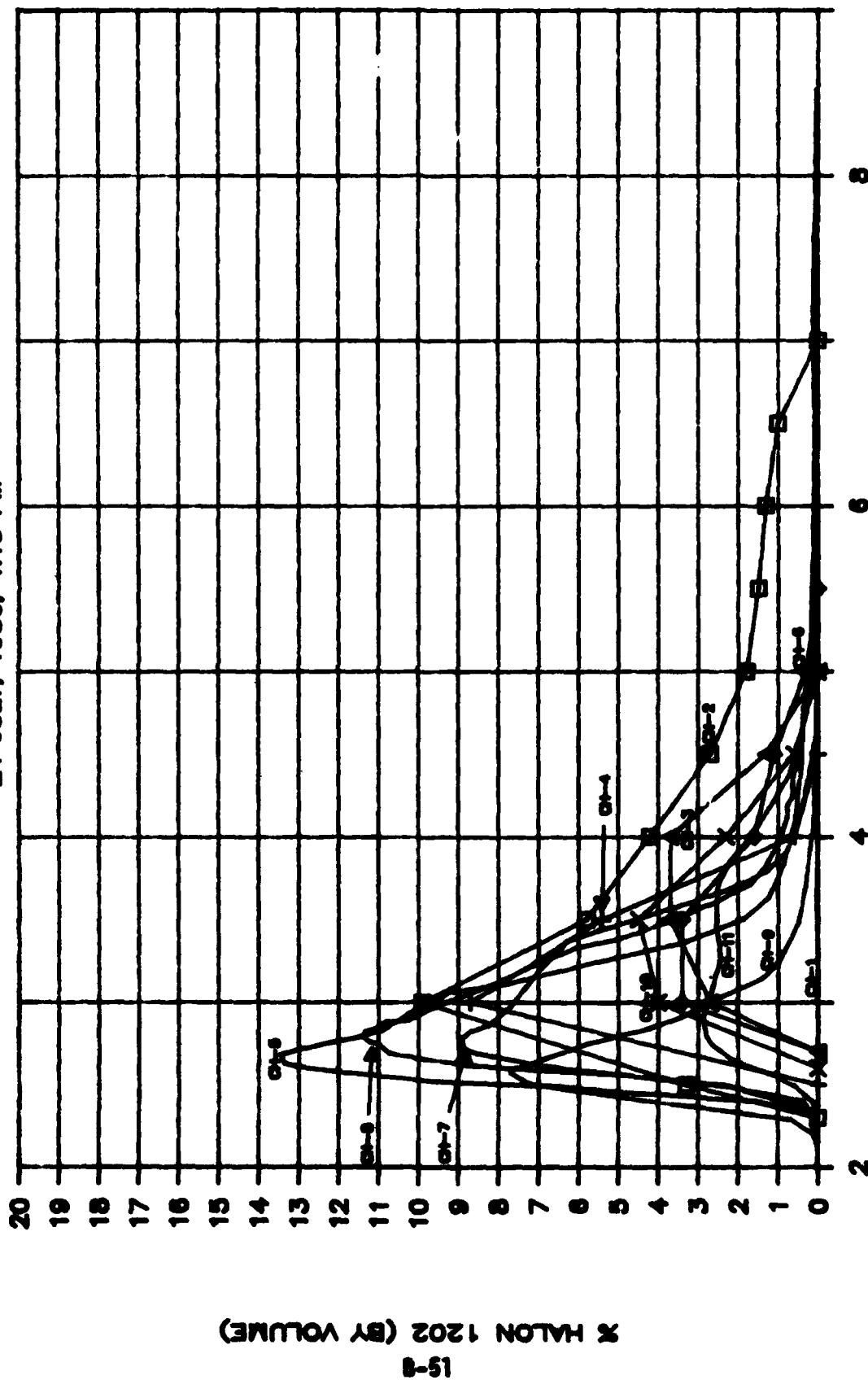
Figure B-36. Test #14 (F-3), S/L Dash, Zone 1 A/B

AIR FORCE PARTICIPATION IN
THE F-111 HALON 1301 AGENT
DISTRIBUTION TEST AT THE
FAA'S TECHNICAL CENTER,
ATLANTIC CITY, N.J.

Boeing Advanced Systems Company
P. O. Box 3707
Seattle, Washington, 98124

March 1987

An informal summary of test activities
performed during January and February
of 1987 at the Federal Aviation
Administration's Technical Center at
Atlantic City as part of Contract
F33615-84-C-2431

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SECTION I - SUMMARY TEST REPORT:

F-111 AGENT DISTRIBUTION TEST AT THE
FEDERAL AVIATION ADMINISTRATION TECHNICAL CENTER (FAA/TC)

BACKGROUND

In July of 1986, a test of the existing F-111 Halon 1202 engine
compartment fire extinguishing system was conducted at the FAA's
Technical Center using their F-111 test article with an operable
TF-30 engine in its right side engine bay, and with ventilating
air supplied by a remotely located TF-33 engine. TF-30 engine
operation and ventilation airflow simulated various flight
conditions.

While this test was originally intended to investigate the effect
of the installation of the EF-111A's Integrated Drive Generator
(IDG) on agent distribution, we found that the engine compartment
agent distribution system did not meet Mil-E-22285 at any flight
condition, with or without the IDG installed. We found that the
system did comply with the specification at ground operation with
ventilation airflow limited to what the TF-30 engine's ejectors
could supply, which was the one operating condition that had been
tested at General Dynamics during 1969.

OBJECTIVE

The objective of this test program was to investigate whether the
substitution of Halon 1301 in place of Halon 1202 in the F-111's
engine compartment agent bottle would provide compliance with the
specification; and further, if the substitution did not solve the
problem, whether increasing the size of the bottle and the agent
quantity would be required to meet the agent concentration
specification.

TEST SETUP

Because the FAA/TC's Statham equipment is no longer maintainable,
the WPAFB/Boeing Beckman Halonizer equipment was used for all
agent concentration measurements. This equipment (Figure C-1),
while intended for use with medical halothane, has been
successfully employed for several years at WPAFB to determine
Halon 1202 and 1301 concentrations. Each channel is a stand-
alone unit consisting of a detector head containing the sample
cell, chopper and IR detector, rack mounted unit housing a
vacuum, flow controller, signal conditioning, and a digital
display of the measured concentration. Analog output from all
six channels was recorded using a Honeywell Visicorder.

The halonizer equipment and an IBM PC based data reduction system
were housed in a truck adjacent to the F-111, just forward of the
engine compressor face (Figures C-2 and C-3). The data system
included a graphics tablet and mouse to allow the oscillograph
charts to be manually digitized, a dot matrix printer, and a
Hewlett Packard plotter.

Boeing provided 0.070-inch ID sample tubes, about 44 feet long.
Most were entirely 1/8-inch nylon but the four to be installed in
the aft portion of the engine compartment were 0.070-inch ID
stainless steel for the 4-foot portion to be installed inside the
airplane. The 1/4-inch copper sample lines used with the FAA's
Statham equipment during July remained installed and were
employed to locate replacement nylon tubes when several were
damaged by heat from the failed TF-30 engine. The locations of
these sample tubes, within the F-111 engine compartment are shown
in Figure C-4.

C-5
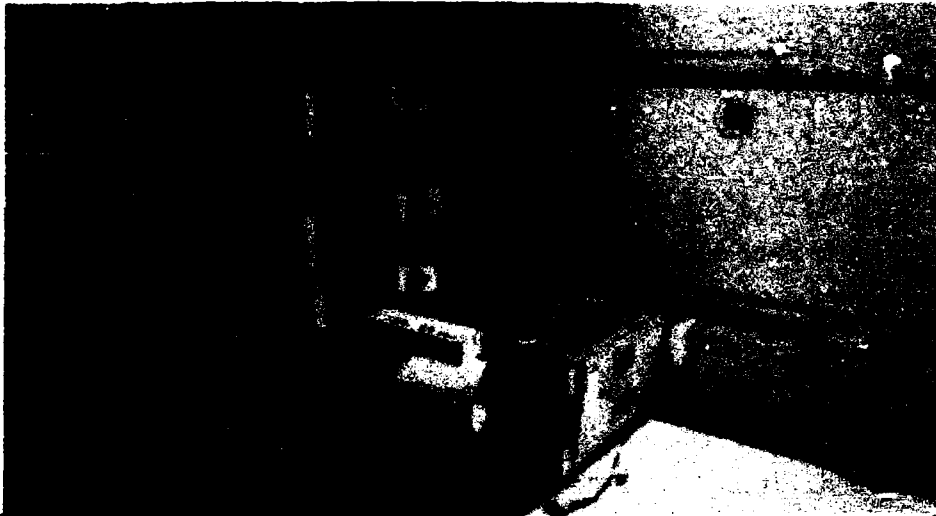
Figure C-1.   Boeing Halon Concentration Instrumentation installed
in Boeing Equipment Truck
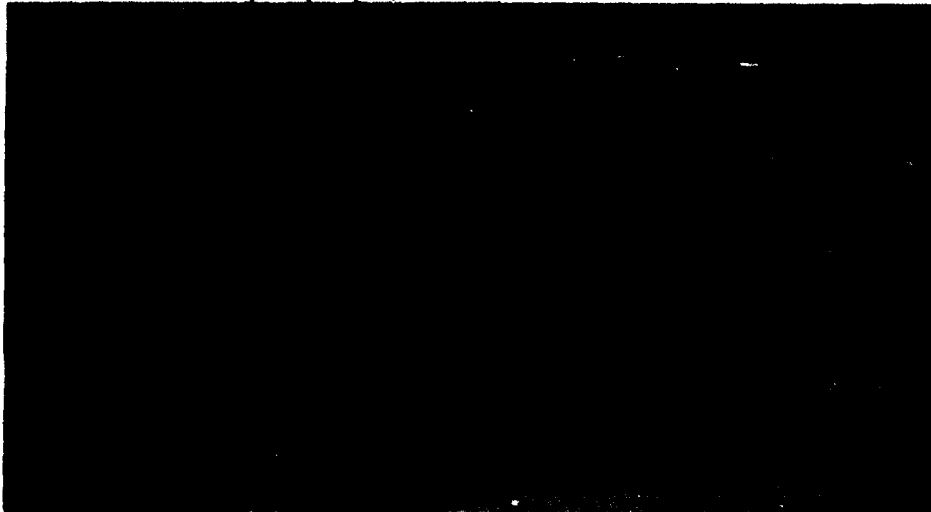
Figure C-2.   Boeing Test Equipment Truck Adjacent
to F-111 Test Article

Figure C-3.   FAA/TC's F-111 Test Article Showing Engine
Compartment Ventilation Air Duct From Remotely
Located TF-33 Engine and Boeing Equipment Truck

PROBE LOCATIONS

PROBE NO	FUSELAGE STATION	CLOCK* POSITION
1	615	2
2	667	5
3	667	7
4	667	10
5	703	2
6	703	5
7	703	7
8	703	10
9	772	2
10	772	5
11	772	7
12	772	10

* AS VIEWED FROM AFT LOOKING FORWARD
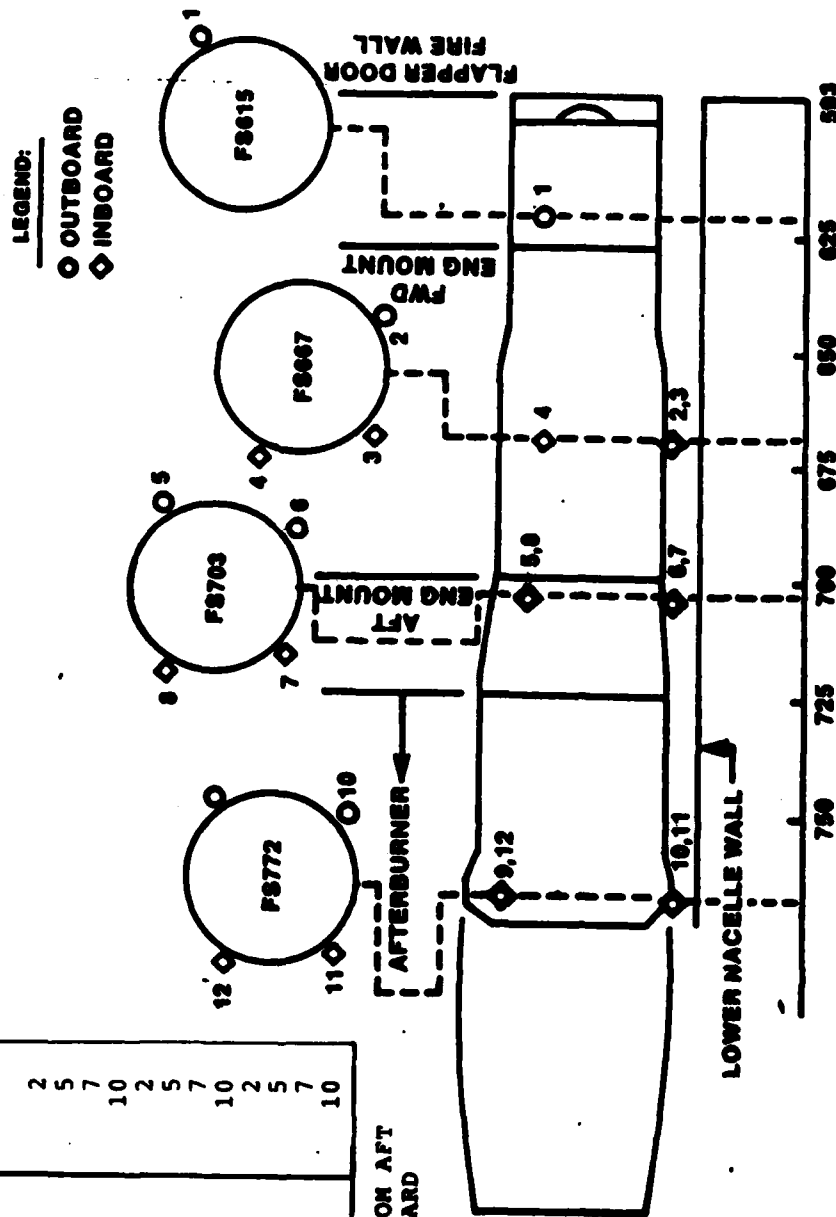
Figure C-4. Sample Tube Locations within the F-111 Engine Compartment   C-7

The FAA/TC was responsible for overall plan and conduct of the test program, for installation of all agent sample tubes, and for the acquisition and reduction of all data other than agent concentration data. They were also solely responsible for final documentation of the test program. Boeing agreed to prepare final plots and tabular data for all halon concentration measurements.

CALIBRATION

Boeing provided a 6-percent Halon 1301 calibration mixture to allow daily adjustment of its instrumentation. This had been prepared at WPAFB and compared with a 6-percent certified mixture obtained from the M. C. White Company of Carney's Point, New Jersey.

TEST CONDITIONS

While it had been planned that the TF-30 engine within the aircraft would be operated, as it had been during the July test, it failed during the first test run and was diagnosed as being unrepairable during the time available. Hence, it was decided to continue the test with the engine compartment ventilation airflow supplied by the TF-33 engine alone. We felt this simplification was justified because the TF-30's effect on the airflow within the engine compartment at flight conditions is limited to the effect of temperature changes within the compartment and to reducing the back pressure at the compartment's exit.

Agent distribution tests were run with 6.1, 10 and 30 lb/sec TF-33 airflow, simulating 82-percent cruise, 78-percent holding and sea level dash, respectively. The ground operation test condition which relies entirely on the TF-30's ejectors for compartment ventilation could not be run.

Available agent bottles included the 380-in^3 bottle normally fitted within the F-111's agent storage compartment (Figure C-5) and Halon 1301 bottles of 630- and 1050-in^3 capacity obtained

C-8

*Figure C-5. Installation of 380-in^3 F-111 Agent
Bottle in F-111 Test Article*
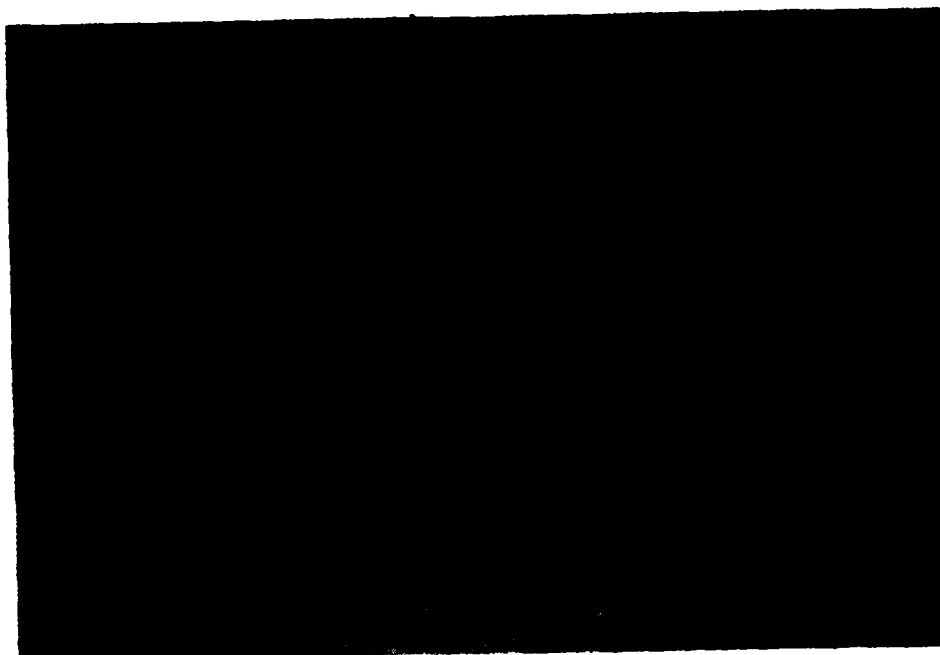
*Figure C-6. Installation of 630-in^3 Halon 1301
Bottle Below F-111 Agent Compartment*

from the Walter Kidde Company. The larger bottles were too large
for the compartment and were secured to the structure supporting
the test article immediately below the compartment (Figure C-6).
They were fired using the same type of pyrotechnic devices as the
F-111 bottle. Employing a 50-percent fill ratio, these bottles
were used for Halon 1301 charges of 11, 18 and 28.5 pounds. All
were topped off with nitrogen to 600 psia prior to the agent
release tests.

Table C-1 identifies TF-33 airflows and bottle sizes employed in
the seven test conditions where the agent concentration tests
were run.

PROCEDURE

In July, all 12 sample tubes ere sampled simultaneously, with the
Boeing equipment measuring six and the FAA/TC equipment measuring
the other six (and one of the Boeing channels for correlation
purposes). For this test program each test condition was run
once to sample the six channels Boeing had measured in July ("A"
tests) and again to sample the six channels that the FAA/TC had
measured in July ("B" tests).

The test procedure employed was consistent throughout the test
program and consisted of the following steps:

1. The TF-33 engine (which provided the ventilation airflow to
the F-111 engine compartment) was started and run up to the
desired operating condition. The gate valve controlling the
ventilation airflow was adjusted as required and the engine was
allowed to stabilize for several minutes.

2. The FAA test engineer checked that the Boeing crew was ready
and initiated a 10-second countdown. At this time final
adjustments of zero and dither were made on the Beckman
equipment. At a count of seven, the Boeing crew started the

oscillograph with which the agent concentration data were acquired. At the count of zero the squib was fired releasing the agent.

3. After the agent concentration had fallen back to zero on all channels, the TF-33 was returned to idle and the agent bottle was changed. If there was to be a change between the "A" and the "B" sample tubes, it was made on a bulkhead at the rear of the Boeing equipment truck, at this time.

4. The cycle was repeated until the supply of charged agent bottles was exhausted.

CORRELATION OF DATA

Because two tests were conducted for each test condition, the squib firing event marker on the oscillograph charts was employed to correlate the two data sets which were acquired at the time that the data were digitized.

TEST RESULTS

As summarized in Table C-1, a total of 14 agent release tests were run at three simulated flight conditions, employing agent bottles of three sizes. Figure C-7 summarizes the minimum concentration sustained at all sample locations within the engine compartment, simultaneously for 1/2 second for each of the three bottle sizes at the three ventilation airflows investigated. Figure C-8 shows the same information reformated so that it shows the relationship between compartment airflow and minimum sustained concentration. Combined plots of agent concentration versus time for all seven of the individual test conditions are included in Section II of this Appendix.

Table C-1. Summary Run Log

F-111A HALON 1301 TESTING AT FAA/TC, ATLANTIC CITY, N.J.

RUN NUMBER	DATE	FLIGHT CONDITION	TF-33 AIRFLOW	BOTTLE	QUANTITY HALON	COMMENTS
1A	2/7/87	GRD.OPS.W/EJECTOR				ENGINE FAILED: NO AGENT DUMPED
2A	2/11/87	78% HOLDING	10 LB/SEC	F-111	11 LBS	
2B	2/11/87	78% HOLDING	10 LB/SEC	F-111	11 LBS	
3B	2/11/87	78% HOLDING	10 LB/SEC	630 IN^3	18 LBS	
3A	2/11/87	78% HOLDING	10 LB/SEC	630 IN^3	18 LBS	
4A	2/11/87	78% HOLDING	10 LB/SEC	1050 IN^3	28.5 LBS	
4B	2/11/87	78% HOLDING	10 LB/SEC	1050 IN^3	28.5 LBS	
5B	2/12/87	S/L M=1.2 DASH	30 LB/SEC	630 IN^3	18 LBS	
5A	2/12/87	S/L M=1.2 DASH	30 LB/SEC	630 IN^3	18 LBS	
6A	2/13/87	S/L M=1.2 DASH	30 LB/SEC	1050 IN^3	28.5 LBS	
6B	2/13/87	S/L M=1.2 DASH	30 LB/SEC	1050 IN^3	28.5 LBS	
7B	2/13/87	82% CRUISE	7 LB/SEC	630 IN^3	18	
7A	2/13/87	82% CRUISE	7 LB/SEC	630 IN^3	18	
8A	2/13/87	82% CRUISE	7 LB/SEC	F-111	11	
8B	2/13/87	82% CRUISE	7 LB/SEC	F-111	11	

NOTE: "A" tests: Halonizers on Channels 1, 3, 5, 7, 9 and 11
      "B" tests: Halonizers on Channels 2, 4, 6, 3, 10 and 12
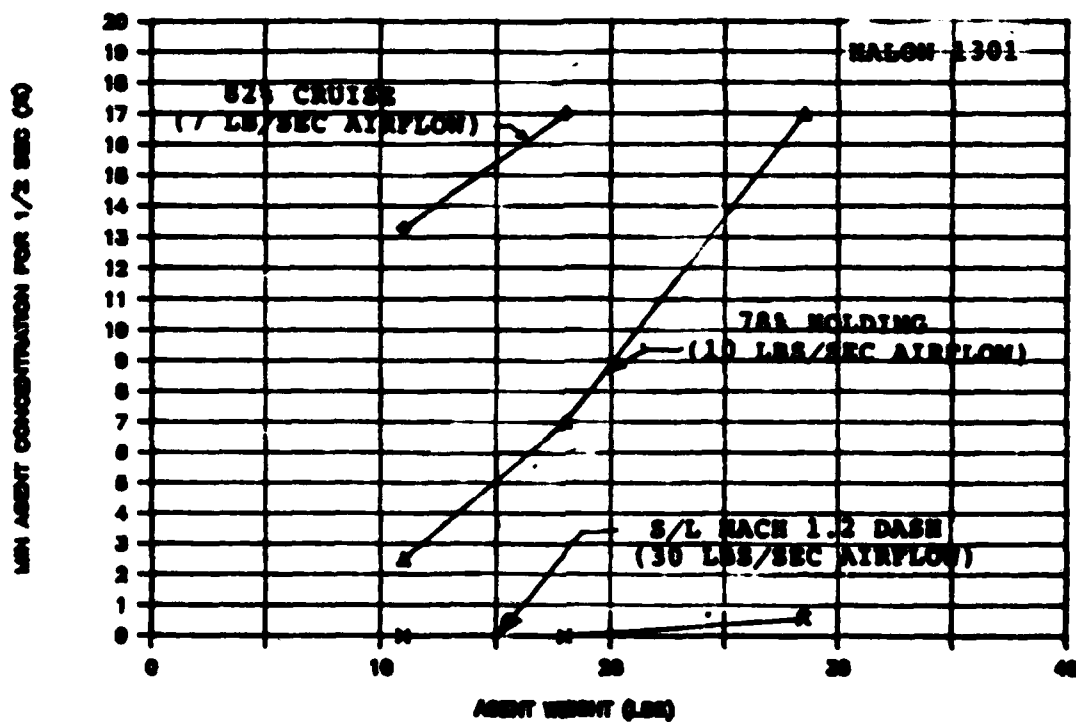
Figure C-7. Summary of Test Results
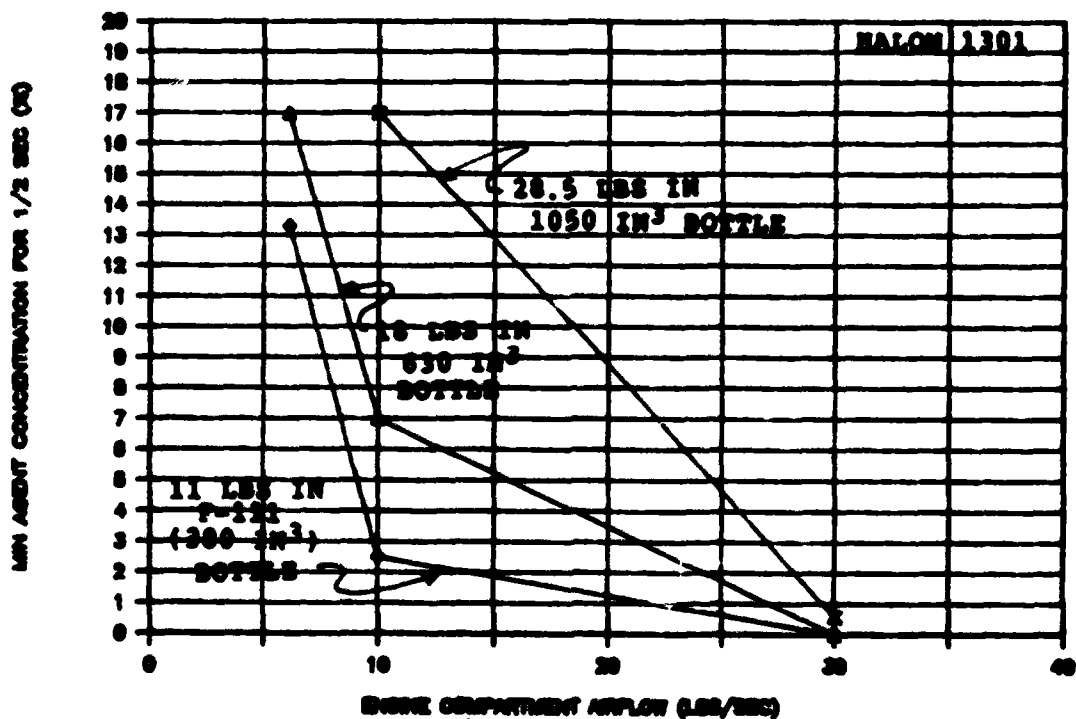
Figure C-8. Effect of Airflow on Minimum Agent Concentration

C-13

SECTION II. HALON CONCENTRATION DATA

FIGURE	TITLE	PAGE

Figure C-9. Test 2A and 2B / F-111 Bottle - 78% Holding

C-15
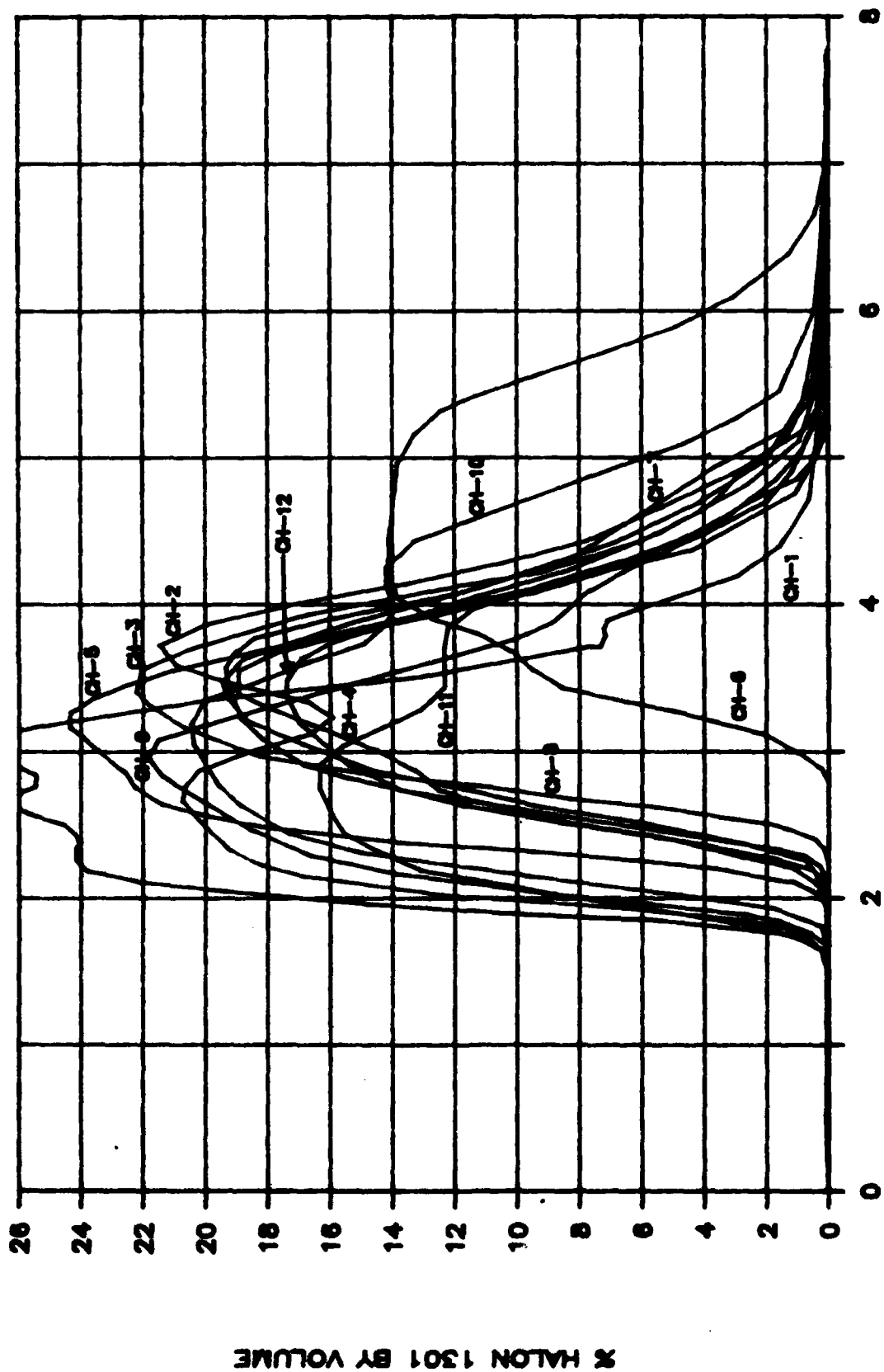
Figure C-10.   Test 3A and 3B / 630 in³ Bottle -78% Holding

% HALON 1301 BY VOLUME

TIME (SECONDS)

C-16
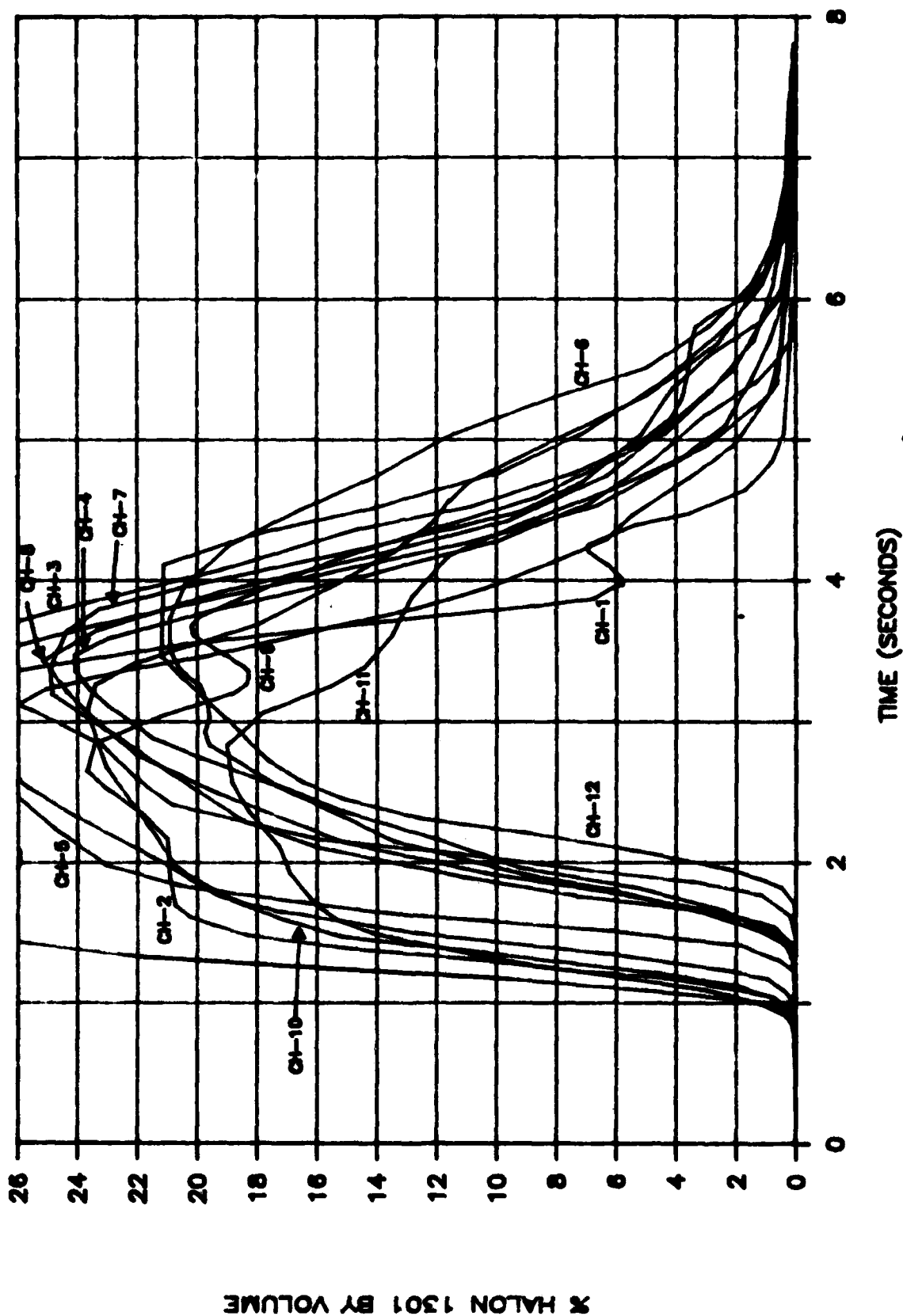
Figure C-11. Test 4A and 4B / 1050 in³ Bottle - 78% Holding
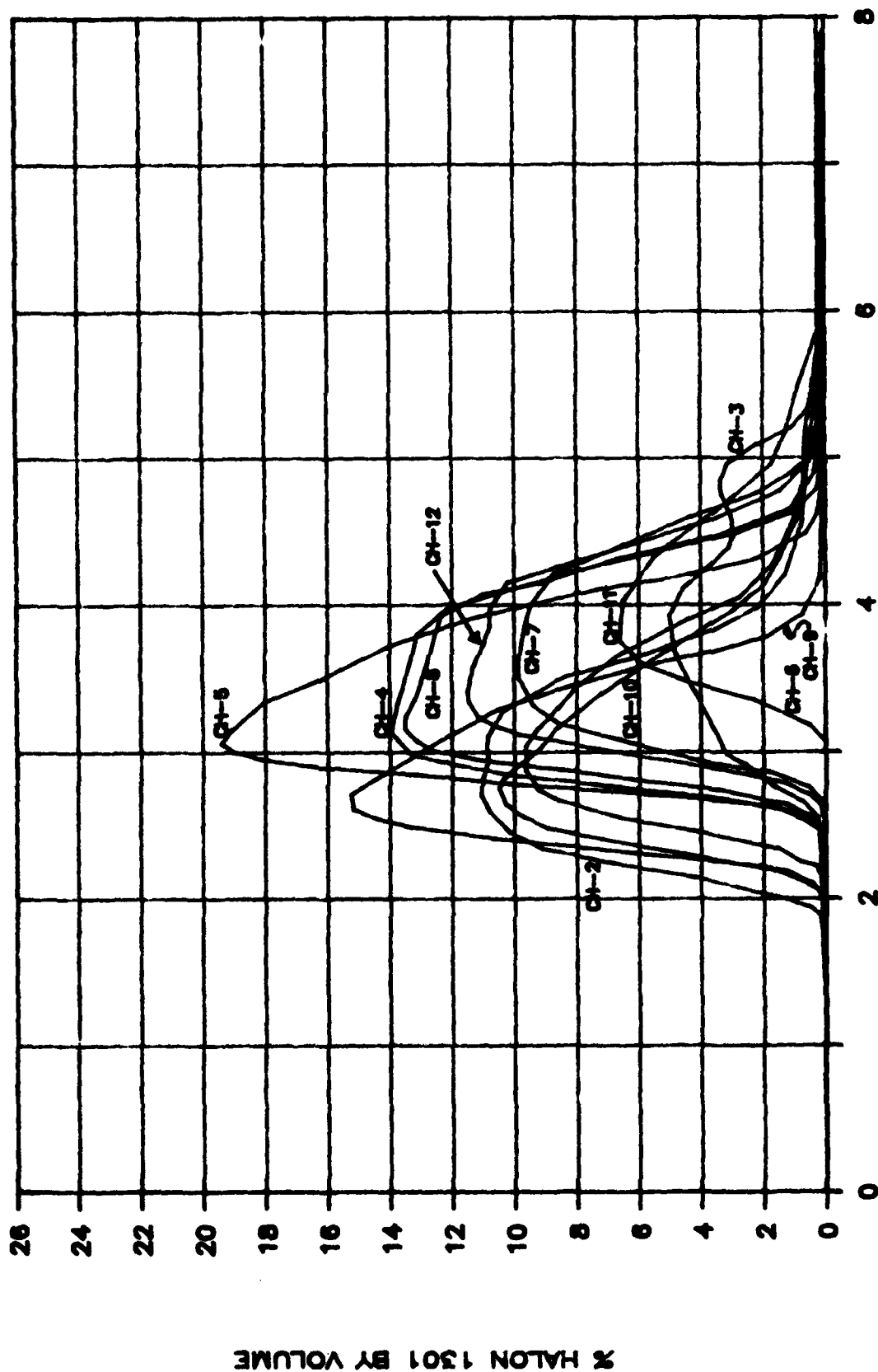
Figure C-12. Test 5A and 5B / 630 in³ Bottle - S/L Mach 1.2 Dash
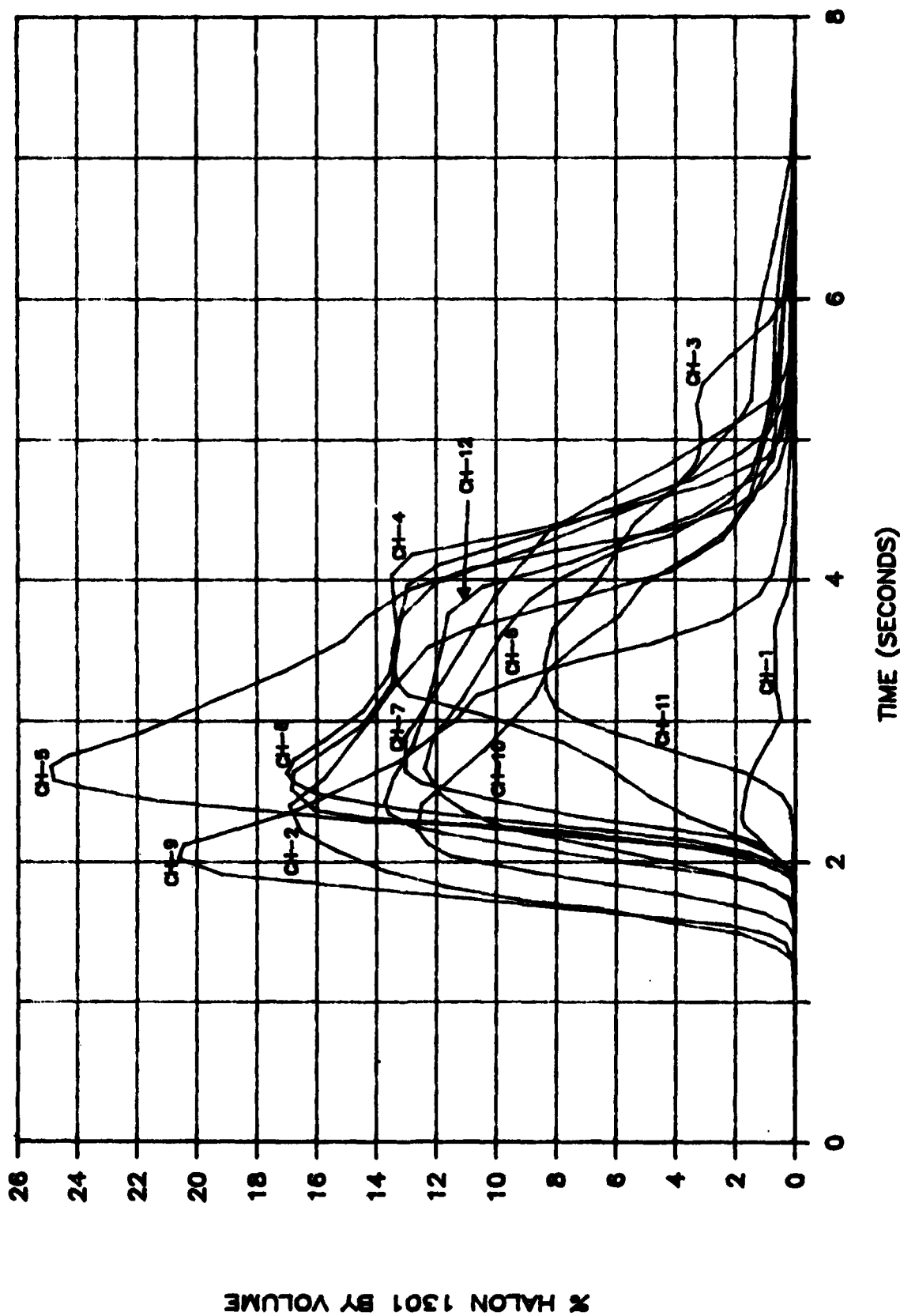
Figure C-13. Test 6A and 6B / 1050 in³ Bottle - S/L Mach 1.2 Dash

% HALON 1301 BY VOLUME

Figure C-14. Test 7A and 7B / 630 in³ Bottle - 82% Cruise

C-20

Figure C-15. Test 8A and 8B / F-111 Bottle - 82% Cruise

% HALON 1301 BY VOLUME

C-21

MIL-F-87168(USAF)
20 June 1983

PORTIONS OF MILITARY SPECIFICATION

FIRE AND EXPLOSION HAZARD PROTECTION SYSTEMS, AIRCRAFT, GENERAL SPECIFICATION FOR

BMAC, 15 May, 1987

PROPOSED REVISIONS TO MIL-F-87168 RELATED TO ENGINE COMPARTMENT FIRE EXTINGUISHING

Left column

(page 7)
3.2.2.3.3 Ventilation Termination. For all those compartments identified in accordance with 3.2.2.3.1 which are provided with ventilation or cooling prevention designs, means shall be provided to terminate the ventilation or cooling airflow when termination of this airflow will contribute to the extinguishment of fire occurring within these compartments. These provisions shall function _____ any provided fire extinguishing system.

3.2.2.3.9 Engine Compartment Fire Extinguishing. Fire extinguishing systems shall be provided for fire control and termination in all engine compartments identified in accordance with 3.2.2.3.1, when fire within these engine compartments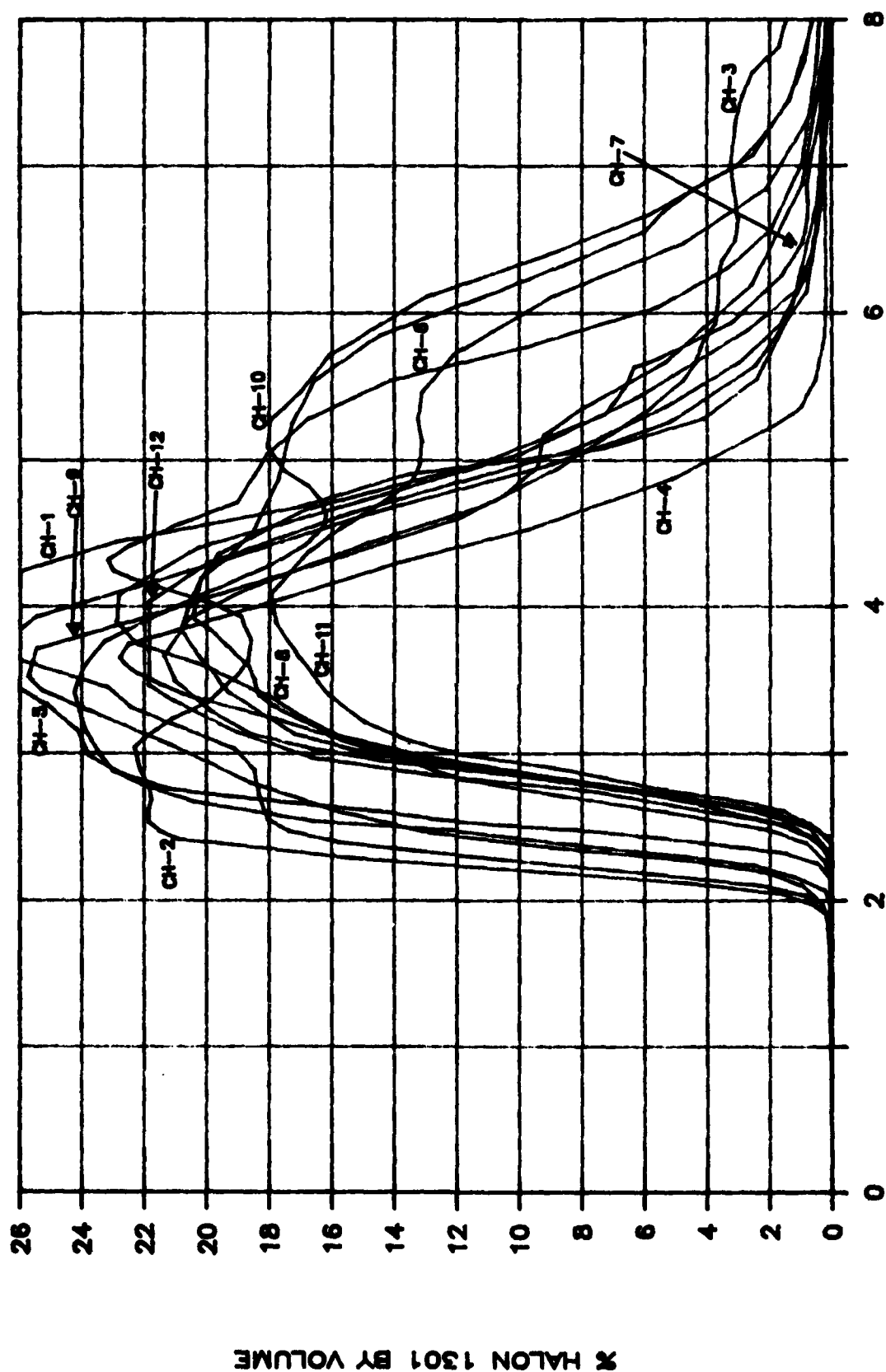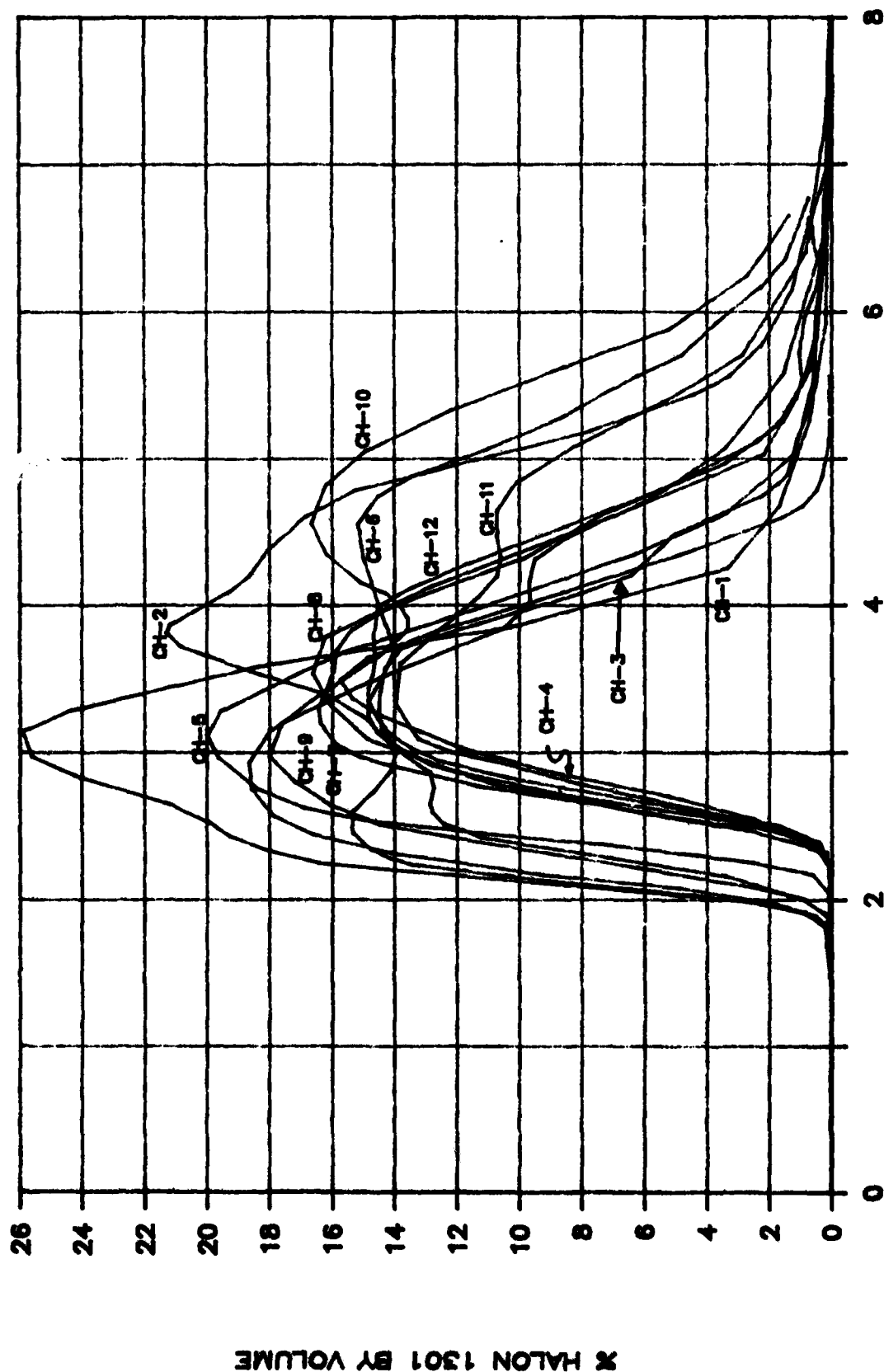(s) cannot be controlled and contained by other lesser means. The system shall provide within the compartment a concentration of agent sufficient to extinguish any fire within a time duration sufficient to minimize damage within the compartment and prevent the spread of fire to other compartments. This agent concentration shall be maintained within the compartment for time duration sufficient to prevent reignition of the fire.

(page 9)
3.6 Interface requirements. The following interfaces shall be provided to insure compatibility of the provided fire and explosion hazard protection with the other aircraft designs, systems, equipment and components:

a. Survivability/vulnerability provisions - Fire and explosion hazard protection provided as survivability/vulnerability provisions shall comply with the requirements herein. Survivability/vulnerability (combat conditions) provisions and fire and explosion hazard protection provisions for non-combat conditions having similar purposes may be common items or the survivability/vulnerability provisions may be extensions of fire and explosion hazard protection provided for non-combat conditions.

Requirements to provide additional protection for combat

Right column

3.2.2.3.3 NO CHANGE

3.2.2.3.9 Engine Compartment Fire Extinguishing. Fire extinguishing systems shall be provided for fire control and termination in all engine compartments identified in accordance with 3.2.2.3.1, when fire within these engine compartments(s) cannot be controlled and contained by other lesser means. The system shall provide within the compartment a concentration of agent sufficient to extinguish any fire within a time duration sufficient to minimize damage within the compartment and prevent the spread of fire to other compartments. This agent concentration shall be maintained within the compartment for time duration sufficient to prevent reignition of the fire. In addition, the engine compartment and extinguishing systems design shall provide protection against potential combat damage caused fires to the maximum extent consistent with other aircraft design and fire protection requirements.

3.6 Interface requirements. The following interfaces shall be provided to insure compatibility of the provided fire and explosion hazard protection with the other aircraft designs, systems, equipment and components:

a. Survivability/vulnerability provisions - Fire and explosion hazard protection provided as survivability/vulnerability provisions shall comply with the requirements herein. Survivability/vulnerability (combat conditions) provisions and fire and explosion hazard protection provisions for non-combat conditions having similar purposes may be common items or the survivability/vulnerability provisions may be extensions of fire and explosion hazard protection provided for non-combat conditions having similar purposes are generally common requirements. Survivability/vulnerability provisions will be extensions of the fire and explosion hazard protection provided for non-combat conditions.

Requirements to provide additional protection for combat

conditions are in "Aeronautical Systems Mission Completion in a Combat Environment" to be published.

b. Electrical power and systems All fire and explosion hazard protection electrical components shall operate on electrical power defined _____. Each protection system requiring electrical power shall be provided such power from an individual circuit during all phases of operation. Failure of any single electrical power source shall not disable a critical protection system. Also, the operation of electrical powered fire and explosion hazard protection system shall not interfere with the normal operation of other electrical systems.

c. Fuel system Fluid control and explosion suppression provisions provided by this specification shall not degrade the performance of the fuel system. Also, these provisions may be common with similar fuel system provisions.

d. Engine Fire and explosion hazard protection provided for engine compartment hazards shall not degrade or interfere with performance of the engine.

e. Engine installation Fire and explosion hazard protection provisions and engine installation provisions with similar purposes may be common items.

f. Crew station Fire and explosion hazard detection and control systems actuation display devices, operating devices and integrity assurance provisions provided in accordance with this specification shall comply with the air vehicle crew station requirements.

g. Maintenance and ground test Fire and explosion hazard protection provisions shall be designed for ease of maintenance and shall include necessary features for ground test. The provided maintenance and ground test features shall comply with the air vehicle requirements for such.

(page 71)
3.2.2.3.3 Ventilation Termination. For all those compartments identified in accordance with 3.2.2.3.1 which are provided with ventilation or cooling prevention designs, means shall be provided to terminate the ventilation or cooling airflow when termination of this airflow will contribute to the extinguishment of fire occurring within these compartments. These provisions shall function _____ any provided fire extinguishing system.

REQUIREMENT RATIONALE (3.2.2.3.3)

The objective of this requirement is to limit the fire size and intensity by cutting off air to the fire.

REQUIREMENT GUIDANCE

Ventilation shutoff is an obvious approach to reduce the severity of an existing fire. Some installations have used cooling air intake doors to achieve nacelle or compartment isolation. During a fire emergency, the doors close with actuation of the firewall shutoff valves. However, with the advent of the extinguishing agent concentration analyzer and jet engine nacelle installations with low air flow, the need for engine nacelle ventilation shutoff has been almost eliminated. With the analyzer, it is possible to determine agent concentration under air flow conditions. There are still other compartments that may benefit from ventilation shutoff. The use of this control method will need to be determined separately for each particular compartment.

REQUIREMENT LESSONS LEARNED

Performance Parameters:

Include availability of space for ventilation termination, location chosen for ventilation termination, actuation time, type (mechanical or electrical), material selection, and environmental conditions at chosen locations.

Background and Source of Criteria:

This requirement is not directly stated in the present specifications.

REQUIREMENT LESSONS LEARNED

The preferred location for the shutoff devices and controls is

---

3.2.2.3.3 NO CHANGE

REQUIREMENT RATIONALE (3.2.2.3.3)

The objective of this requirement is to limit the fire size and intensity by cutting off air to the fire. In addition, in the event that the compartment is equipped with an extinguishing agent distribution system, termination of ventilation airflow will increase the effectiveness of that system.

REQUIREMENT GUIDANCE

Ventilation shutoff is an obvious approach to reduce the severity of a fire in a ventilated compartment. Some installations have used cooling air intake doors to achieve nacelle or compartment isolation. During a fire emergency, the doors close with actuation of the firewall shutoff valves. The use of engine compartment fire extinguishing systems whose effectiveness is demonstrated with extinguishing agent concentration analyzers has not completely eliminated the advantage of ventilation termination, particularly in engine compartments. Shutoff of ventilation airflow will increase agent concentration and duration.

Results of recent engine compartment fire tests have indicated that this will provide additional safety margin even when compliance with agent concentration specification is demonstrated with agent analyzers. The use of this control method will need to be determined separately for each particular compartment.

Performance Parameters:

NO CHANGE

Background and Source of Criteria:

NO CHANGE

REQUIREMENT LESSONS LEARNED

NO CHANGE

outside the fire zone. If they are located inside the fire zone, they must be able to withstand 2000°F fire for 5 minutes without failure.

4.2.2.3.3 Ventilation Termination. By analysis and inspection it shall be verified that the ventilation termination specified in 3.2.2.3.3 has been provided in all necessary locations in accordance with 3.2.2.3.3. The adequacy of the ventilation termination provisions shall be verified by _____

VERIFICATION RATIONALE (4.2.2.3.3)

The lack of this control method in a required location will complicate, if not defeat, the crew actions necessary to control a potential or actual fire hazard. The same is true if the control provisions are inadequate.

VERIFICATION GUIDANCE

The required analysis and inspection should be done along with the analysis and inspection required by 4.2.2.3.1 and should be part of a fire and explosion hazard analysis done to determine the protection required for the total aircraft. Ground tests and demonstrations should be used to functionally checkout and verify the adequacy of the ventilation termination provisions. The use of ground tests and demonstrations will determine if the provisions work as designed without impacting flight safety.

(page 78)
3.2.2.3.9 Engine Compartment Fire Extinguishing. Fire extinguishing systems shall be provided for fire control and termination in all engine compartments identified in accordance with 3.2.2.3.1. when fire within these engine compartments cannot be controlled and contained by other lesser means. The system shall provide within the compartment a concentration of agent sufficient to extinguish any fire within a time duration sufficient to minimize damage within the compartment and prevent the spread of fire to other compartments. This agent concentration shall be maintained within the compartment for time duration sufficient to prevent reignition of the fire.

REQUIREMENT RATIONALE (3.2.2.3.9)

The purpose of this requirement is to establish the need and performance requirements for engine compartment fire extinguishing.

REQUIREMENT GUIDANCE

a. General. Following shutdown of combustible flow into the protected zone, the extinguishing system must control and

4.2.2.3.3 NO CHANGE

VERIFICATION RATIONALE (4.2.2.3.3)

NO CHANGE

VERIFICATION GUIDANCE

NO CHANGE

3.2.2.3.9 Engine Compartment Fire Extinguishing. Fire extinguishing systems shall be provided for fire control and termination in all engine compartments identified in accordance with 3.2.2.3.1. when fire within these engine compartments cannot be controlled and contained by other lesser means. The system shall provide within the compartment a concentration of agent sufficient to extinguish any fire within a time duration sufficient to minimize damage within the compartment and prevent the spread of fire to other compartments. This agent concentration shall be maintained within the compartment for time duration sufficient to prevent reignition of the fire. In addition, the engine compartment and extinguishing systems design shall provide protection against potential compartment damage caused fires to the maximum extent consistent with other aircraft design and fire protection requirements.

REQUIREMENT RATIONALE (3.2.2.3.9)

NO CHANGE

REQUIREMENT GUIDANCE

NO CHANGE

extinguish the fire and control a possible reignition of the fire. The recommended extinguishing agent for hydrocarbon-air fires is Bromotrifluoromethane (Halon 1301) (CBrF$_3$) described in MIL-B-12218. To control hydrocarbon-air fires such that damage within the affected compartment is kept to a minimum, fire spread to other compartments will be prevented, and reignition will be prevented, the recommended Halon 1301 concentration and duration is at least 6 percent by volume in air for a least 0.5 seconds. These recommendations are based on conditions at normal cruise and may need to be adjusted for other flight conditions or unusual fire situations. Current agent discharge times are on the order of one second. This may vary between agents; but the aim is to provide the necessary concentration of agent within the shortest possible time after fire awareness.

b. Quantity of agent: As a design guide, the following formulas may be used to determine the minimum quantity (weight) of agent to be discharged into each engine   NO CHANGE

(1) For rough nacelle interior with low airflow and for smooth nacelle interior regardless of airflow, whichever of the following formulas provides the large value of W: NO CHANGE

$W = 0.03V$
$W = 0.03V + 0.25Wa$

(2) For rough nacelle interior with high airflow   NO CHANGE

$W = 31.03V + 0.25Wa$

(3) For deep frame nacelle interior with high airflow   NO CHANGE

$W = 0.16V + 0.50Wa$

Where: W = Weight of agent in pounds

Wa = Pounds of air per second passing through the zone at normal cruising condition

V = Net volume of the zone in cubic feet (gross volume of the zone less the volume of major items of equipment)

Definitions: Definitions:

(a) Low airflow signifies airflow rate of 1 pound or less per second at cruise   NO CHANGE

(b) High airflow signifies airflow rate exceeding 1 pound per second at cruise   NO CHANGE

(c) Smooth nacelle denotes no circumferential ribs protruding into nacelle   CHANGE "nacelle" to "nacelle"

(d) Rough nacelle denotes circumferential ribs protruding   NO CHANGE

D-5

less than 6 inches into nacelle

(e) Deep frame nacelle denotes circumferential ribs protruding (6 inches or more into nacelle or nacelle configuration with cavities 6 inches or more in depth (measured transversely))

For potential fire zones not located in nacelles, the formula of (1) may be used.

Where long discharge times are used, an increase in the value of V obtained in the formulas may be required in order to compensate for agent lost in wetting the discharge lines.

Performance Parameters

Include the location of system, location of agent storage containers, agent quantity, agent, system actuation method, type of compartment (fuselage, wing, nacelle), material selection, and environmental conditions at system location.

Background and Source of Criteria

Development of engine fire extinguishing equipment for the protection of aircraft is in flight parallels aircraft development. The need for fire extinguishing systems is reflected in AFSC DH 1-6, AFSC DH 2-2, AFSC DH 2-3 and MIL-J-83204 and design criteria contained in MIL-J-22288.

EQUIPMENT LESSONS LEARNED

In military aircraft, single engine aircraft and usually not fitted with fire extinguishing systems. One new Air Force aircraft such as the B-52 and KC-135, the engines are located in pods below the wing and separated from the rest of the aircraft by a pylon. The engine compartment is isolated from the pylon with a horizontal firewall. These aircraft have no fire extinguishing system installed on the basis that it is improbable that a nacelle fire would be totally destructive to the aircraft. There are also other military multi-engine combat aircraft such as the F-4 which do not incorporate fire extinguishing systems on a calculated risk basis. However, almost without exception fire extinguishing is provided in all military transport and cargo type aircraft engine nacelles.

EQUIPMENT LESSONS LEARNED

Modern aircraft engine installation fire extinguishing system generally employ a halogenated hydrocarbon type fire extinguishant (Table III) because of its greater effectiveness and attendant reduced system weight penalty. Table IV illustrates the two types of systems currently in use. The conventional and high rate discharge (HRD) systems are very similar with the exception of the method of agent distribution. The HRD system utilized open-end nozzles and relies on the high velocity of the agent discharge for proper dispersal within the nacelle. Consequently, high vapor pressure agents such as Halon 1301 are best suited for HRD applications. In contrast, the conventional

---

NO CHANGE

NO CHANGE

NO CHANGE

Performance Parameters

NO CHANGE

Background and Source of Criteria

NO CHANGE

EQUIPMENT LESSONS LEARNED

CHANGE "installer" to "installer"

Modern aircraft engine installation fire extinguishing systems generally employ a halogenated hydrocarbon type fire extinguishant (Table III) because of its greater effectiveness and attendant reduced system weight penalty. Table IV illustrates the two types of systems currently in use. The conventional and high rate discharge (HRD) systems are very similar with the exception of the method of agent distribution. The HRD system utilized open-end nozzles and relies on the high velocity of the agent discharge for proper dispersal within the nacelle. Consequently, high vapor pressure agents such as Halon 1301 are best suited for HRD applications. In contrast, the conventional

system being utilized perforated tubing for agent distribution with consequent penalties of restricted flow and generally higher total system weight. Low vapor pressure agents such as Bromochloromethane (Halon 1011) (CH₂BrCl) are best suited for the latter application. Dibromodifluoromethane (Halon 1202) (CBr₂F₂), an intermediate volatility extinguishant, has been problematic when used in HRD systems. Evidence exists that the characteristics of this agent may lead to uneven distribution within the compartment, particularly when the agent has been stored at a low temperature for an extended period as is in an unheated compartment during an extended high-altitude mission or when it is discharged into a low temperature ventilation airflow.

Hence it is particularly important that system verification tests be conducted with appropriate simulation of minimum anticipated agent storage temperature, minimum anticipated ventilation airflow temperature as well as with appropriate ventilation flowrates when the system is to employ Halon 1202.

NO CHANGE

Combat damage to an aircraft engine compartment could range from minor perforation in the engine compartment outer walls to unsurvivable major aircraft damage. A properly designed engine compartment fire extinguishing system can improve survivability when the combat damage results in an engine compartment fire but the structural damage is limited to perforation of the engine compartment exterior panels, the engine case or the engine bleed lines.

Recent Air Force analysis and test work has indicated that engine compartment combat damage protection should include:

a. Provision of ventilation termination. Higher concentrations and longer concentration duration will be maintained helping to extinguish fires resulting from combat damage, even when this damage results in additional airflow entering the compartment from other uncontrolled openings.

b. Provision of additional extinguishing agents. While MIL-E-22285 specified agent quantities based on compartment airflow associated with non-combat situations, analysis should be employed to estimate probable additional airflow due to perforation of compartment outer walls, engine case and bleed air lines in likely combat damage. Agent quantities based on these should be specified where other critical aircraft design objectives are not consequently compromised.

system utilized perforated tubing for agent distribution with consequent penalties of restricted flow and generally higher total system weight. Low vapor pressure agents such as Bromochloromethane (Halon 1011) (CH₂BrCl) are best suited for the latter application. Dibromodifluoromethane (Halon 1202) (CBr₂F₂), an intermediate volatility extinguishant, has been used successfully in both types of systems. Recently developed aircraft utilize the HRD type system.

The USAF has had excellent experience with the various halogenated agents. A review of accidents and incidents over a six-year period (1964-1970) showed that these fire extinguishing system installations have been more than 98% effective. In cases where the system has failed, extenuating circumstances were usually involved such as lack of rapid fire detection, utilization of improper fire emergency procedures and mechanically damaged nozzles.

Air Force technical development activities in this area in recent years have been very limited. A successful effort was completed in 1980 for the development of a Pyrotechnic Gas Discharge Fire Extinguishing System capable of effective performance in the operating temperature range from -54 degrees Celsius (-65 degrees Fahrenheit) to 230 degrees Celsius (450 degrees Fahrenheit). This system utilizes Dibromotetrafluoroethane (Halon 2402) (C₂Br₂F₄) as the extinguishant and was developed primarily for high performance aircraft applications (Mach 2.5+) where high environmental operating temperatures will be experienced. To date this type of system has not been applied.

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c. Rapid detection, fuel shutoff and extinguishant deployment; The longer that a combat caused fire is allowed to burn the more likely it is that components within the compartment will reach temperature sufficient to reignite remaining combustibles even after the fire is initially extinguished by the release of an extinguishing agent.

d. Avoidance of elevated engine compartment ventilation air pressure; Elevated compartment pressure such as would be encountered during low-altitude high-speed operation with high recovery ram inlets has been found to exacerbate the problem of reignition of residual combustibles. Engine compartment ventilation air inlet design should minimize compartment pressure where this is consistent with other aircraft design requirements.

4.2.2.3.9 Engine Compartment Fire Extinguishing. By analysis, test and inspection it shall be verified that adequate fire extinguishing systems have been provided in all necessary locations in accordance with 3.2.2.3.9. By analysis and inspection it shall also be verified that these systems also provide adequate protection against survivable combat damage. It shall be verified by testing with agent concentration instrumentation that the system will produce and maintain an adequate agent concentration as required.

VERIFICATION GUIDANCE

The required analysis and inspection should be done along with the analysis and inspection required by 4.2.2.3.1 and should be part of a fire and explosion hazard analysis done to determine the protection required for the total aircraft. While all potential hazards associated with combat damage cannot be included in this analysis, probable survivable engine compartment damage will be considered. This analysis should include the effects on compartment airflow due to external skin damage and engine case damage and bleed duct damage.

Laboratory, component, ground and flight tests and demonstrations may be used to verify the adequacy of the provided fire extinguishing system(s). Under actual or simulated cruise condition or at some other preferred flight condition, whereat airflow, pressure and temperature conditions will be as severe as at cruise, the system should be discharged and agent concentration and duration goals should be verified by use of an appropriate method of measuring agent concentration (such as the Statham Analyzer). Simulation should include refrigerating the agent in its storage container to the lowest temperature anticipated during cruise prior to its release. Airflow rate should be as high as anticipated. If Halon 1202 is employed, the lowest airflow temperature anticipated in flight should be used. Through use of the Statham Analyzer, it is possible to determine agent concentration and duration and establish adequacy of the fire extinguishing system without the need for fire testing. In addition, the fire extinguishing system can be tailored to the

4.2.2.3.9 Engine Compartment Fire Extinguishing. By analysis and inspection it shall be verified that fire extinguishing systems have been provided in all necessary locations in accordance with 3.2.2.3.9. It shall be verified by that the system will produce and maintain an agent concentration as required.

VERIFICATION GUIDANCE

The required analysis and inspection should be done along with the analysis and inspection required by 4.2.2.3.1 and should be part of a fire and explosion hazard analysis done to determine the protection required for the total aircraft. Laboratory, component, ground and flight tests and demonstrations may be used to verify the adequacy of the provided fire extinguishing system(s). Under actual or simulated cruise condition or at some other preferred flight condition, the system should be discharged and agent concentration and duration goals should be verified by an appropriate method of measuring agent concentration (such as the Statham Analyzer). Through use of the Statham Analyzer, it is possible to determine agent concentration and duration and establish adequacy of the fire extinguishing system without the need for fire testing. In addition, the fire extinguishing system can be tailored to the installation to provide a minimum weight system.

installation to provide a minimum weight system.

REQUIREMENT LESSONS LEARNED

The F-111 is equipped with a Halon 1202 agent release system that was demonstrated in an agent release test performed in 1969 using Statham analyzers. Testing was conducted at a single simulated operating condition, ground operation with ejectors. Analysis was employed to demonstrate that internal airflow was sufficient to extinguish engine compartment fires at the substantially higher airflows experienced at various flight conditions.

Air Force operational experience with the F-111 has indicated that not all in-flight fires are extinguished by the ventilation airflow. A ground test program conducted by the FAA in 1980, with simulated cruise airflow, demonstrated that the original analysis was incorrect and that there were areas of stagnation and of reverse flow. In addition, an agent release test, conducted by the FAA in 1986, demonstrated that inadequate agent concentrations existed in all but the original ground test condition.

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APPENDIX E

ANALYSIS OF HIGH INDICATED HALON 1202 CONCENTRATIONS:

Using the following procedures, it is feasible to estimate total mass of agent dumped into the AEN from agent concentration data. If the AEN test section is considered to be a control volume through which a certain volumetric flow of air and agent passes, the following relationship is valid for the total weight of agent:

$$W_e = \int_0^t C_e \rho_e V_a \, dt$$

For the AEN testing, ρ_e and V_a were held constant during any particular test, allowing the following simplification:

$$W_e = \rho_e V_a \int_0^t C_e \, dt$$

Where: W_e = Total weight of extinguishing agent

C_e = Volumetric concentration of extinguishing agent

ρ_e = Density of extinguishing agent at the pressure and temperature conditions in the AEN

V_a = Volumetric flow rate of ventilation air

For the purposes of this analysis, the following integral approximation was utilized (essentially the area under the concentration curve):

$$W_e \approx \rho_e V_a \sum_0^t C_e \Delta t$$

E-1

This approximation was then used to compute agent weights for specific tests using Halon 1301 and 1202. The tests chosen were from Figures 16 and 17 (top left hand figures) in Section 4.5.2. The average concentration from six sample lines is shown in Figure E1. For the specific conditions used in these two tests, the following variable values were used:

$$V_a = \frac{1 \text{ lb/sec}}{0.075 \text{ lbs/ft}^3} = 13.3 \text{ ft}^3/\text{sec}$$

$$\rho e = \frac{P}{R\ T} = 0.388 \text{ lbs/ft}^3 \text{ [Halon 1301]} \quad \begin{array}{l} \text{at } 66^\circ F \\ \text{and} \\ 14.7 \text{psia} \end{array}$$
$$= 0.547 \text{ lbs/ft}^3 \text{ [Halon 1202]}$$

Then, for Halon 1301,

$$W_{1301} = \frac{(0.388)(13.3)[1.0+6.1+9.4+9.4+8.0+6.0+4.4+2.9+1.8+1.0+.6+.4+.4+.2](0.1)}{100}$$

$$= 0.27 \text{ lbs of Halon 1301}$$

This compares favorably to 0.36 lbs actually dumped; the ratio of computed to actual weight is 0.75.

Then, for Halon 1202,

$$W_{1202} = \frac{(0.547)(13.3)[1.6+8.3+13.4+15.5+16.6+16+14.7+13+9.5+6.4+4.6+3.8+3.6+3.5+1.5(10)](0.1)}{100}$$

$$= 1.06 \text{ lbs of Halon 1202}$$

This does not compare favorably to the 0.4 lbs actually dumped; the ratio of computed to actual agent is 2.56.

These comparisons suggest that some measurement problem occurred with the Halon 1202 testing and that the observed high indicated 1202 concentrations did not actually exist in the AEN.

66 DEG. F AIR/20 DEG. F AGENT

VENTILATION AIRFLOW OF 1 LB/SEC

AVERAGE CONCENTRATION WITH
0.4 LBS OF HALON 1202 DISCHARGED

AVERAGE CONCENTRATION WITH
0.36 LBS OF HALON 1301 DISCHARGED

AGENT CONCENTRATION (%)

TIME (SECONDS)