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Investigation of Cable and Cable System Fire Test Parameters

Task A: IEEE 383 Flame Test

Underwriters Laboratories Inc.

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U.S. Nuclear Regulatory
Commission**

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ABSTRACT

The flame test in the Institute of Electrical and Electronics Engineers (IEEE) Standard 383 was investigated. The investigation was to develop possible modifications in test equipment and test procedure that would increase the repeatability of results and provide additional information useful in assessing cable system performance in response to a real fire. Several fire experiments were conducted varying different test parameters. The experimental data were analyzed and modifications of both test equipment and test procedure were developed. These modifications were: an enclosure for the sample, defining cable damage; cable fastening and the cable tray to be used; establishing tolerances for exhaust of the enclosure; starting temperature of the ambient air and cable sample; location of the burner and the flow rates of fuel and air into the burner. Suggested also, was to report the maximum flame height versus time and the rate of heat released versus time as additional information that could be useful in assessing cable system performance.

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ACKNOWLEDGEMENTS

The US Nuclear Regulatory Commission through its Office of Nuclear Regulatory Research maintains an ongoing fire protection research program. The program is intended to obtain data in support of current regulatory guides and standards for fire protection and control in light water reactor power plants and to establish an improved technical basis for modifying these guides and standards where appropriate. The investigation described in this Report is one task of an element of this program.

This investigation was conducted at Underwriters Laboratories facility in Northbrook, IL. The authors wish to thank the technical and engineering staff members, especially, Tom Plens, Chris Johnson, Stan Lesiak and Sandi Hansen, for their effort in conducting the experiments and preparing the data.

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PREVIOUS REPORTS

Title	Reference	Date
Development And Verification Of Fire Tests For Cable Systems And System Components, Quarterly Reports 2 and 3.	NUREG/CR-0152	June 1978
Development And Verification Of Fire Tests For Cable Systems And System Components, Quarterly Report 4.	NUREG/CR-0346	September 1978
Development And Verification Of Fire Tests For Cable Systems And System Components, Quarterly Report 12.	NUREG/CR-1552	September 1980

1. INTRODUCTION

1.1 BACKGROUND:

The US Nuclear Regulatory Commission (NRC), through its Office of Nuclear Regulatory Research (RES), initiated fire protection research in 1975[1] with an investigation of a limited cable tray separation verification program to obtain data for evaluating some guidelines of Regulatory Guide 1.75[2]. After the Browns Ferry fire and the recommendations made by the Special Review Group,[3] RES established an expanded fire protection research program to augment the cable separation studies and to investigate other fire protection concerns.

One fire protection concern is the combustibility of electric cables. The NRC guidelines for electric cables are contained in Section 9.5.1 of NUREG 0800[4], and one guideline is that cables must pass the flame test as described in IEEE Standard 383-1974[5]. Of interest are repeatability of the flame-test results and the correlation of test results of a sample with a single layer of cable to the performance of a cable system where several layers of cable are used. If test results are not sufficiently repeatable, cable may be accepted with undesirable flame propagation characteristics. Additionally, if the test results do not sufficiently correlate to fire performance of cable systems in the plant, acceptable cable may not significantly reduce the potential fire hazard in the plant. Investigation of this flame test method with respect to these concerns is the subject of this Report.

1.2 IEEE 383 FLAME TEST METHOD:

The flame test method described in IEEE 383 is a laboratory-scale test. The sample consists of several 8.0 ft (2.5 m)[+] lengths of cable. The cables are installed in a single layer in a vertical cable tray. The cables are placed to fill the center 6 in. (150 mm) portion of the 12 in. (300 mm) wide tray with each cable length separated by about one-half of its diameter and fastened to the top and bottom rungs of the tray. For example, if the sample is 7C/12 AWG control cable with a diameter of approximately 1/2 in. (1.2 mm), about eight cable lengths are used and installed with about a 1/4 in. (0.6 mm) spacing.

+ - In this Report, equivalent SI units included in parentheses may be approximate.

The ignition source can be either a controlled diffusion flame or a flame resulting from the burning of an oily rag. The diffusion flame is the most widely used and is produced by burning either propane or natural gas with premixed air. The flame is shaped by a ribbon type burner head (American Gas Furnace Type 10L11-55). The desired size and composition of the diffusion flame is obtained by controlling the pressure of the fuel and air delivered to the burner head and by specifying that the flame temperature should be approximately 1500°F (815°C).

The test is conducted by placing the sample in an environment specified as "free from spurious air current". For the diffusion flame, the burner head is placed about 3 in. (80 mm) behind, and 24 in. (610 mm) above the base of the tray; and is located midway between cable tray rungs. The flame is applied to the sample for 20 min and the test is continued until all fire activity ceases. For the oily rag procedure, the rag is placed in front of and approximately 24 in. (610 mm) above the bottom of the tray with the rag held in place against the cables. The rag is ignited and allowed to burn until it is consumed. For both procedures, the maximum cable damage is measured. The cable is found acceptable if the cable damage does not reach the top of the sample.

1.3 OBJECTIVES, SCOPE AND PLAN:

This program was to investigate possible modifications to the test equipment and test procedure described in the IEEE 383-74 cable flame test with respect to increasing the repeatability of test results and providing additional information useful in assessing cable-system fire performance.

In connection with this overall objective, the following specific items were investigated experimentally:

1. Forced exhaust of the environment surrounding the sample.
2. Increase in the number of cable lengths used in the sample.
3. Variation in the ignition-flame characteristics and location
4. Repeatability, practicability and usefulness of supplemental performance measurements, i.e.:
   a) Maximum flame height
   b) Rate of heat release
   c) Cable temperatures

The organization of the experiments investigated is shown in Table 1. To consolidate experimentation, two or more non-interdependent test parameters were investigated in the same experiment, such as forced exhaust, flame propagation measurement and cable temperature measurement.

2. EXPERIMENTAL PROCEDURE

2.1 FACILITIES:

The laboratory buildings used for the cable experiments are shown in Fig. 1. One of the buildings was heated, if needed, to obtain the desired initial temperature. The buildings were exhausted by a system that included smoke incineration. The system provided one air change every 240 s - 560 s. While the exhaust system was operating there was sufficient air leakage into the rooms that atmospheric pressure was maintained.

The laboratory building room that was used for the ignition flame experiments was about 81 ft (24.4 m) by 102 ft (31.1 m) by 44 ft (13.4 m) high. The room was heated to normal laboratory temperatures (about 65°F (18°C)) and was ventilated by natural convection.

2.2 EQUIPMENT:

Enclosure

All experiments were conducted with the four sided enclosure as shown in Figs. 2, 3 and 4. Air entered into the enclosure through two 12 in. (305 mm) high by 8 ft (2.5 m) openings along the base parallel to the front and rear of the tray. The products of combustion flowed through the open top by free convection. In experiments which investigated forced exhaust, a hood with a duct system was placed on top of the enclosure as shown in Fig. 4. A 24 in. (60 cm) square baffle was suspended beneath the exhaust duct outlet to divert air flow away from the sample. A fan was located in the exhaust duct downstream from the enclosure. The fan was dampered to permit changes in exhaust flow rate.

Ignition Flame Apparatus And Fuel

The burner head and mixer used for the ignition flame was the same as that referenced in IEEE 383 as being satisfactory for purposes of the flame test. The burner was a 10 in. (254 mm) wide, 11-55 drilling, ribbon burner which was manufactured by the American Gas Furnace Co. (Model 10L11-55). The air/fuel mixer was a Venturi type, also manufactured by American Gas Furnace Co. (Model No. 14-18). The flow of propane and air into the burner was measured by flowmeters (Fig. 5).

For the experiments with two burner heads, a valve and an orifice meter, with 1/4 in. (6 mm) orifice plate, were located upstream from each burner for measuring and balancing the flow to each burner.

Bottled commercial grade propane having a nominal heating value of 2500 Btu/ft^3 (93 MJ/m^3) was used as fuel. The heating value was obtained by test with a recording calorimeter on representative samples from the lot of propane used.

Cable Tray

The cable tray used to support the cable samples was an open-ladder type (Fig. 6). The tray was 8 ft (2.44 m) high and 12 in. (305 mm) wide. The side rails were channels, 3-3/8 in. (86 mm) deep with 1 in. (25 mm) flanges and fabricated from 0.060 in. (1.5 mm) thick cold-rolled steel. The channel shaped rungs were 1 in. (25 mm) wide with 1/2 in. (13 mm) flanges and fabricated from 0.125 in. (32 mm) thick cold-rolled steel. The rungs were tack-welded to the side rails at 9 in. (229 mm) intervals.

2.3 SAMPLES:

In all experiments, except the experiments investigating flame characteristics, cables were used as test samples. Five cable constructions were investigated to provide data over a range of cable insulation and jacket materials. Since the test method and not the specific cable constructions was investigated, cables are identified in the test results only by a code. Descriptions of the cable constructions are summarized in Table 2.

In the flame characteristics experiments, a 12 in. (0.305 m) wide by 8 ft (2.44 m) high board was used to simulate a cable sample. The board was nominally 1/2 in. (12 mm) thick and was manufactured from predominately inorganic materials. Several holes were cut into the board for mounting calorimeters and thermocouples.

2.4 INSTRUMENTATION:

Temperature

Type K, 30 AWG, chromel-alumal thermocouples were used to measure cable and board surface temperatures. The location of the thermocouples in the board surface and in the cable jacket are shown in Figs. 7 and 8, respectively. Type K thermocouple assemblies of 28 AWG chromel-alumel wire enclosed within 0.0624 in. (1.6 mm) Inconel sheaths were used to measure air temperatures as shown in Fig. 9.

Heat Flux

Calorimeters were used to measure the total heat flux from the ignition flames. The calorimeters had a viewing angle of 180°. Their surfaces were flat black and the body was OFHC copper. The full-scale range was 15 Btu/ft^2-s (170 kW/m^2) at 10 mV. Water at about 75°F (24°C), was circulated through copper cooling tubes on the body.

Pressure

Pressure differentials across the orifice meter in the fuel and air lines to the burner heads were measured with differential pressure manometers.

Gas Velocity

The velocity of the air entering the enclosure along the base openings was measured with a hot-wire anemometer. The exhaust gas velocity inside of the duct and gas velocity near the sample were calculated from the pressure differential measured with bidirectional probes connected to an electronic pressure gauge (Fig. 10). The probes were fabricated from 0.56 in. (14 mm) diameter stainless steel tube that was 1.25 in. (32 mm) long. The tube was divided in half into an upstream and downstream compartment by a 0.56 in. (14 mm) disk. The differential pressure between these two compartments was measured by the electronic pressure gauge. Velocity was calculated using the temperature at the probe and the differential pressure.

Oxygen Concentration

Oxygen concentrations of the air near the sample and in the exhaust duct (Fig. 10) were measured continuously by paramagnetic analyzer manufactured by the Bacharack Instrument Co.

Recorders And Data Acquisition System

Voltage outputs from the thermocouples were connected to either multi-point or continuous strip chart recorders. If used, the voltage output from the oxygen analyzer was connected to continuous strip chart recorders in Experiments 1-23. In the remaining cable experiments the voltage outputs from the thermocouples, oxygen cell and electronic barometers were connected to an Accurex Autodata 9 data logger. For the ignition flame experiments, the voltage outputs of the thermocouples were connected to multi-point strip chart recorders and the voltage outputs from the calorimeters were connected to continuous strip chart recorders.

Photography

Experiments were recorded on 35 mm color slides. The camera was an Olympus OM-2 with a 50 mm f 1.8 lens.

2.5 METHOD:

Cable Experiments

The experiments were conducted in accordance with the method described in Par. 2.5 of IEEE 383, except for certain equipment or procedure details, under investigation.

Cable samples were prepared by cutting cables into approximately 8 ft (2.44 m) lengths and installing the lengths into the cable tray. The cables were installed in a single layer except for the experiments with increased cable loading. They filled the center 6 in. (152 mm) portion of the tray and were spaced about one-half the cable diameter apart. When the cable loading was increased (Experiments 1-6), the cable was installed in a specific pattern of multiple layers shown in Fig. 11. Since the cable diameter was different for each cable construction, the number of cable lengths installed into the tray was different for each cable construction.

The cables were fastened to the tray rungs with either 0.062 in. (1.57 mm) diameter steel wire or with nylon ties. In Experiments 7-48, each cable was fastened to every other rung (18 in. (0.460 m)) with steel wire. In Experiment 1-5, the cables were fastened to the top and bottom rungs with steel wire and to every third ladder rung (27 in. (0.68 m) apart) with nylon ties. In Experiment 6, the cables were fastened in the same locations as in Experiments 1-5, but using steel wires throughout.

For Experiments 7-48, if the temperature of the test room was less than 55°F (13°C) or the desired initial test temperatures, the room was heated to the desired temperature.

For Experiments 36-48, the desired exhaust rate was established prior to the start of the test as determined by the calculated air velocity in the exhaust duct.

The tray with cable was placed in the test stand. To start the test, a small pilot flame was ignited and then the propane and air flows increased to the desired flows. Except for Experiments 13-16, 19 and 20, the air flow was established at 163 SCFH (1,280 cm^3/s) and the propane flow was established at 28 SCFH (220 cm^3/s).

The ignition flame was applied for 20 min, except in Experiments 1-6 in which the flame was applied for 23 to 47 min. In several other experiments, the flame was extinguished earlier since the cable material was consumed and continuation of the experiment would not have provided additional fire performance data of interest. During each experiment, visual observations were made of the response of the cable jacket and insulation materials to the fire and the maximum flame height was recorded. Photographs of the fire activity at random times were obtained. After each experiment, the maximum height of cable jacket damage above the burner was determined.

For Experiments 1-6, the temperatures of the air and core of the cable bundle and six cable jacket thermocouples were recorded on multi-point strip chart recorders. The remaining cable temperatures were recorded on continuous strip chart recorders. The air velocity entering the enclosure was measured and individual readings recorded. During each experiment, the oxygen concentration of the air near the sample was recorded on continuous strip chart recorders.

For Experiments 7-10 and 21-23, the cable jacket temperatures were recorded on continuous pen type strip recorders. The ambient, propane and supply-air temperatures were recorded on multi-point strip-chart recorders.

For Experiments 23-48, the temperatures, pressures and oxygen concentration were recorded by the data acquisition system.

Flame Characteristics Experiments

The flame characteristics experiments were conducted with the instrumented board in lieu of the cable sample.

To start each experiment, the air flow and propane flow to the burner head was adjusted to the appropriate meter settings. The height of the burner head was then adjusted to obtain the maximum recorded heat flux at the calorimeter 12 in. (0.305 m) above the floor. The experiment was continued until the temperatures and fluxes had reached a quasi-steady state. During each experiment, visual observations were made of the ignition flame and photographs of the flame were taken.

The board and air temperatures were recorded on multi-point strip chart recorders. The outputs from the calorimeters were recorded on continuous pen type strip recorders.

3. RESULTS AND DISCUSSION

3.1 CONTROL EXPERIMENTS:

Five groups of experiments were conducted utilizing the five cable types within the enclosure. The enclosure was without a top which allowed gases to be exhausted by free convection. The results of these experiments were used as control data for comparison with the remaining experiments. The cable reference number of cables per sample, the initial air temperature and initial cable jacket temperature for each experiment are given in Table 3.

Flame Height

As shown in Figs. 12-16, the maximum flame height versus time was similar for experiments with the same cable construction, except for Experiment 10. In that experiment the flame height was about the same as in Experiments 7, 8 and 9 during most of the experiment, but flame propagation along the sample persisted longer, and the maximum flame height reached was greater in Experiment 10. However, Experiment 10 is suspect since the air temperature prior to the experiment had risen to about 95°F (35°C) due to a malfunction of the room heater and then cooled to 64°F (18°C). It is possible that parts of the cable, cable tray, and enclosure were still above the air temperature at the start of the experiment, and that may have caused the difference in performance.

Damage

The maximum and average cable damage of the sample for each experiment are given in Table 3. The maximum cable damage varied over a range of 3 in. (76 mm) for Cable A, 2 in. (51 mm) for Cable B, 4 in. (102 mm) for Cable C and 2 in. (51 mm) for Cable D. For Cable E, damage reached the top of the tray in all experiments. Experiments 10 and 23 were excluded from the comparison because of uncertainty of the initial temperature.

Gas Velocity

The upward gas velocities measured near the samples* were extremely unsteady in all experiments and difficult to interpret. For comparison, average gas velocities near the sample versus time for Cables D and E are shown on Fig. 17. These average gas velocities were calculated at 15 s intervals from the pressure and temperature data for all experiments with the same cable construction. These average velocities were quite unsteady because of the inherent unsteadiness of the flames.

Oxygen Concentration

The minimum oxygen concentrations of the ambient atmosphere near* the samples are shown in Table 4. As shown, the decrease in oxygen concentration was slight, 20.7 percent being the minimum oxygen concentration for the control experiments (Exp. 34).

3.2 FORCED-EXHAUST EXPERIMENTS:

Five groups of experiments were conducted to investigate exhaust of the enclosure. For these experiments, the top of the enclosure was covered with the hood and connected through an exhaust duct to a fan. Nominal exhaust rates of 1200 ft^3/min (566 l/s), 1500 ft^3/min (710 l/s) or 1800 ft^3/min (849 l/s) were established prior to the fire tests. During each test, the exhaust rate was not adjusted to maintain the pretest value, but was allowed to vary from the initial value as temperature changed in the enclosure. The cable reference, number of cables per sample, initial air temperature and nominal exhaust rate for each experiment are given in Table 5.

* - Probe located 4-1/2 in. (114 mm) from tray as shown in Fig. 10.

Flame Height

The average of the maximum flame heights versus time for each group of experiments is shown in Fig. 18 for Cables C, D and E at several forced-exhaust rates and at the control natural-convection condition. For each cable type, the curves are essentially the same, with the exception of the Type D cable at 1500 ft^3/min (710 l/s). In that case, the shape of the flame height versus time curve was essentially the same as in the control experiment, but the flame activity was delayed and occurred about two minutes later.

Damage

The maximum cable damage for each experiment is given in Table 5. The average of the maximum cable damage for each group of experiments with Cables C and D, are shown in Fig. 19. Within any group of experiments, results with forced exhaust differed by 1.5 in. (38 mm) or less from the results of the control experiments. This is within the variation in maximum damage height of 2 in. (51 mm) to 4 in. (102 mm) recorded for the control experiments. Type E cable was damaged to the top of the tray in all experiments so variation in cable damage could not be obtained.

Gas Velocity

The average gas velocities (as defined previously) near the sample for Cables C, D and E at various exhaust flow rates are plotted versus time in Figs. 20 through 22. Like the control experiments, these velocities were not steady because of the inherent unsteadiness of the flames. They tended to increase as the amount of forced exhaust increased, especially for Cable E. The changes in velocity were apparently insignificant in relation to the flame induced velocities along the samples, because forced exhaust had no significant effect on flame propagation rates and maximum cable damage.

Oxygen Concentration

The minimum oxygen concentrations of the ambient atmosphere near the sample during the experiments are given in Table 4. Again, the decrease in oxygen concentration was slight, amounting to about 0.52 percent for cable Type E with a nominal exhaust rate of 1500 ft^3/min (708 l/s).

3.3 CABLE LOADING EXPERIMENTS:

Six experiments were conducted to investigate effects of increased cable loading. A loading of 40 percent (cable area/tray area) with one cable construction (Cable A) was investigated. The cable lengths were installed in a woven pattern (Fig. 11), with each pair of cable lengths secured to the tray with steel wire ties at the top and bottom rungs. Nylon ties were used at every third ladder rung (about 27 in. (690 mm) apart) along the remaining sample, except in Experiment 6, cables were fastened similarly using steel wire ties exclusively.

These experiments were conducted within the enclosure. With the increased cable loading, the ignition flame was unable to penetrate through the sample. Consequently, two ribbon burners were used to provide flame exposure to both the front and back surfaces of the sample. The theoretical rate of heat released (TRHR)* of 70,000 Btu/h (20.5 kW) from the ignition flame was maintained, but the fuel/air mixture was split about equally between the two burners. The burners were located 6 in. (150 mm) above the base of the sample. The initial air and cable jacket temperatures and duration for each experiment are given in Table 6, along with other data.

Flame Height

As shown in Figs. 23-25, the maximum flame height versus time was different on the front and rear surfaces, and varied from experiment to experiment. During each experiment, the cable bundle became fused due to the slow melting of the cable jacket. Flaming was observed principally on the outside of the fused mass. In Experiment 6 with all steel ties, the fused mass of cable was larger than in Experiments 1-5 with all plastic ties. Additionally, flaming was not uniform across the width of the sample and tended to propagate faster along one side of the sample.

Damage

The maximum and average damages of the sample for each experiment are given in Table 6. Like the flame propagation, the maximum damage varied between experiments, with maximum damage sometimes occurring on the front surface and at other times on the rear surface. In Experiment 6 with steel ties, the maximum cable damage was 52 in. (1.31 m) as compared to 72 in. (1.83 m) for the other experiments with nylon ties.

* - Flow rate times the nominal heating value of propane.

The maximum cable damage was greater with increased cable loading, 72 in. (1.83 m), as compared to the control experiments, with one layer of cable 25 in. (0.64 m). This is consistent with other fire experiments which showed that cables that sustained damage below the top of the tray when tested in a single layer propagated flames at a greater rate and sustained greater damage when tested with increased cable loading.[6] However, because of the potential lack of repeatability of results with increased cable loading, testing a sample with increased cable loading does not seem practical, at least for this one cable type. Repeatability might increase if all tie wires are steel because restraint would be provided against random cable movement. However, this appears to cause artificial reduction of flame propagation and cable damage by increasing the tendency of the cables to fuse into a solid mass, at least for the tested cable construction.

Oxygen Concentration

The minimum oxygen concentrations near the sample are given in Table 6. The minimum oxygen concentration varied and was 18 percent for cable A. This may have resulted from combustion products being produced at a rate which exceeded the exhaust rate for the test room. This decrease may have had an effect on the rate of flame propagation along the sample, but the variation of maximum flame height and cable damage appeared to be mainly dependent upon the random formation and movement of the fused cable bundle.

Air Flow

The air velocities through the inlet of the enclosure were measured occasionally with a hand held anemometer. The velocities varied from 100 ft/min (0.508 m/s) to 160 ft/min (0.813 m/s), with the maximum velocity occurring when the cable burning was at its peak.

3.4 IGNITION FLAME CHARACTERISTICS EXPERIMENTS:

The flame characteristics experiments were conducted with an instrumented board of inorganic material in lieu of the cable sample. The board was instrumented with calorimeters and thermocouples so as to measure the heat flux from the flame and temperatures of the board surface and air along the sample. the experiments were conducted within the enclosure with free convection exhaust. The general pattern for these experiments was to vary the air flow rate for each burner location and each fuel flow investigated. The parameters changed are summarized in Table 7.

Flame Stability

During the experiments, several undesirable characteristics of the flame were observed:

1. Sporadic detachment from the surface of the instrumented board.

2. Curling of the flame edges away from the board toward the center of flame.

3. Deflection of the flame downward and back under the burner head, rather than upward along the surface of the board.

All of these conditions are referred to here as unsteady flame conditions. Where the flame remained attached to the board and was only deflected upward along the board, the flame was considered steady.

The burner heights, burner distances and nominal air-fuel ratios at each fuel flow investigated and observations regarding the condition of the flame are given in Tables 8 through 10.

At the lower air-fuel ratios at all distances from the board, the flame appeared very long and luminous with the flame sporadically blown away from the board and with the flame ends curled back toward the center of the flame. An example is shown in Fig. 26. At the higher air-fuel ratios, the flame appeared stable, smaller and blue in color. An example is shown in Fig. 26.

As the fuel flow was increased, the flames became longer and impinged on the surface of the board sample along a greater length. For example, at 35,000 Btu/h (10.2 k W) the flame length was about 12 in. (300 mm), while at 105,000 Btu/h (30.8 k W) the flame length was about 24 in. (610 mm).

When the burner was far from the sample, the flame tended to detach from the board surface and the flame ends would curl toward the center of the flame as shown in Fig. 27. When the burner was near to the sample, the flame deflected off the board and issued back under the burner head as shown in Fig. 27. For each fuel flow and air-fuel ratio, the burner spacings that produced stable flames are given in Table 11. An example of a stable flame is shown in Fig. 28.

Heat Flux And Temperature

The heat flux and the temperature of the air and surface of the board fluctuated greatly even when the flame appeared to be stable. In spite of these fluctuations, the data were used as qualitative indicators of flame performance. The maximum flame heat flux and board temperature for stable flames at various fuel flows are given in Table 12. The maximum heat flux and air temperature near the sample board for some stable flames are shown versus the height above the burner in Figs. 29 and 30, respectively. As shown, the maximum heat flux and gas temperatures increased with increasing fuel flow.

3.5 IGNITION-FLAME SENSITIVITY EXPERIMENTS:

Five groups of experiments were conducted to investigate the sensitivity of the results to changes in the ignition flame parameters. The burner distance was varied from 2.5 to 3.5 in. (52 to 89 mm). The air/fuel ratio was varied from 5.5/1 to 6.5/1. The fuel flow was varied from 65,000 to 75,000 Btu/h (19 to 22 kW). The test parameters investigated and initial air temperature for each experiment are given in Tables 13 and 14.

Several effects were observed when the test parameters were varied, but maximum damage height is the most definitive effect for present purposes. Control Experiments 7, 8 and 9 establish the basic repeatability of the height of damage at ±1-1/2 in.

As shown in results of Experiments 11 and 12, varying the burner distance ±1/2 in. from the specified 3 in. has a significant effect on cable performance. About a 10 in. difference in height of cable damage was recorded between Experiments 11 and 12. However, little difference in height of cable damage was observed between Experiments 17 and 18 where the burner distance was varied ±1/8 in.

In Experiments 13 and 14, the air input rate was varied plus 10 percent and minus 6 percent, respectively. The results of these tests show that little difference in cable damage is produced by such a variation in the supply air. This is to be expected, since the air/fuel ratio of the standard ignition flame is approximately 6/1, whereas the stoichiometric air/fuel ratio is about 23/1. With such a fuel-rich mixture, slight variations in the amount of air should not have a significant effect on the flame heat output.

The fuel input rate was changed in Experiments 15, 16, 19 and 20. Cable damage for each of the experiments is shown in Table 14. As shown, there was more cable damage when the fuel was decreased. There was an approximate 10 in. increase in cable damage between Experiments 16 and 15 in which the fuel input was decreased from 30 SCFH (236 cm^3/s) to 26 SCFH (205 cm^3/s). This may have been caused by the lower fuel flow rate producing a flame that engulfed the cable sample more than passing between the cable lengths and impinging on one side of the sample only. However, there was only a 1 in. difference in cable damage when the fuel input was between 27 SCFH (212 cm^3/s) and 29 SCFH (228 cm^3/s).

Visual observations and cable damage measured in previous cable fire tests suggest that a significant difference in results may be caused by a large variation in initial room temperature. Four cable fire tests according to IEEE 383 were conducted as part of another investigation [7,8]. A summary of the results is shown in Table 15.

The four tests were conducted on one cable construction with samples obtained from the same cable reel. Besides the variations of initial room temperatures, barometric pressure and humidity, the only difference between Experiments A-B and C-D was the spacing of cable ties and burner height. However, after allowance for the burner height, Experiments C and D sustained greater cable damage than did Experiments A and B, which were conducted at lower initial starting temperatures.

3.6 SUPPLEMENTAL PERFORMANCE MEASUREMENTS:

During conduct of experiments to investigate other test conditions, supplemental performance measurements were obtained to investigate recording flame propagation, cable temperature and rate of heat released (RHR). In all experiments, the travel of the maximum flame height was recorded. In 16 experiments cable temperatures were measured by thermocouples imbedded in the cable jacket at 6 in. (150 mm) intervals. In 13 experiments with forced exhaust, the oxygen concentration in the exhaust gases was measured and the RHR was calculated using the oxygen consumption technique[8].

Flame Propagation

The curves of maximum flame height versus time are shown in Figs. 12-16, 18, 23-25 and 33-35. The curves were similar, but not identical for experiments within the same group. The variability in the curve was probably caused by the randomness of the flame and difficulty in recording precise flame heights (these flame heights were obtained from visual observation with values recorded in minimum 3 in. (75 mm) increments).

The data did not require additional instrumentation and could be readily obtained. While such data are too variable to be useful for establishing acceptance criteria for cable flammability, they may be useful in describing gross fire performance.

Cable Jacket Temperatures

The cable-jacket temperatures were recorded in Experiments 1-10 and 21-26 are given in Tables 16-31. By comparing the temperatures, one can see that the cable temperatures were not the same for experiments within the same group. This is more readily seen by a plot of temperatures. Plots of temperatures versus time for two thermocouples selected at random from Experiments 7, 8 and 9 are shown in Fig. 34.

Cable jacket temperatures were measured by twelve thermocouples. However, the techniques and time required for proper placement of the thermocouples may make it impractical to include this measurement in a standard test of this nature.

Rate Of Heat Release

During the forced exhaust experiments, Exp. 36-48 an approximate value of the heat released was calculated using the oxygen consumption technique with simplified procedures, based on the oxygen concentration and flow rate in the exhaust duct during the experiments.

The RHR was calculated by the following equation:[9]

$$Q = \frac{17.2\ V\ (0.21 - X)}{(A - B\ X)} - Q_1$$

where Q_1 = rate of heat release for gas burner, MW

Q = net rate of heat release, MW

X = % oxygen in exhaust duct

V = flow in exhaust duct, m^3/s

A = molor expansion factor for fraction of air depleted of oxygen

B = ratio of moles of combustion products formed to moles of oxygen consumed.

The RHR versus time for these experiments is shown in Figs. 35-37. As shown, the RHR curves were not identical for experiments within the same group. This was probably due to the simplified procedure used in calculating the RHR, the instrumentation used and other associated factors.

To calculate the rate of heat release requires additional instrumentation such as a paramagnetic analyzer to measure O_2 concentration, and appropriate flow measurement devices. However, dependent upon the accuracy desired and willingness to put up with experimental inconveniences for instrumentation, a number of options could be used, each of which require different calculation procedures[9]. As with the flame height versus time data, the RHR data could be useful in assessing cable system performance.

4. DISCUSSION OF MODIFICATIONS

The results of these experiments and other relevant data indicate that changing some of the test conditions investigated may increase the repeatability of IEEE 383 test results or provide additional useful information. We suggest that the following changes be implemented.

4.1 TEST EQUIPMENT:

- An enclosure similar to that shown in Figs.2 through 4 should be used. The results from Experiments 36 through 48 showed that the enclosure provided a stable environment for the ignition flame and burning sample. The enclosure limited the random air movement near the sample while providing air for combustion and an outlet for exhaust gases.

- Size and construction of the cable tray used for sample support should be specified. The rungs along the rear surface of the cable retard the flame propagation. Changes in the size, shape and spacings of the cable tray affect the flame propagation and repeatability of results. Although any open ladder type tray would be adequate, the tray used in these experiments provided good results, and is a reasonable choice for standardization. Details of the tray are given in Fig. 6.

- Fuel and air flow rates to the burner should be measured with flowmeters that are compensated for gas density in lieu of manometers. The present IEEE 383 method of monitoring fuel and air rates is by measuring the pressure of each in the supply lines before the mixer. Previous experience has shown that monitoring pressure is a coarse means of regulating a flame since any restrictions in the line, changes in density of the fuel and air, and the heat produced by the burning sample have significant effects on the recorded pressures. Accordingly, measuring these pressures should be eliminated.

- Additional instrumentation is suggested for supplemental performance measurements. For calculating RHR, the temperature, oxygen concentration and velocity of the exhaust gases is to be measured. A 28 AWG Type K chromel-alumel thermocouple with an Inconel sheath, a continuous sampling paramagnetic oxygen analyzer and a bidirectional probe with an electronic manometer were found to be adequate as a minimum.

<u>4.2 TEST PROCEDURE:</u>

- An exhaust rate of 1500 ± 3000 ft³/min (710 ± 14 l/s) should be established prior to the test. The data from Experiments 36 through 48 showed that this exhaust rate was sufficient to exhaust products of combustion without accumulation that would cause reduction of the oxygen concentration; and did not affect the air flow near the sample. The data also shows that variation of the flow rate within the tolerance specified would not significantly affect the results.

- Each cable should be fastened to every other tray rung with steel tie wire. This fastening method limited the random movement of cables during the fire test as shown by comparing results of Experiment 6 to Experiments 1 through 5.

- The location of the burner should be specified as 3 ± 1/8 in. (76 ± 3 mm) behind the rear cable tray surface. In Experiments 17 and 18 with these tolerances, maximum cable damage was within the range established by the control experiments for the cable construction tested.

- The burner height should be specified as 24 ± 1/8 (609 ± 3 mm). Although the effect of burner height was not investigated, the proximity of the burner to a ladder rung would have a significant effect on the results. Additionally, the height above the bottom of the tray to which damage extends will depend on the height of the burner above the bottom of the tray. Establishing a tolerance will increase the repeatability of the reported maximum damage height.

- A standard initial temperature for the cable sample and the air near the sample should be specified. The initial temperature for each group of control experiments (see Table 3) was controlled within a range of 6°F (3°C) with the results from each group having acceptable repeatability. Although the median starting temperature for each group varied, it is suggested that a temperature of 75 ± 5°F (24 ± 3°C) be used for maximum convenience.

- A sample with increased cable loading does not appear practical at this time. Results from Experiments 1 through 6 indicated that testing such a sample results in more cable damage than in the IEEE 383 configuration, but the results are less repeatable because of random movements of the cable during burning, at least for the cable construction used in these experiments.

- Propane should be the only fuel used for the ignition flame. The heating value of the propane should be obtained to determine the required propane flow for the ignition flame. This value can be obtained either from the fuel supplier or by measurement with a suitable calorimeter. For a heating value of 2500 Btu/ft^3 (93 MJ/m^3), the propane should be specified as 28 ± 1 SCFH (220 ± 8 cm^3/s). The air to the mixer should be controlled at 163 ± 10 SCFH (1280 ± 80 cm^3/s). In Experiments 13, 14, 19 and 20 using these tolerances, the cable damage was within the range established by the control experiments. The flame temperature specifications presently used should be eliminated since the temperature is difficult to measure and does not add to control of the flame.

- The maximum flame height versus time should be plotted and consideration should be given to calculating the rate of heat released using the oxygen-consumption technique. These data would provide an additional means to discern significantly different cable performance when the maximum cable damage is about the same.

- Cable-jacket temperatures lacked repeatability and the technique and time required for installing the cable jacket thermocouples seem too demanding for inclusion into the test method at this time.

- Cable damage should be defined. Although more or less sophisticated determinations of jacket and insulation properties might be conceived for assessing damage, these do not appear to be necessary. A definition of damage as melting, blistering, or charring was sufficient for these experiments.

These suggested changes are based upon the results of a limited number of experiments. Further experimentation should be conducted, if a larger data group is desired to evaluate the suggested changes.

4.3 TEST CRITERIA:

It appears that additional test data, such as flame propagation and the rate of heat released, may be useful in comparing the relative flammability of cable constructions. The development of a ranking system for cable constructions with regard to cable damage, rate of heat released and flame propagation appears feasible and is suggested. It is recommended that further study be conducted to investigate the practicability of such a system and to develop the method to be used.

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TABLE 1

EXPERIMENTAL PLAN

Experiment Number	Group	Parameter Investigated	Cable	Comparison Data Group
7,8,9,10	I	Control	A	-
21,22,23	II	Control	B	-
24,25,26 30,31,32	III	Control	C	-
33,34,35	IV	Control	D	-
27,28,29	V	Control	E	-
42,43,44	VI	Forced Exhaust	C	III
39,40,41	VII	Forced Exhaust	D	IV
36,37,38	VIII	Forced Exhaust	E	V
47,48	IX	Forced Exhaust	D	VII
45,46	X	Forced Exhaust	E	VIII
1,2,3,4,5,6	XI	Cable Loading	A	I
11,12	XII	Burner Distance	A	I
17,18	XIII	Burner Distance	A	I
13,14	XIV	Air Flow	A	I
15,16	XV	Fuel Flow	A	I
19,20	XVI	Fuel Flow	A	I
*	XVII	Flame Characteristics	**	***

* - 42 experiments conducted

** - instrumented board used in lieu of cable

*** - comparisons made were not limited to one group but to all flame characteristics experiments.

Cable constructions described in Table 2.

TABLE ?
CABLE CONSTRUCTIONS

Approximate Cable Cross Section Diameter in. (mm)	Conductor* Insulation/Jacket Material	Approximate Conductor Insulation/ Jacket Thickness, in. (mm)	Cable* Jacket Material	Approximate Cable Jacket Thickness, in. (mm)
0.515 (13.1)	Polyvinyl chloride/nylon	0.022/0.006	Polyvinyl chloride	0.050 (1.30)
0.618 (15.7)	Crosslinked polyethylene	0.044/* (1.12/**)	Polychloroprene rubber	0.068 (1.7)
0.785 (19.9)	Ethylene propylene rubber/ chlorosulphonated polyethylene	0.028/0.017 (0.71/0.43)	Chlorosulphonated polyethylene	0.134 (3.4)
0.493 (15.3)	Crosslinked polyolefin	0.030/** (0.76/**)	Crosslinked polyolefin	0.054 (1.4)
0.602 (15.3)	Polyethylene/polyvinyl chloride	0.029/0.012 (0.74/0.31)	Polyvinyl chloride	0.062 (1.6)

All cables were 7C/1? AWG with stranded copper conductors.

* Identification of materials was based upon the manufacturer's product literature.

** Conductors did not have a jacket.

TABLE 3
CONTROL EXPERIMENTS

Exp. No.	Cable Ref.	Cable No.	Maximum Cable Damage in. (m)+	Average++ Cable Damage in. (m)+	Initial Air Temperature F(C)	Initial Cable Temperature F(C)
9	A	8	*44.0 (1.12)	*41.2 (1.05)	59 (15)	60 (16)
7	A	8	*45.0 (1.14)	*43.7 (1.11)	64 (18)	60 (16)
8	A	8	*47.0 (1.19)	*45.3 (1.15)	58 (15)	62 (17)
10	A	8	*63.0 (1.60)	*59.6 (1.51)	64 (18)	63 (17)
22	B	7	*24.0 (0.61)	*23.7 (0.61)	64 (18)	57 (14)
21	B	7	*26.0 (0.66)	*24.0 (0.61)	63 (17)	56 (13)
23	B	7	*29.0 (0.74)	*26.6 (0.67)	64 (18)	63 (17)
24	C	6	**22.0 (0.56)	**21.3 (0.54)	67 (19)	66 (19)
25	C	6	**25.0 (0.64)	**22.4 (0.57)	69 (21)	68 (20)
26	C	6	**25.0 (0.64)	**22.6 (0.57)	67 (19)	68 (20)
30	C	6	**21.5 (0.55)	1	70 (22)	1
31	C	6	**21.5 (0.55)	1	71 (22)	1
32	C	6	**21.0 (0.53)	1	69 (21)	1
33	D	8	*25.0 (0.64)	1	70 (21)	1
34	D	8	*26.0 (0.66)	1	69 (21)	1
35	D	8	*27.0 (0.69)	1	68 (20)	1
27	E	7	***72.0 (1.83)	1	72 (22)	1
28	E	7	***72.0 (1.83)	1	72 (22)	1
29	E	7	***72.0 (1.83)	1	74 (23)	1

* - Front Surface   ** - Rear Surface   *** - Both Surfaces

Fuel Input - 28 SCFH (220 cm^3/s)
Air Input - 163 SCFH (1,280 cm^3/s)
Enclosure without top

\+ - Distance above burner.

++ - Arithmetric average for all lengths in the sample

1 - Measurement of damage to individual cable lengths was not obtained, so an average could not be calculated.

TABLE 4
OXYGEN CONCENTRATIONS NEAR SAMPLE

Cable C		Cable A		Cable D		Cable E	
Exp. No.	Min. O_2 Percent+	Exp. No.	Min. O_2 Percent+	Exp. No.	Min. O_2 Percent+	Exp. No.	Min. O_2 Percent+
30	20.94	1	18	33	20.81	27	20.95
31	20.85	2	19	34	20.70	28	20.97
32	20.79	3	20	35	20.85	29	20.90
39	20.58	4	20	42	20.77	36	20.70
40	20.63	5	NA	43	20.84	37	20.72
41	20.46	6	20	44	20.88	38	20.48
				47	20.57	45	20.73
				48	20.77	46	20.75

\+ - Sensor calibrated to 21 percent O_2 of air. Value is the minimum concentration during period of increasing flame propagation.

NA - Instrumentation malfunction; measurement not obtained.

TABLE 5
Forced Exhaust Experiments

Exp. No.	Exhaust Rate ft^3/min (l/s)	Cable Ref.	Cable No.	Maximum Cable+ Damage in. (m)	Initial Air Temperature F (C)
36	1500 (708)	E	7	72.0 (1.83)	72 (22)
37	1500 (708)	E	7	72.0 (1.83)	72 (22)
38	1500 (708)	E	7	72.0 (1.83)	74 (23)
39	1500 (708)	D	8	28.0 (0.71)	76 (24)
40	1500 (708)	D	8	26.0 (0.66)	70 (21)
41	1500 (708)	D	8	27.0 (0.69)	76 (24)
42	1500 (708)	C	6	23.5 (0.60)	73 (23)
43	1500 (708)	C	6	22.0 (0.56)	69 (21)
44	1500 (708)	C	6	22.0 (0.56)	69 (21)
45	1200 (566)	E	7	72.0 (1.83)	74 (23)
46	1200 (566)	E	7	72.0 (1.83)	76 (24)
47	1800 (849)	D	8	24.0 (0.61)	78 (25)
48	1800 (849)	D	8	25.0 (0.64)	77 (25)

Fuel Input - 28 SCFH (220 cm^3/s).
Air Input - 163 SCFH (1,280 cm^3/s).
Enclosure with exhaust system.

\+ - Distance above burner.

TABLE 6
CABLE LOADING EXPERIMENTS

	Experiment					
	1	2	3	4	5	6**
Starting Air Temperature F (C)	15 (-9)	31 (0)	64 (18)	30 (-1)	63 (17)	67 (19)
Initial Cable Jacket Temperature F (C)	-	30 (-1)	68 (20)	30 (4)	55 (19)	70 (21)
Maximum Cable Damage+ in. (m)						
Front Surface	72 (1.83)	72 (1.83)	72 (1.83)	72 (1.83)	39 (0.99)	24 (0.61)
Rear Surface	48 (1.22)	33 (0.84)	72 (1.83)	63 (1.60)	72 (1.83)	52 (1.31)
Maximum Inlet Air Flow ft/min (m/s)	100 (0.508)	120 (0.610)	155 (0.787)	160 (0.813)	150 (0.762)	150 (0.762)
Minimum O_2 Concentration Percent	18	19	20	20	NA	20
Ignition Flame Duration min (s)	30 (1800)	47 (2820)	23 (1380)	40 (2400)	35 (2100)	45 (2700)

Fuel Input - 28 SCFH (220 cm^3/s)
Air Input - 163 SCFH (1,280 cm^3/s)
Two burners used with one burner per side
Burners located 6.0 in. (150 mm) from base of tray and 2.75 in. (70 mm) from sample.
Fuel - Air flow split between burners.
Cables installed and fastened to rungs as shown in Fig. 11

** - Test conducted with all steel ties. Remaining tests used nylon ties for intermediate fasteners.

+ - Nominalized distance above burner. Calculated by damage height minus 24 in. (0.061 m).

NA - Recorder malfunction and measurement not obtained.

TABLE 7
Flame Characteristics Conditions

Fuel Flow Btu/h (W)	Burner Height in. (mm)	Burner Distance in. (mm)	Air/Fuel Ratio
35,000 (10,200)	6.88 to 11.25 (175 to 280)	0.50 to 2.75 (13 to 70)	3/1 to 11/1
70,000 (20,500)	10.12 to 12.00 (257 to 305)	1.00 to 3.00 (25 to 76)	4/1 to 5.5/1
105,000 (30,800)	8.00 to 11.25 (203 to 280)	1.50 to 6.00 (27 to 150)	2.5/1 to 6/1

TABLE 8
IGNITION - FLAME CHARACTERISTICS
35,000 Btu/h (10.2 kW)

Burner Height* in. (mm)	Burner Distance in. (mm)	Nominal Air/Fuel Ratio	Flame Condition
** 10.75 (273)	1.75 (44)	3.0/1	U
** 10.75 (273)	1.38 (35)	3.0/1	U
** 10.75 (273)	1.38 (35)	6.5/1	U
** 10.75 (273)	1.38 (35)	11.0/1	U
11.25 (286)	0.50 (13)	3.0/1	S
11.25 (286)	0.50 (13)	5.0/1	U
11.25 (286)	0.50 (13)	6.5/1	U
7.25 (184)	1.50 (38)	3.0/1	U
7.88 (200)	1.50 (38)	5.0/1	U
8.63 (219)	1.50 (38)	6.5/1	U
9.50 (241)	1.50 (38)	8.0/1	U
10.63 (270)	1.50 (38)	10.0/1	U
6.88 (175)	2.75 (70)	3.0/1	U
6.88 (175)	2.75 (70)	5.0/1	U
7.63 (193)	2.75 (70)	6.5/1	S
7.50 (216)	2.75 (70)	8.0/1	S
9.00 (229)	2.75 (70)	10.0/1	S

All experiments conducted in enclosure which was divided in half to simulate a two burner condition.

* - Burner height was adjusted so as to provide maximum flame impingement 12 in. (300 mm) above the base of the sample board.

** - These experiments conducted without openings along the base of the enclosure. Remaining experiments conducted with about a 12 in. (300 mm) opening along the base.

U - Unsteady flame condition.

S - Steady flame condition.

TABLE 9
IGNITION - FLAME CHARACTERISTICS
70,000 Btu/h (20.5 kW)

Burner Height* in. (mm)	Burner Distance in. (mm)	Nominal Air/Fuel Ratio	Flame Condition
11.50 (292)	1.00 (25)	4.0/1	U
12.00 (305)	1.00 (25)	5.0/1	U
8.00 (203)	1.00 (25)	5.5/1	U
11.13 (283)	2.00 (51)	4.0/1	S
11.25 (286)	2.00 (51)	5.0/1	U
10.13 (257)	2.00 (76)	4.0/1	U
10.38 (264)	3.00 (76)	5.0/1	S
10.50 (267)	3.00 (76)	5.5/1	S

All experiments conducted in enclosure which was divided in half to simulate a two burner condition.

* - Burner height has adjusted so as to provide maximum flame impingement 12 in. (300 mm) above the base of the sample.

S - Steady flame.

U - Unsteady flame.

TABLE 10
IGNITION - FLAME CHARACTERISTICS
105,000 Btu/h (30 kW)

Burner Height* in. (mm)	Burner Distance in. (mm)	Nominal Air/Fuel Ratio	Flame Condition
9.50 (241)	1.50 (38)	2.5/1	S
11.25 (286)	1.50 (38)	3.5/1	U
11.25 (285)	1.50 (38)	5.0/1	U
8.00 (203)	2.00 (51)	3.5/1	S
9.88 (251)	3.00 (76)	2.5/1	U
10.00 (254)	3.00 (76)	3.5/1	U
10.62 (270)	3.00 (76)	5.0/1	U
10.75 (273)**	3.25 (83)	2.5/1	U
8.00 (203)	4.00 (102)	3.5/1	U
8.00 (203)	5.00 (127)	2.5/1	U
8.50 (216)	5.00 (127)	3.5/1	U
9.50 (241)	5.00 (127)	5.0/1	S
10.62 (270)	5.00 (127)	6.0/1	U
8.00 (203)	6.00 (152)	3.5/1	U
9.25 (235)	6.00 (152)	3.5/1	U
9.25 (235)	6.00 (152)	5.0/1	U
9.88 (251)	6.00 (152)	5.0/1	U

All experiments conducted in enclosure which was divided in half to simulate a two burner condition.

* - Burner height was adjusted attempting maximum flame impingement 12 in. (300 mm) above the base of the sample.

** - This experiment was conducted without openings along the base of the enclosure.

U - Unsteady flame.

S - Steady flame.

TABLE 11

BURNER-BOARD DISTANCES FOR STABLE FLAMES

Fuel Flow, 35,000 Btu/h - (10.2 kW)

Air/Fuel Ratio	Stable Flame Distances, in. (mm)
3.0/1	0.50 (13)
6.5/1	2.75 (70)
8.0/1	2.75 (70)
10.0/1	2.75 (70)

Fuel Flow, 70,000 Btu/h - (20.5 kW)

Air/Fuel Ratio	Stable Flame Distances, in. (mm)
4.0/1	2.00 (51)
5.0/1	3.00 (76)
5.5/1	3.00 (76)

Fuel Flow 105,000 Btu/h - (30.8 kW)

Air/Fuel Ratio	Stable Flame Distances, in. (mm)
2.5/1	1.50 (38)
3.5/1	2.00 (51)
5.0/1	5.00 (127)

TABLE 12

MAXIMUM IGNITION FLAME HEAT FLUX AND TEMPERATURE

Fuel Flow Btu/h (kW)	Approximate Maximum Heat Flux, Btu/ft^2s (kW/m^2)	Approximate Maximum Sample Temperature, °F(°C)
35,000* (10.2)	3.1 (35)	1150 (620)
70,000** (20.5)	3.4 (39)	1250 (676)
105,000*** (30.8)	3.8 (43)	1275 (690)

* - 6.5/1 air to fuel ratio, 3.75 in. (70 mm) spacing

** - 5.5/1 air to fuel ratio, 3.00 in. (76 mm) spacing

*** - 5.0/1 air to fuel ratio, 5.00 in. (127 mm) spacing

TABLE 13

FLAME SENSITIVITY DATA

Burner Distance Experiments

Exp. No.	Burner Distance in. (mm)	Initial Air Temperature °F(°C)	Maximum Cable Damage+ in. (m)
12	2.500 (64)	64 (18)	39.0 (0.99)
11	3.500 (89)	63 (17)	48.5 (1.23)
18	2.875 (73)	64 (18)	52.0 (1.32)
17	3.125 (79)	65 (18)	50.0 (1.27)

Cable Type A.

Eight lengths of cable installed in tray.

Fuel Input - 28 SCFH (220 cm^3/s).

Air Input - 163 SCFH (1280 cm^3/s).

Enclosure without top.

+ - Distance above burner.

TABLE 14

FLAME SENSITIVITY DATA

Air And Fuel Flow Experiments

Exp. No.	Fuel Input SCFH (cm^3/s)	Air Input SCFH (cm^3/s)	Maximum Cable Damage in. (m)+	Initial Air Temperature °F (°C)
15	26.0 (205)	163 (1,280)	54 (1.37)	61 (16)
16	30.0 (236)	163 (1,280)	44 (1.12)	65 (18)
20	27.0 (212)	163 (1,280)	48 (1.22)	62 (17)
19	29.0 (228)	163 (1,280)	47 (1.19)	64 (18)
14	28.0 (220)	153 (1,280)	44 (1.12)	65 (18)
13	28.0 (220)	180 (1,415)	45 (1.14)	64 (18)

Cable A.

Eight lengths of cable installed in tray.

Burner distance 3 in. (76 mm).

Enclosure without top.

Cables fastened to rungs as shown in Fig. 11.

\+ - Distance above burner.

TABLE 15

Supplemental Cable Experiments - Initial Temperature

	Exp. A	Exp. B	Exp. C	Exp. D
Cable tie spacing in. (m)	27 (0.69)	27 (0.69)	18 (0.46)	18 (0.46)
Initial room temperature, °F, (°C)	42 (6)	42 (6)	70 (21)	72 (22)
Maximum height of cable damage, in. (m)*	72 (1.83)	78 (1.98)	82 (2.08)	83 (2.10)

*Adjusted to allow for differences in burner height.

TABLE 16

EXPERIMENT 1

Cable A Jacket Temperatures, °F

Time, s	Height Above Base, in. (m) 18 (0.37)	30 (0.76)	42 (1.22)	54 (1.37)	66 (1.68)	78 (1.98)
120	1620	440	930	75	130	60
180	1590	470	1120	130	180	90
240	1440	520	1340	340	240	125
300	1495	640	1350	450	285	155
360	1540	755	1285	545	320	180
420	1580	840	1210	695	370	230
480	1630	835	1160	725	390	280
540	1620	840	1155	770	400	335
600	1645	855	1165	750	405	390
660	1670	880	1175	570	415	430

TABLE 17

EXPERIMENT 2

Cable A Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	24 (0.61)	36 (0.91)	60 (1.52)	72 (1.83)	90 (2.29)
60	190	100	60	60	55
120	270	135	70	70	60
180	365	170	85	80	65
240	480	210	90	85	70
300	640	255	100	90	75
360	810	340	110	105	80
420	860	400	125	115	80
480	795	460	140	130	85
540	820	590	160	145	100
600	835	755	185	160	110
660	810	760	205	180	115
720	815	715	225	195	130
780	810	565	230	200	130
840	870	510	215	190	130
900	890	510	215	185	130
960	850	495	215	185	130
1020	825	450	210	180	130
1080	805	430	215	180	130
1140	805	420	215	180	130
1200	800	415	215	175	130

TABLE 18

EXPERIMENT 3

Cable A Jacket Temperature, °F

Height Above Base, in. (m)

Time, s	24 (0.61)	48 (1.22)	60 (1.52)	72 (1.83)
120	120	85	85	80
180	225	115	100	95
240	325	135	115	105
300	450	155	130	115
360	635	185	145	125
420	825	225	160	135
480	910	270	185	150
540	915	295	200	155
600	870	360	230	175
660	885	440	270	190
720	970	585	335	225
780	980	785	450	270
840	900	1225	580	335
900	755	1365	840	400
960	680	1365	1100	490
1020	660	1195	1045	595
1080	605	1115	960	745
1140	580	1050	1005	875
1200	565	980	855	900

TABLE 19

EXPERIMENT 4

Cable A Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	18 (0.61)	30 (1.22)	42 (1.52)	54 (1.83)	66 (2.10)	78 (2.44)
60	400	300	200	150	110	90
120	720	555	230	175	135	105
180	740	605	255	170	135	105
240	765	720	250	170	135	105
300	790	725	230	175	140	110
360	810	490	226	170	135	115
420	825	360	225	175	135	115
480	840	345	225	175	135	120
540	855	335	220	175	140	120
600	880	325	220	175	140	125
660	920	325	220	175	145	130
720	945	325	220	175	140	130
780	960	320	220	165	135	130
840	980	325	220	170	140	135
900	980	340	225	170	145	140
960	985	335	225	170	145	140
1020	1010	320	225	170	145	145
1080	1030	310	215	165	145	150
1140	1035	305	210	165	140	155
1200	1045	300	205	160	140	155

TABLE 20

EXPERIMENT 5

Cable A Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	24 (0.61)	48 (1.22)	72 (1.83)	84 (2.10)	96 (2.44)
60	180	115	90	85	80
120	230	130	100	90	85
180	295	145	105	95	90
240	380	155	110	100	90
300	585	200	125	105	95
360	810	245	135	120	100
420	870	290	150	130	110
480	900	330	160	135	115
540	955	405	180	150	125
600	955	600	195	155	130
660	950	985	230	180	140
720	925	1065	250	185	140
780	890	900	265	200	150
840	845	560	250	190	155
900	810	460	235	185	150
960	780	410	225	180	155
1020	810	380	220	180	155
1080	815	365	210	175	155
1140	825	355	205	175	155
1200	835	340	195	170	155

TABLE 21

EXPERIMENT 6

Cable A Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	24 (0.61)	48 (1.22)	60 (1.52)	72 (1.83)	84 (2.10)	96 (2.44)
60	130	100	85	85	85	80
120	210	130	100	95	90	85
180	325	155	110	105	95	90
240	400	160	120	110	100	90
300	485	180	135	120	105	95
360	595	195	140	120	105	95
420	730	220	155	130	115	100
480	770	255	165	135	120	105
540	785	295	180	145	125	110
600	785	335	195	155	130	110
660	765	385	215	165	135	115
720	790	460	245	180	145	125
780	770	475	250	185	150	130
840	750	410	240	180	150	130
900	735	360	230	170	145	125
960	705	330	220	165	140	125
1020	685	310	220	160	140	125
1080	680	295	210	160	135	125
1140	650	280	210	160	135	125
1200	665	270	205	160	135	125

TABLE 22

EXPERIMENT 7

Cable A Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	30 (0.76)	36 (0.91)	42 (1.07)	48 (1.22)	54 (1.37)	60 (1.52)	66 (1.68)	72 (1.83)	78 (1.98)	84 (2.1)	90 (2.29)	96 (2.44)
Pretest	64	57	64	57	66	64	57	66	57	57	55	55
60	1349	348	219	397	110	171	91	110	100	-	108	65
120	1460	364	294	453	136	210	106	126	124	-	119	71
180	1488	430	403	529	183	274	126	143	143	91	141	77
249	1347	420	499	639	400	406	171	188	186	108	162	88
300	1557	476	581	708	388	519	208	221	234	123	186	98
360	1615	537	575	731	442	615	236	230	258	132	191	100
420	1223	662	476	-	409	595	214	101	252	134	197	106
480	1306	582	332	-	364	517	171	93	230	130	193	101
540	1434	489	307	-	241	408	175	84	217	120	186	99
600	1568	484	306	-	217	363	165	77	201	117	182	98
660	1425	476	305	-	200	341	156	73	193	114	175	98
720	1212	473	307	-	195	334	154	67	191	112	174	97
780	1343	462	396	-	187	319	148	65	186	110	174	93
840	1497	456	290	-	187	311	145	64	185	110	174	92
900	1202	431	258	-	177	296	141	61	180	110	169	91
960	1469	431	296	-	175	294	134	59	175	110	165	90
1020	1335	428	278	-	173	282	132	55	175	105	165	89
1080	1529	415	300	-	173	276	132	55	174	105	162	88
1140	1438	408	273	-	171	274	132	55	182	104	160	88
1200	1319	406	262	-	169	274	132	55	184	101	160	88

TABLE 23

EXPERIMENT 8

Cable A Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	30 (0.76)	36 (0.91)	42 (1.07)	48 (1.22)	54 (1.37)	60 (1.52)	66 (1.68)	72 (1.83)	78 (1.98)	84 (2.1)	90 (2.29)	96 (2.44)
Pretest	60	60	66	57	67	60	-	57	77	51	64	66
60	1504	1549	373	714	161	174	121	99	130	104	90	86
120	1579	1624	607	808	217	217	152	134	165	134	108	99
180	1530	1571	981	948	305	319	204	165	212	152	143	112
240	1561	1548	1166	1201	554	453	283	230	283	195	173	234
300	1526	1593	1252	64	820	769	409	319	314	234	186	156
360	1606	1606	1308	55	1010	769	449	364	306	252	195	177
420	1615	1615	821	46	1032	756	431	372	278	252	186	186
480	1482	1548	607	46	506	542	364	332	252	230	186	182
540	1517	1606	595	46	386	449	341	301	234	221	166	177
600	1200	1593	533	46	373	863	319	287	230	212	221	173
660	1054	1438	542	46	355	799	305	274	221	208	163	169
720	1257	1650	684	46	296	884	292	270	217	204	169	169
780	1222	1526	542	46	323	341	279	252	208	195	165	165
840	1482	1615	641	46	319	328	269	252	208	195	165	165
900	1200	1615	628	46	319	296	261	252	199	186	165	165
960	1394	1504	684	41	296	314	252	239	195	186	161	161
1020	1504	1504	585	41	314	296	239	230	195	186	156	161
1080	1540	1438	607	41	319	296	234	230	195	182	156	156
1140	1504	1460	607	41	296	292	230	230	195	192	156	152
1200	1579	1517	607	41	327	292	225	225	190	182	156	152

TABLE 24

EXPERIMENT 9

Cable A Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	30 (0.76)	36 (0.91)	42 (1.07)	48 (1.22)	54 (1.37)	60 (1.52)	66 (1.68)	72 (1.83)	78 (1.98)	84 (2.1)	90 (2.29)	96 (2.44)
Pretest	60	60		60	64	55	51	55	60	57	60	77
60	1593	598	453	300	190	173	143	121	112	100	95	90
120	1595	795	598	108	247	217	169	143	134	121	108	100
180	1416	1412	778	104	390	305	225	169	156	138	121	177
240	1521	1505	841	112	585	426	296	212	186	160	143	125
300	1438	1482	867	598	624	519	359	247	217	186	160	143
360	1329	1373	850	812	675	593	399	269	234	195	169	177
420	1570	1200	816	705	675	546	372	274	234	190	169	152
480	1222	1061	714	576	537	395	309	260	212	182	165	152
540	1351	926	667	506	431	336	374	252	195	169	160	147
600	1394	905	649	475	386	287	256	237	190	165	156	143
660	1705	947	649	475	363	296	252	234	186	165	152	143
720	1526	880	628	449	345	283	238	230	182	160	147	143
780	1265	816	615	440	336	274	234	221	182	160	147	143
840	1287	816	606	431	323	265	230	212	173	156	147	138
900	1570	774	589	431	319	260	225	208	173	152	143	138
960	1438	778	606	435	314	256	221	208	169	152	143	138
1020	1222	761	580	413	309	252	217	208	169	147	143	138
1080	1570	756	546	417	300	252	212	204	165	147	143	134
1140	1450	735	541	413	296	252	212	204	165	147	143	134
1200	1482	714	537	408	296	247	208	199	165	143	143	134

TABLE 25

EXPERIMENT 10

Cable A Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	30 (0.76)	36 (0.91)	42 (1.07)	48 (1.22)	54 (1.37)	60 (1.52)	66 (1.68)	72 (1.83)	78 (1.98)	84 (2.1)	90 (2.29)	96 (2.44)
Pretest	55	55	60	75	55	60	55	77	55	94	55	55
60	1638	386	520	278	152	169	143	93	104	121	113	99
120	1330	515	547	346	195	199	165	108	121	139	126	99
180	948	778	865	589	292	283	208	139	143	161	148	121
240	1268	939	926	832	431	431	300	187	187	167	167	143
300	1393	956	948	816	628	533	391	261	234	230	199	165
360	1415	1045	964	637	693	632	554	319	300	259	220	187
420	757	986	645	714	671	667	736	395	328	283	243	208
480	1437	985	624	554	804	641	863	524	445	359	287	234
540	1086	981	607	528	1074	641	884	624	520	409	309	252
600	1188	896	589	515	581	619	799	706	549	445	328	265
660	1393	842	585	515	507	541	748	684	541	454	328	259
720	1437	799	585	489	453	467	515	624	520	377	300	257
780	948	744	563	444	409	431	395	489	453	341	274	243
840	1265	752	563	453	422	399	346	431	413	323	260	230
900	1265	714	520	418	368	373	319	399	386	309	247	226
960	884	706	547	427	355	350	300	364	359	300	238	213
1020	1308	736	520	395	341	328	278	332	332	283	234	208
1080	1286	795	511	399	319	300	257	309	314	319	226	195
1140	1201	795	520	391	319	311	252	265	300	265	221	190
1200	1265	778	497	386	314	287	252	274	274	252	213	186

TABLE 26

EXPERIMENT 21

Cable B Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	30 (0.76)	36 (0.91)	42 (1.07)	48 (1.22)	54 (1.37)	60 (1.52)	66 (1.68)	72 (1.83)	78 (1.98)	84 (2.1)	90 (2.29)	96 (2.44)
Pretest	57	60	66	55	57	54	48	55	57	55	55	52
60	1011	454	243	37	143	143	121	95	108	95	95	51
120	1180	515	291	234	160	164	134	104	112	108	99	81
180	1062	555	305	252	177	173	138	113	121	121	104	95
240	965	714	318	270	190	164	147	121	134	126	108	100
300	965	859	336	296	212	204	160	135	117	135	121	104
360	990	1032	368	319	230	221	169	135	147	135	126	113
420	1015	1019	466	382	265	247	190	152	156	152	138	121
480	1138	905	628	449	296	265	204	165	164	165	143	126
540	1145	948	837	498	323	283	221	178	177	165	152	135
600	1158	1007	901	537	345	286	225	182	182	174	152	139
660	1231	1074	930	546	359	327	234	181	187	178	138	143
720	1300	1104	930	542	363	314	234	195	187	195	152	143
780	1338	1104	943	520	359	309	234	195	187	174	152	143
840	1333	1159	1011	515	359	309	230	195	187	178	152	143
900	1330	1163	1040	515	350	305	230	195	187	178	152	143
960	1321	1176	1074	515	341	300	230	195	187	178	152	143
1020	133	1189	1091	515	341	296	230	195	187	178	152	143
1080	1343	1202	1108	511	332	291	225	195	187	178	152	143
1140	1343	1270	1176	515	327	291	230	195	187	178	152	143
1200	1352	1287	1201	511	323	283	225	195	185	178	152	143

TABLE 27

EXPERIMENT 22

Cable B Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	30 (0.76)	36 (0.91)	42 (1.07)	48 (1.22)	54 (1.37)	60 (1.52)	66 (1.68)	72 (1.83)	78 (1.98)	84 (2.1)	90 (2.29)	96 (2.44)
Pretest	60	56	-	56	54	73	55	55	55	55	53	56
60	1460	431	238	199	134	1637	138	99	117	95	77	95
120	761	511	274	217	147	1286	138	112	121	99	90	99
180	697	502	283	234	164	1108	143	117	125	104	95	104
240	680	519	287	247	177	671	147	125	130	108	99	112
300	688	697	300	260	190	871	156	181	138	121	104	117
360	863	778	323	283	208	744	164	431	143	125	112	125
420	820	1053	354	318	225	905	177	476	147	130	112	130
480	1342	1074	449	299	247	875	204	169	169	143	125	138
540	854	761	692	413	274	841	204	177	169	147	134	143
600	909	863	718	435	296	947	212	186	177	156	143	147
660	841	926	854	449	314	833	212	186	177	160	147	151
720	930	964	867	462	323	905	208	195	182	160	147	151
780	930	989	871	484	336	918	230	204	190	164	147	156
840	947	998	854	458	332	956	225	204	186	160	151	160
900	989	1023	841	453	327	989	229	204	186	164	151	160
960	1006	1044	854	453	323	1006	221	204	186	164	151	160
1020	994	1049	863	444	318	985	217	204	182	160	151	160
1080	1006	1057	880	453	314	994	208	204	182	160	151	160
1140	960	1053	909	444	309	977	212	204	182	160	151	160
1200	968	1070	939	444	300	964	208	208	182	160	147	160

TABLE 28

EXPERIMENT 23

Cable B Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	30 (0.76)	36 (0.91)	42 (1.07)	48 (1.22)	54 (1.37)	60 (1.52)	66 (1.68)	72 (1.83)	78 (1.98)	84 (2.1)	90 (2.29)	96 (2.44)
Pretest	64	66	55	66	64	64	64		62	66	62	66
60	1615	413	248	190	147	138	125	147	125	104	99	99
120	1544	511	301	238	182	164	143	164	138	121	108	108
180	1710	576	323	260	188	182	160	182	143	138	117	121
240	1638	602	332	269	297	186	169	180	147	143	125	125
300	1615	863	255	287	239	199	177	195	151	143	130	130
360	1710	880	400	318	247	212	186	208	164	151	138	138
420	1683	981	511	386	278	432	208	225	177	164	147	147
480	1660	867	620	475	323	743	234	243	190	182	156	160
540	1593	927	897	563	363	93	252	256	208	186	164	164
600	1575	1011	935	624	408	323	269	274	225	195	177	173
660	1580	1079	1019	671	422	345	274	274	225	199	177	177
720	1478	1185	994	752	408	341	274	279	221	208	182	177
780	1535	1159	1008	701	299	332	274	279	212	208	182	182
840	1482	1163	1019	688	386	327	269	279	208	204	182	182
900	1513	1137	1024	671	372	318	265	279	208	204	182	182
960	1465	1159	998	680	363	1314	260	279	204	199	186	182
1020	1434	1159	1011	662	359	200	252	279	199	195	186	182
1080	1307	1146	914	671	354	200	252	274	204	195	186	182
1140	1382	1219	918	671	345	296	252	274	199	180	182	182
1200	1352	1184	948	649	341	291	247	274	199	190	182	182

TABLE 29

EXPERIMENT 24

Cable C Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	30 (0.76)	36 (0.91)	42 (1.07)	48 (1.22)	54 (1.37)	60 (1.52)	66 (1.68)	72 (1.83)	78 (1.98)	84 (2.1)	90 (2.29)	96 (2.44)
Pretest	-	-	-	69	69	69	68	68	61	61	61	69
60	1456	407	235	170	118	129	114	98	81	79	75	89
120	1508	403	275	200	137	140	127	107	88	86	81	97
180	1559	339	240	206	151	149	142	118	98	94	87	106
240	1549	324	242	225	171	160	154	128	103	100	93	93
300	1557	322	254	236	190	171	166	139	110	107	98	119
360	1460	327	271	247	208	181	174	148	116	112	103	125
420	1576	339	287	261	223	192	183	158	123	119	108	131
480	1513	350	303	272	236	203	192	166	128	125	112	137
540	1497	361	321	283	247	211	200	174	133	126	117	142
600	1266	373	332	294	259	220	208	181	167	162	122	147
660	1062	380	340	299	269	227	216	189	174	167	152	152
720	1148	389	347	306	279	237	222	195	179	170	157	156
780	1050	399	359	315	287	243	227	201	184	169	161	160
840	681	410	372	325	296	248	232	207	189	176	166	164
900	418	418	382	329	302	253	238	213	195	183	170	168
960	473	429	387	335	307	1258	240	216	199	185	173	170
1020	598	447	297	343	314	266	247	220	203	188	176	173
1080	674	456	403	345	319	270	250	223	207	193	178	175
1140	944	456	403	346	323	271	251	225	209	201	181	177
1200	617	456	403	348	327	272	253	227	210	194	182	178

TABLE 30

EXPERIMENT 25

Cable C Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	30 (0.76)	36 (0.91)	42 (1.07)	48 (1.22)	54 (1.37)	60 (1.52)	66 (1.68)	72 (1.83)	78 (1.98)	84 (2.1)	90 (2.29)	96 (2.44)
Pretest	-	-	-	69	69	69	70	70	65	65	69	70
60	1562	293	188	153	128	127	121	103	101	96	90	86
120	1639	372	226	182	150	143	139	115	112	107	99	95
180	1609	347	235	197	169	154	152	127	122	116	106	103
240	1467	336	240	210	186	164	164	137	129	124	113	110
300	1592	337	257	229	294	176	172	147	137	130	119	117
360	1581	341	272	245	219	187	182	156	145	138	126	123
420	1577	349	286	260	233	198	191	166	153	145	132	129
480	1554	357	295	269	244	205	198	173	159	151	138	135
540	1489	368	307	278	255	214	205	179	165	155	143	139
600	1619	379	319	286	261	219	208	174	169	159	147	144
660	1644	392	331	293	270	227	216	191	175	165	152	148
720	1629	405	343	302	280	236	224	198	181	170	157	153
780	1612	415	350	307	284	240	227	201	184	172	160	155
840	1627	429	358	314	290	245	232	207	189	177	164	160
900	1662	436	361	316	294	249	234	211	192	180	167	163
960	1650	447	370	324	297	1254	237	212	194	181	169	165
1020	1639	453	380	329	300	255	238	215	197	184	171	167
1080	1637	462	381	332	302	256	239	215	198	185	173	168
1140	1645	462	380	330	302	255	238	215	197	185	173	169
1200	1534	463	379	331	300	254	238	214	197	185	174	169

TABLE 31

EXPERIMENT 25

Cable C Jacket Temperatures, °F

Height Above Base, in. (m)

Time, s	30 (0.76)	36 (0.91)	42 (1.07)	48 (1.22)	54 (1.37)	60 (1.52)	66 (1.68)	72 (1.83)	78 (1.98)	84 (2.1)	90 (2.29)	96 (2.44)
Pretest	68	68	68	68	68	68	68	67	67	67	67	67
60	1453	1543	225	158	132	118	114	100	100	93	85	67
120	1452	1351	257	190	150	134	131	111	112	104	-	89
180	1344	1672	244	200	165	146	142	121	120	112	100	105
240	977	1724	253	219	180	157	151	130	126	120	106	112
300	1360	1768	265	233	198	168	160	139	133	126	-	117
360	1362	1770	283	249	213	181	171	148	141	131	-	122
420	1348	1748	299	261	228	192	181	157	148	138	-	128
480	1218	1663	310	269	238	200	188	164	154	144	-	132
540	1111	1760	325	282	250	210	196	172	160	149	134	137
600	1130	1747	342	294	262	220	204	179	166	155	141	142
660	1183	1731	354	305	272	228	211	185	171	158	145	145
720	1220	1738	364	309	278	234	217	190	175	163	148	148
780	995	1605	374	317	286	240	220	194	178	165	151	151
840	1048	1763	383	323	289	244	221	198	180	167	154	153
900	1206	1521	389	326	295	248	228	203	183	170	157	155
960	889	1758	394	330	299	253	230	206	186	173	160	158
1020	1113	1768	396	336	303	257	233	210	189	175	162	160
1080	1147	1706	398	340	307	261	236	212	193	177	164	161
1140	1172	1767	398	342	309	262	237	212	194	179	165	161
1200	718	1205	398	341	307	261	235	211	191	177	165	160

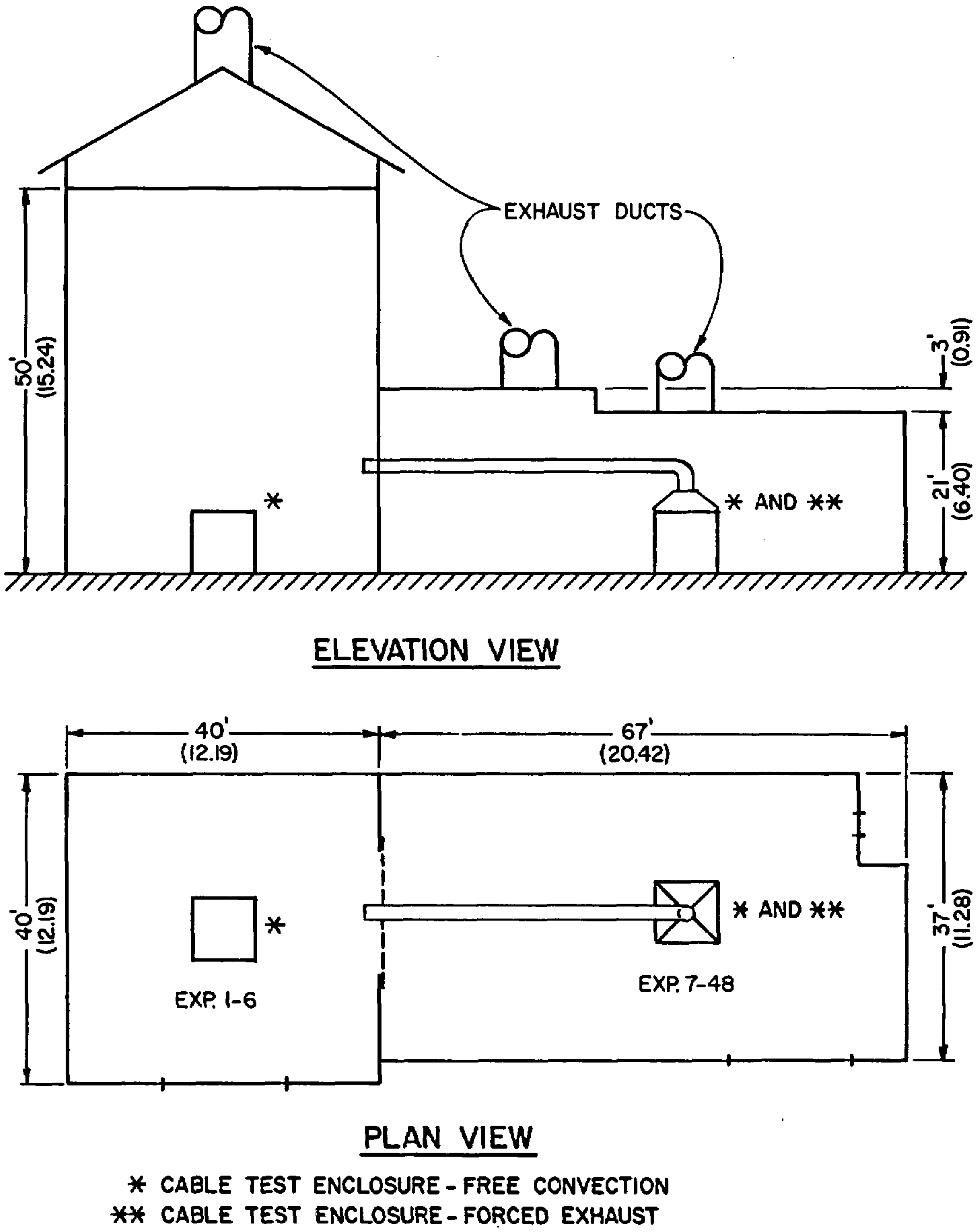


Figure 1- Test rooms

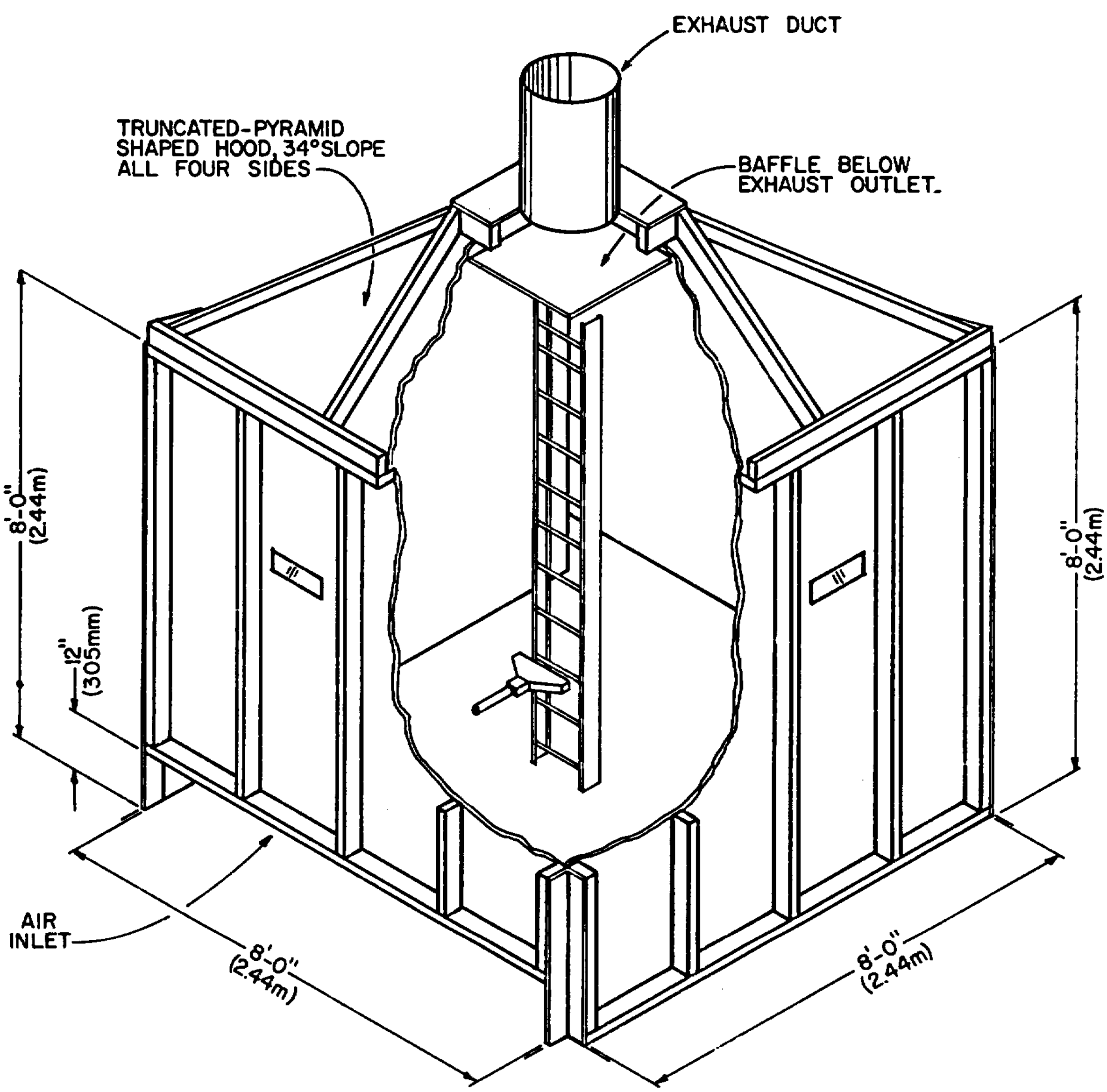


Figure 2- Cable test enclosure

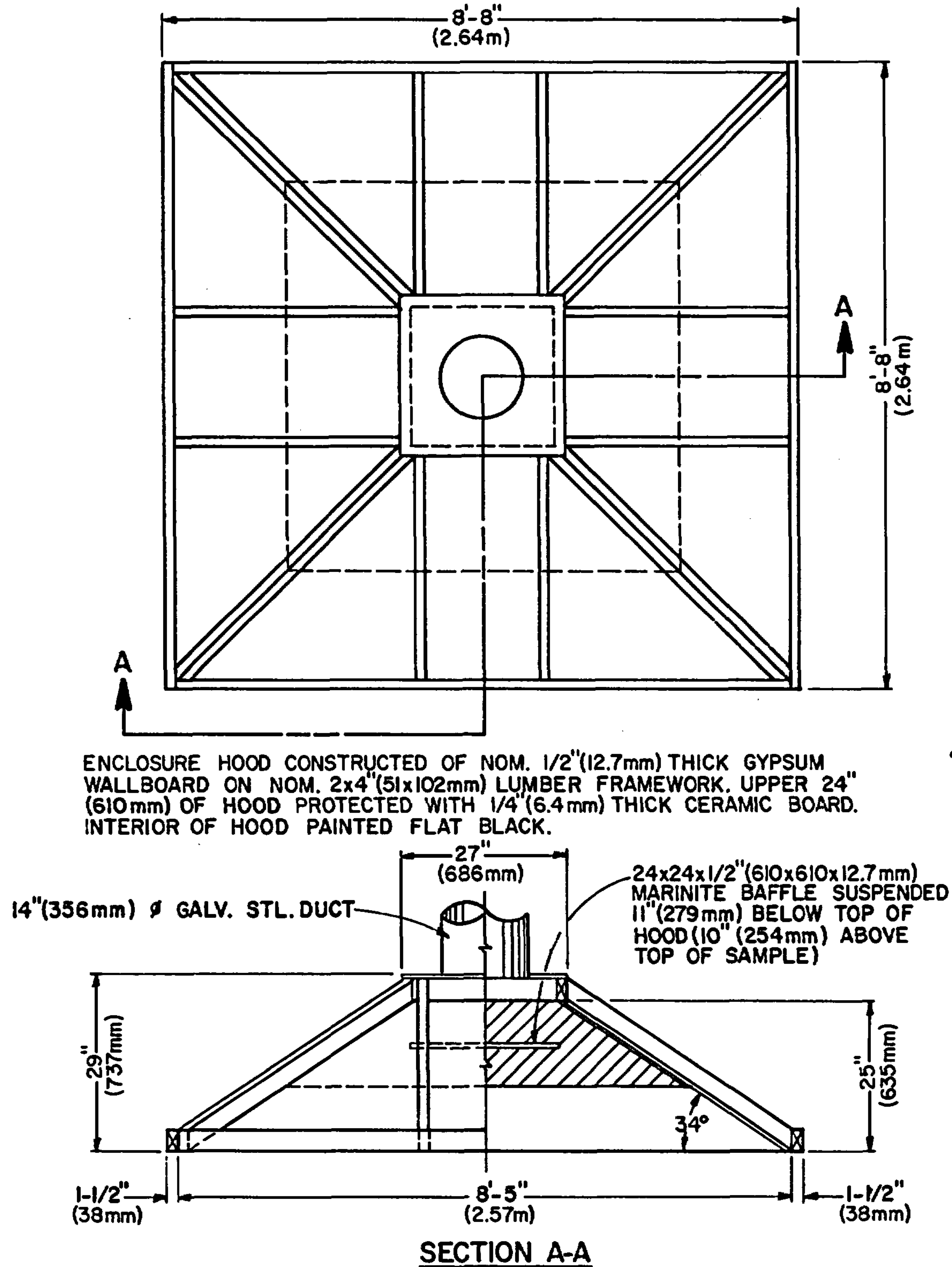


Figure 3- Cable test enclosure

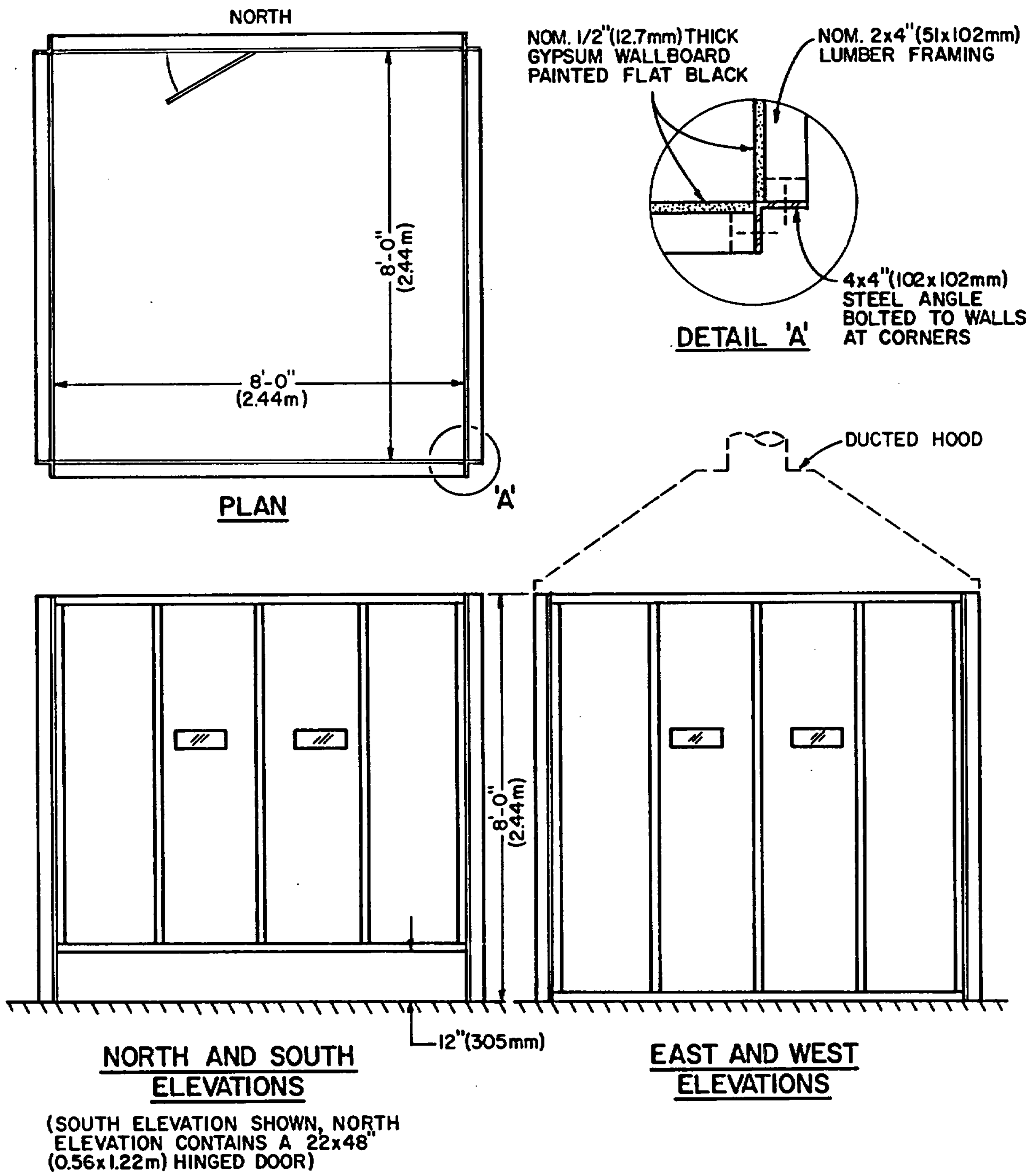
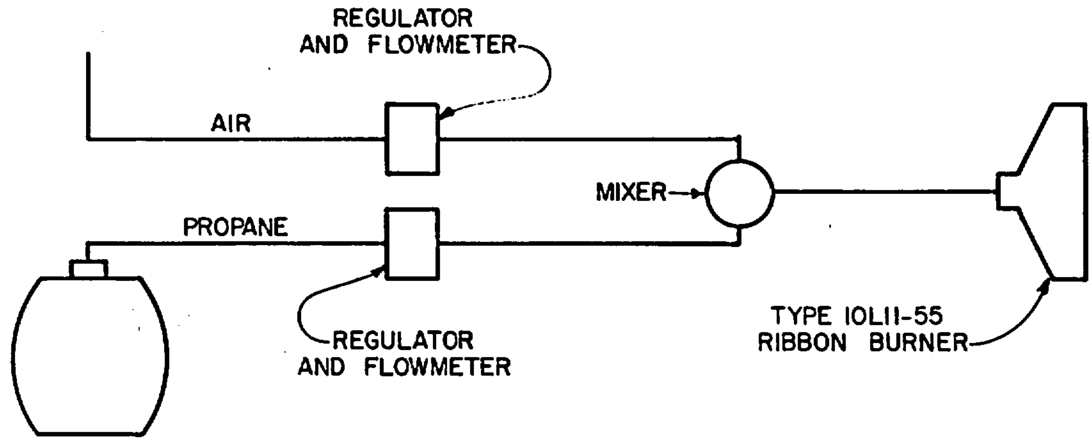
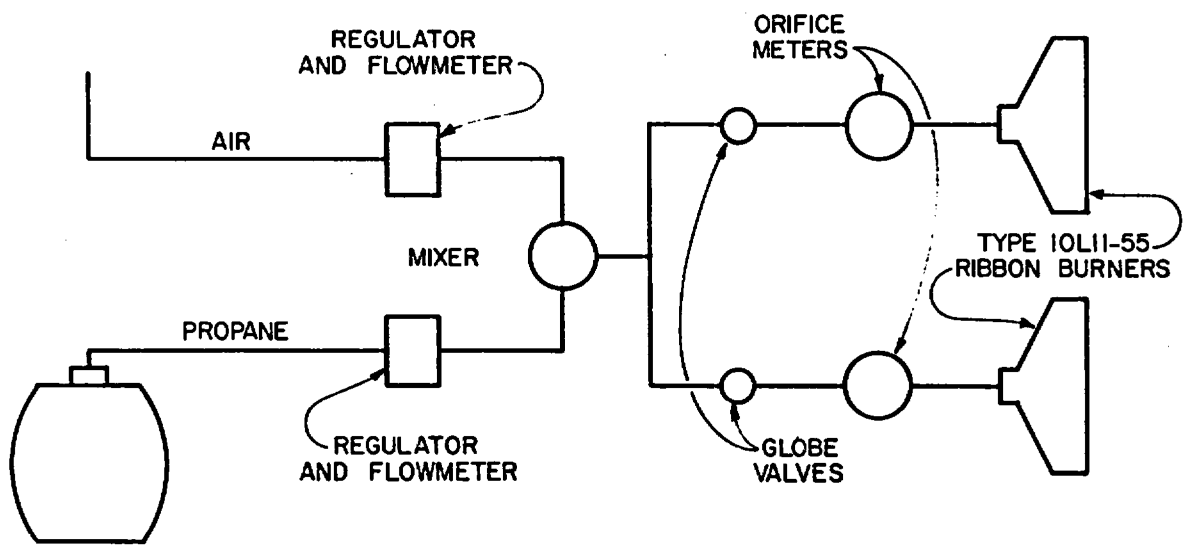


Figure 14- Cable test enclosure



EXPERIMENTS 7-48



EXPERIMENTS 1-6

Figure 5- Burner apparatus

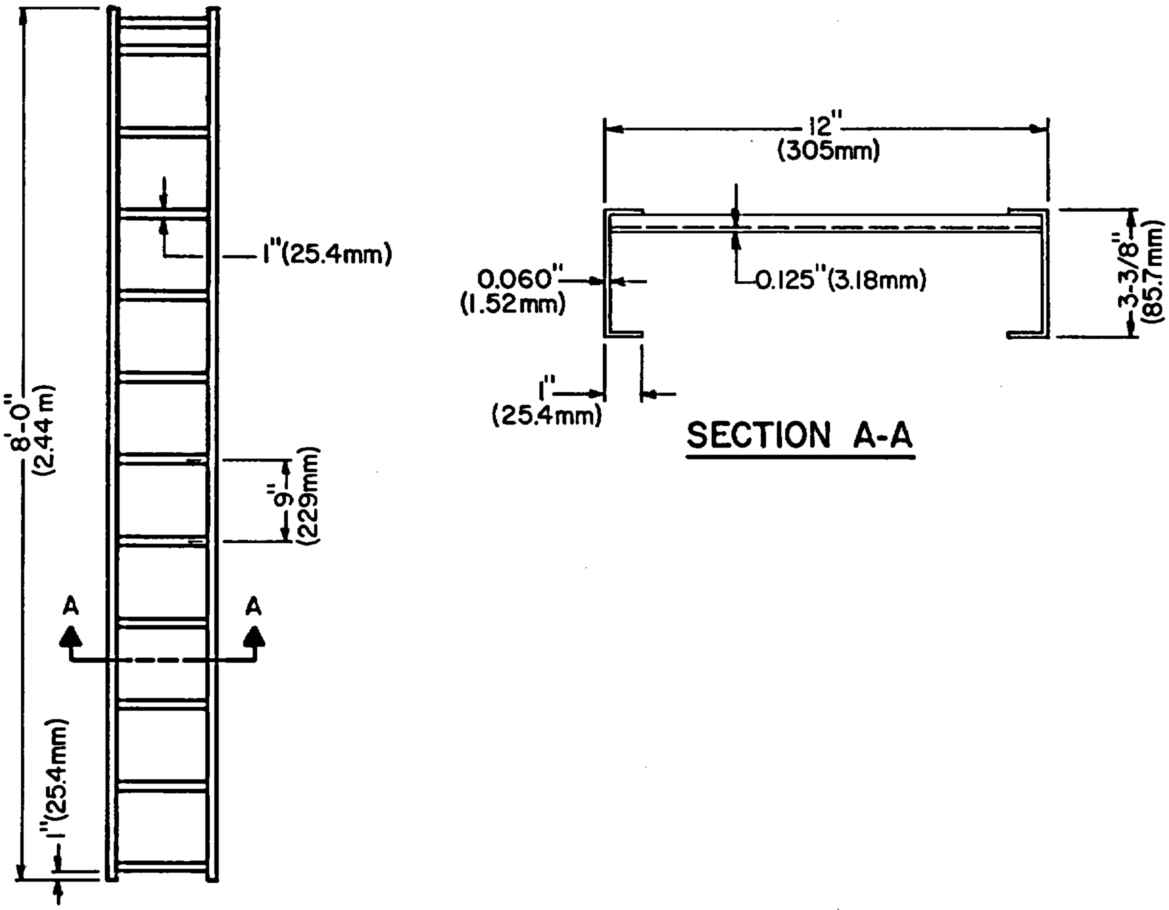


Figure 6- Cable tray

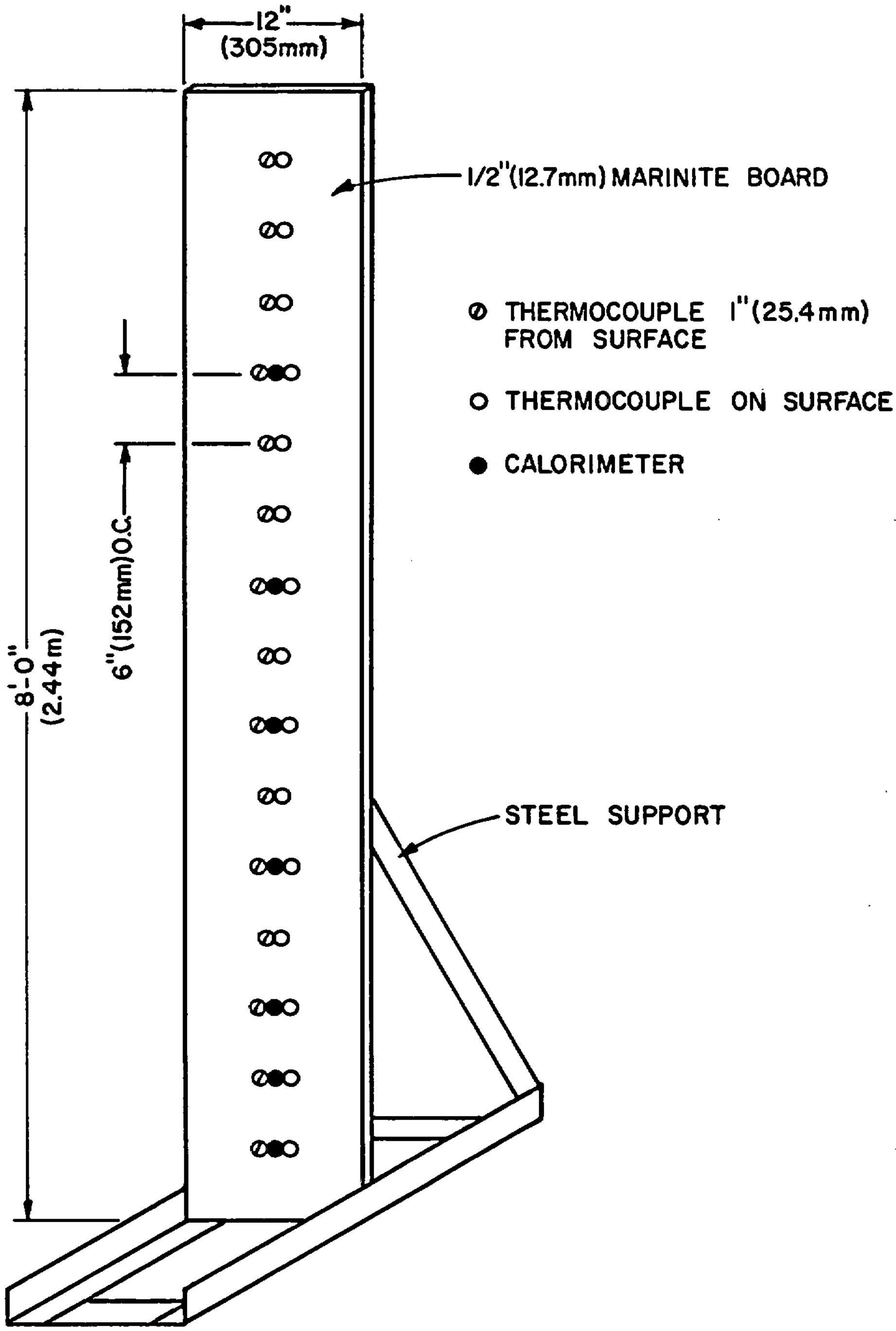
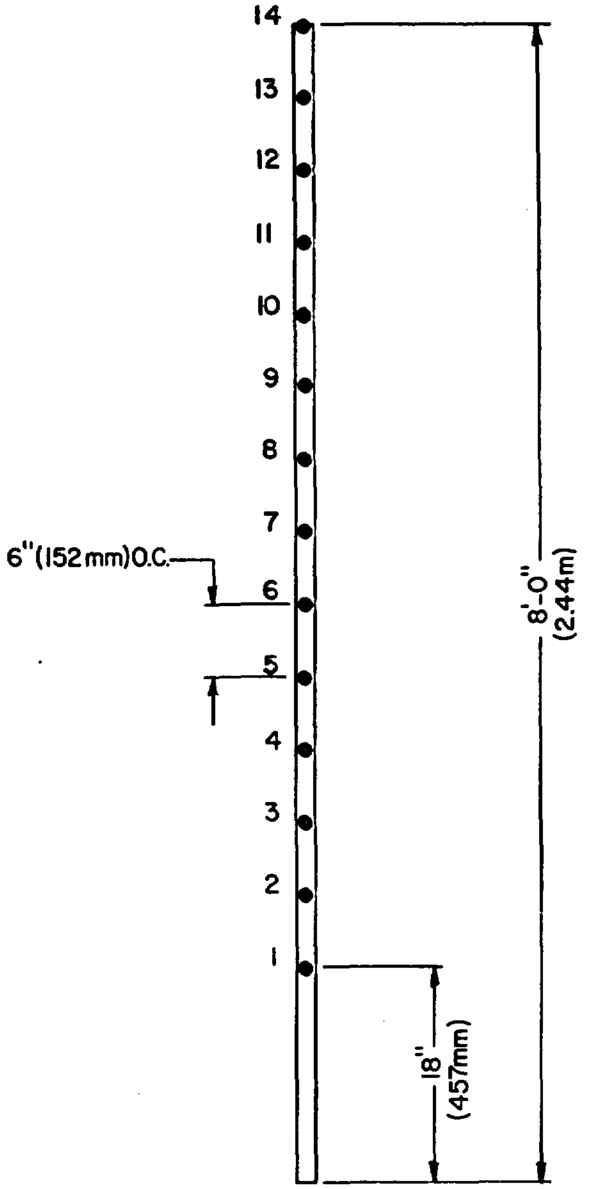
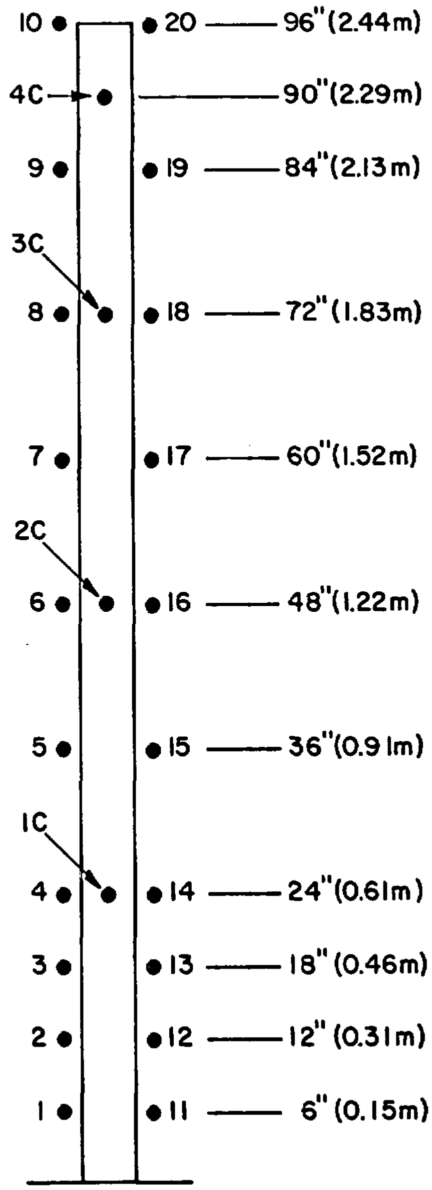


Figure 7- Simulated cable sample board



THERMOCOUPLES INSTALLED INTO CABLE JACKET AND COVERED WITH ADHESIVE. THERMOCOUPLE NOS. 2,4,7, 10,13 AND 14 NOT USED IN EXP. 1.

Figure 8 - Cable thermocouple locations



ALL AIR THERMOCOUPLES LOCATED 3/8"(9.53mm) FROM SURFACE OF CABLE TRAY. CORE THERMOCOUPLES LOCATED IN THE CENTER OF THE CABLE BUNDLE ALONG THE CENTERLINE OF THE CABLE TRAY.

Figure 9- Air and cable bundle thermocouple locations

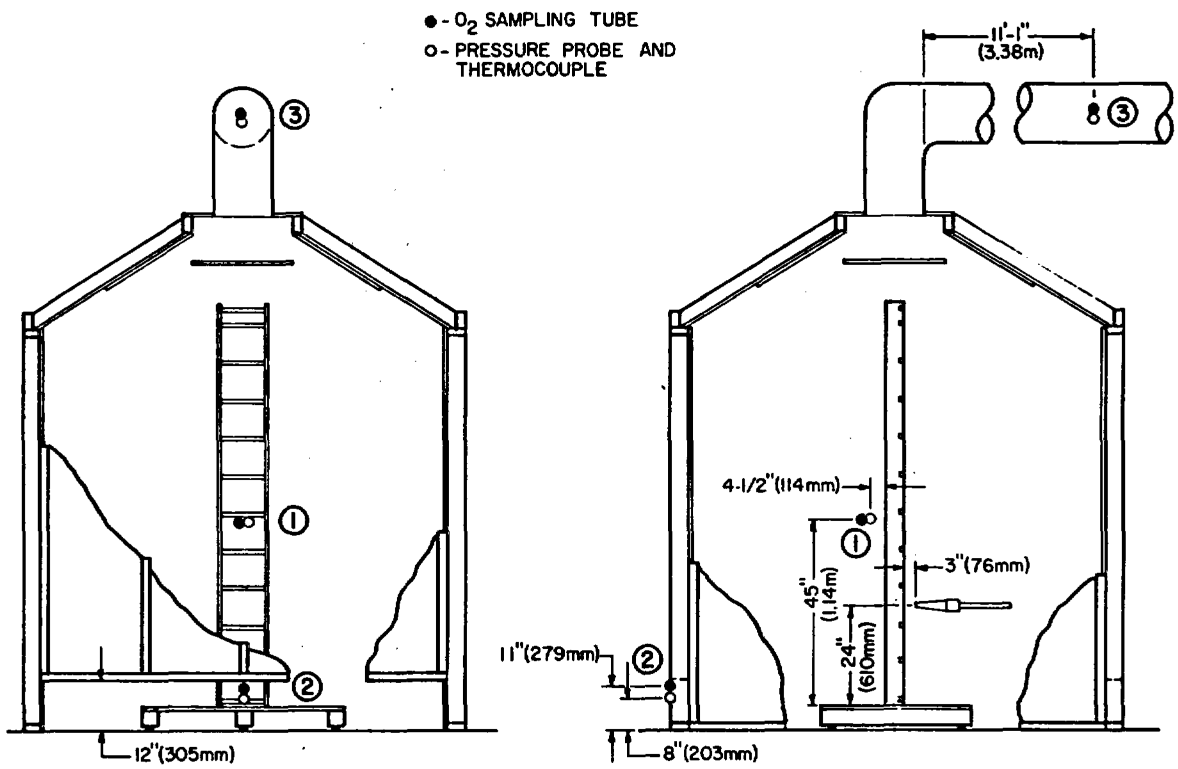
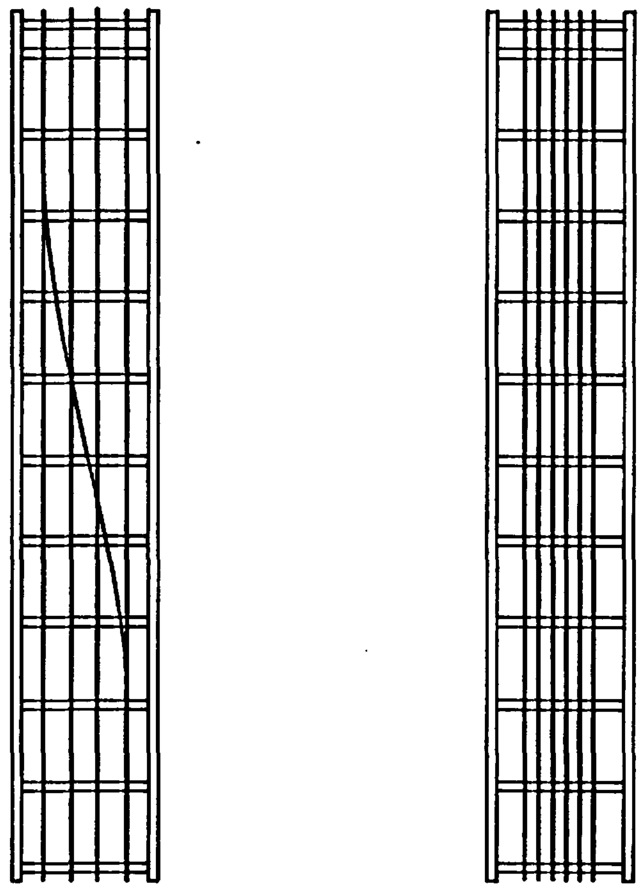


Figure 10 - Oxygen and pressure measurement locations



EXP. 1 - 6
FOUR LAYERS OF 17 CABLES. CABLES BUNDLED INTO GROUPS OF FOUR. THE EXTRA CABLE PER LAYER WAS INTERWEAVED WITH THE OTHER CABLE GROUPS IN THE LAYER.

EXP. 7 - 48
SEPARATION BETWEEN CABLES EQUAL TO 1/2 CABLE DIAMETER.

Figure 11- Installation of cable

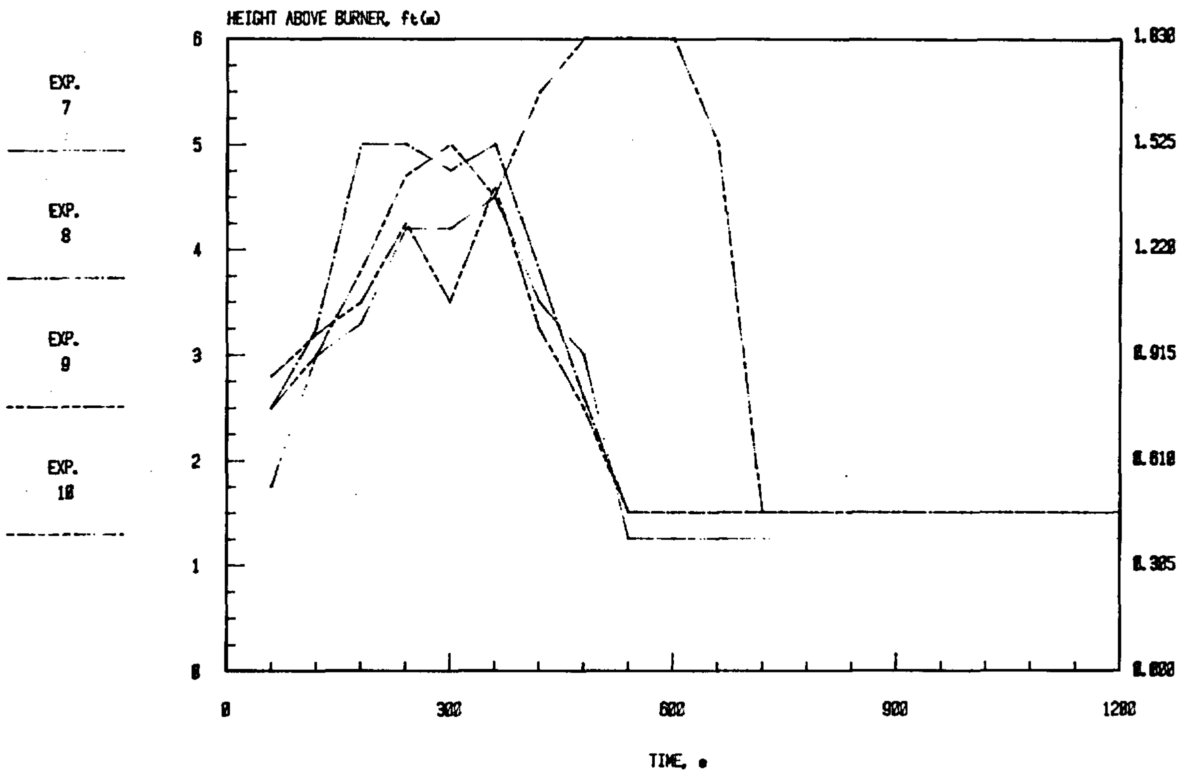


Figure 12- Flame propagation of cable A,
Enclosure Experiments

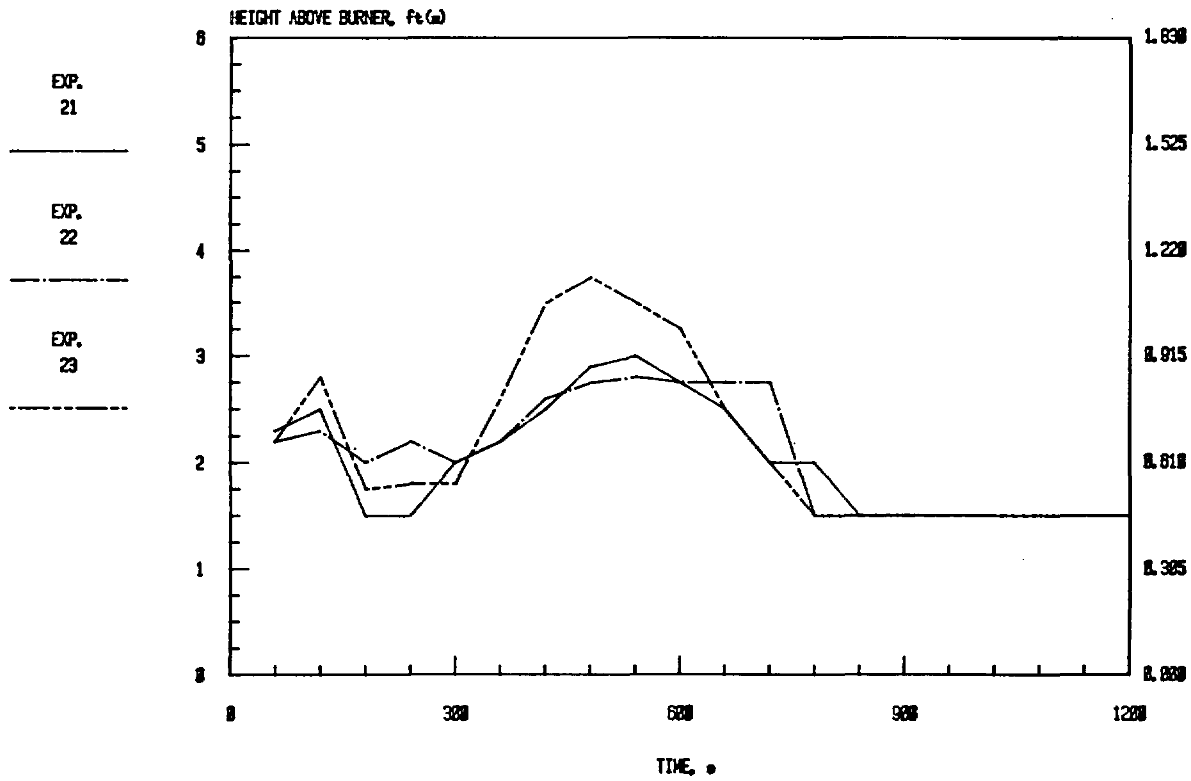


Figure 13- Flame propagation of cable B,
Enclosure Experiments

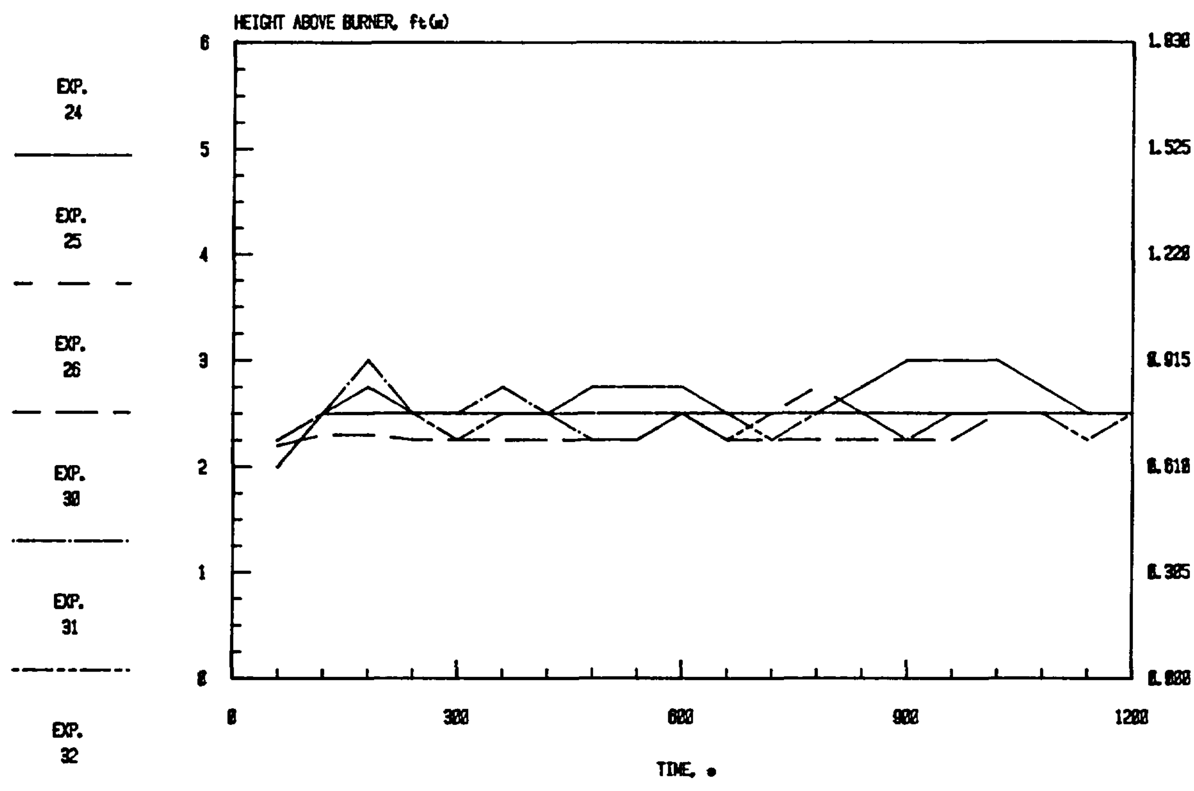


Figure 14- Flame propagation of cable C, Enclosure Experiments

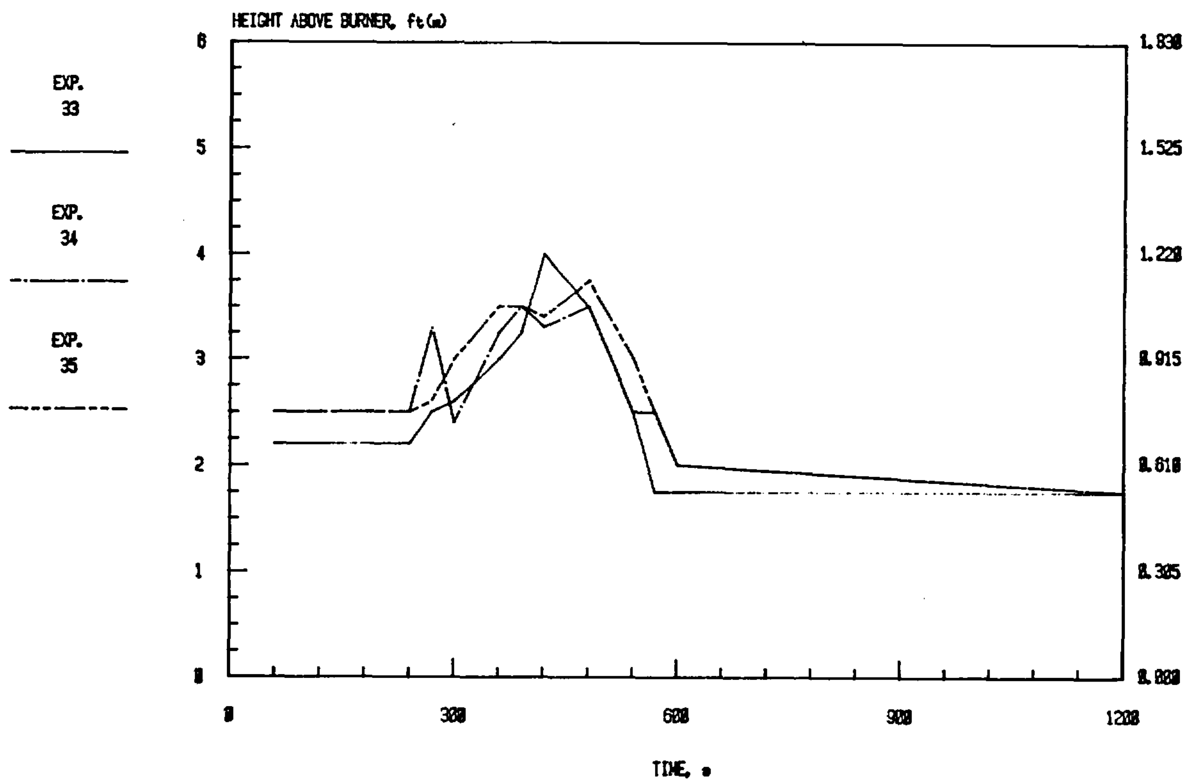


Figure 15- Flame propagation of cable D, Enclosure Experiments

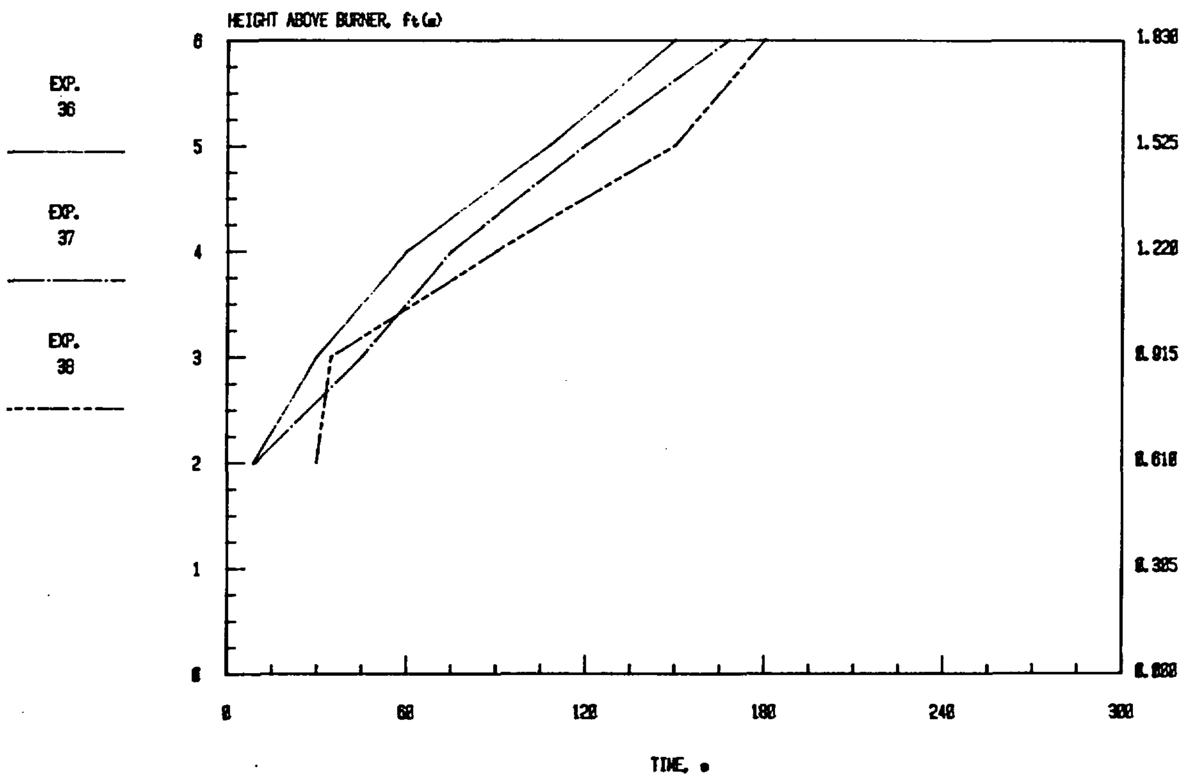


Figure 16- Flame propagation of cable E,
Enclosure Experiments

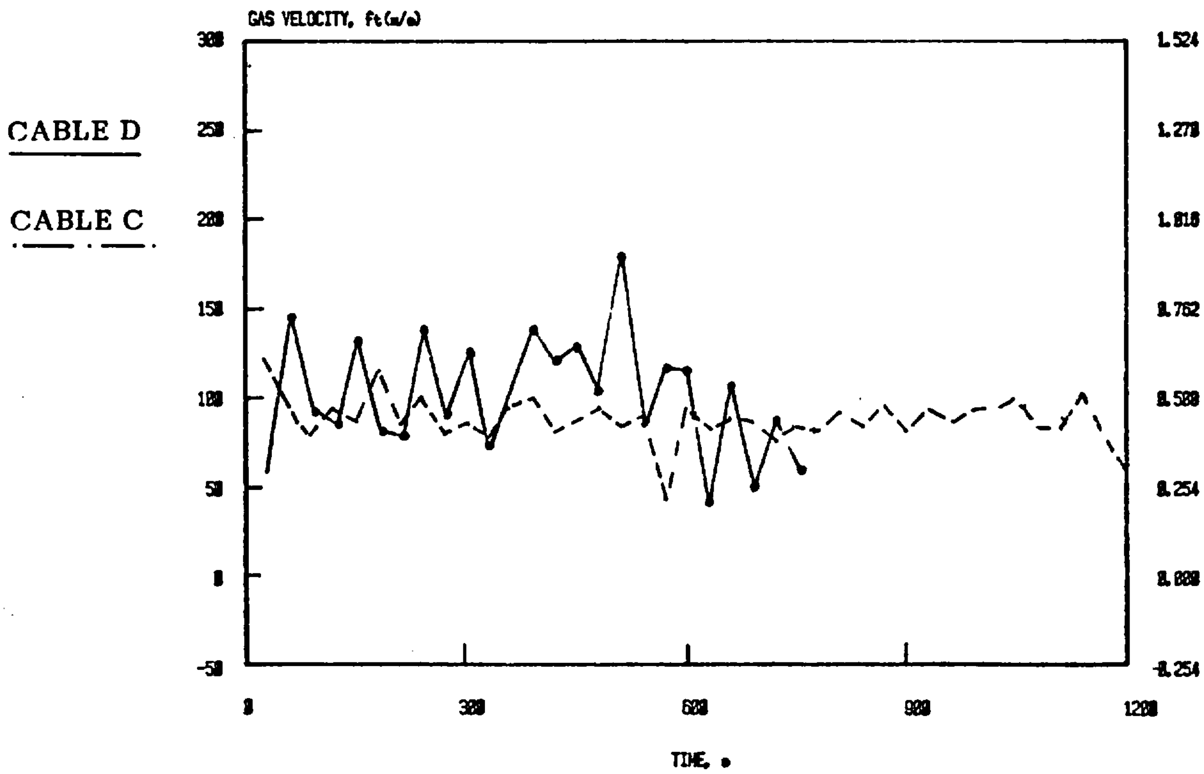


Figure 17 - Gas Velocity Near Sample - Control Experiments

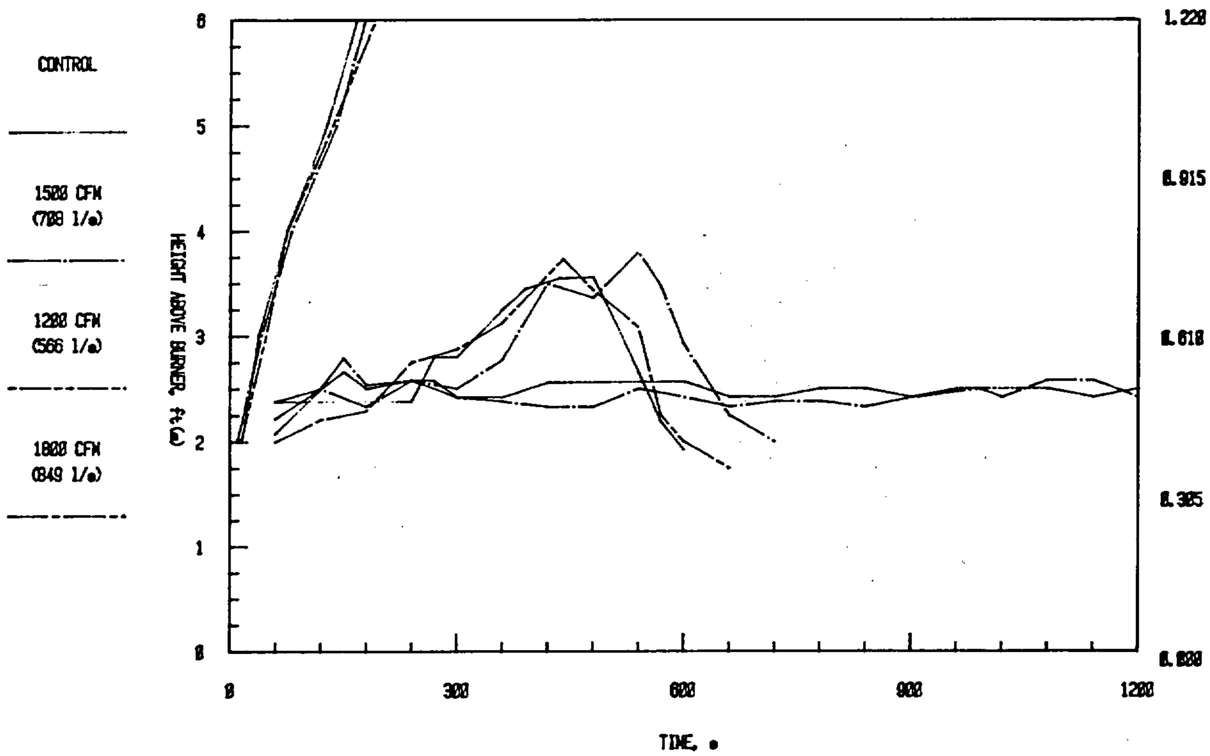


Figure 18- Comparison of average flame propagation

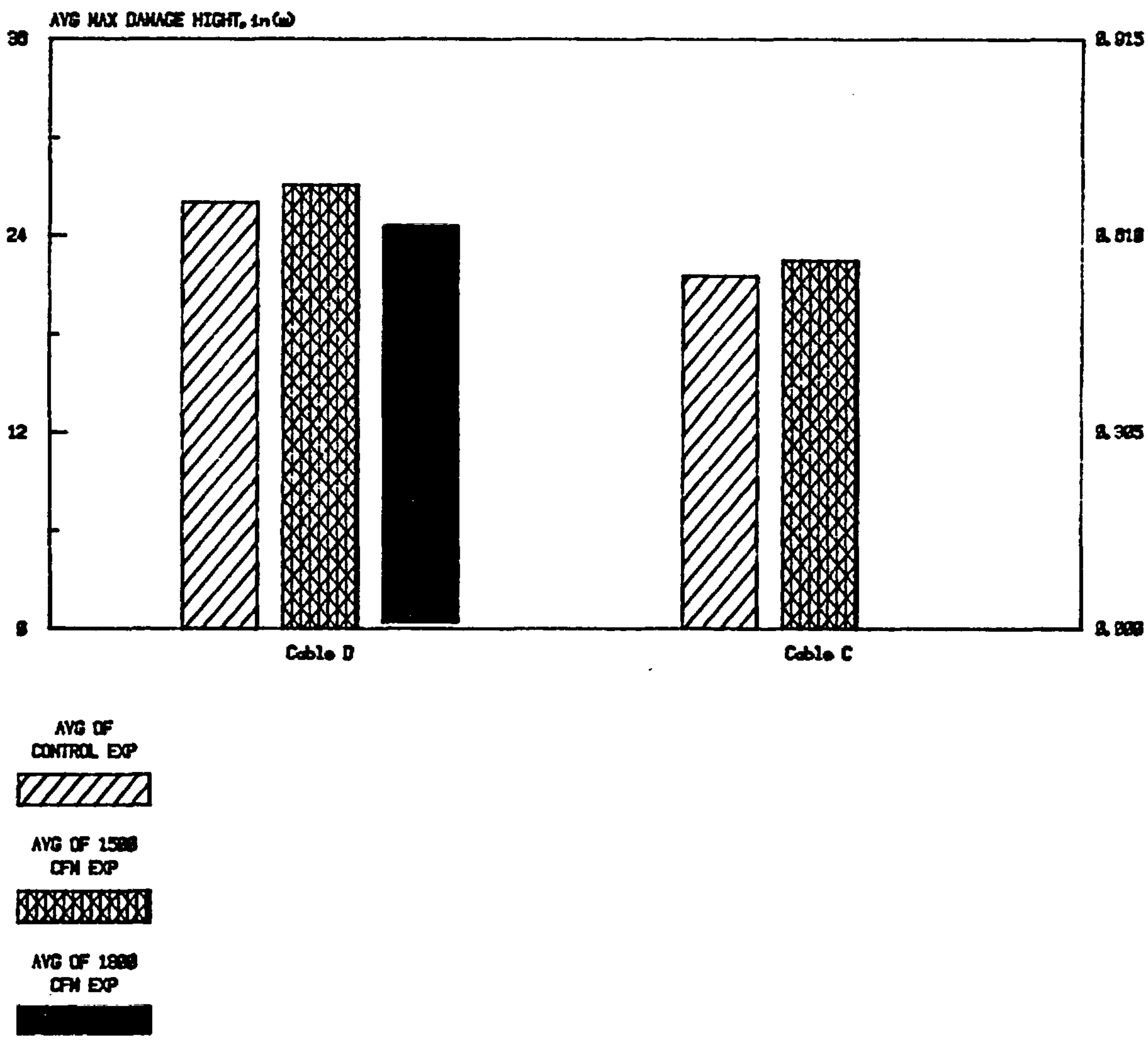


Figure 19- Comparison of average maximum cable damage

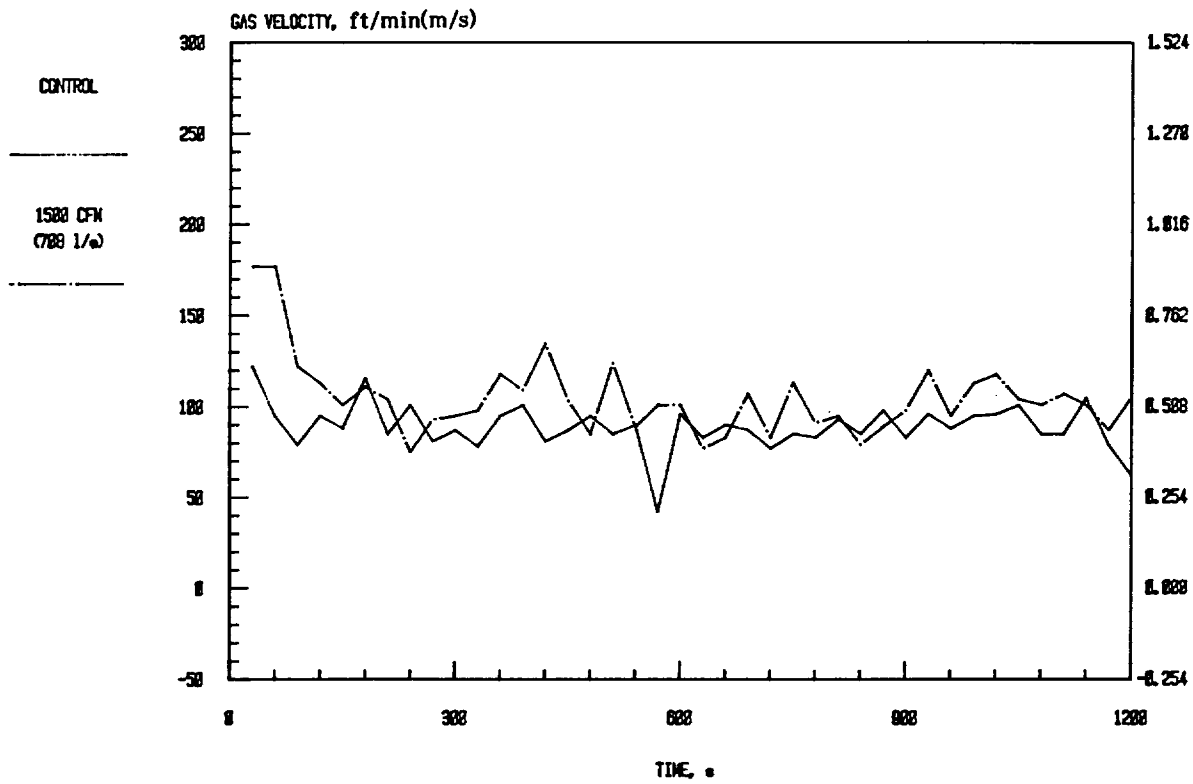


Figure 20- Average gas velocity near cable C

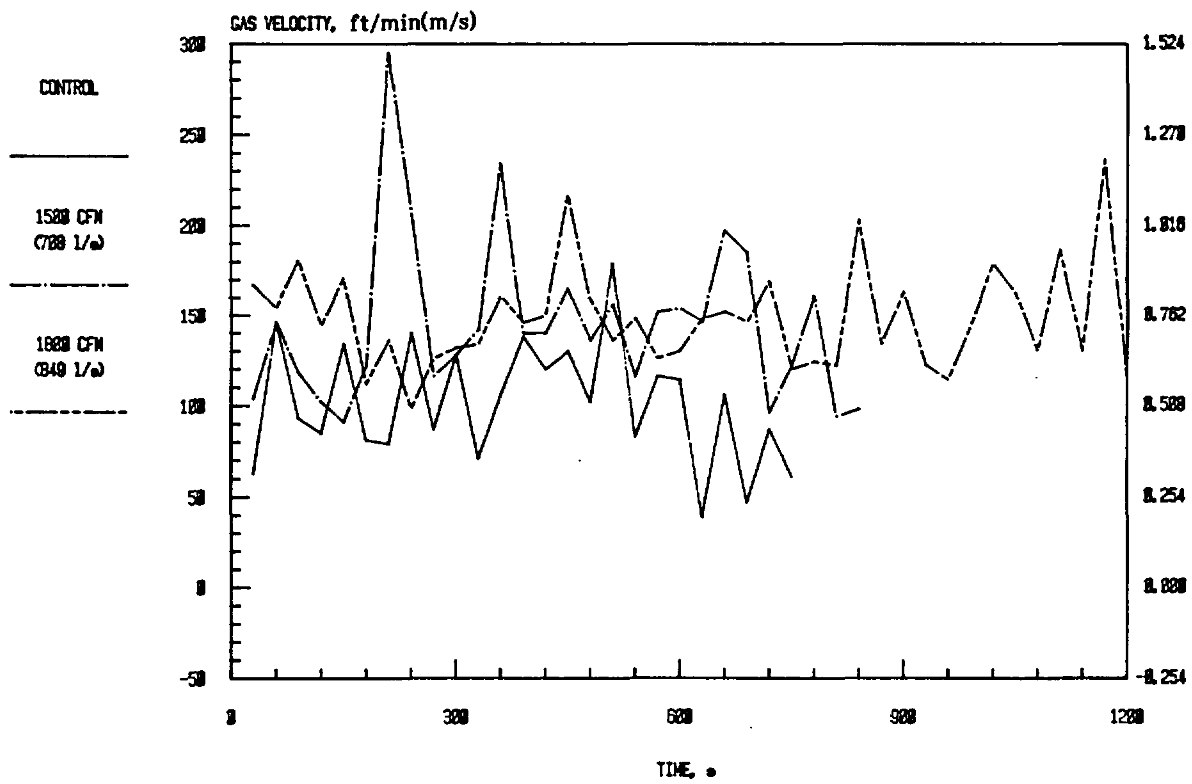


Figure 21- Average gas velocity near cable D

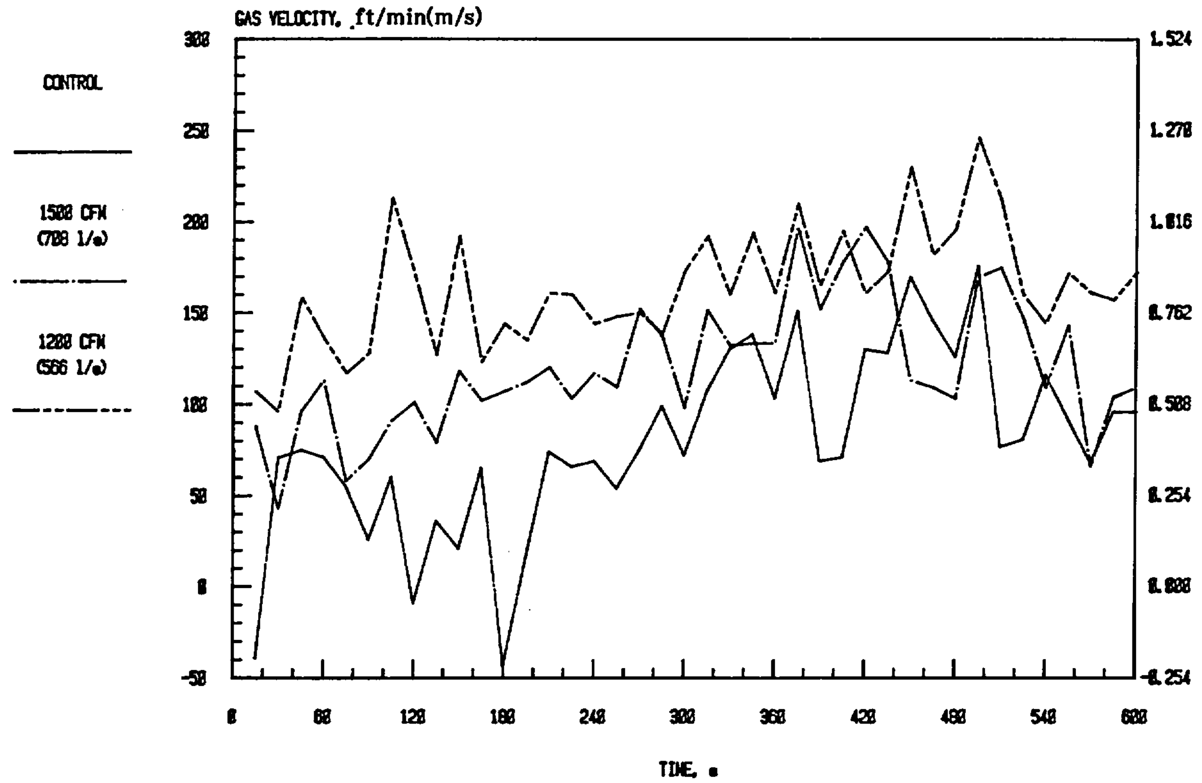


Figure 22- Average gas velocity near cable E

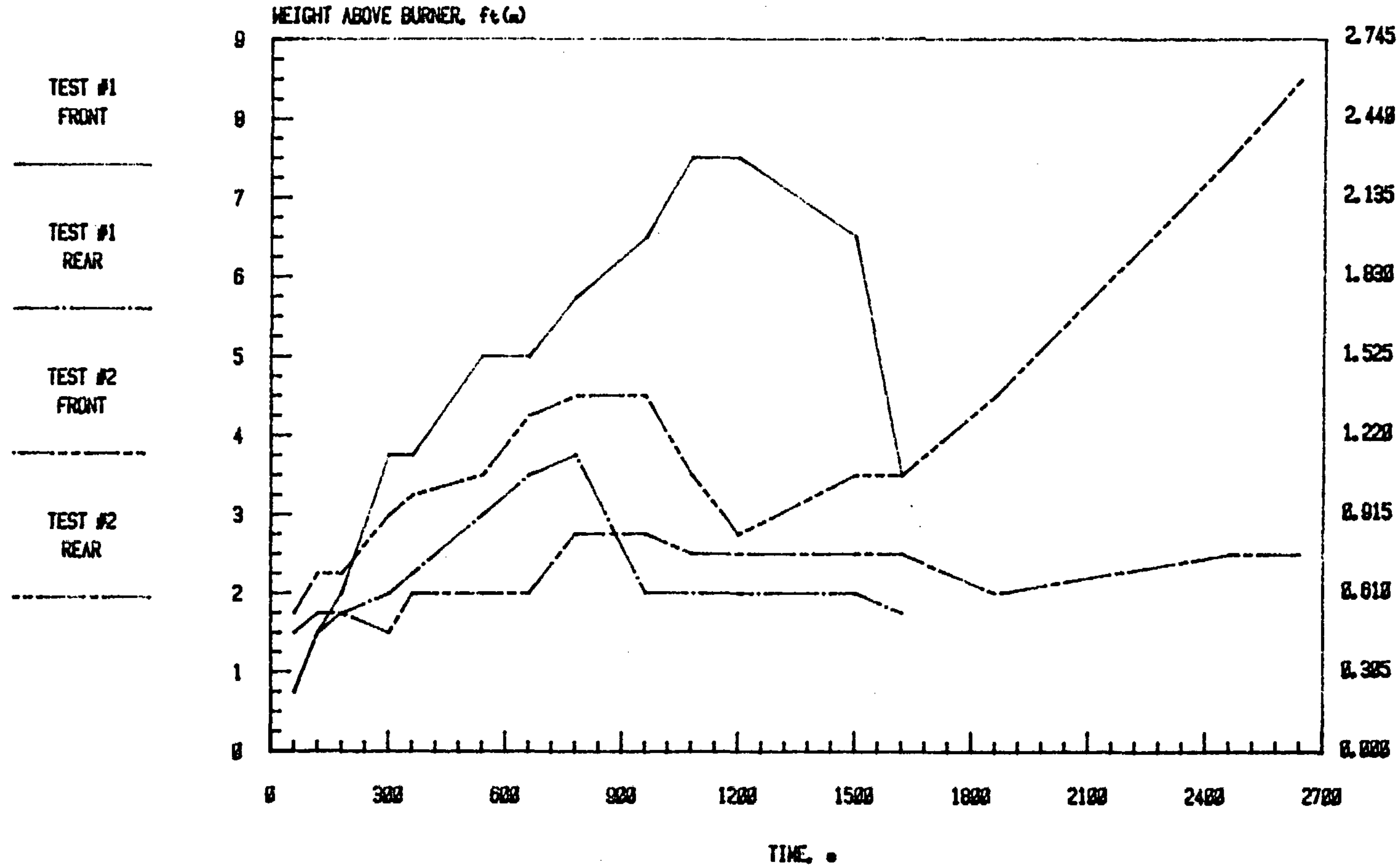


Figure 23 - Flame-Propagation in Increased Cable Loading Experiments

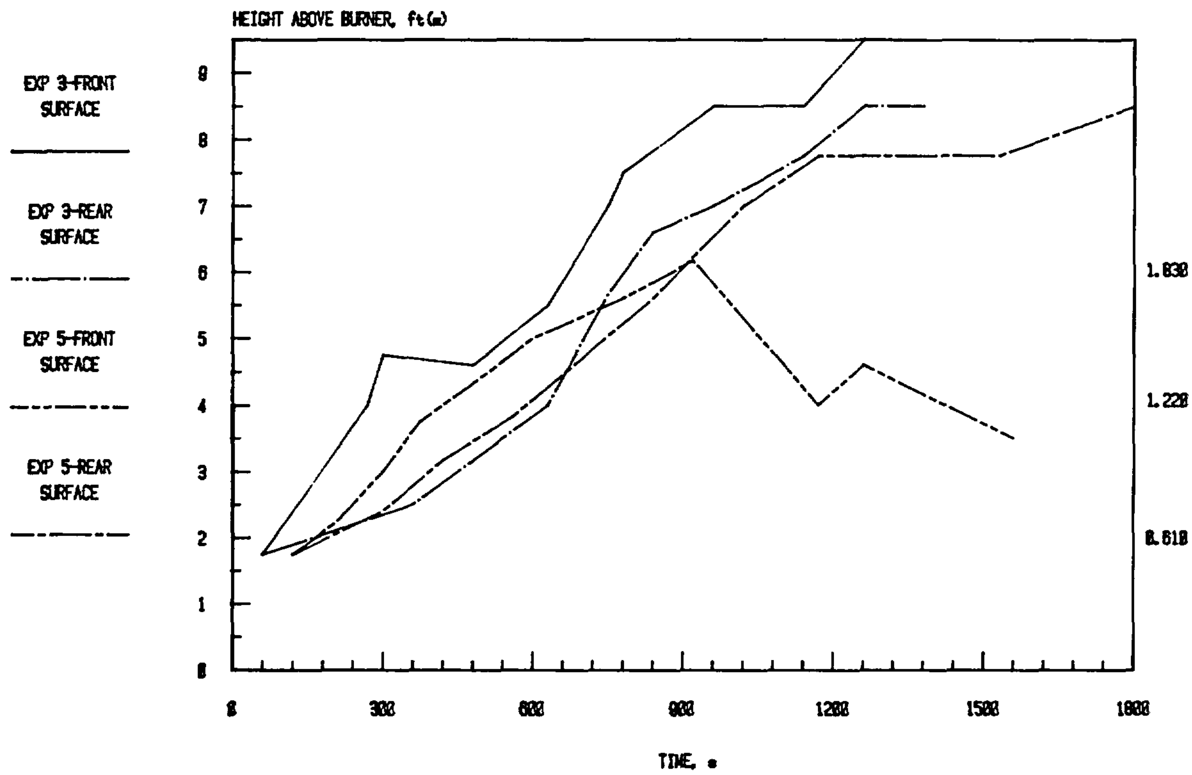


Figure 24- Flame propagation in increased cable loading experiments

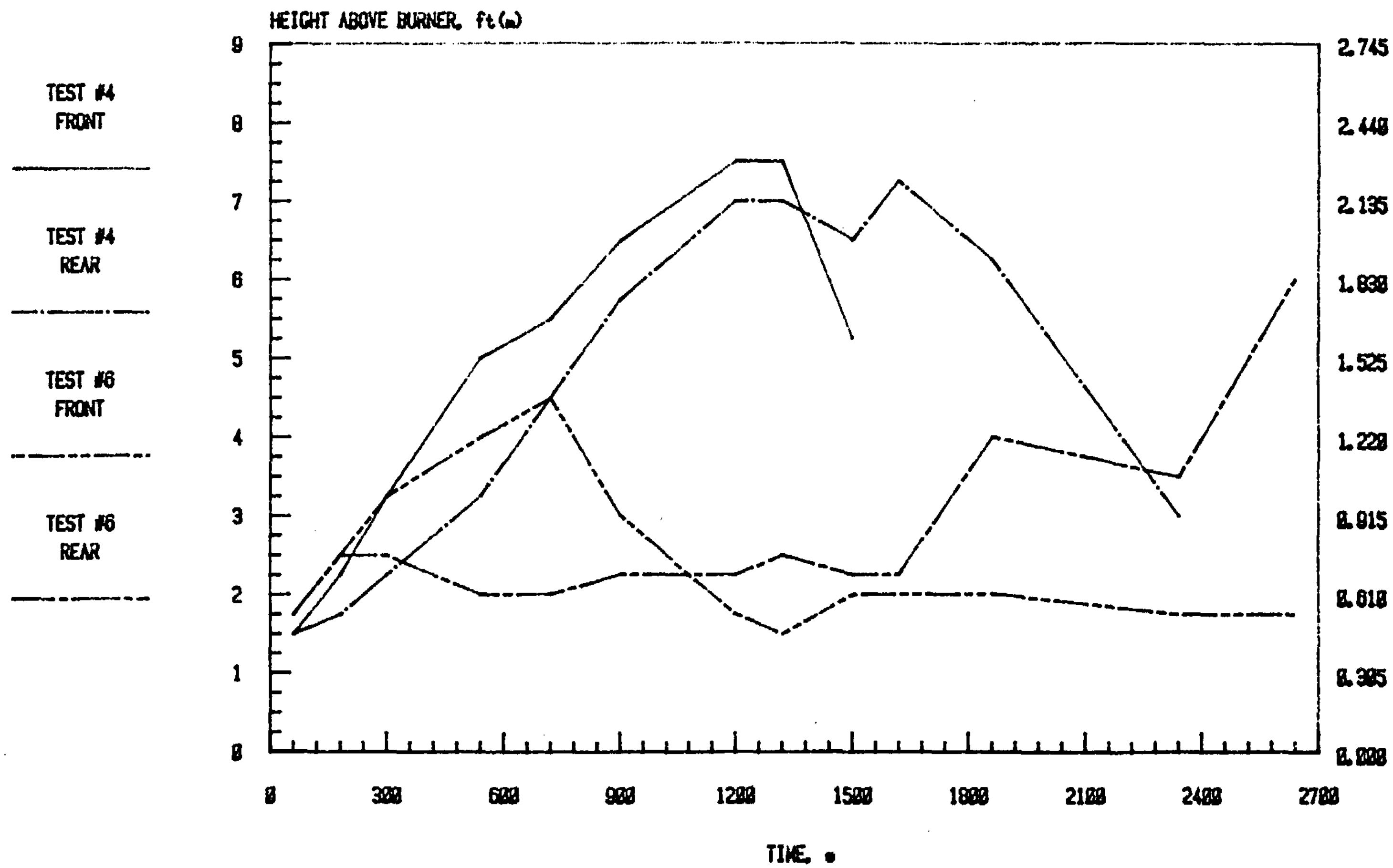
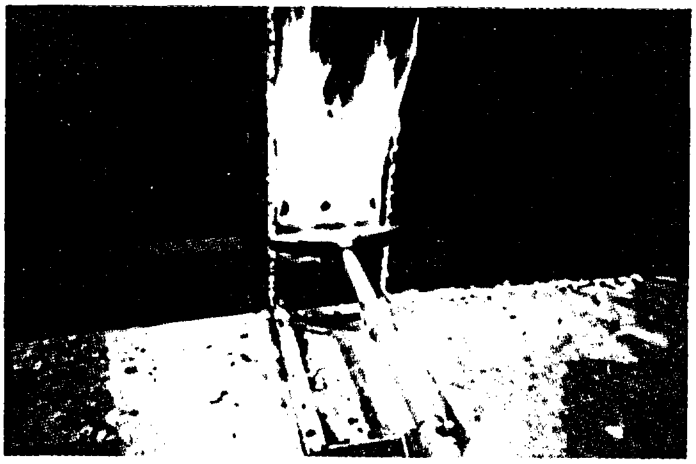
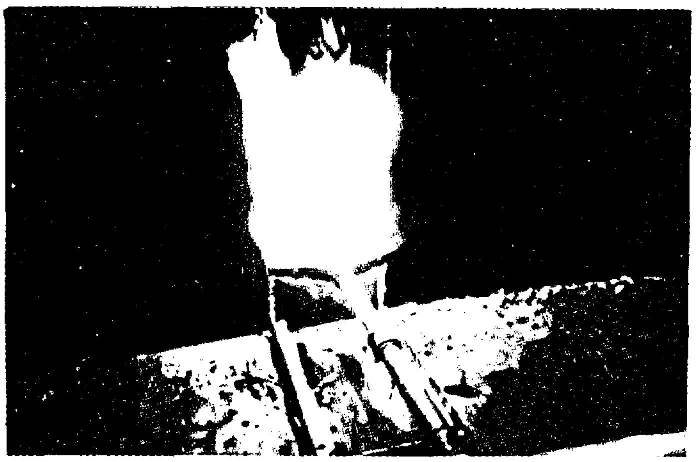


Figure 25 - Flame Propagation in Increased Cable Loading Experiments



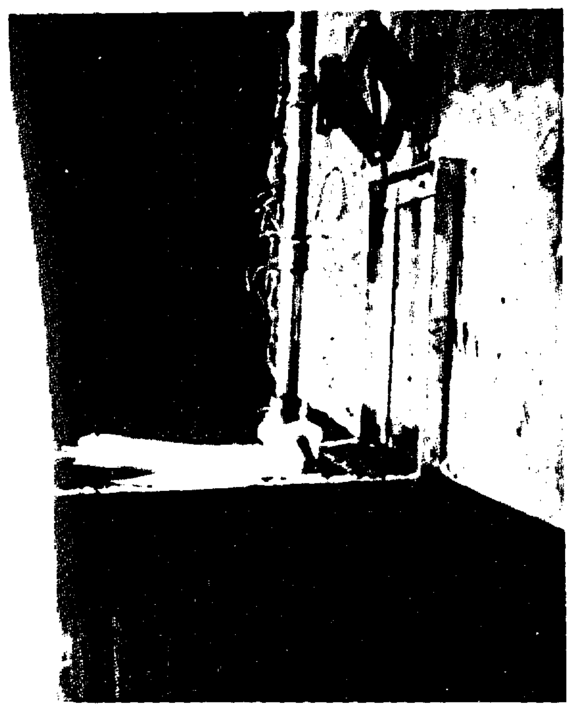
At high air/fuel ratio



At low air/fuel ratio

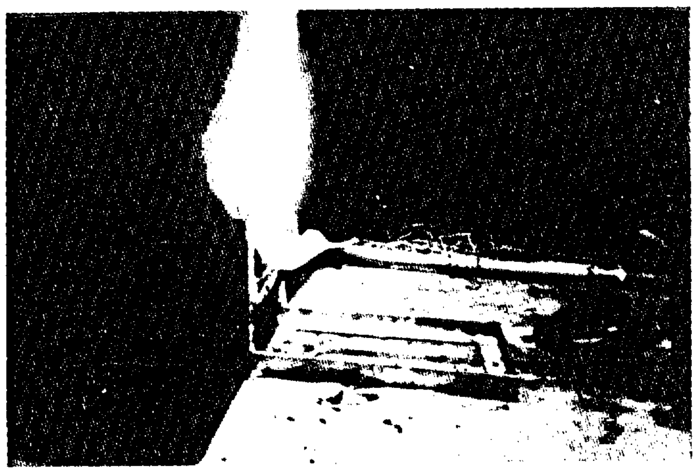
Figure 26- Apperance of flame at high and low air/fuel ratios

At far burner distance



At close burner distance

Figure 27- Appearance of flame at close and far burner distances



Stable 70,000 flame

Figure 28- Appearance of stable flame

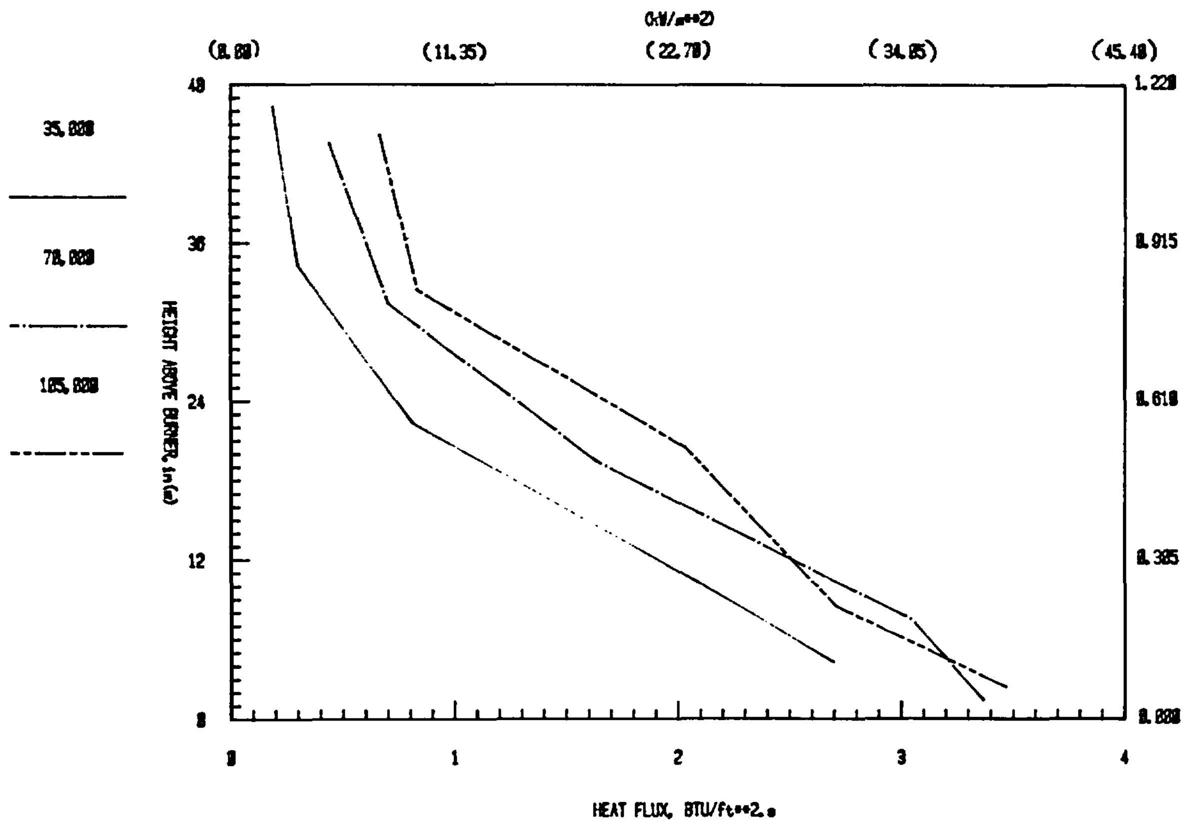


Figure 29- Heat flux of flames at different theoretical rates of heat released

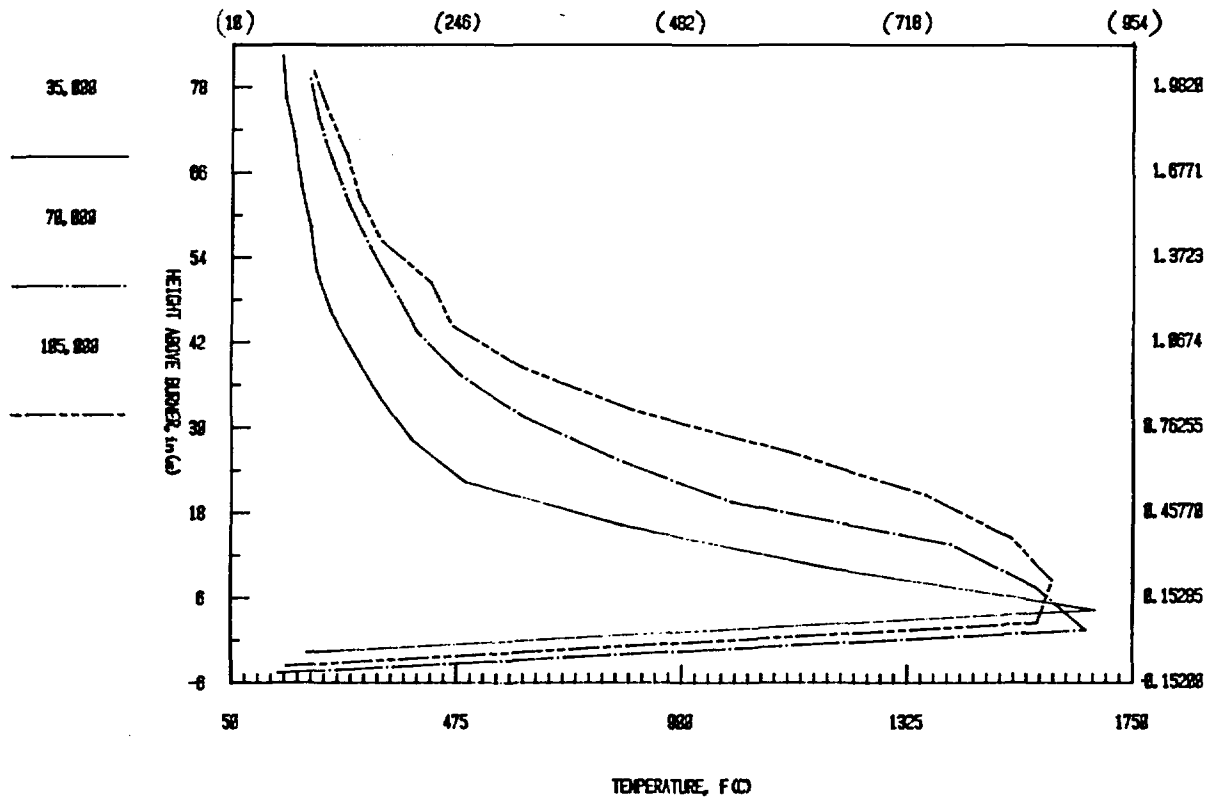


Figure 30- Temperatures of flames at different theoretical rates of heat released

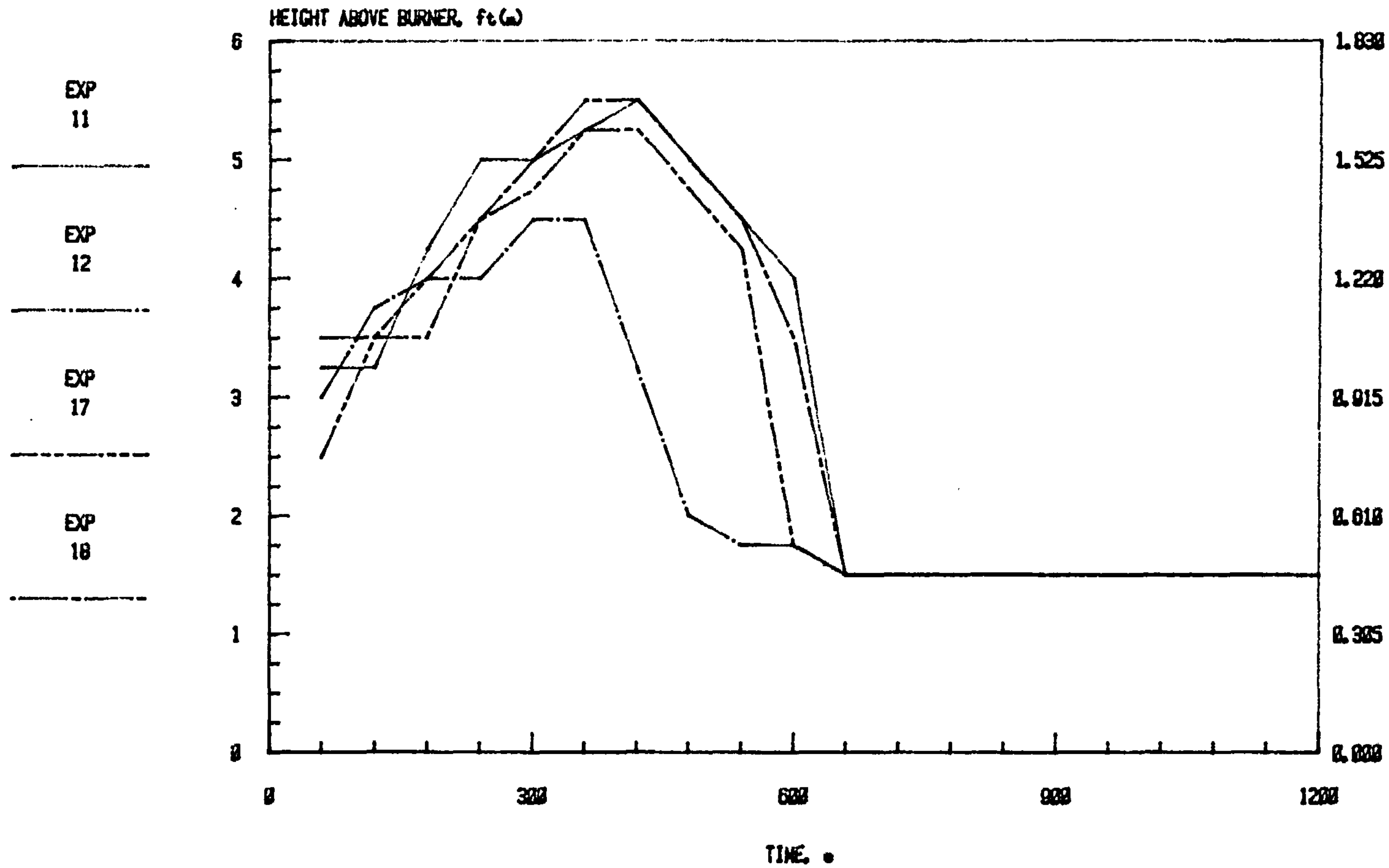


Figure 31 - Comparison of Flame Propagation - Burner Distance

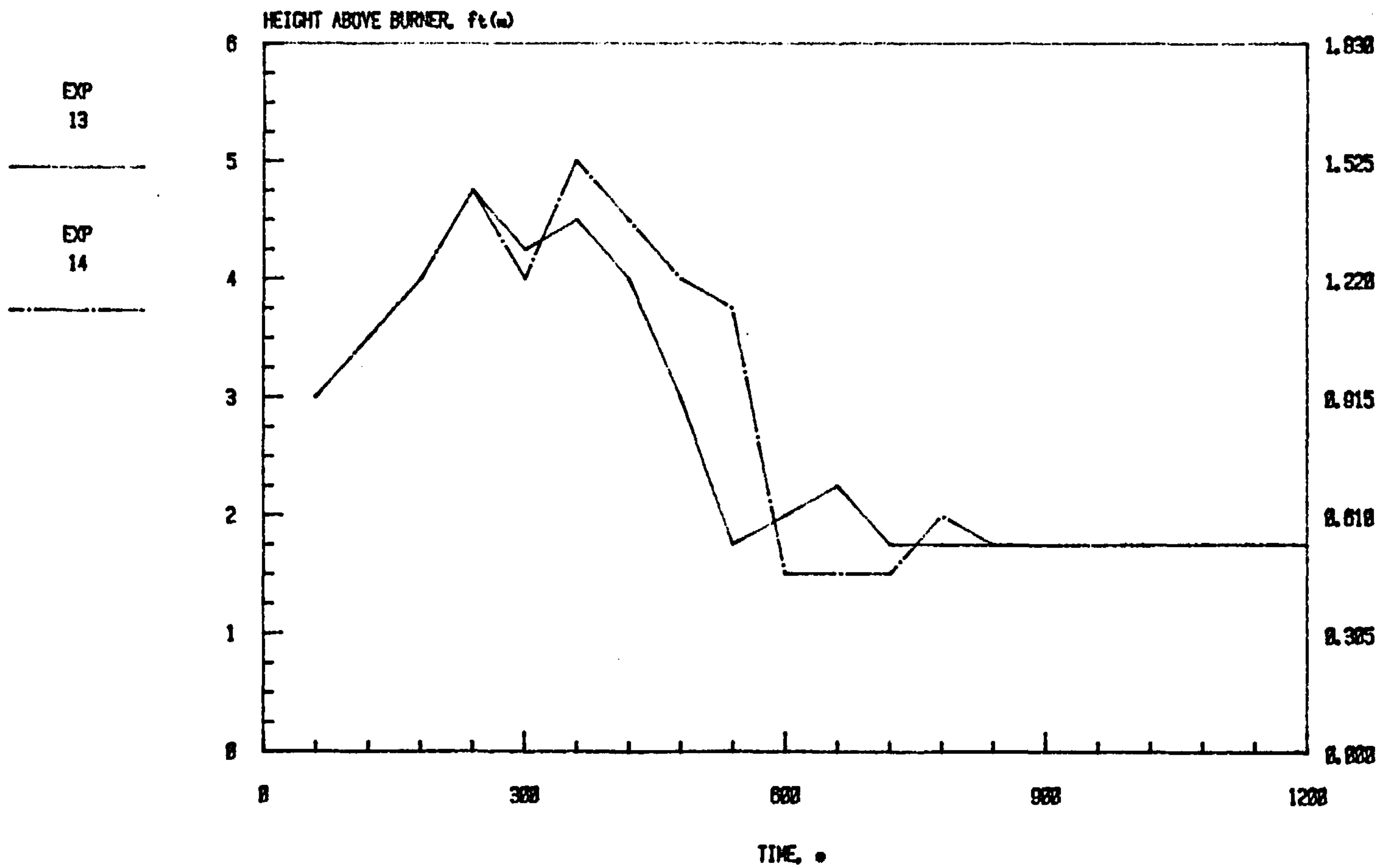


Figure 32 - Comparison of Flame Propagation - Air Flow

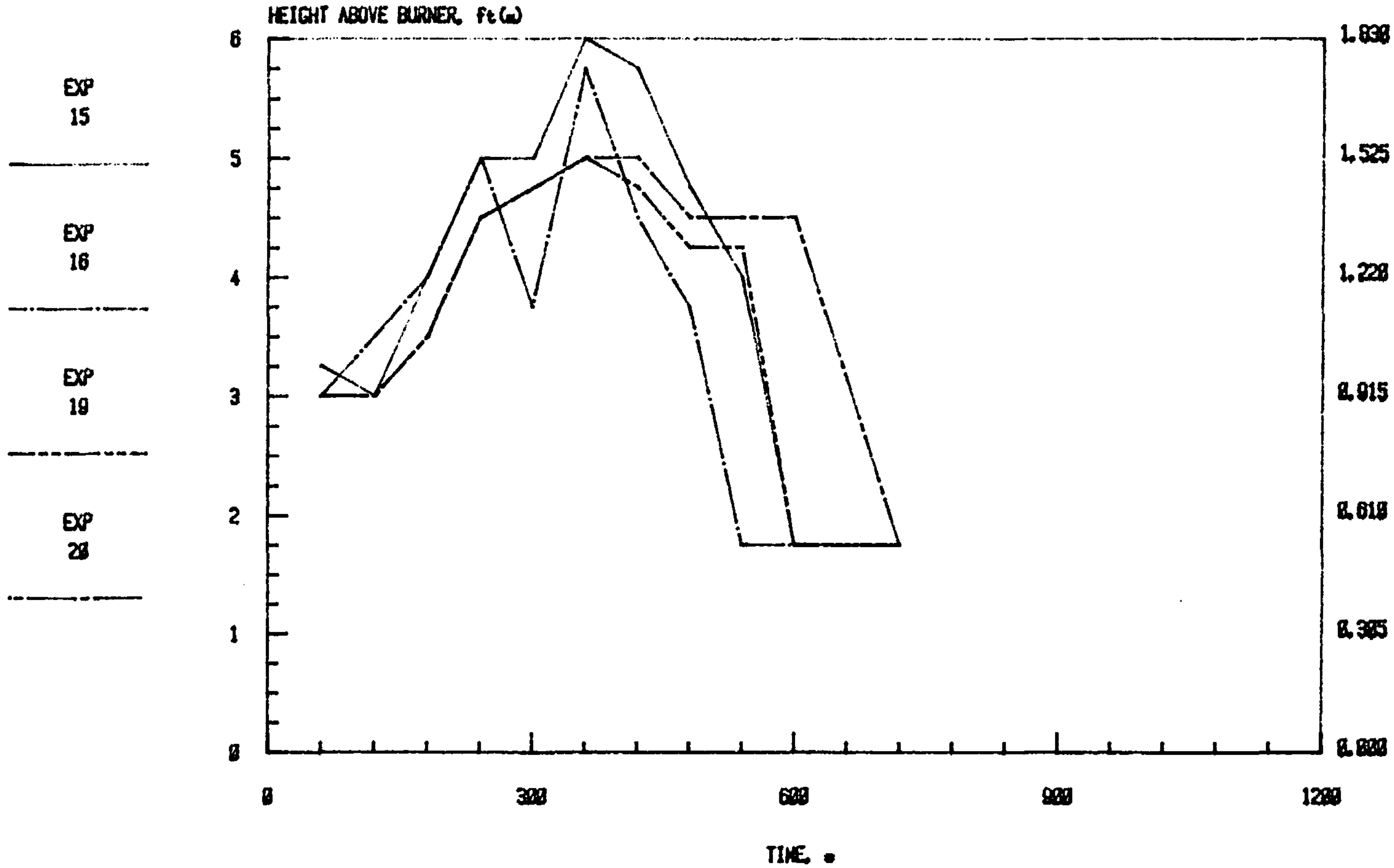


Figure 33 - Comparison of Flame Propagation - Fuel Flow

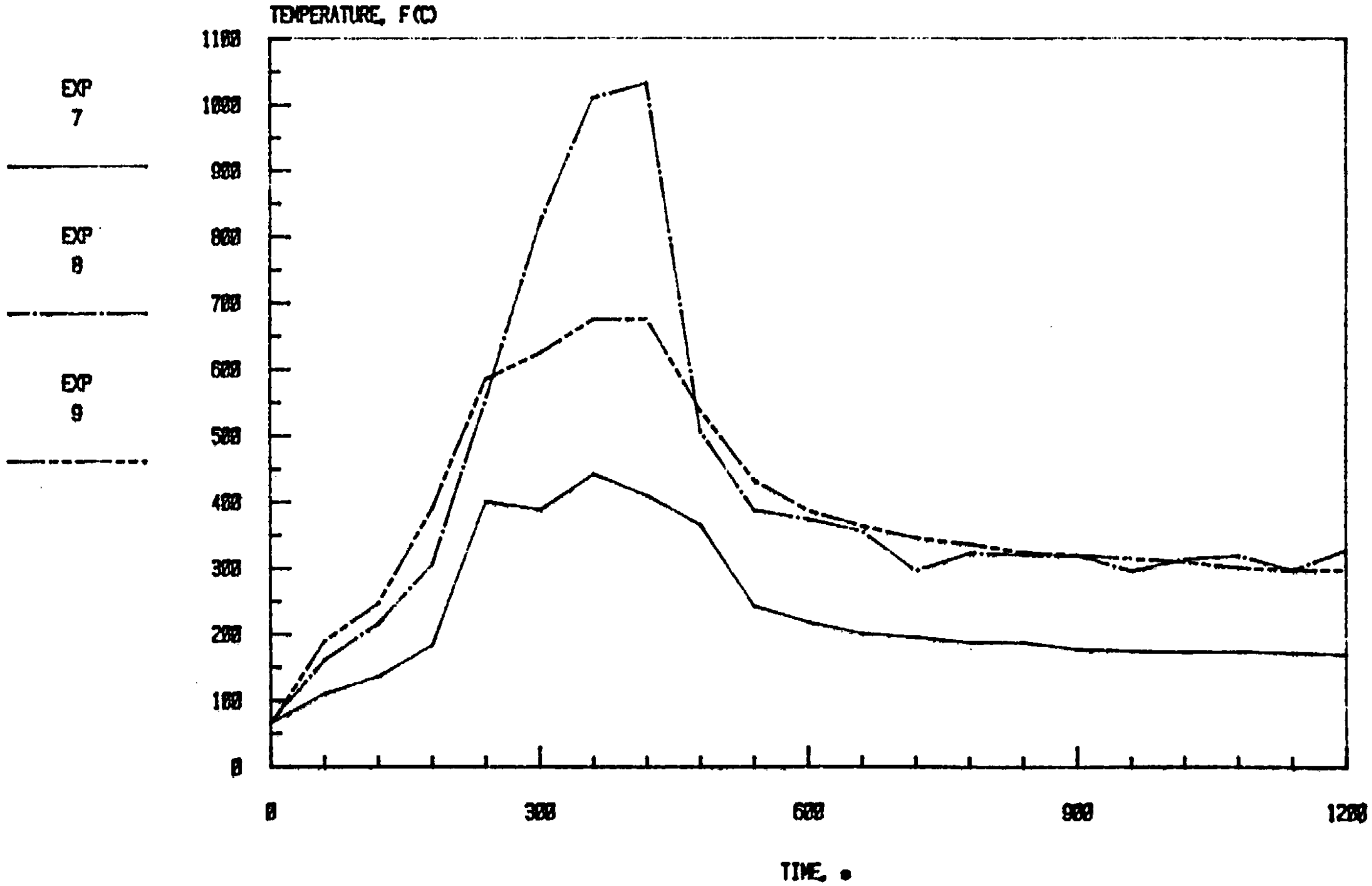


Figure 34 - Cable Temperature at 2.5 Ft. Above Burner Versus Time - Experiments 7, 8 and 9

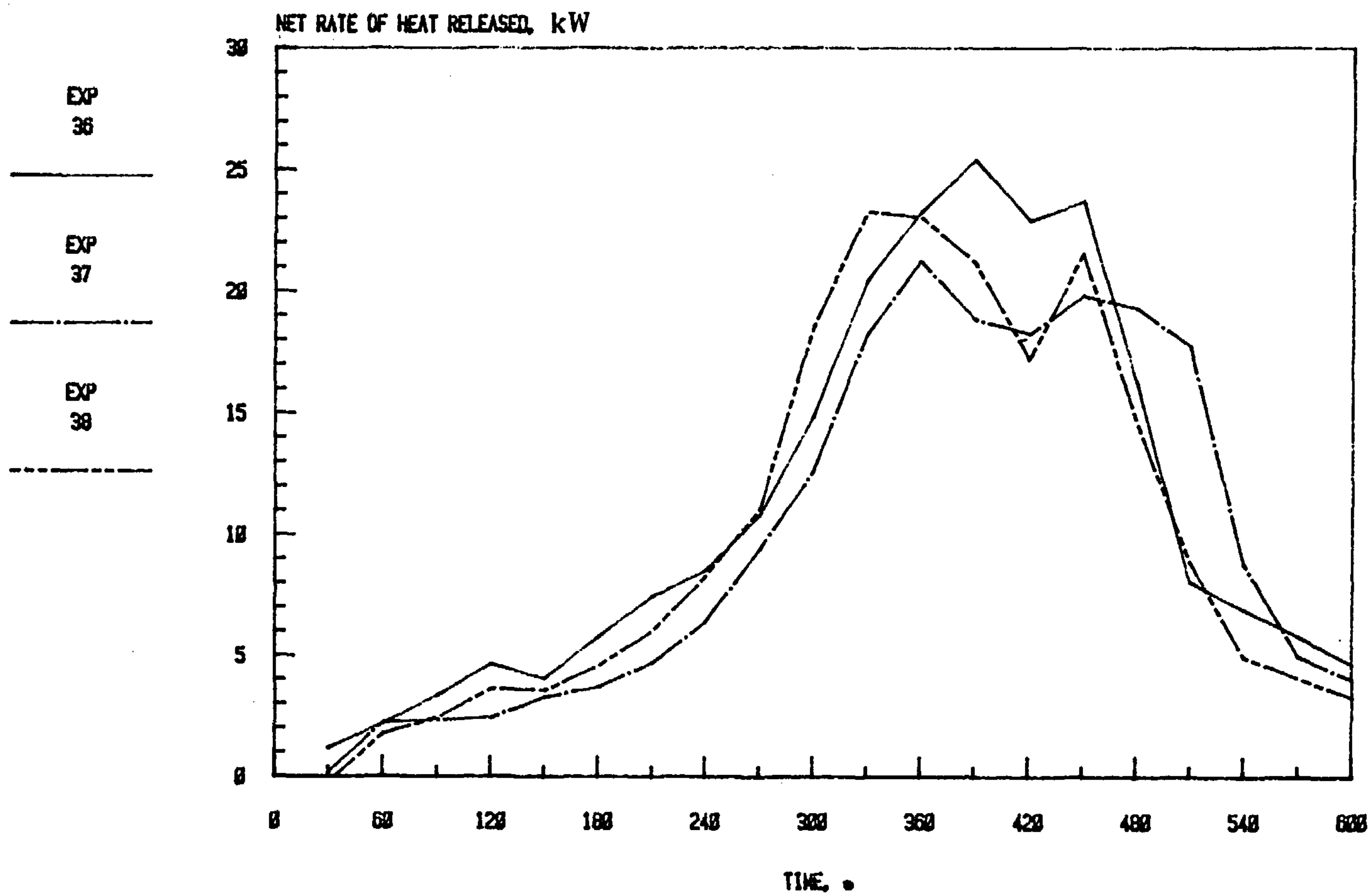


Figure 35 - Rate of Heat Released Versus Time

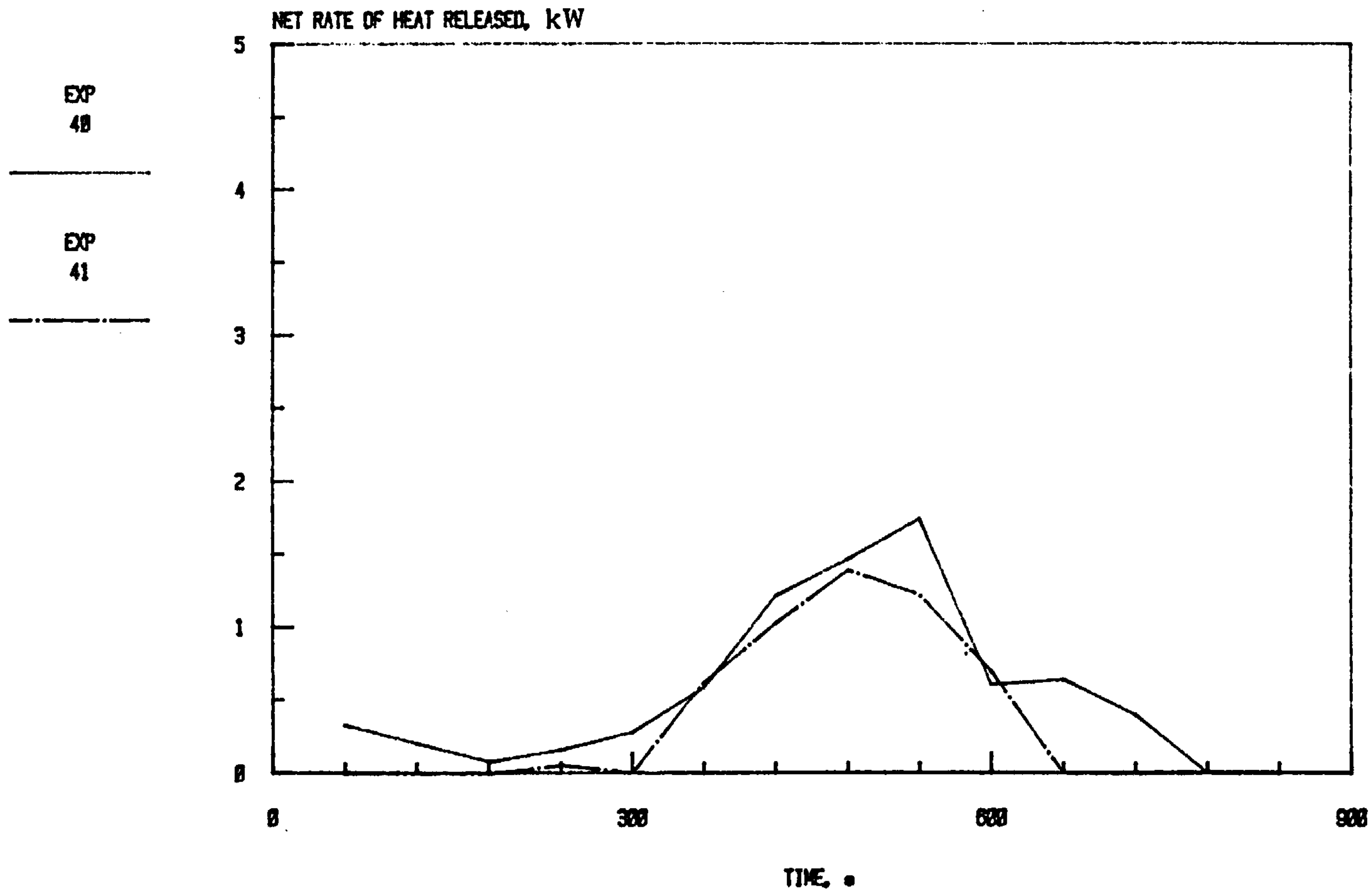


Figure 36 - Rate of Heat Released Versus Time

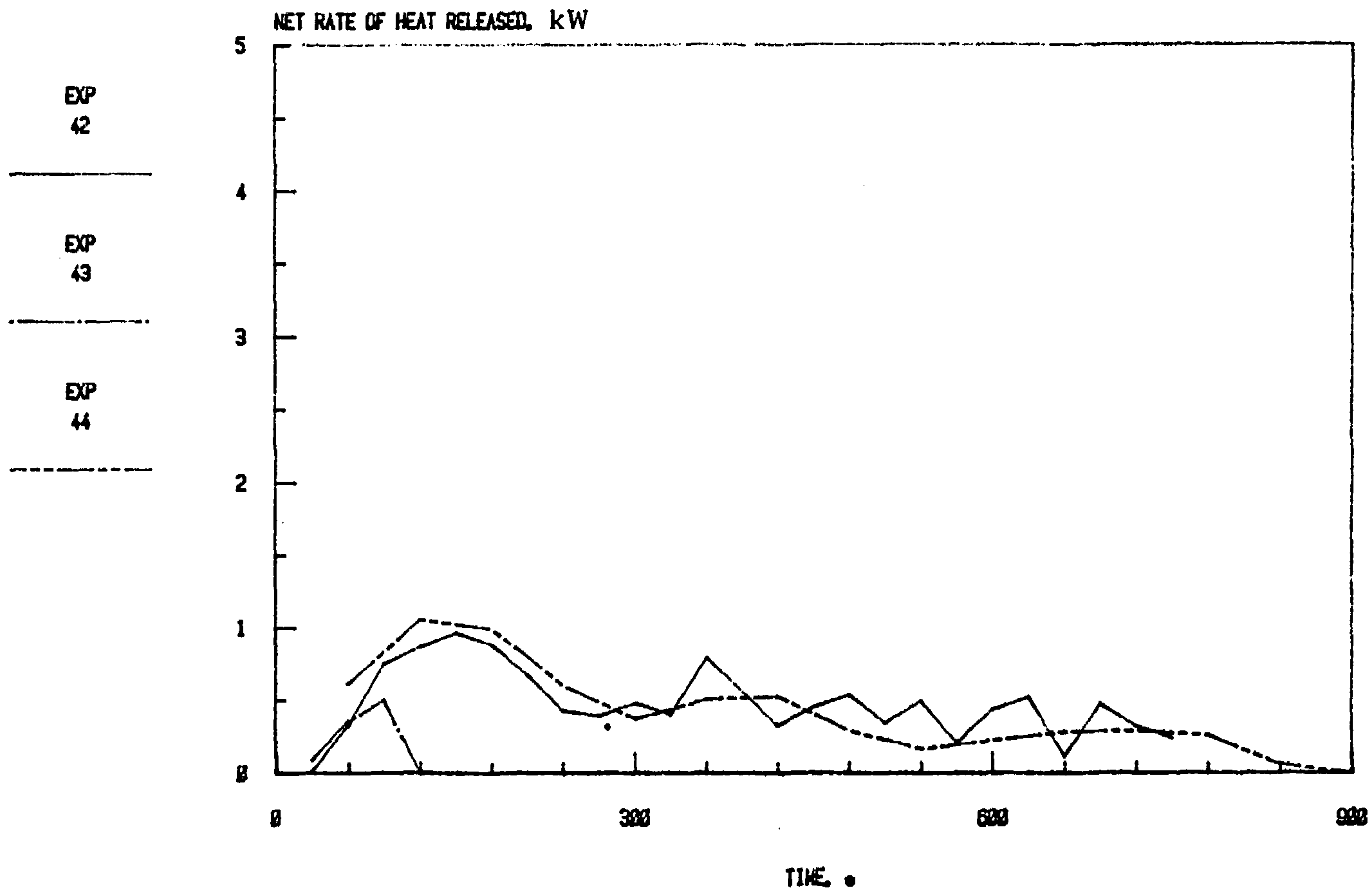


Figure 37 - Rate of Heat Released Versus Time

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16. ABSTRACT *(200 words or less)*

The flame test in the Institute of Electrical and Electronics Engineers (IEEE) Standard 383 was investigated. The investigation was to develop possible modifications in test equipment and test procedure that would increase the repeatability of results and provide additional information useful in assessing cable system performance in response to a real fire. Several fire experiments were conducted varying different test parameters. The experimental data were analyzed and modifications of both test equipment and test procedure were developed to increase repeatability. These modifications were: An enclosure for the sample, defining cable damage; cable fastening and the cable tray to be used; establishing tolerances for exhaust of the enclosure; starting temperature of the ambient air cable sample; location of the burner and the flow rates of fuel and air into the burner. Suggested also, was to report the maximum flame height versus time and the rate of heat released versus time as additional information that would be useful in assessing cable system performance.

17. KEY WORDS AND DOCUMENT ANALYSIS 17a. DESCRIPTORS

IEEE 383, Flame Test, Repeatability, Enclosure, Exhaust Flow, Fuel Flow, Burner Location, Damage Definition, Starting Temperature, Fasteners

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