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CRITERIA FOR AIRCRAFT INSTALLATION AND UTILIZATION OF AN EXTINGUISHING AGENT CONCENTRATION RECORDER

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DEPARTMENT OF TRANSPORTATION UNITED STATES OF AMERICA

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16. Abstract

For a number of years, the Federal Aviation Administration (FAA) has been active in the field of testing and evaluation of aircraft powerplant fire-extinguishing systems. In this area, the FAA has supplied the specialized test equipment and experienced personnel necessary for such testing and has been, essentially, the sole organization providing these services within the United States. This report describes the specialized test equipment, provides criteria for the installation and operation of this equipment, and provides the guidelines for utilization of the equipment for the conduct of meaningful test programs.

The extinguishing agent concentration recorder, as specialized gas analyzer test equipment, and its operational principle are described. Guidelines are presented for the location and installation of extinguishing agent concentration sampling probes within the test article. Also included in the report are sections concerning importance of agent distribution system conformity; factors which influence agent distribution and concentration; suggested flight and ground test procedures; the relative importance of flight tests and ground tests with and without supplemental airflow; and test data form, reduction, interpretation, and presentation. The value and recognition of the utilization of the gas analyzer test equipment as the most effective means of determining the performance of an aircraft extinguishing system are also discussed.

17. Key Words

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INTRODUCTION

Purpose

The purpose of this project was to establish criteria for the aircraft installation and utilization of an extinguishing agent concentration recorder and to provide general guidelines for the testing of aircraft powerplant fire-extinguishing systems.

Background

From 1959 to 1968, the Federal Aviation Administration's (FAA) National Aviation Facilities Experimental Center (NAFEC) was actively engaged in the evaluation of aircraft powerplant fire-extinguishing systems. NAFEC's activity in this field consisted, primarily, of providing specialized fire-extinguishing agent concentration recorder equipment and cognizant personnel to organizations requesting assistance in the evaluation of aircraft extinguishing systems. The test equipment and associated services were provided to the FAA's Flight Standards Service, all branches of the United States military services, various foreign military services and manufacturers, and domestic aircraft manufacturers. Testing was conducted and data obtained for all types of aircraft including STOL, VTOL, helicopters, large transport category aircraft, military aircraft, executive aircraft, turbojet, turbopropeller, and reciprocating engine aircraft.

The scope of the report was limited by two factors. The first factor was the type of extinguishing agent utilized in the aircraft industry. The majority of information obtained during the past 8 years was for systems utilizing monobromotrifluoromethane ($CBrF_3$), with dibromodifluoromethane (CBr_2F_2) being the next most commonly used agent. Several carbon dioxide systems were also tested.

The second limiting factor was the type of test equipment used for the test and evaluation programs. All testing was conducted utilizing a specialized extinguishing agent concentration recorder. The extinguishing agent concentration recorder equipment, the principle of which was based on the difference in flow characteristics of gases, was developed explicitly to provide an instrument capable of continuously measuring the percentage and duration of agent concentration in aircraft nacelle compartments. The equipment and method of application became accepted as the prime means of establishing the effectiveness of aircraft powerplant fire-extinguishing systems. The operational principle and theory of the instrument were described in detail in Civil Aeronautics Administration Technical Development Report No. 206, entitled "Aircraft Fire Extinguishment, Part III, An Instrument for Evaluating Extinguishing Systems," dated June 1953. A further description of the equipment, as well as its basic installation and operation, was presented in the FAA's Technical Development Report No. 403, entitled "Aircraft Installation and Operation of an Extinguishing Agent Concentration Recorder," dated September 1959.

General guidelines are provided in this report for the conduct of a meaningful test program; however, care must be taken to treat each aircraft system individually. Each system tested will present particular problems or new applications not common to previous programs. Aircraft mission, nacelle cooling methods, internal nacelle compressor interstage airbleed, engine configuration and type, extinguishing system design, and aircraft flight envelope and performance characteristics are some of the many variables which must be treated as an integrated unit for the proper evaluation of an aircraft system. In addition to the testing of prime powerplant fire-extinguishing systems, the equipment and basic methods have also been utilized for testing of aircraft fire-extinguishing systems for auxiliary power units (APU), wheelwell areas, control bays, and cargo compartments.

Description of Equipment: The agent concentration recorder equipment consisted of a recording oscillograph, a vacuum pump, a control unit, 3 gas analyzer units, and 12 agent sampling probes. One typical model of equipment, the GA-2A, is shown in Figures 1 and 2. The vacuum pump was used to draw the gas samples from the nacelle through the sampling probes to the analyzer units. The analyzer units were thermally insulated and temperature regulated at 250°F and were the core of the analyzer. A typical analyzer cell within the analyzer unit is shown in Figure 3. From the sampling probe, the gas sample passed through the temperature-regulating, porous metal plug where a common temperature was achieved for all the cells. The sample then passed through the second porous metal plug, across which a pressure drop occurs as a function of the viscosity and volumetric flow rate of the gas. The pressure drop was sensed by the transducer assembly, and the resulting transducer output was transmitted to the recording oscillograph. Finally, prior to being exhausted through the vacuum manifold, the gas sample passed through the critical flow orifice. Proper operation of the analyzer was dependent upon the maintenance of critical flow through this orifice. The gas analyzer was calibrated for all commonly used extinguishing agents.

DISCUSSION

Guidelines for Installation and Location of Extinguishing Agent Sampling Probes

Probe Location: An important factor in the conduct of a meaningful test program is the proper installation and location of the agent sampling probes. Since the existing concentration recorders make use of a maximum of 12 probes, careful consideration must be given to the selection of areas to be sampled in order to provide a maximum of useful

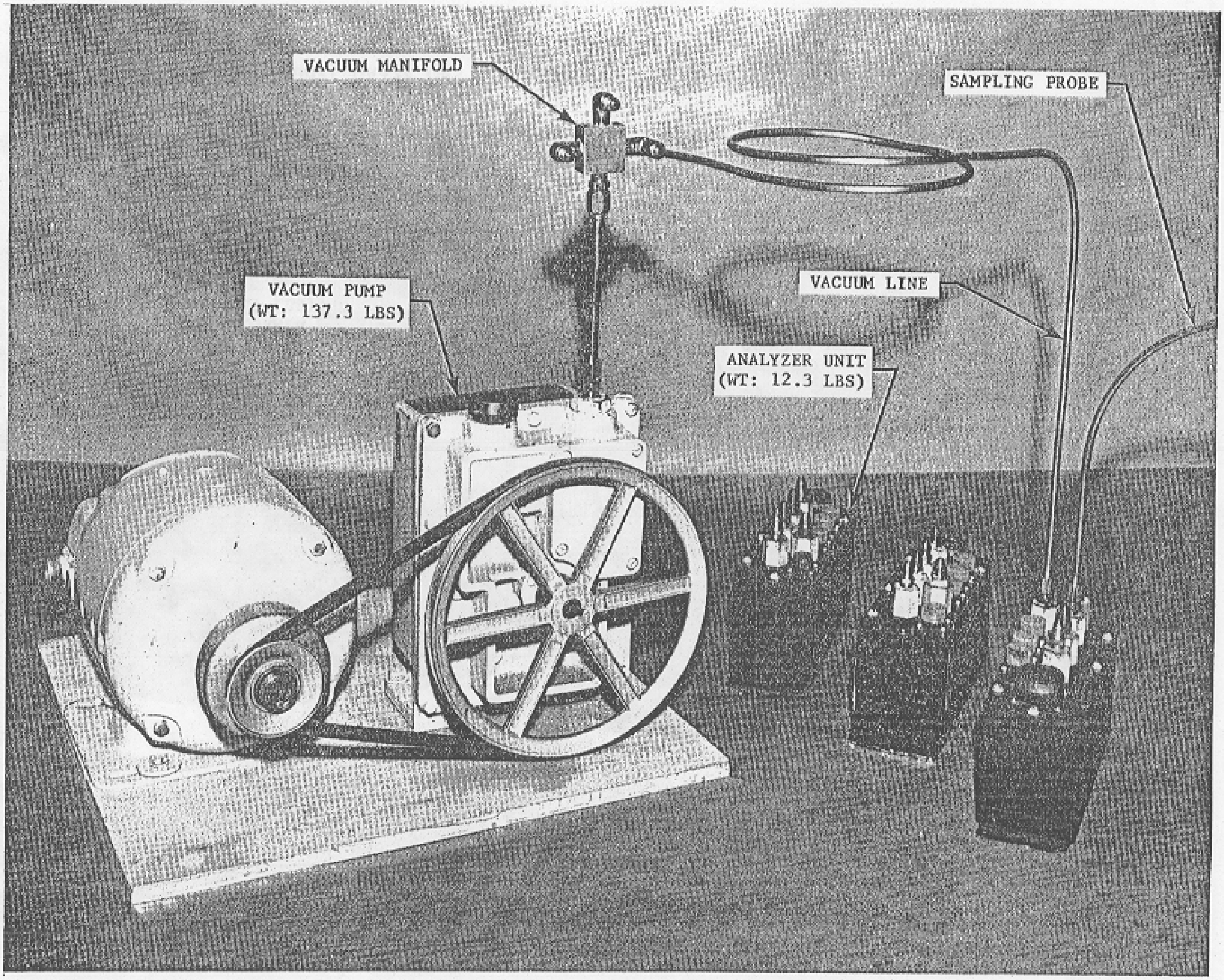


FIG. 1 MODEL GA-2A GAS ANALYZER UNITS AND VACUUM PUMP.

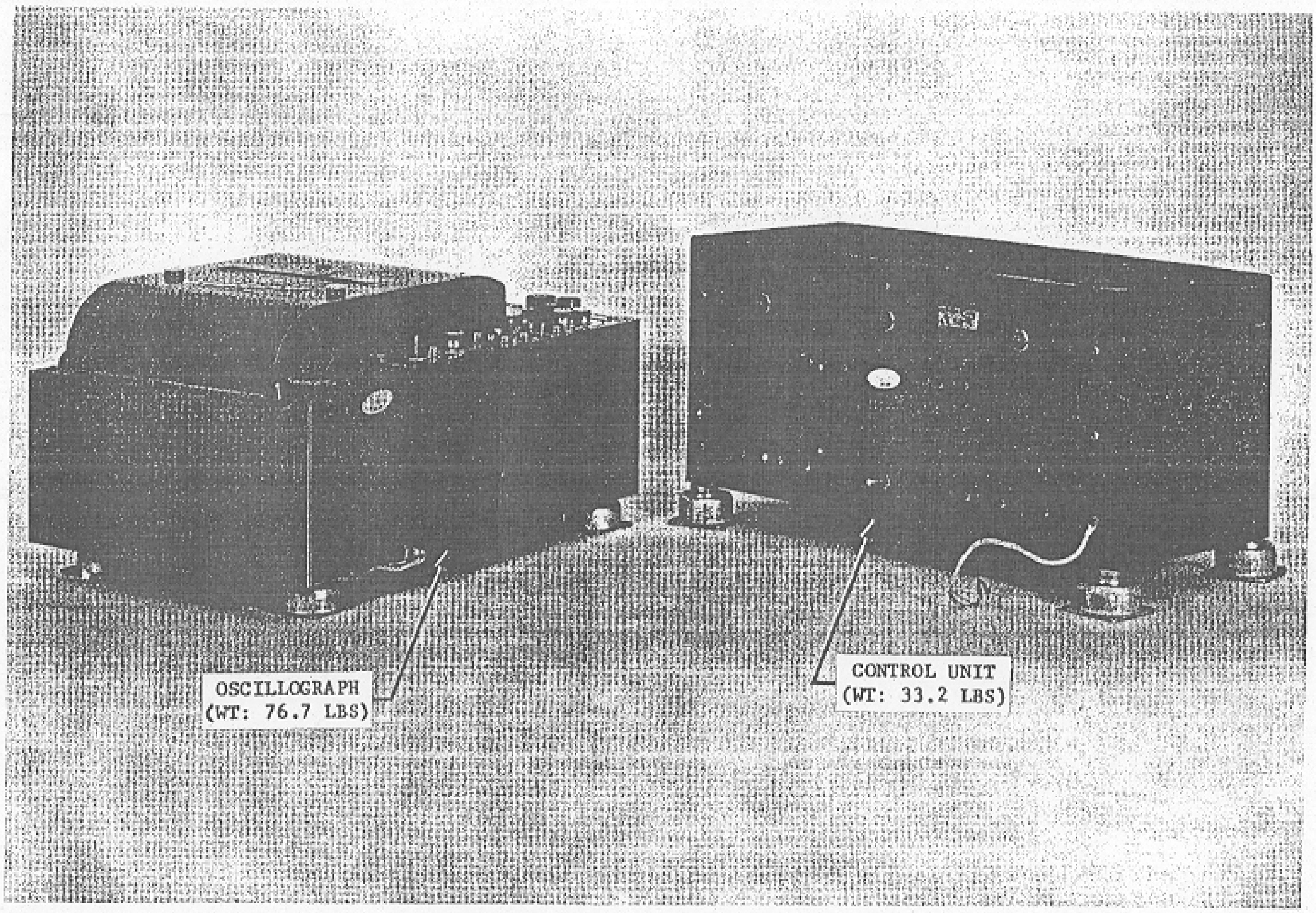
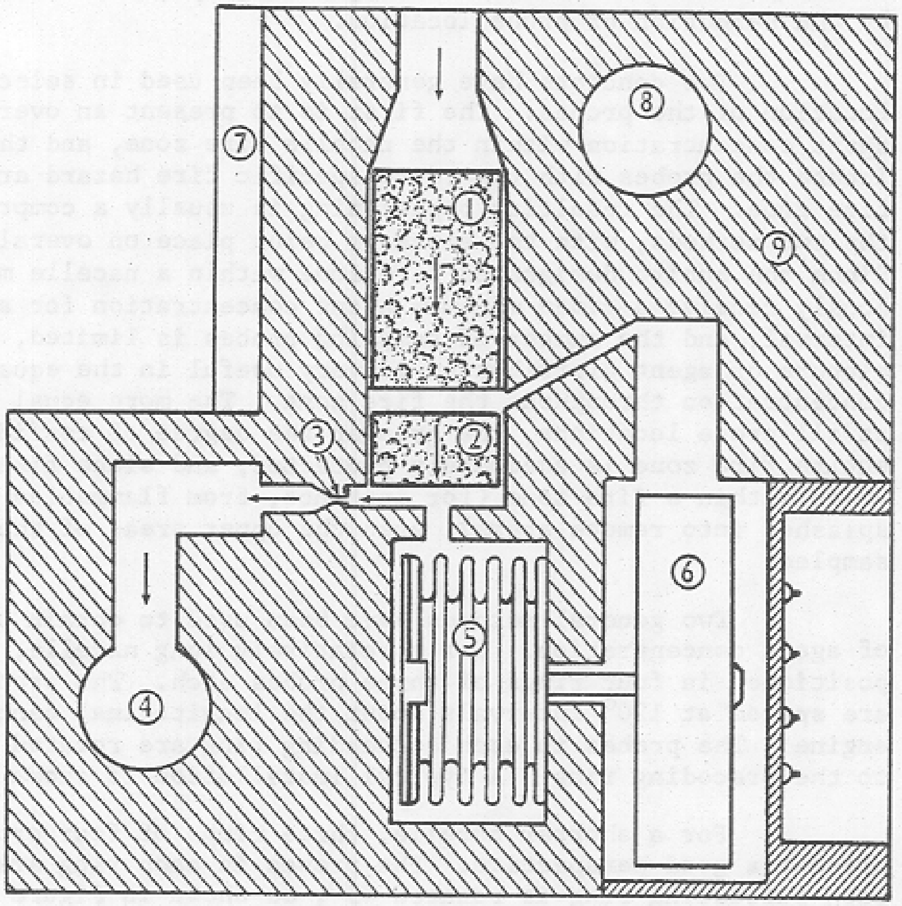


FIG. 2 MODEL GA-2A GAS ANALYZER CONTROL UNIT AND OSCILLOGRAPH



1 - TEMPERATURE-REGULATING POROUS PLUG
2 - PRESSURE-DROP POROUS PLUG
3 - CRITICAL FLOW ORIFICE
4 - VACUUM MANIFOLD
5 - PRESSURE-SENSITIVE BELLOWS } TRANSDUCER ASSEMBLY
6 - STRAIN GAGE
7 - HEATING ELEMENT
8 - THERMOSTAT TEMPERATURE CONTROL
9 - METAL BLOCK

FIG. 3 TYPICAL GAS ANALYZER CELL

data per test, and also to provide a complete program composite for the judgment of overall system performance. The expeditious development of an acceptable aircraft fire-extinguishing system can also be influenced by the selection of probe location.

Two concepts have generally been used in selecting the location of the probes. The first is to present an overall picture of agent concentration within the nacelle fire zone, and the second is to locate the probes with regard to specific fire hazard areas within the fire zone. The resulting positioning is usually a compromise between the two methods, with the emphasis being place on overall concentration. Since the entire designated fire zone within a nacelle must simultaneously receive a given minimum agent concentration for a specified time interval, and the number of sampling probes is limited, a composite picture of agent distribution is very useful in the equalization of concentration throughout the fire zone. The more equal the concentration at all probe locations, the greater the degree of confidence that the entire fire zone is adequately protected, and since fire may occur anywhere within a fire zone (for instance, from flammables sprayed or splashed into remote areas), even the upper areas of the zone should be sampled.

Two general methods have been used to obtain overall pictures of agent concentration. For a relatively long nacelle, probes are positioned in four rings of three probes each. The probes in each ring are spaced at 120° intervals about the longitudinal centerline of the engine. The probes in each succeeding ring are rotated 60° with respect to the preceding ring. A typical installation is shown in Figure 4.

For a shorter nacelle, three rings of four probes each will present a good perspective. The probes in each ring are 90° apart and each succeeding ring is rotated 45°, as shown in Figure 5.

Many variations of these methods are possible. The positioning may start with any ring or any angular location. Also, by deviating slightly from the ring station location, or the suggested angular positioning within the rings, or by varying the radial distance, many specific fire hazard areas may be investigated without disrupting the overall coverage.

The investigation of specific fire hazard areas and areas of expected low concentration is important for a proper evaluation and should be given consideration when locating the probes. Examples of such areas within an engine nacelle or APU compartment are areas where flammables might collect in the event of spillage, recessed areas, areas of expected high airflow, areas remote from agent discharge nozzles, electrical or hot surface ignition sources areas, and areas adjacent to fuel lines and couplings. Examples of specific areas in a wheelwell are those adjacent to flammable fluid lines that could be severed by shredded portions of a rotating tire or, in the event of a brake overheat and tire ignition, areas adjacent to the tires.

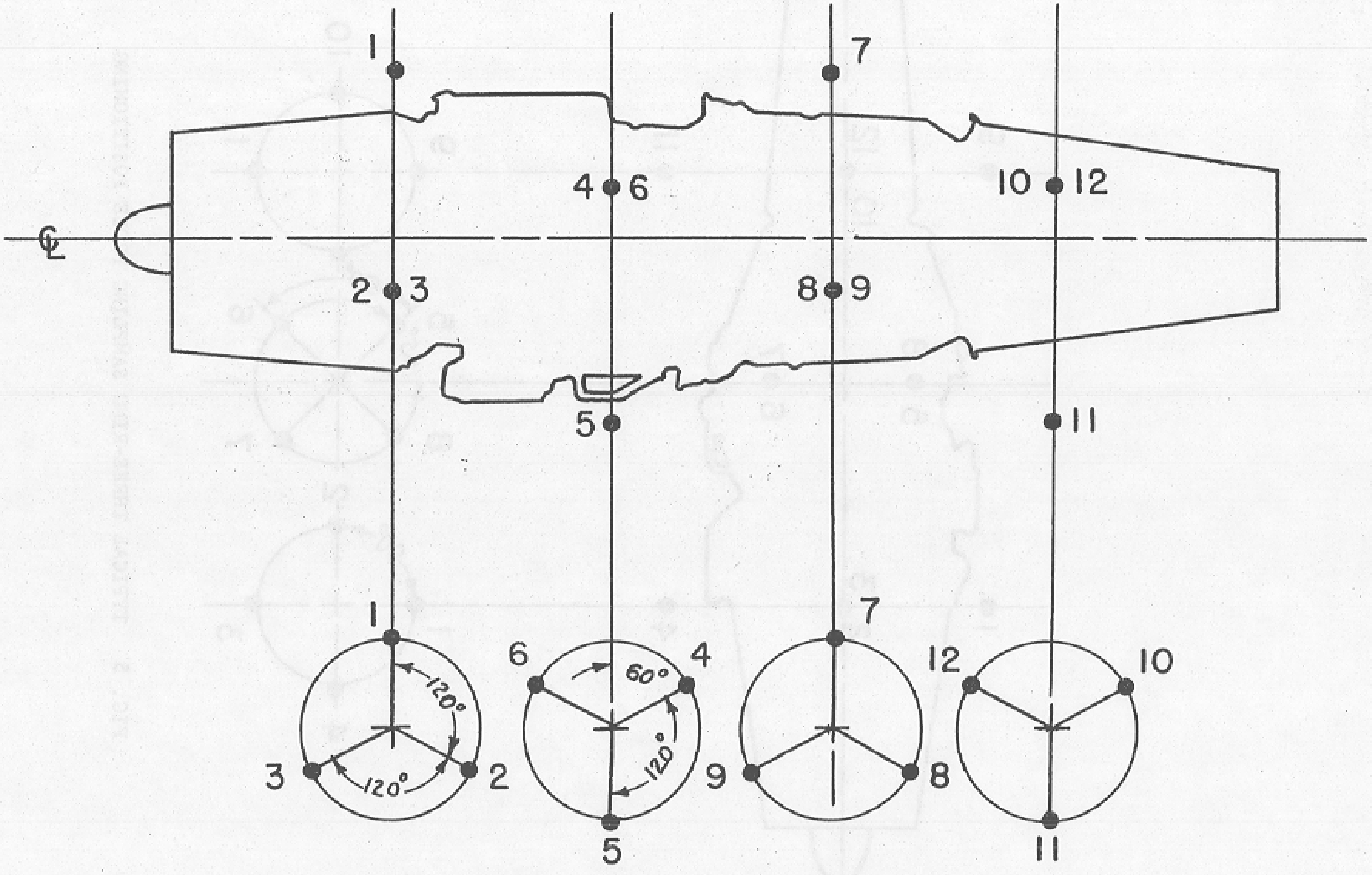


FIG. 4 TYPICAL FOUR-RING SAMPLING PROBE POSITIONING

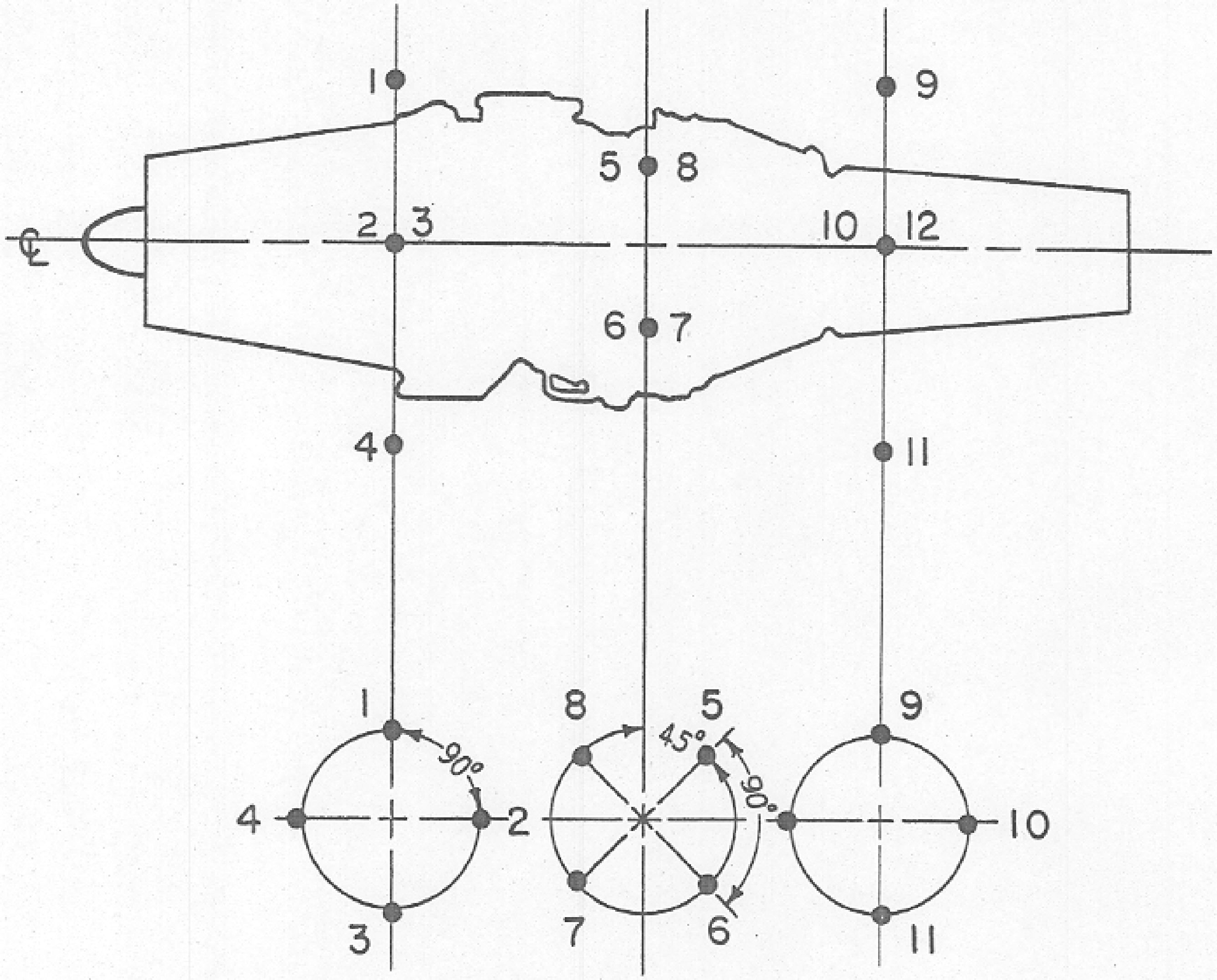


FIG. 5 TYPICAL THREE-RING SAMPLING PROBE POSITIONING

Since the equipment described was limited to 12 probes per test, aircraft with extremely large nacelle fire zones or aircraft with several related fire zones to be tested may require relocation of the initially installed probes or installation of supplementary probes and the conduct of duplicate tests under the condition demonstrated to be the most adverse during the course of the program.

Probe Installation: A number of guidelines should be observed during the physical installation of the probes. The probes, which are 1/4-inch-outside-diameter open-end tubes, should preferably be either copper or aluminum. Copper is more commonly used due to its greater flexibility in initial routing and coiling, and subsequent rerouting, recoiling, and relocating which may occur during a program. The length of the probes from the analyzer units to the terminal ends within the test area should be kept to a minimum to avoid excessive pressure drops and loss of critical flow at the critical flow orifices in the analyzer units. Additionally, the wall thickness of the sampling probe tubing should be as small as possible (0.030 inch or less).

All probes must be of the same length to allow identical flow times from the nacelle to the analyzer units. Therefore, the length of the longest probe should be determined first, and then all other probes should be cut to this length. Coiling of the excess tubing will then be required for the majority of the probes, particularly in a large nacelle where there is a long distance between the probe locations closest to and farthest from the analyzer units. This differential may be kept to a minimum by careful consideration of available probe routing. The coiling of excess tubing should be accomplished outside the nacelle to avoid disruption of actual airflow and agent distribution. The coils should be of as large a diameter as practical to minimize line losses.

Within the nacelle, the probes should be clamped or tied securely to the nacelle or engine at several points to prevent shifting during the program, and particularly during a flight test program. If shifting does occur, misinterpretation of data can result. Shifting of the tubing could also cause interference with moveable engine controls or chaffing of flammable or electrical lines. If practical, the probe should be firmly secured as closely as possible to the free end. The open ends of the probes should be several inches from any object that might cause probe blockage or flow obstruction when the vacuum pump is operating. These clearances and the probe positions should be checked at intervals throughout the program.

The open ends of the probes should be positioned normal to the local airflow or the expected local airflow to sense the static pressure. If located close enough to an agent discharge nozzle to be more influenced by pressures from the agent stream than from the local airflow, the probes should be positioned normal to the agent flow.

Positioning the open ends parallel to and facing downstream of the flowing gases necessitates a 180° turn of the gases prior to probe entry, and with the flow velocities existing in a high-rate discharge system or a high-performance aircraft nacelle, erroneous concentration versus time indications may result. Conversely, probes facing directly into a discharge stream may result in erroneous concentration versus time readings due to gas compression within the probe. The closer the probe end to the agent discharge nozzle or source of airflow, the more severe will be the effect.

When installing the probes, and throughout the program, line obstructions and contamination must be avoided. Prior to connecting the probes to the analyzer units, the open ends of the probes must be deburred and the lines cleared with high-pressure dry air or nitrogen. If, during the course of the program, there is a possibility that moisture, fuel, oil, or other contaminants have entered the probe lines, they must be disconnected from the analyzer units and cleared. No high-pressure gas used for clearing must enter the analyzer units. Short radius bends and sudden reversals in line direction should be avoided, and tubing crimped during installation, in course of the program, or in shifting to a second nacelle should be replaced.

Numbered tabs or tape should be placed approximately 4 inches from both ends of each probe to insure proper identification in the event the probes are disconnected from the analyzer units or moved during the program. Misidentification of a probe's location will create confusion in data interpretation during system development. Finally, after probe positioning is completed and before the first test, photographs should be taken of each probe's location and a careful dimensional record (including clock position and in which direction the open end points) should be made to assure that the exact duplicate positioning will result if the probes are moved or future additional tests are required.

Importance of Distribution System Conformity on System Development and Subsequent Production Installations

Throughout the test period and at the termination of the program, careful records of system configuration and conformity must be maintained to insure a successful program. During the program, each system change should be documented. This documentation is necessary for correlation with the test data to air in system development and to properly evaluate overall final system performance. Also, in the course of a development program, a specific system may be developed to its maximum potential without achieving acceptability, and a detailed record of past changes and results may allow logical "backtracking" to a more favorable configuration.

When an acceptable system is obtained, a complete photographic record and exact dimensioning of the system should be made by the company and substantiated by the cognizant agency or service prior to disturbing the system in any way. All system line lengths and diameters, fittings, orifice sizes, and discharge nozzle or outlet configurations should be recorded. Specific attention should be given to the spatial angular positioning of all agent discharge nozzles, particularly those located adjacent to a distribution line connection or fitting that might cause an angular nozzle change if loosened.

If requirements are such that only one nacelle of a multiengine aircraft is to be tested, an extinguishing system layout should be prepared for the other nacelle(s), and a determination made of whether the acceptable system will fit in the other nacelle(s) with regard to routing, attachment points, nozzle angles, and engine or nacelle obstructions. In general, different production manufacturing jigs will be required for opposite nacelles. Care must be taken that the same relative nozzle angles are used for each nacelle. In one case, an approved left-hand nacelle system was found to be installed in the right-hand nacelles of a number of production aircraft, thus creating an untested right-hand system.

For production design purposes, any agent distribution system connections or fittings which could influence the position of the agent discharge nozzle or outlet should be indexed, keyed, fixed, or somehow position identified so that exact conformity will result on every production installation with respect to the test installation. Another important consideration with regard to production system design is field or user maintenance relative to system disconnection, removal, and reinstallation. In general, personnel not intimately associated with the development program are not aware of how critical nozzle angles or positions are for duplication of test results. Thus, it is of additional significance that the production system nozzle orientation be clearly designated.

Several points regarding system development and subsequent production design which have been observed during past test programs can be of benefit to future programs. For instance, in several cases, when systems developed during test programs have been installed in production aircraft, various agent distribution lines have been used as steps or handholds by maintenance personnel. This practice can lead to changes in conformity of individual aircraft systems. Several companies have had to provide sheet metal line covers and "NO-HANDHOLD" markings.

Next, to facilitate and expedite a program, aluminum agent distribution lines may be used for test and development purposes. The aluminum tubing is much more easily worked and modified than the production stainless steel lines. Care must be taken, however, that the production stainless steel lines have the same inside diameters and the same general flow coefficients as the aluminum lines used in the development.

Another point, commonly overlooked, is the adaptability of a test system to mass production. This is particularly evidenced in welding and tube joining. For instance, where two tubes are joined by welding, such as a main line and branch line, provision must be made for cleaning the interior of each line of any weld material at the tube junction. If this is not accomplished, weld material which has run internally may effectively change line diameters and create line obstructions which alter agent distribution. Cleaning and inspection should also be carefully controlled during the development program.

Finally, it is imperative that production and design personnel have continued contact with the cognizant test program personnel, and notify the test personnel of even the slightest alteration proposed for the system. Posttest changes have been observed in system attachment points, nozzle angles, and routing for such reasons as nacelle configuration changes, clearances, and convenience.

Factors Which Influence Agent Distribution and Concentration

Agent distribution and concentration are affected by many factors such as secondary airflow, nacelle configuration, engine configuration, compartment obstructions, and ambient environmental conditions. Since the majority of these contributing factors is generally in a state of flux when aircraft are in the experimental or prototype stage, the extinguishing system tests should be scheduled as late as possible in the certification or acceptance program. The tests should definitely be scheduled after the final nacelle cooling configuration has been determined. A number of systems have had to be retested at later dates due to nacelle cooling airflow changes. If any changes are under consideration, additional tests should be conducted in conjunction with the regular program in order to indicate the possible effects of the changes. Data thus obtained may be used to substantiate a change without further extinguishing system tests at a later date.

One factor which has a pronounced effect on agent concentration and distribution is the discharge of turbine engine compressor interstage bleed air into a nacelle. The effects of this discharge air must be carefully investigated when testing extinguishing system performance. Various engines have differing bleed band or bleed port opening and closing schedules, and these schedules must be considered with regard to bleed airflows existing during extinguishing system discharge. In general, for engines of this type, the bleed air device will be fully open when the extinguishing system is discharged, and appreciable airflow can be introduced into the nacelle. In some aircraft, bleed air discharge into the engine compartment can be over 2 pounds per second during extinguishing system activation. Under the proper compressor discharge conditions, nacelle secondary airflow can completely reverse;

that is, normal nacelle ventilating air inlets can become outlets. A typical example of the effect of compressor bleed air upon system performance is presented in Figure 6. The two tests illustrated were conducted on the ground with the aircraft parked; thus, the effects of bleed flow are isolated at each of the 12 sampling probe locations.

Note should be made that during several system development programs, the compressor interstage bleed air has been used very effectively to aid in distribution of $CBrF_3$ agent, which is normally a gas following nozzle discharge and, thus, lends itself readily to mixture with the bleed air. CBr_2F_2, which is generally a liquid at discharge, can better penetrate and carry through the blast of compressor discharge air.

Another factor which has a pronounced effect on agent concentration and distribution, and one which is generally not given proper consideration during aircraft fire-extinguishing system testing, is the adverse influence of low environmental temperature on the performance of a system using gaseous nitrogen as a propellant. The low temperatures may be the result of either high-altitude flight or winter ground conditions. The primary cause of decay in system performance is attributed to the drop in pressure within the agent storage containers in a low-temperature environment. This pressure drop, coupled with distribution system line losses, can radically affect agent distribution. The majority of aircraft tested have had their containers mounted in spaces that may be subjected to low-ambient-temperature conditions. Test programs have generally been conducted in moderate (above $30^{\circ}F$) temperature environments, and the more marginal the results under these conditions, the more questionable will be the system performance at an extremely low ($-65^{\circ}F$) ambient temperature. While testing at low temperature has been very limited, some comparative data have been obtained for $CBrF_3$ and CBr_2F_2. Comparative data were obtained for both agents by discharging them through an aircraft's system at approximately $50^{\circ}F$ ambient temperature, then repeating the discharge through the same system after the containers had been cooled overnight to $-60^{\circ}F$. Typical test results are presented in Figure 7 for $CBrF_3$, which illustrates the change in concentration at each of the 12 probe locations. Similar results are presented for CBr_2F_2 in Figure 8. Both sets of data were collected with engine operating on a test stand and agent containers and plumbing installed in a wing section above the nacelle as in the production aircraft. At discharge, container temperatures had risen to $-40^{\circ}F$. The data indicate that low temperature has a more adverse effect on $CBrF_3$ distribution. This set of data was a limited, exploratory by-product of a standard evaluation program, and care must be used in application of the results. The data are presented only as a general indication of the influence of low temperature on agent distribution. Additional low-temperature environmental data were gathered during a more comprehensive FAA test program and are presented in FAA Final Report No. NA-69-26, (DS-68-26) entitled "An Investigation of In-Flight Fire Protection with a Turbofan Powerplant Installation," dated April 1969.

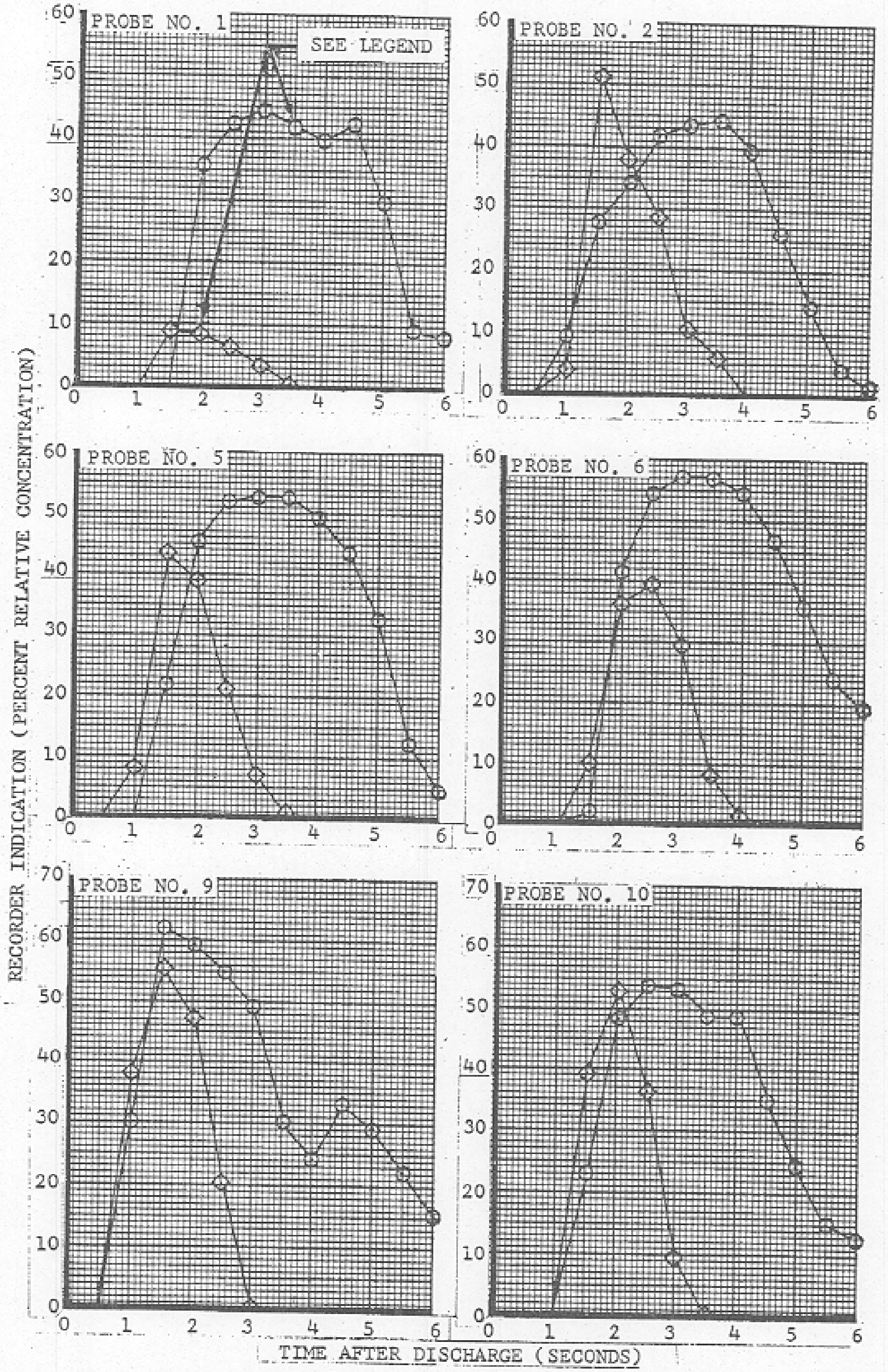
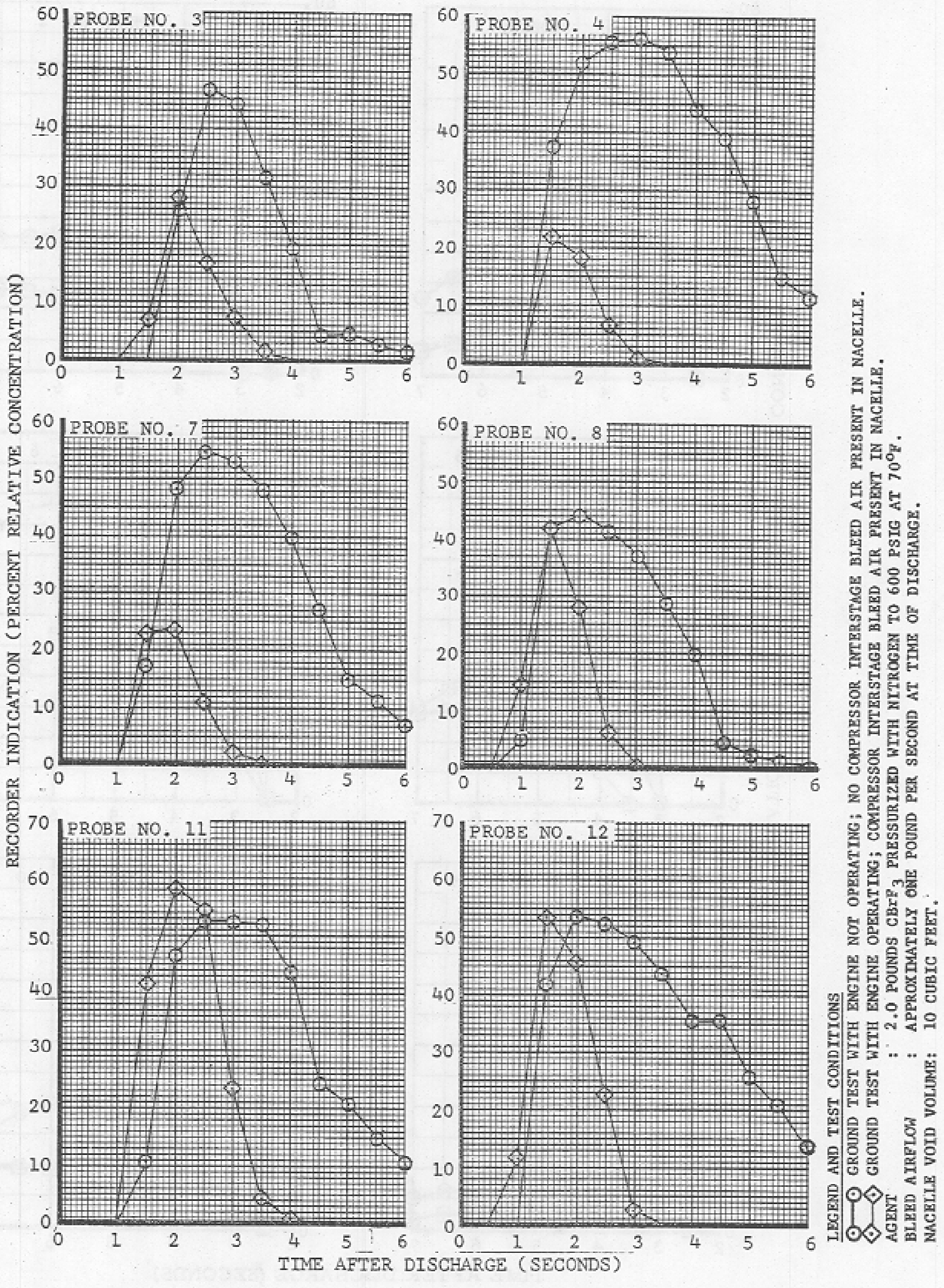


FIG. 6 TYPICAL EFFECT OF TURBINE ENGINE COMPRESSOR INTERSTAGE BLEED AIR UPON PERFORMANCE OF ENGINE COMPARTMENT FIRE-EXTINGUISHING SYSTEM USING CBrF$_3$



LEGEND AND TEST CONDITIONS

⊙—⊙ GROUND TEST WITH ENGINE NOT OPERATING; NO COMPRESSOR INTERSTAGE BLEED AIR PRESENT IN NACELLE.

◇—◇ GROUND TEST WITH ENGINE OPERATING; COMPRESSOR INTERSTAGE BLEED AIR PRESENT IN NACELLE.

AGENT : 2.0 POUNDS $CBrF_3$ PRESSURIZED WITH NITROGEN TO 600 PSIG AT 70°F.

BLEED AIRFLOW : APPROXIMATELY ONE POUND PER SECOND AT TIME OF DISCHARGE.

NACELLE VOID VOLUME: 10 CUBIC FEET.

FIG. 6 (CONTINUED)

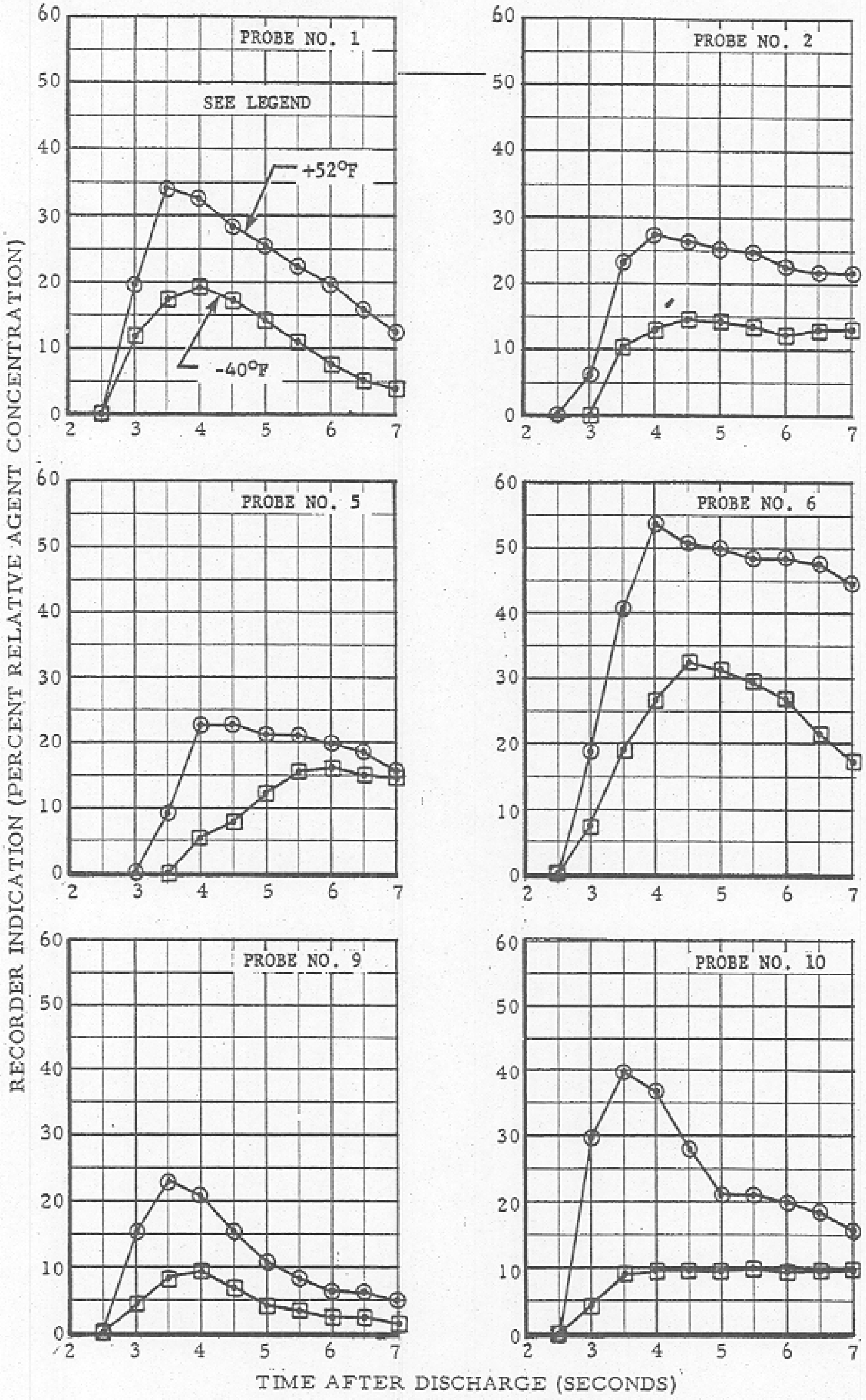


FIG. 7 EFFECT OF LOW TEMPERATURE STORAGE OF AGENT CONTAINER UPON PERFORMANCE OF ENGINE COMPARTMENT FIRE EXTINGUISHING SYSTEM USING $CBrF_3$

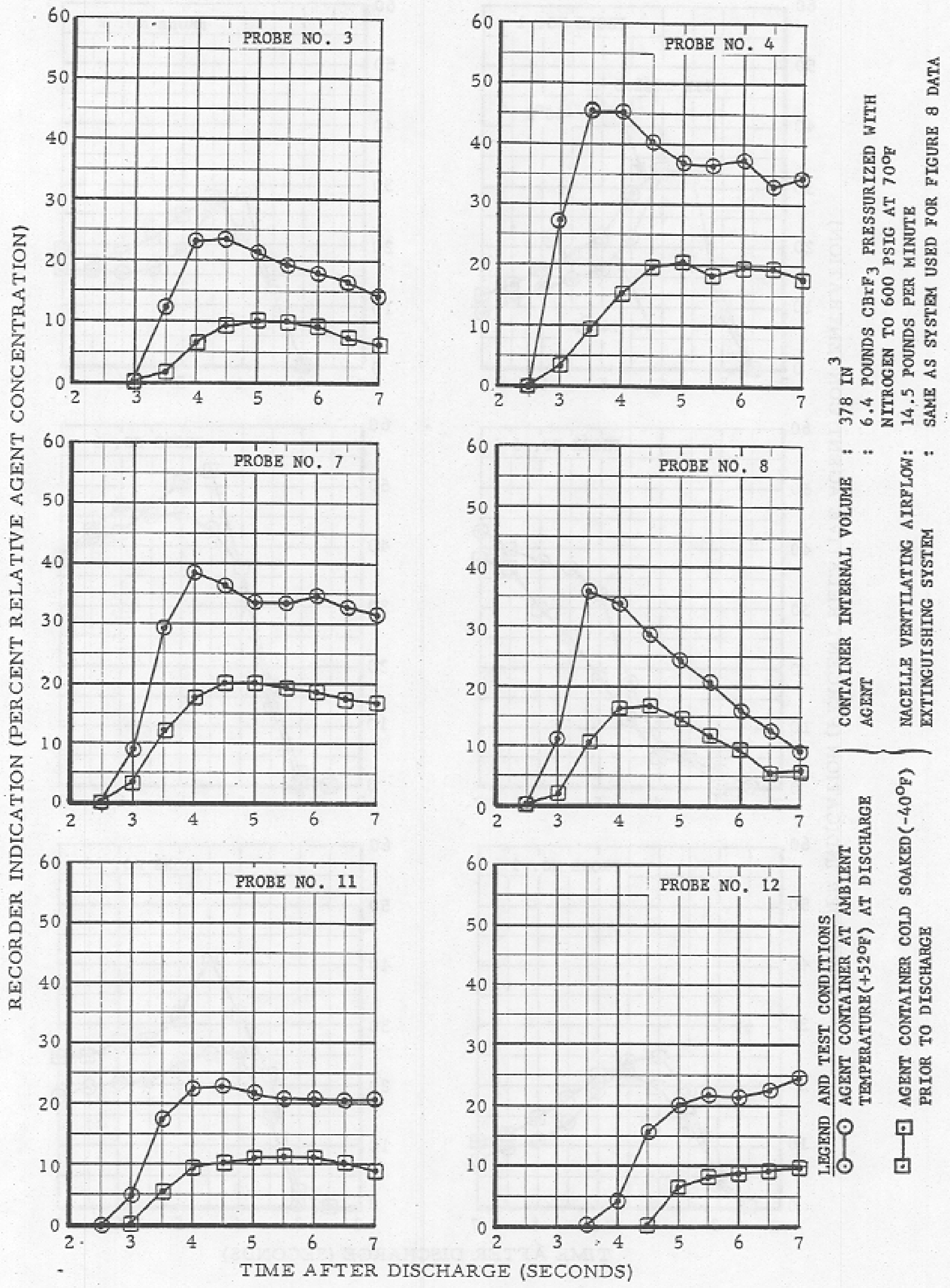


FIG. 7 (CONTINUED)

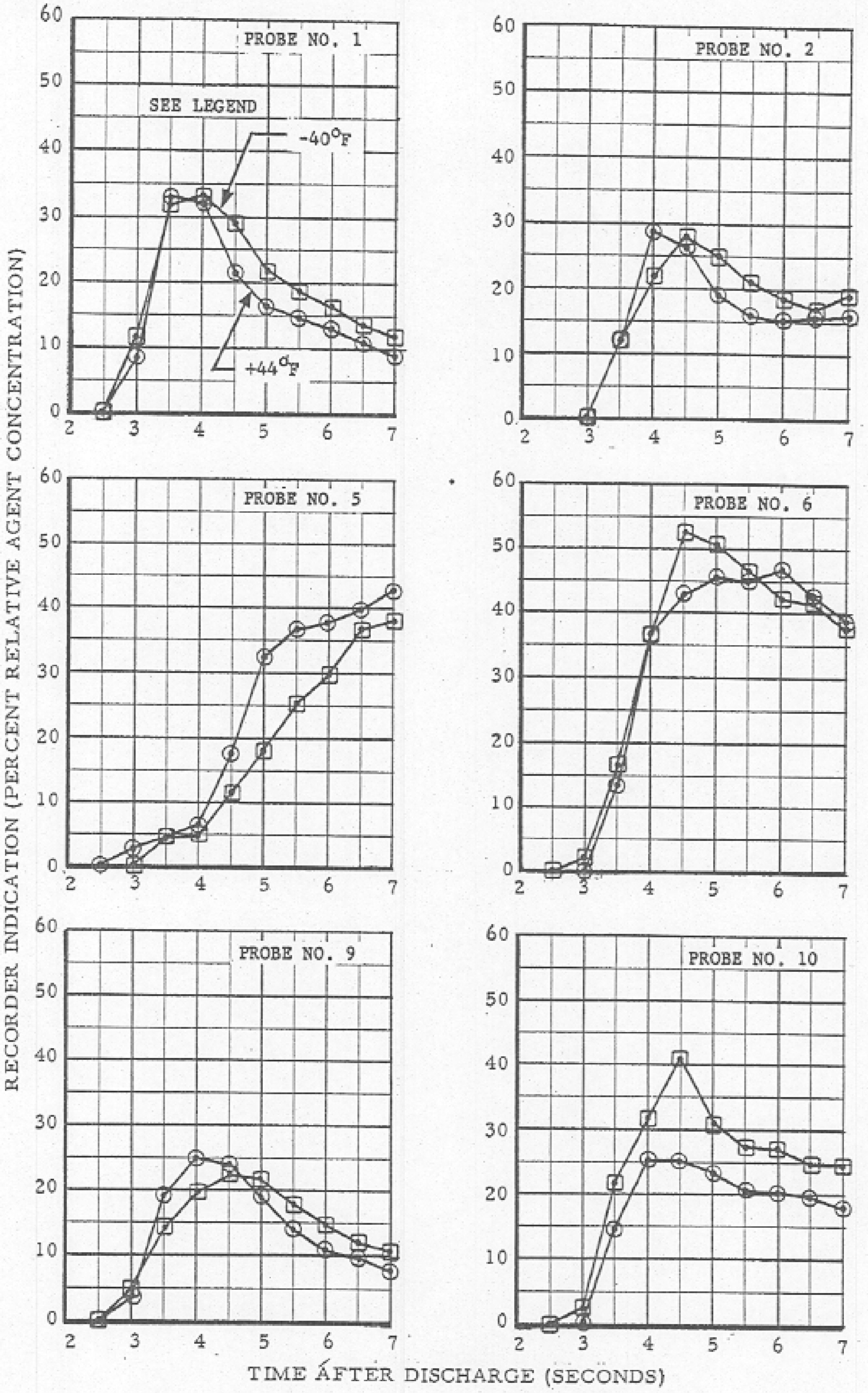


FIG. 8 EFFECT OF LOW TEMPERATURE STORAGE OF AGENT CONTAINER UPON PERFORMANCE OF ENGINE COMPARTMENT FIRE EXTINGUISHING SYSTEM USING CBr_2F_2

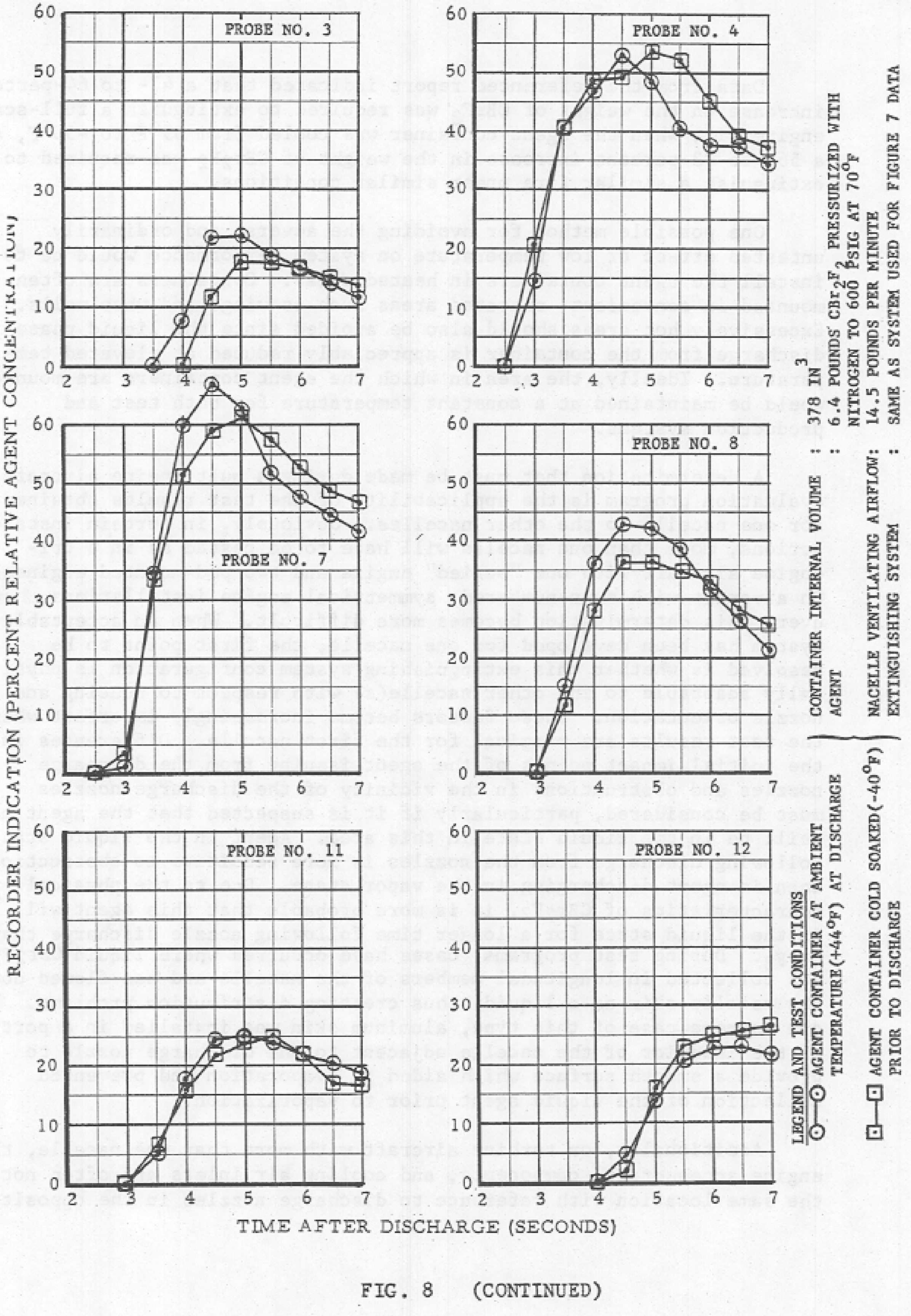


FIG. 8 (CONTINUED)

Data from the referenced report indicated that a 47- to 64-percent increase in the weight of $CBrF_3$ was required to extinguish a full-scale engine fire when the agent container was cooled from 59°F to -50°F, and a 56- to 73-percent increase in the weight of CBr_2F_2 was required to extinguish a similar fire under similar conditions.

One possible method for avoiding the adverse and ordinarily untested effect of low temperature on system performance would be to install the agent containers in heated areas. Containers are often mounted in convenient, unheated areas such as wings and wheelwells. Excessively hot areas should also be avoided since the liquid phase discharge from the container is appreciably reduced at elevated temperature. Ideally, the area in which the agent containers are mounted would be maintained at a constant temperature for both test and production systems.

A determination that must be made during a multiengine aircraft evaluation program is the applicability of the test results obtained for one nacelle to the other nacelles. Obviously, in certain installations, more than one nacelle will have to be tested as in a tri-engine aircraft with one "buried" engine and two pod-mounted engines. On aircraft with even-numbered, symmetrical engine installations, however, this determination becomes more difficult. When an acceptable system has been developed for one nacelle, the first point to be resolved is whether this extinguishing system configuration is physically adaptable to the other nacelle(s) with respect to routing and nozzle orientation. These factors become increasingly important when the test results are marginal for the first nacelle. Differences in the initial impact points of the agent issuing from the discharge nozzles and obstructions in the vicinity of the discharge nozzles must be considered, particularly if it is suspected that the agent may still be in the liquid state in this area. Agent in the liquid state following discharge from the nozzles is more sensitive to obstructions than is agent discharging in the vapor state. Due to the physical characteristics of CBr_2F_2, it is more probable that this agent will be in the liquid state for a longer time following nozzle discharge than $CBrF_3$. During test programs, cases have occurred where liquid CBr_2F_2 has collected in longitudal members of the nacelle and has flowed down the nacelle skin as a liquid, thus creating distribution problems. In one extreme case of this type, aluminum skin was installed in a portion of the interior of the nacelle adjacent to the discharge nozzle to provide a smooth surface which aided in evaporation and prevented collection of the liquid agent prior to vaporization.

Additionally, on turbine aircraft with more than one nacelle, the engine accessories, components, and cooling air inlets are often not in the same location with reference to discharge nozzles in the opposite nacelle. These location differences must be examined in light of their expected effect on distribution. Programs where more than one nacelle has been tested are very limited in number. However, of those programs where more than one nacelle was tested and where results for the first nacelle tested were marginal and duplication of results in the opposite nacelle was questionable, the majority has required system changes for the second nacelle. If, after careful consideration, it is decided that the other nacelle(s) should be tested, it is usually sufficient to test only the most adverse condition encountered during the testing of the first nacelle. When shifting the agent concentration recorder probes to a second nacelle, the procedure generally followed is that the probes are shifted with respect to the nacelle rather than to the engine. For example, a probe that is outboard (9 o'clock) in the left-hand nacelle would be in a corresponding outboard (3 o'clock) location in the right-hand nacelle. This method produces more comparable results and allows an analysis of overall concentration changes in the void volume of the nacelle. Occasionally, the same sampling tubes used for one nacelle will be used for testing the second nacelle, and a careful examination should be made to assure that the tubes have not been crimped during shifting.

Another factor which can influence agent distribution within a nacelle is the placement or location of discharge nozzles with respect to nacelle cooling air inlets and outlets. Cases have been experienced where discharge nozzles have been located directly in line with cooling air screens and louvers. Depending upon the distance from the nozzle to the screen or louver, the spread angle of the nozzle, the agent, and the area of the nacelle opening, all or a large portion of the agent issuing from that nozzle may be discharged overboard without adding to the extinguishing capability of the system. Therefore, the path of the agent discharge from each nozzle should be traced and, if necessary, adjusted to assure that maximum utilization is made of the total quantity of agent discharged into the nacelle.

An occasional and basically inadvertent factor which can influence agent distribution within a nacelle is the location of obstructions near the discharge nozzles on the test aircraft. Since the extinguishing system tests are conducted almost exclusively on experimental or prototype models of a particular aircraft, additional company test instrumentation and equipment are usually installed in the nacelle. Hence, a visual examination should be made for instrumentation harnesses, wire bundles, and measurement equipment on the test aircraft which will not appear on production aircraft but which may cause changes in agent distribution.

Flight or Ground Test Procedures and Conditions

Although specific test procedures and conditions will vary from aircraft to aircraft, a number of basic guidelines will be presented for general application. Each test program should be designed to realistically simulate the most adverse conditions under which the extinguishing system will be expected to perform.

One of the first considerations in establishing a test program is the designated engine fire-emergency procedure for the aircraft. Tests should be conducted using the proposed or specified fire-emergency procedures for each particular aircraft. If no procedure exists, one should be developed prior to test initiation. The tested procedure should then be specified in the appropriate section of the aircraft's flight manual. A typical fire-emergency procedure for a turbopropeller engine is as follows:

1. Engine power lever -- OFF
2. Engine fuel/oil valve -- OFF
3. Engine fuel boost pump -- OFF
4. Propeller -- FEATHER
5. Emergency "T-handle" -- PULL
6. Extinguishing agent discharge selector switch - BOTTLE 1 AND/OR BOTTLE 2

For test purposes, certain portions of designated procedures which do not affect agent distribution have been modified, eliminated, or only simulated if it was reasonably suspected that extensive test repetition of a specific phase of the procedure might cause engine damage.

With the present type extinguishing agent concentration recorder equipment, the normal calibration countdown (described on Page 28) should be adjusted and coordinated with the aircraft fire-emergency procedure to give near-maximum or higher than the normal secondary airflows expected in an actual emergency. Also, by initiating the emergency procedure at a specific point in the countdown and by coordinating each step in the remaining portion of the procedure with the countdown, repeatability of the test condition and lessening of test variables are assured. The rapidity of pilot reaction during planned tests, the practices emergency procedure, and the adjusted countdown will insure a positive safety margin with respect to severity of compressor bleed flows and other sources of nacelle secondary airflows with respect to an actual fire emergency.

Ground Test Condition: A series of ground tests is usually conducted during an extinguishing system evaluation program. Nacelle fires can and have originated on the ground, and they should be extinguishable with the aircraft's system. The importance of the ground test phase will vary with the type of aircraft and its mission. Certain civil transport aircraft, such as executive type and helicopters, as well as many types of larger military aircraft, have the capability and requirement to occasionally operate from airfields or landing areas with limited or no ground firefighting equipment. Even on a well protected airfield, costly damage can occur prior to arrival of ground firefighting units.

Several conditions may be used, individually or in combination, to establish ground system performance and to provide more comprehensive overall evaluation data. One of these conditions is the ground test with the aircraft parked and engine(s) not operating. This condition can be used to approximate system performance during a fire emergency occurring during an engine start. On certain nacelle/engine configurations, however, the bleed airflow and induced secondary cooling airflow developed during the engine start cycle will not be present. Of possibly more importance for overall system analysis and development purposes, this condition establishes a zero-flow baseline for more accurately determining the effects of airflow on system performance. It is also the condition which can be most exactly repeated with a minimum number of variables.

A second ground condition is that in which the aircraft is parked and the engine operating. Operating parameters are set so that maximum secondary airflow will be present in the nacelle. This secondary nacelle airflow may result from a number of areas such as compressor airbleed devices, auxiliary cooling blowers, engine ejector pumping, rotor downwash, or propeller flow. If no secondary airflow is created by operating the engine, this test is generally not conducted; however, heat generated by an operating engine does assist in vaporization of agent in certain circumstances. This test condition can also be used to isolate flight-induced flows from the engine-induced flows. Since flight test time is expensive, the ground system discharges are useful not only in providing applicable evaluation and development data, but also in uncovering test equipment or aircraft system peculiarities or faults prior to flight. Due to the fact that the ground tests are usually the least severe tests, only one or two such tests are generally made at the beginning of a program. If a number of development tests are required, the ground tests are usually eliminated from the development series and are not repeated until an acceptable system is achieved. Relatively isolated cases have occurred where the ground test condition has provided the least satisfactory agent distribution.

Flight Test Condition -- Fixed-Wing Aircraft: Four general flight conditions have been established for the testing of fixed-wing aircraft. The first of these, and the one most commonly used for system performance determination, is the maximum airspeed in level flight condition. This condition will normally present the maximum ram cooling air effect and generally establishes the low concentration limit of the extinguishing system performance envelope when coupled with the zero-flow ground test data curves. With the high-speed condition, normal test procedure following engine shutdown and agent discharge is to attempt to maintain a constant airspeed rather than a constant altitude.

The second and third conditions are approach and takeoff. These conditions have not been used to the extent of the level flight maximum speed condition in system evaluations. When they have been used, however, some systems have performed less satisfactorily in these conditions than in level flight. They should be considered in view of possible effects on systems performance due to such factors as aircraft attitude, engine power setting, and climb or descent rate based on the aircraft's climb or descent configuration. The takeoff and maximum airspeed conditions are generally considered to have the most severe fire potential due to high fuel flows, line pressures, temperatures, and airflows.

A fourth condition occasionally tested is a low- or loiter-speed condition. This condition can be used to validate the assumption that the maximum airspeed condition is the most severe level flight condition. The data points should lie between the zero flow and maximum airspeed data points. There have been cases where the higher airflows associated with the maximum speed conditions have actually assisted in the agent distribution. Also, at lower airspeeds, and consequent lower cooling inlet ram pressures, secondary airflows in a nacelle may change radically from the high-speed condition if factors such as bleed air-flows begin to dominate the ram airflows. While it is not practical to test all flight regimes during an evaluation, it has been found that the four specified conditions will present a satisfactory comprehensive picture of system performance.

Flight Test Conditions -- Rotary-Wing Aircraft: A number of basic flight conditions have been established for testing extinguishing systems in rotary-winged aircraft. The helicopter test programs, in general, have been more involved than those for fixed-wing aircraft. The specific flight profiles and missions of helicopters can create a greater variety of nacelle airflows than those of a fixed-wing aircraft. Rotor downwash, coupled with various climb and descent conditions, can cause changes in agent distribution. Cooling air screens or openings on the bottom of the nacelle may contribute low local flows in a forward flight condition, but in a high rate-of-descent condition they may cause high ram flows which can radically change agent distribution. Single-engine and multiengine helicoptors also present different problems. During a fire emergency, a multiengine helicopter may continue level flight, climb, hover, or descent with partial power, while a single-engine helicopter would normally begin an autorotative descent. Conditions tested during various helicopter programs have included the following:

1. V_{ne} (velocity never-exceed) in level flight
2. 0.4 V_{ne} in level flight
3. V_{ne} autorotation

4. Partial power descent
5. Transition from normal cruise in level flight to autorotation
6. Climb
7. Hover out-of-ground-effect

Additional Conditions and Considerations: While generalized flight and ground test conditions may be established for an aircraft based upon its type and performance, the specific program will depend on a combination of performance, nacelle ventilation configuration, and engine bleed characteristics, if bleed air is discharged into the nacelle. The engine bleed device opening schedule should be determined, and agent discharge should be made as soon after opening as possible to obtain the highest bleed airflows. For test purposes, a microswitch can be installed in the engine compartment and connected to an indicator light in the pilot's compartment to provide a visual positive indication of bleed device position. Test programs have been conducted where engine compressor bleed discharge has caused reversals in normal nacelle cooling airflow patterns in all test conditions; that is, all nacelle cooling air inlets, including generator ram cooling inlets, have become outlets following bleed band opening. Other cases have occurred where, at high forward speeds, bleed air has diminished but not overcome incoming ram cooling air. Then, at lower forward speeds, the bleed air has completely overcome the ram cooling air. The engine bleed air, therefore, can be an important factor in agent distribution and should be considered when establishing a test program.

There are a number of other possible sources of airflow within the nacelle which must be investigated for each specific aircraft. Exhaust of generator cooling air within a nacelle can contribute to relatively high local airflows. On a propeller-driven aircraft, propeller contributions to nacelle airflow should be considered. Since propeller feathering is normally accomplished as part of the fire-emergency procedure prior to agent discharge, no additive flows are produced; however, a pulsating-type nacelle flow may result as the propeller rotates in front of cooling air inlets. It is also possible for blade stoppage to occur directly in front of a cooling air inlet, thus altering normal cooling airflow.

During past programs, several aircraft with uncommon nacelle airflow sources have been tested, and are presented to indicate the variety of sources that can affect agent distribution. In one of these programs, nacelle cooling on the ground and at low flight speeds was accomplished by means of auxiliary blowers. As aircraft airspeed increased and adequate cooling could be achieved by ram flow, the blowers would shut down. Much higher nacelle airflows existed during ground- and low-airspeed conditions than on ram-cooled nacelles. Certain engine configurations can also create special test conditions. For instance, during testing of a nacelle containing a "reverse-flow" PT6A turboprop engine, fire protection was provided for the primary air inlet plenum section of the engine as well as the accessory and burner sections of the engine. Inlet plenum section protection was provided since flammable fluid lines from the accessory section to the burner section were routed through the inlet section. It was relatively difficult to obtain the required agent concentration in this section due to the high primary airflow.

Flight tests should be conducted at as low an altitude as is practical for the given test condition in order to obtain high secondary airflows. The majority of the extinguishing system flight tests has been conducted at pressure altitudes between 2,000 and 5,000 feet.

With the present type extinguishing agent concentration recorder equipment, flight tests should be conducted with the aircraft unpressurized so that the pressure differential between individual components of the instrumentation system is minimized. During wind tunnel utilization of the extinguishing agent concentration recorder equipment, with the system vacuum pump off, baseline calibration shifts have occurred when the sampling probes installed in the tunnel were exposed to lower static pressures than those which existed in the control room where the remainder of the system was installed. These shifts resulted in questionable data. The reasons for the calibration shifts were never fully determined; however, indications were that the overall system pressure differential had caused a system reverse-flow condition to exist. Similar large pressure differential conditions could exist during a flight test with the extinguishing agent concentration recorder equipment mounted in a pressurized cabin and the probes terminating in an unpressurized nacelle. This condition should, therefore, be avoided.

Also, during a flight test program, large changes in altitude should be avoided during the air calibration and agent discharge recording periods. Since the differential pressure drop across the equipment transducers as described in the "Discussion" section is a function of the ambient pressure of the gas sample, large altitude changes during test calibration and concentration recording periods can cause continuously varying differential pressure drops. These altitude-induced gas sample pressure changes can add to or subtract from the actual extinguishing agent concentration-induced pressure drops and can result in data which are erroneous and exceedingly difficult to correct. Maximum altitude changes are normally experienced in the descent test condition, particularly in helicopter programs. Altitude losses of approximately 1,800 feet have been experienced during the normal combined 20-second calibration and concentration recording periods when in full autorotation at 5,000-feet-per-minute rate of descent. Altitude changes greater than this should be avoided.

The critical concentration recording period normally ends 10 seconds after discharge, at which time agent concentration has usually peaked and then fallen below minimum required values. This 10-second period, plus the previous 10-second calibration period, should be examined for possible ambient pressure-induced errors if large altitude changes are involved. If possible, with altitude changes of 1,000 feet or more occurring during the calibration and concentration recording periods, a second air calibration should be made at the observed altitude through which the aircraft was passing 10 seconds after discharge. For longer test recording periods, the altitude for the second calibration should be adjusted accordingly. Care should be taken to allow sufficient time for the nacelle airflow to clear the nacelle of agent prior to obtaining the second calibration. The probes should also be cleared of agent by operating the vacuum pump. The first and second calibrations should then be compared and inspected for possible calibration shifts. The altitude loss must be reduced if large shifts are indicated.

For the majority of test conditions, the aircraft's airspeed, attitude, and any other pertinent factors which might influence distribution should be stabilized from the time of agent discharge until the recording period is completed. This lessens the agent distribution variables and increases the accuracy of data analysis. If a system development program is required, this also allows more exact test condition duplication which is very important for determination of the effect of system changes on overall system performance. In this respect, tests specified as level flight maximum velocity tests are normally accompanied by a planned altitude loss following engine shutdown in order to maintain the desired airspeed and nacelle airflows.

On occasion, APU and wheelwell compartments have been tested during the course of a program. APU compartment tests are conducted as ground tests, unless the APU is rated as "flight-operable." No special conditions are used for APU testing; however, the APU should be operated and the specific fire-emergency shutdown and discharge procedures should be followed. Any special features such as automatic sequencing of compartment ventilation shutoff devices and extinguishing system actuation should be tested under actual discharge conditions. Wheelwell tests are conducted with the landing gear retracted and the wheelwell doors closed, under the flight conditions normally associated with the takeoff. Particular attention should be given to the areas immediately adjacent to the tires where a fire due to brake overheat might occur, and to areas in the vicinity of the tires which contain flammable fluid lines that might be severed by a rotating shredded tire.

An additional factor which can affect agent concentration is the distribution line pressure losses between the agent container and the system discharge outlets. Tests should be conducted using the branch of the system's distribution lines that has the greatest line losses in order to obtain results representing the most adverse operating conditions. Line length, valves, fittings, connectors, and orifices should be considered when determining the losses. During system tests, it is important to use lines having losses equivalent to those that will occur in the production system.

Test Data: Form, Reduction, Interpretation, and Presentation

An important portion of each test program is the utilization of the test data obtained from the extinguishing agent concentration recorder. Individuals or organizations ultimately responsible for the acceptance or certification of an aircraft extinguishing system should be familiar with the fundamentals of the data phase of the program. The following data section is intended to convey a basic understanding of the type of data obtained, the reduction of the data to a useable form, general interpretation of significant factors, and the most comprehensive methods of presenting the data for evaluation purposes. Based upon past experience, this section contains the data phase information most commonly requested by organizations for which these tests have been conducted.

Data Form and Reduction: A typical flight test oscillograph record obtained by utilization of the extinguishing agent concentration recorder is presented in Figure 9. The 12 pressure transducer outputs, the agent container discharge indicator trace, 2 static reference traces, and pulsed timing trace are shown on this record. The polarity of 6 of the 12 oscillograph galvanometers representing the transducer outputs are reversed to allow maximum deflection within the width of the oscillograph paper. A normal test consists of a 10-second verbal countdown (equipment operator to pilot) between the start of the air calibration and the container discharge. Figure 10 illustrates the countdown sequence. At the count of "10," the oscillograph is activated, and since the vacuum pump is off and no flow exists in the system, a straight baseline is produced for each of the 12 differential pressure transducers. At the count of "5," the vacuum pump is activated, and each transducer presents a stabilized 100-percent air deflection. Generally, at the count of "3," the engine shutdown procedure is initiated. At the count of "0," the agent container is discharged, and the exact instant of discharge is indicated by the oscillograph's event marker. Within several seconds, depending on the time for the agent to reach the sampling probe and the sampling probe length, the traces will deflect additionally and indicate that a mixture of agent and air is passing through the transducer assemblies. The agent concentrations will peak, and the traces will normally return to their 100-percent air positions within 10 seconds after discharge in a flight test. In a flight test, therefore, it is important that the pilot maintains a stabilized flight test condition for at least 10 seconds after he discharges the agent. Longer recording periods will require longer condition-holding periods.

The air calibration procedure is repeated for each test. In addition to providing a continuous test-by-test calibration check, the calibration procedure also insures an immediate pretest check of equipment operation, thus allowing a halt to the test to be called if a malfunction is indicated prior to container discharge.

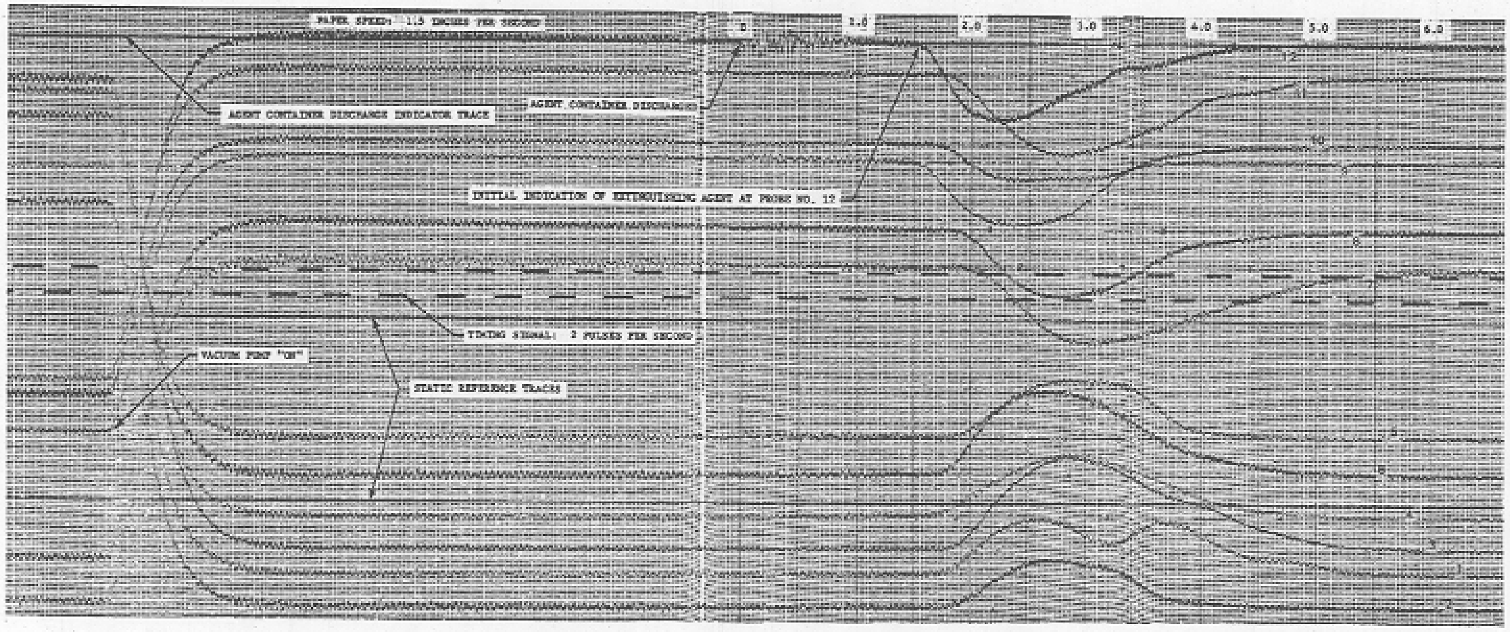
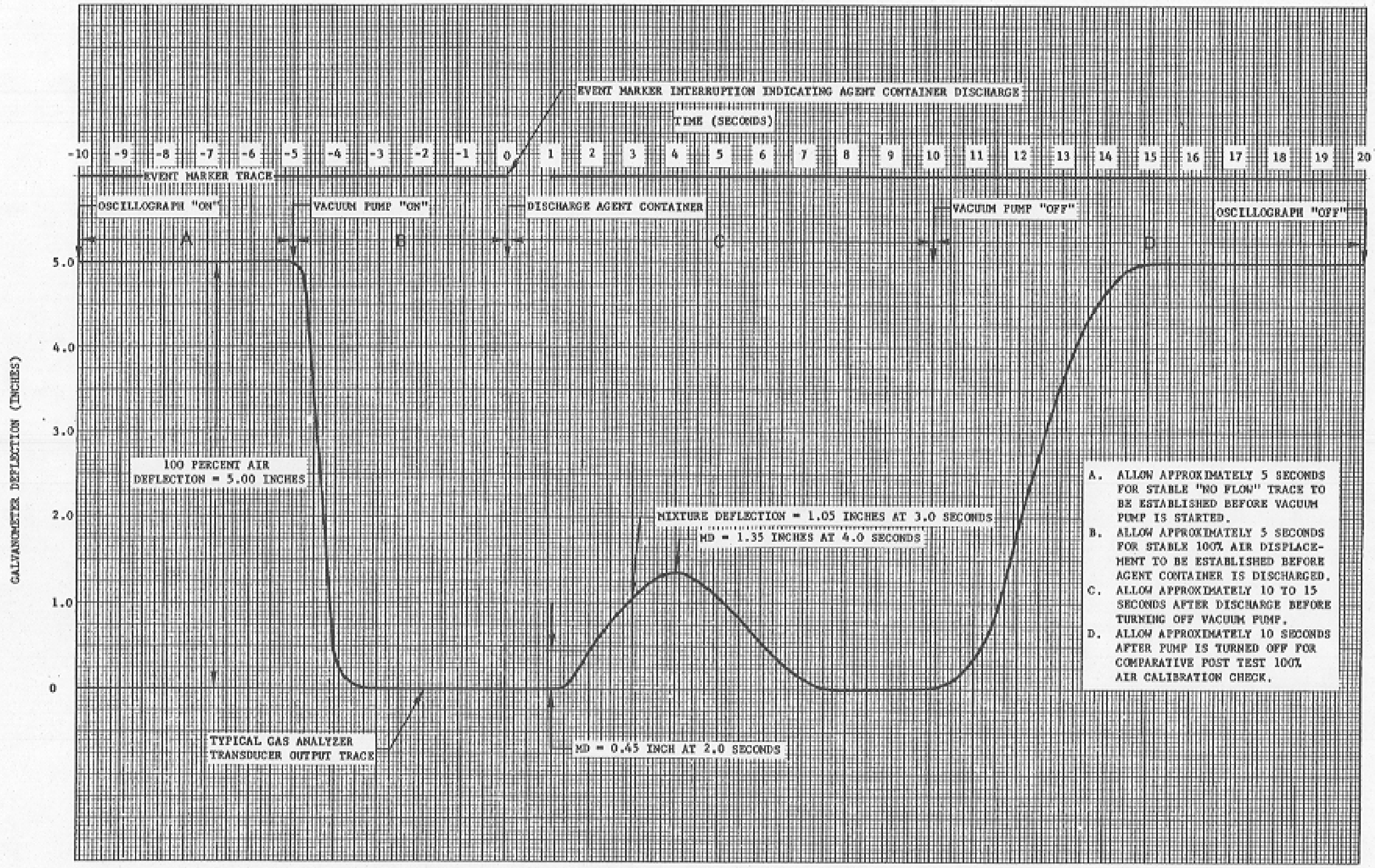


FIG. 9 TYPICAL FLIGHT TEST OSCILLOGRAPH RECORD



A. ALLOW APPROXIMATELY 5 SECONDS FOR STABLE "NO FLOW" TRACE TO BE ESTABLISHED BEFORE VACUUM PUMP IS STARTED.

B. ALLOW APPROXIMATELY 5 SECONDS FOR STABLE 100% AIR DISPLACEMENT TO BE ESTABLISHED BEFORE AGENT CONTAINER IS DISCHARGED.

C. ALLOW APPROXIMATELY 10 TO 15 SECONDS AFTER DISCHARGE BEFORE TURNING OFF VACUUM PUMP.

D. ALLOW APPROXIMATELY 10 SECONDS AFTER PUMP IS TURNED OFF FOR COMPARATIVE POST TEST 100% AIR CALIBRATION CHECK.

FIG. 10 GRAPHICAL REPRESENTATION OF TYPICAL TEST TRACE

Figure 10 illustrates a graphical representation of a typical test trace which will be used to demonstrate several agent concentration sample calculations. The percent relative agent concentration formula, as described in Technical Development Report No. 403, is:

$$RC = \frac{MD}{AD - (AD \times CR)} \times 100\%$$

where RC = percent relative agent concentration

MD = displacement of agent/air mixture from 100-percent air reference

AD = displacement of 100-percent air reference from static no-flow baseline

CR = calibration ratio for specific agent. For example purposes, assume monobromotrifluoromethane ($CBrF_3$) with CR = 0.401. For other agent calibration ratios, reference Technical Development Report No. 403.

For simplification of computation, this formula is rearranged to give:

$$RC = MD \times \frac{100}{AD\ (1 - CR)}$$

the term $\frac{100}{AD\,(1 - CR)}$ remains constant for each trace during each test and is calculated first. From Figure 10, AD = 5.00 inches and

$$\frac{100}{AD\ (1 - CR)} = \frac{100}{5.00\ (1 - 0.401)} = \frac{33.4\%}{\text{inch}}$$

The constant (33.4/inch) for this specific trace is then multiplied by the mixture defection at each time point at which concentration is desired:

RC at 2.0 seconds = 33.4/inch x 0.45 inch = 15.0%

RC at 3.0 seconds = 33.4/inch x 1.05 inch = 35.1%

RC at 4.0 seconds = 33.4/inch x 1.35 inch = 45.1%

The $\frac{100}{AD\ (1 - CR)}$ term must be recalculated for each of the 12 data channels. The percent relative agent concentration, as indicated by the recorder, may be converted to actual volumetric or weight percent by use of data contained in Technical Development Report No. 403.

Due to the repetitious operations required to calculate the value of $\frac{100}{AD\ (1 - CR)}$ for each data channel for each test, a computer printout was obtained for this parameter for the most commonly used agent, $CBrF_3$. This printout is presented in Table 1-I of Appendix A. In this table AD is represented by N, and values of AD are shown from 3.00 inches deflection to 6.99 inches deflection in increments of 0.01 inch. Corresponding values of $\frac{1}{AD\ (1 - CR)}$ are also given. These values must be multiplied by 100. This table is extremely valuable and time saving to those involved in data reduction or verification. A similar table for CBr_2F_2 would also be useful.

For the majority of tests, an adequate number of data points upon which to base an evaluation may be obtained by reducing the oscillograph trace at one-half second time intervals beginning with the instant of agent discharge as zero time. All channels must be reduced at common-time intervals; for instance, at 1.5, 2.0, and 2.5 seconds after discharge. When using one-half second data reduction intervals and an apparently acceptable system is obtained, the oscillograph record should be reexamined within the time intervals being used for the acceptance to determine if any unusual trace shapes are present. Occasionally, trace shapes change appreciably between one-half second reading intervals. Some systems that are marginal with respect to time may require deviation from the normal one-half-second data reading interval to show acceptability. No restriction is placed on timing, with the exception that the recommended minimum concentration is indicated at all probes simultaneously within a fire zone for the specified time period. In nacelles with several fire zones separated by an adequate firewall, each fire zone may be treated individually with respect to the "simultaneous" requirement. Since timing is a factor in system acceptance and since a variation in oscillograph paper drive speed could occur, it has been found very beneficial to record an accurate external timing pulse on the oscillograph record during each test. This may be accomplished by means of an intervalometer. A rate of 2 pulses per second has been found adequate.

Data Interpretation: A complete discussion of data interpretation is beyond the scope of this report. The ability to comprehensively and advantageously interpret the data can best be gained through long-term association with gas analyzer test programs. A generalized discussion, however, should prove beneficial in establishing a basic understanding of this subject.

The first factors to be noted are the 100-percent air calibrations. During each program, a test-by-test comparison should be made of these calibrations. The air calibration for any one channel should not vary by more than 5 percent from its calibration value recorded for previous tests in the series, unless ambient conditions such as test altitude, pressure, or temperature also vary radically.

If a large variation either positive or negative in value does occur in any one channel, a similar change in value should be present in all channels. An unusual variation in a single channel or in four channels common to the same transducer bank usually indicates a transducer malfunction. A large shift in the relative position of any trace on the oscillograph record between tests can also indicate a transducer or galvanometer malfunction. If a distinct decrease in the air calibration is noted between tests in a current series or from a previous test program, a leakage in the vacuum lines downstream of the transducers may be present. If a sharp decrease occurs in agent concentration between two tests in a series, a vacuum leakage upstream of the transducers may be present. Partial blockage of the pourous plugs in the transducer assemblies may also cause air calibration or agent deflection changes. All filters should be changed at intervals related to the equipment usage.

The instant of container discharge or discharge switch actuation must be recorded by the oscillograph as an aid in data interpretation. Effects of system changes on agent distribution phasing for system development purposes are extremely difficult to assess unless a common time base is present between tests. The time in which all channels begin indicating the presence of agent following discharge should not vary by more than one-half second for a given test, nor should this time vary appreciably for any channel between tests. Any extreme time variations should be checked for possible equipment malfunction.

Certain general trends are normally observable during ground and flight tests. In ground tests, particularly with engine inoperative, agent concentration may be detected for periods of time exceeding 30 seconds, curves normally flatten out after initial peaking, and slopes of the dissipation portion of the curves are very slight. Agent buildup during a ground test may not be as rapid or uniform as in flight due to the absence of secondary airflow. Since the agents are heavier than air, the higher elevations in the nacelle will have greater agent dissipation rates than the lower portions of the nacelle. During flight tests with high secondary airflows, agent buildup and dissipation may occur in under 5 seconds. Generally, as the secondary airflow increases, the slope of the dissipation section of the curve will increase, and peak concentration values will decrease. Occasionally, during propeller or rotor aircraft programs, certain traces may exhibit a periodic pulsation which may be attributed to nacelle airflow interruption by the propeller or rotor blades.

When involved in the development of a system, it is recommended that the development be directed toward extending the time for which the recommended minimum concentration is maintained, rather than developing high-peak concentrations for short durations. High-peak, short-duration relative concentrations above 15-percent recorder indication have little practical extinguishment value. This can be illustrated by a typical fuel/air versus agent concentration flammability limit curve shown in Figure 11. This curve indicates that above approximately 6 percent of $CBrF_3$ by volume, no mixture of fuel and air is flammable. The indicated 6 percent corresponds to a 15-percent volumetric relative recorder indication. Therefore, reducing high concentrations to values approaching 15-percent relative concentration will not adversely affect the agent's extinguishing capability, but can serve to extend the duration of the recommended agent concentration in the nacelle. An extension of extinguishment duration will allow additional nacelle cooling which aids in preventing hot surface reignition. Also, the lower concentration for longer durations generally indicates a more equalized distribution throughout the entire nacelle.

It should be noted, for interpretive purposes, that the initial indicated time between discharge and recorder agent indication and, also, the indicated buildup of agent are influenced by the diffusion rate of the gaseous agent, the flow velocity, and the length of the sampling probes. Figure 12 presents a typical experimental curve showing the elapsed time required for the recorder to respond to the presence of $CBrF_3$ for various sampling probe lengths.

Data Presentation: Tabular data sheets for all tests conducted during a program should be submitted to the personnel of the agency or service responsible for final acceptance of the extinguishing system. Two forms of data sheets have become standardized and are presented for the purpose of continuing this standardization. The first, shown in Figure 2.1 of Appendix B, is used for basic data reduction and contains all pertinent data values, such as 100-percent air deflections (AD), mixture deflections (MD), and calculated relative agent concentration. Typical values are illustrated for Probe No. 1. The first number in the 100-percent air column represents the 100-percent AD in inches obtained from the oscillograph record. The second number in this column represents the value of AD (1-CR) and the third number represents $\frac{1}{AD\ (1 - CR)}$. The first row of numbers in the Seconds After Discharge columns represents the MD in inches obtained from the oscillograph record. The second row of numbers in these columns represents the percent relative agent concentration. These numbers are obtained by multiplying each MD by the value of $\frac{100}{AD\ (1 - CR)}$.

The second data sheet form, shown in Figure 2.2 of Appendix B, is used for finalized presentation of data and contains only values of time versus percent relative agent concentration. Since this form is the type used for final submission purposes, all pertinent test conditions should be recorded thereon.

A combined plot of all 12 probes should be presented for each of the tests used to demonstrate the acceptability of the finalized extinguishing system. An example of this type of graph is shown in

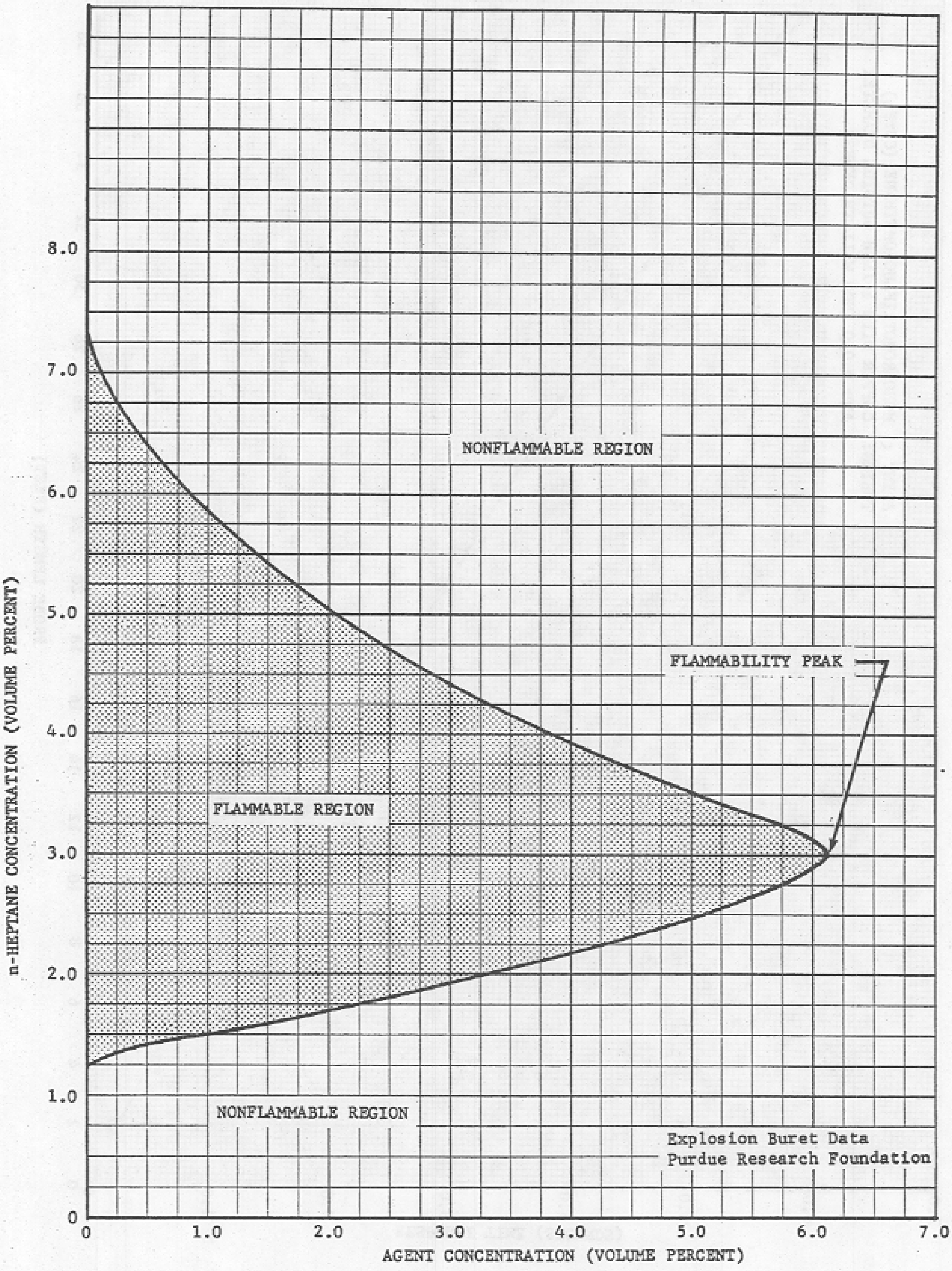


FIG. 11 MONOBROMOTRIFLUOROMETHANE FLAMMABILITY CURVE

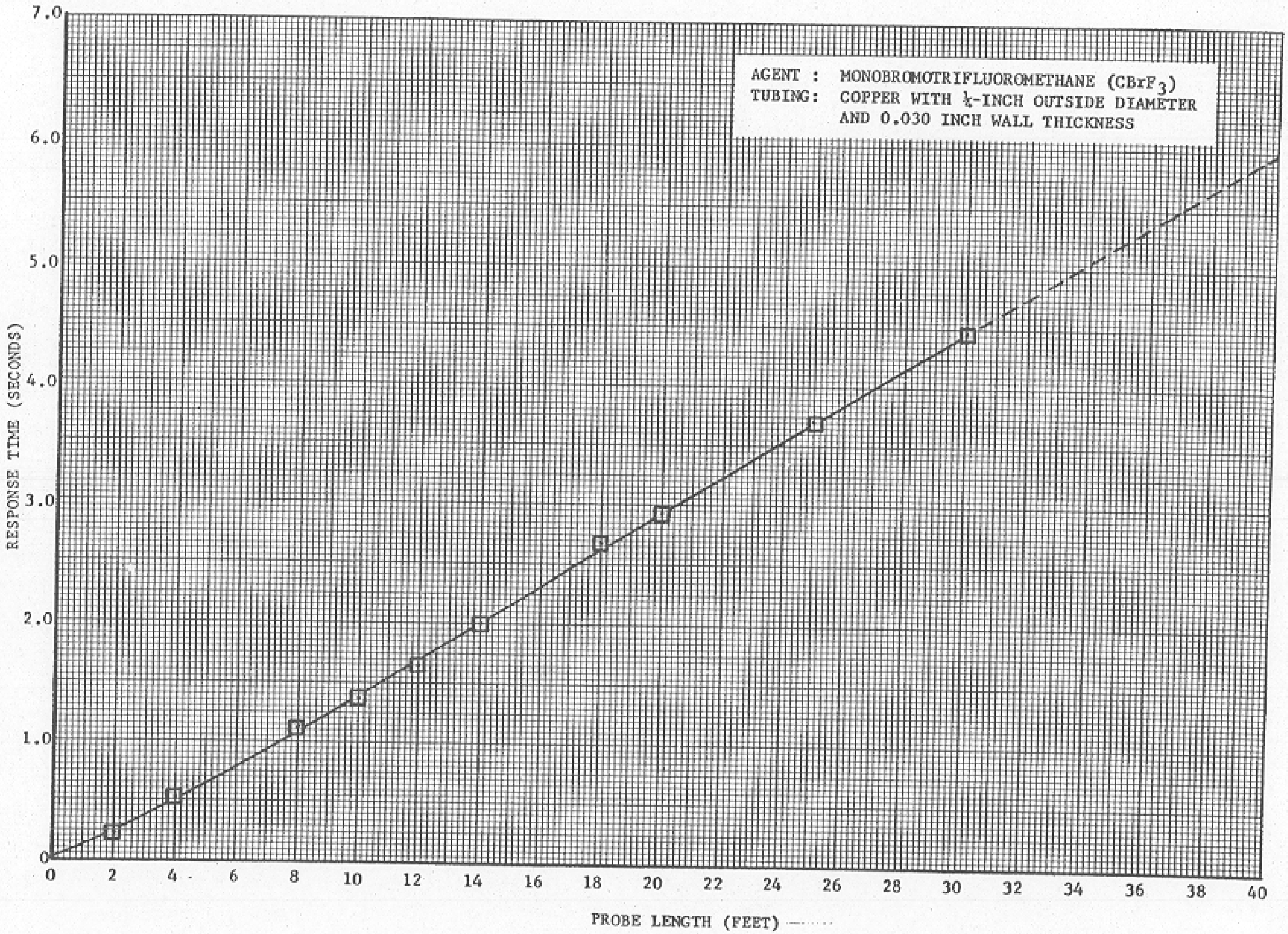


FIG. 12 SAMPLING PROBE LENGTH VERSUS GAS ANALYZER RESPONSE TIME

Figure 13. The cross-hatched area is used to denote the recommended minimum values of time and concentration which must occur simultaneously for all probes within a fire zone. Plots of all tests conducted during the development of a system are not essential.

Since it is frequently difficult to differentiate between individual probes in a combined-type plot, comparative plots have often been found useful. A comparative-type plot is illustrated in Figure 6. Each probe is plotted individually for a given series of tests. This is useful in system development since it presents an overall picture of the effect of system changes on each probe for the entire nacelle. The comparative-type plot can also be used to clearly show the effect of each test condition on the performance of both the overall system and the individual probe. Any system peculiarities may be quickly determined and illustrated with this type of plot which is a useful supplement to the combination plot. When used in conjunction, the comparative plot and the combined plot can provide a very comprehensive picture of system performance for final acceptance purposes.

The oscillograph records for all tests conducted during a program should also be submitted to the accepting agency for inspection and examination for such items as unusual aspects or trends in trace shape and calibration validity.

Relative Importance of Flight Tests and Ground Tests With and Without Supplemental Airflow

A great amount of comparative flight and ground test data has been collected during the FAA's aircraft powerplant fire-extinguishing system evaluation programs. These data, while never specifically gathered to provide a basis for a judgment of the relative importance of flight and ground tests, may be used to indicate general trends. The comparative use of the data is somewhat limited in scope and application since each specific test program, aircraft, extinguishing system, and nacelle configuration have been variable. Direct comparisons are limited, therefore, to individual tests conducted on a specific extinguishing system on the same test aircraft.

No single program or programs have been conducted which would allow a complete comparative analysis to be made. A program for a complete analysis would include a number of carefully controlled tests under conditions of zero secondary airflow within the nacelle, simulated in-flight secondary airflows, and actual in-flight secondary airflows. Data have been collected, as a by-product of normal extinguishing system evaluation programs, for conditions of no flow versus simulated flight flows for certain aircraft, and no flow versus actual flight flows for other aircraft. Certain representative comparisons of these data will be presented to illustrate the general effects of nacelle secondary airflows on extinguishing agent distribution. The comparisons shown are for systems which were improved during the course of a program.

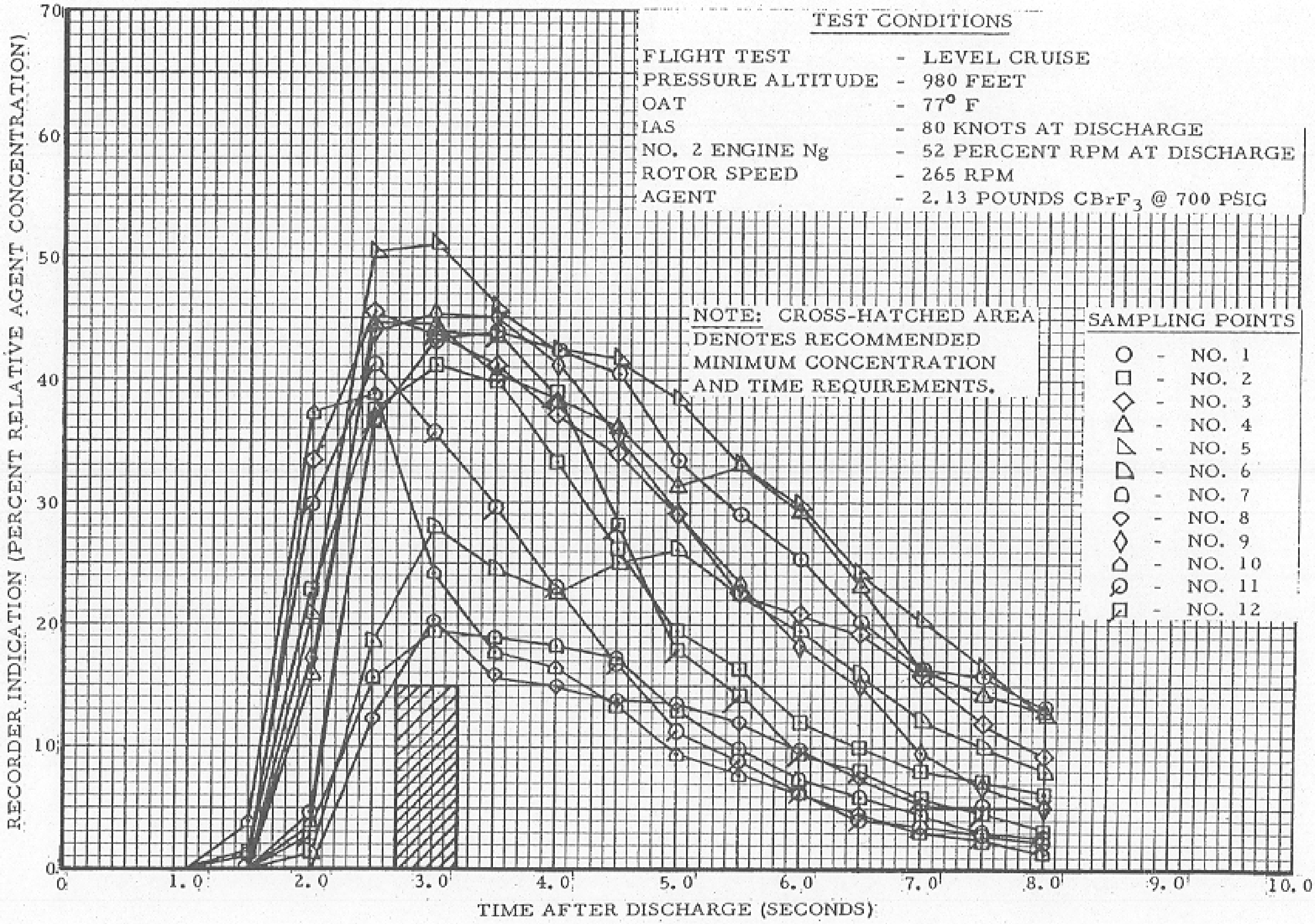


FIG. 13 SAMPLE SUGGESTED GRAPHICAL FORMAT FOR FINAL DATA PRESENTATION

Figure 14 is a comparative plot of a ground test with engine operating and an 80- and 128-knot flight test. The flight tests were conducted in level flight. The data were obtained during a turbine-powered helicopter test program. No engine compressor interstage bleed air was present within the nacelle, and the only airflows present were flight induced. The data indicate a definite increase in agent dissipation rate with increasing aircraft flight speed. The flight test data generally show a marked deviation from the ground test data.

Figure 15 is a comparison of two in-flight tests conducted on an aft pod-mounted engine fixed-wing aircraft. Secondary airflow in the nacelle of this installation was attributed primarily to compressor interstage bleed discharge since in-flight measurements indicated that all normal nacelle ventilating air inlets and outlets were acting as outlets when the compressor bleed ports opened following engine shutdown. The lower secondary airflows occurring during the 165-knot test condition resulted, generally, in better system characteristics than the 350-knot test condition. The differences exhibited in the two conditions indicate that a ground test with engine operating and bleed flow present would produce additional changes in system performance characteristics. A ground test with engine inoperative would produce results entirely unlike any of the flow conditions. If only a static ground test was conducted, it would be improbable that the resulting data could be directly extrapolated to a flight test condition.

Figure 16 is a comparison of a zero-flow, engine inoperative ground test, a ground test with engine operating and compressor bleed air being discharged within the nacelle, and a V_{ne} level flight test with bleed band closed. The V_{ne} test shows only the effects of flight-induced nacelle airflows. The data were collected during a turbine-powered helicopter test program. Again, the in-flight system performance is significantly lower than the static ground test system performance; however, several probes exhibit improved performance with flight airflow within the nacelle. The ground test with bleed flow produces results significantly different than either of the other two conditions. The variations in test results illustrate the difficulty that would be encountered in predicting system performance without the instrument-recorded data.

Figures 17, 18, and 19 illustrate the effect of simulated internal nacelle flight flows on system performance of three different aircraft. For all three aircraft, actual in-flight measurements were made of the nacelle air inlet pressures, and the corresponding nacelle airflows were calculated. Simulated in-flight flows were then provided on the ground by means of a controllable air supply and specifically sized flow ducts connected to the nacelle air inlets. The test data show system performance tendencies similar to those experienced in flight; however, no directly comparative flight data are available. Even with simulated or supplemental secondary airflows, as supplied in the described manner,

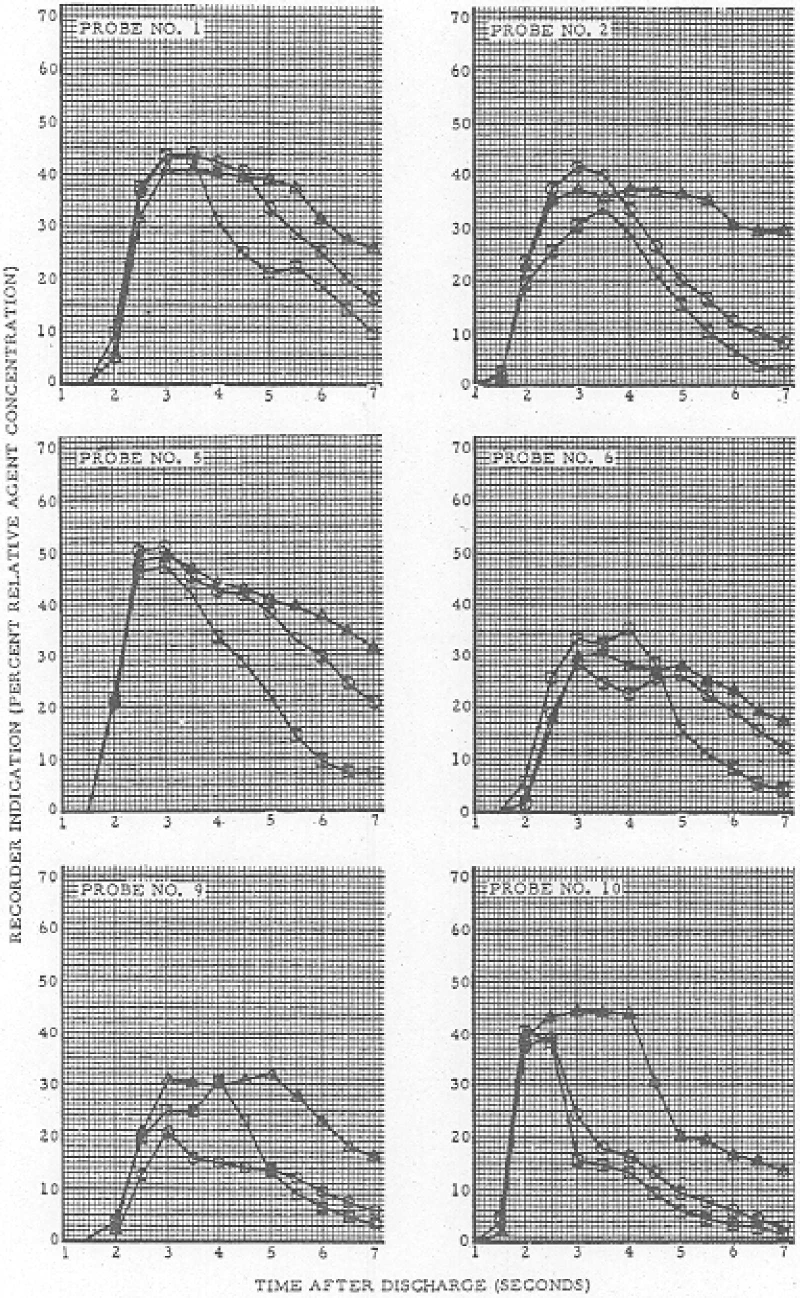
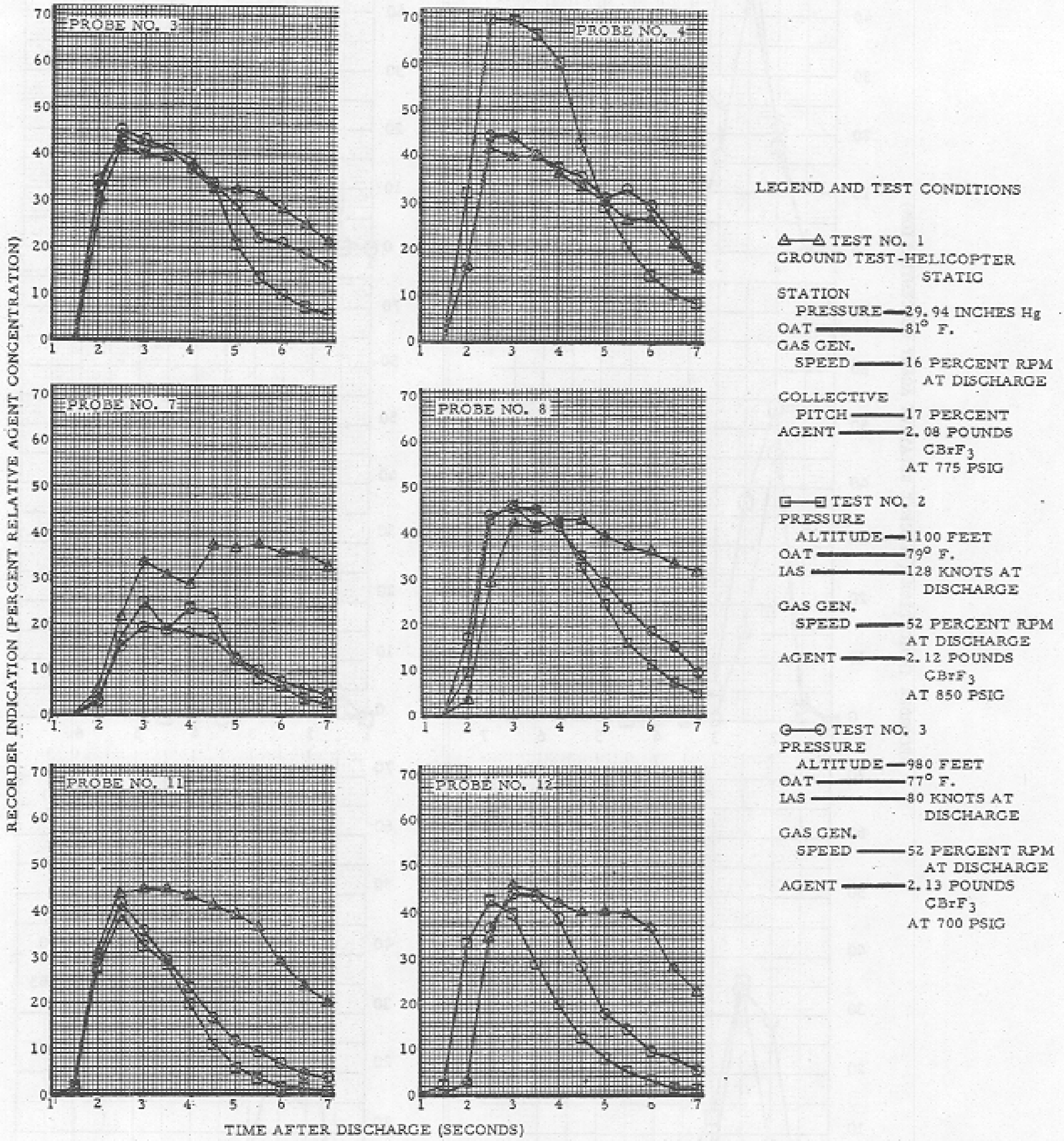


FIG. 14 COMPARATIVE PERFORMANCE OF A TYPICAL POWERPLANT FIRE EXTINGUISHING SYSTEM UNDER FLIGHT AND GROUND TEST CONDITIONS



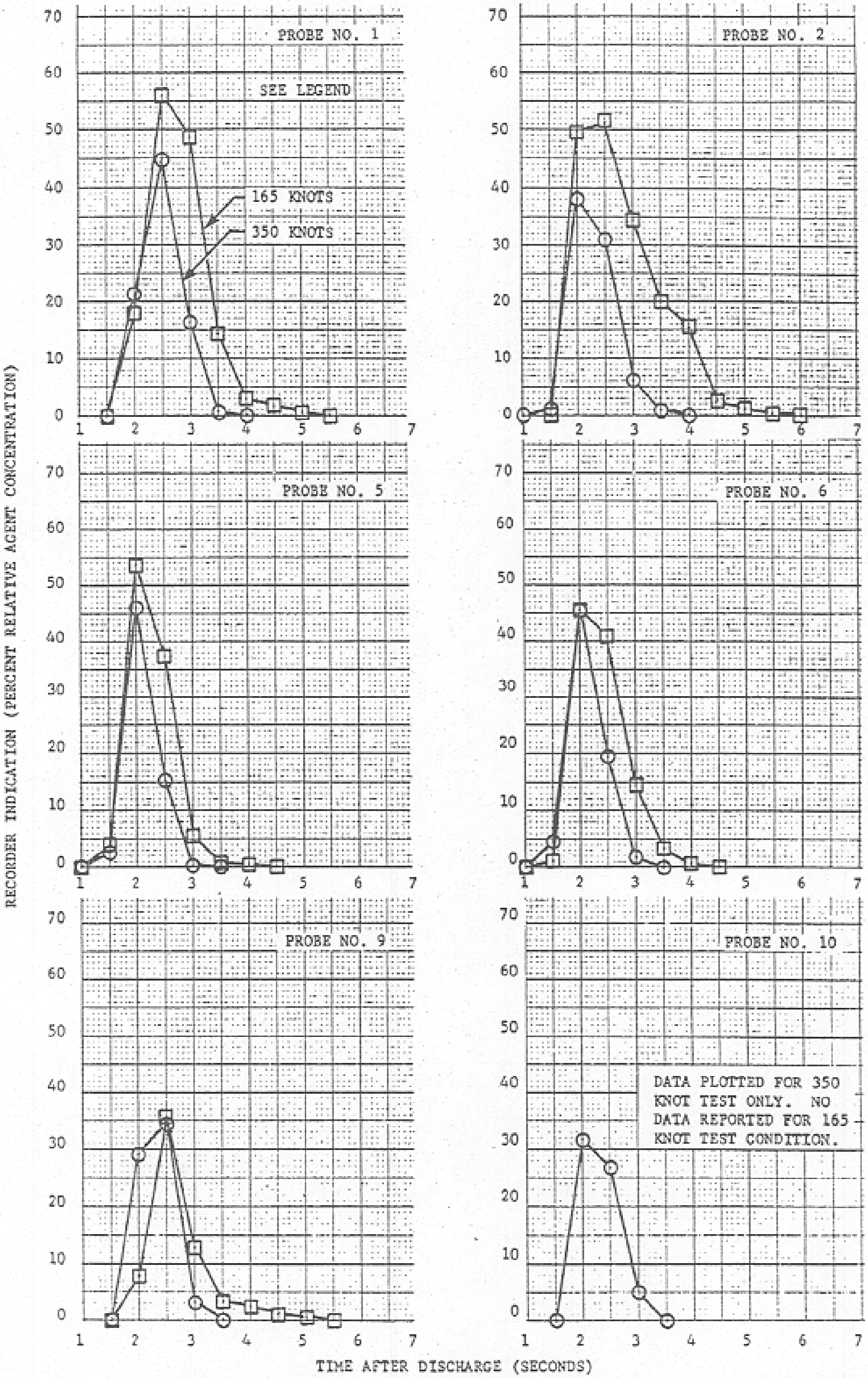
LEGEND AND TEST CONDITIONS

△—△ TEST NO. 1
GROUND TEST-HELICOPTER STATIC
STATION PRESSURE—29.94 INCHES Hg
OAT—81° F.
GAS GEN. SPEED—16 PERCENT RPM AT DISCHARGE
COLLECTIVE PITCH—17 PERCENT
AGENT—2.08 POUNDS $CBrF_3$ AT 775 PSIG

□—□ TEST NO. 2
PRESSURE ALTITUDE—1100 FEET
OAT—79° F.
IAS—128 KNOTS AT DISCHARGE
GAS GEN. SPEED—52 PERCENT RPM AT DISCHARGE
AGENT—2.12 POUNDS $CBrF_3$ AT 850 PSIG

○—○ TEST NO. 3
PRESSURE ALTITUDE—980 FEET
OAT—77° F.
IAS—80 KNOTS AT DISCHARGE
GAS GEN. SPEED—52 PERCENT RPM AT DISCHARGE
AGENT—2.13 POUNDS $CBrF_3$ AT 700 PSIG

FIG. 14 (CONTINUED)



DATA PLOTTED FOR 350 KNOT TEST ONLY. NO DATA REPORTED FOR 165 KNOT TEST CONDITION.

FIG. 15 COMPARATIVE INFLIGHT PERFORMANCE OF A TYPICAL POWERPLANT FIRE EXTINGUISHING SYSTEM WITH ENGINE COMPRESSOR BLEED AIR PRESENT DURING AGENT DISCHARGE

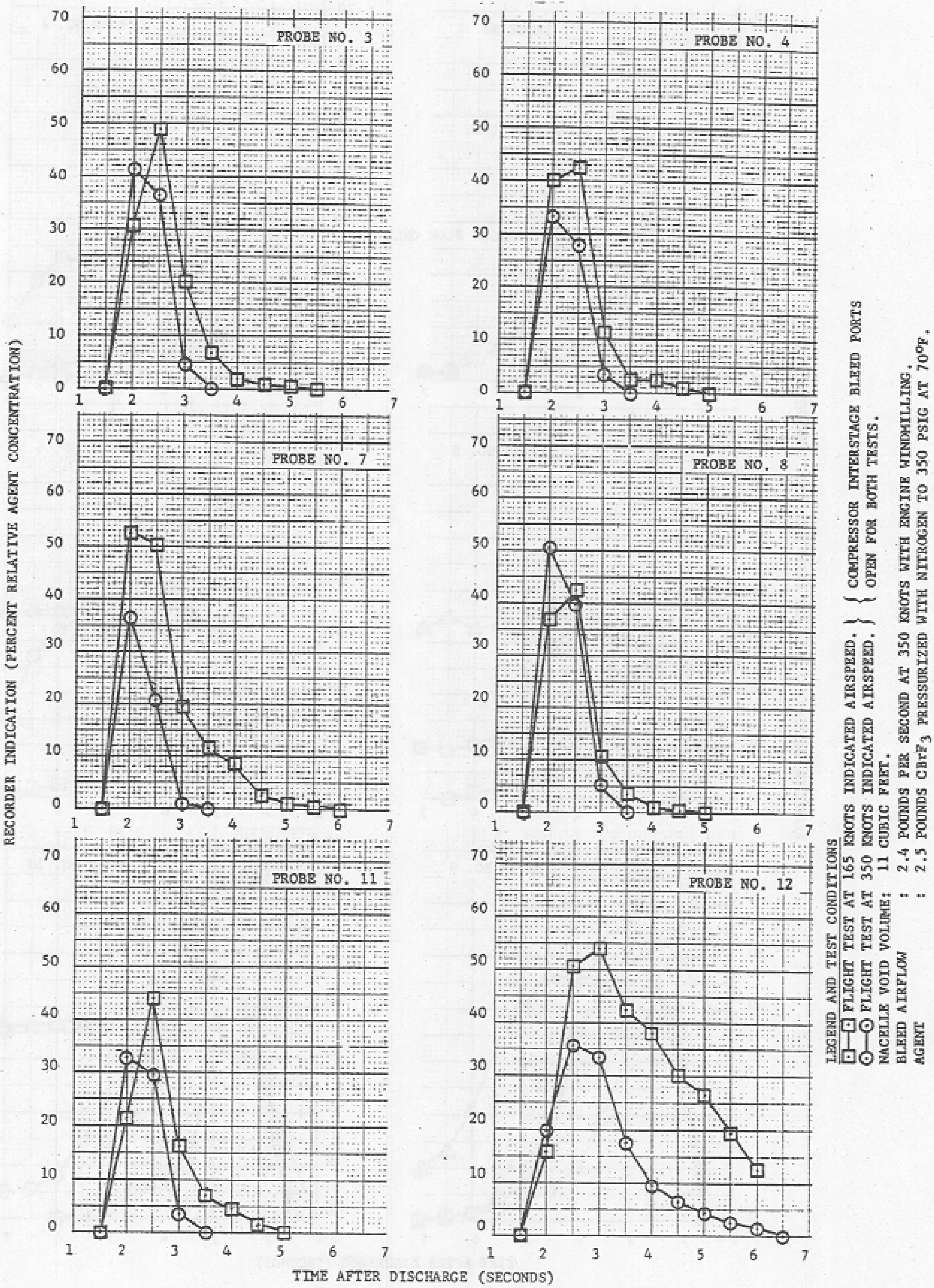


FIG. 15 (CONTINUED)

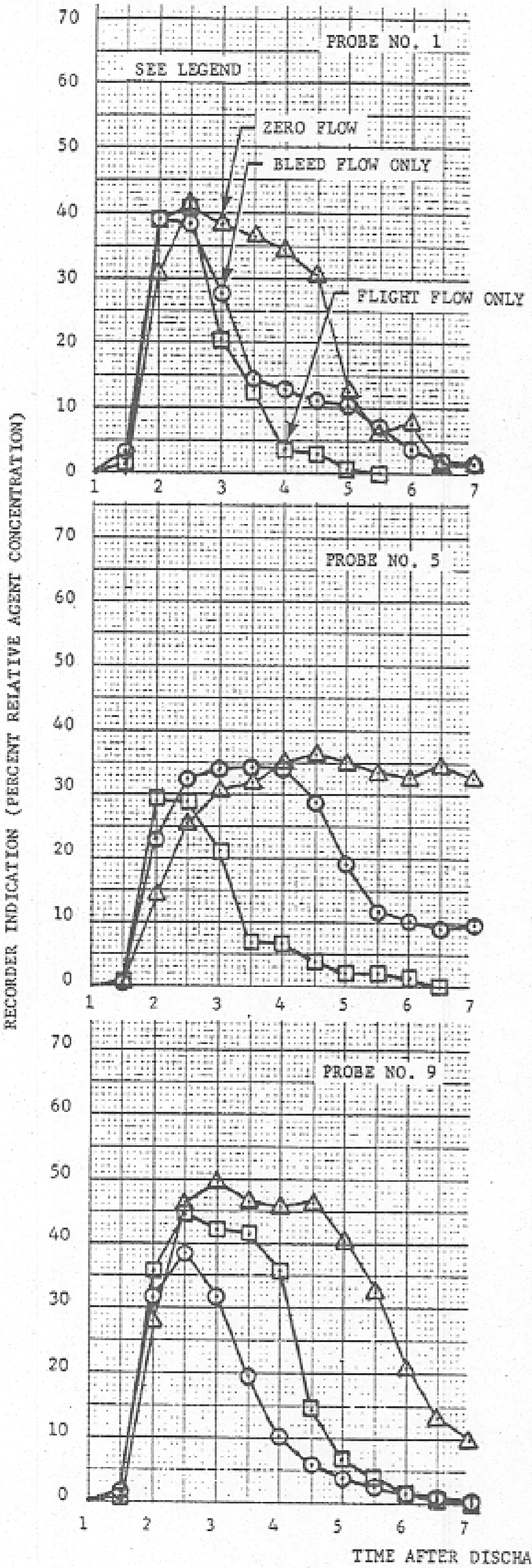


FIG. 16 COMPARATIVE EXTINGUISHING SYSTEM PERFORMANCE FOR CONDITIONS OF ZERO NACELLE AIRFLOW, ENGINE COMPRESSOR BLEED AIRFLOW, AND FLIGHT INDUCED NACELLE AIRFLOW

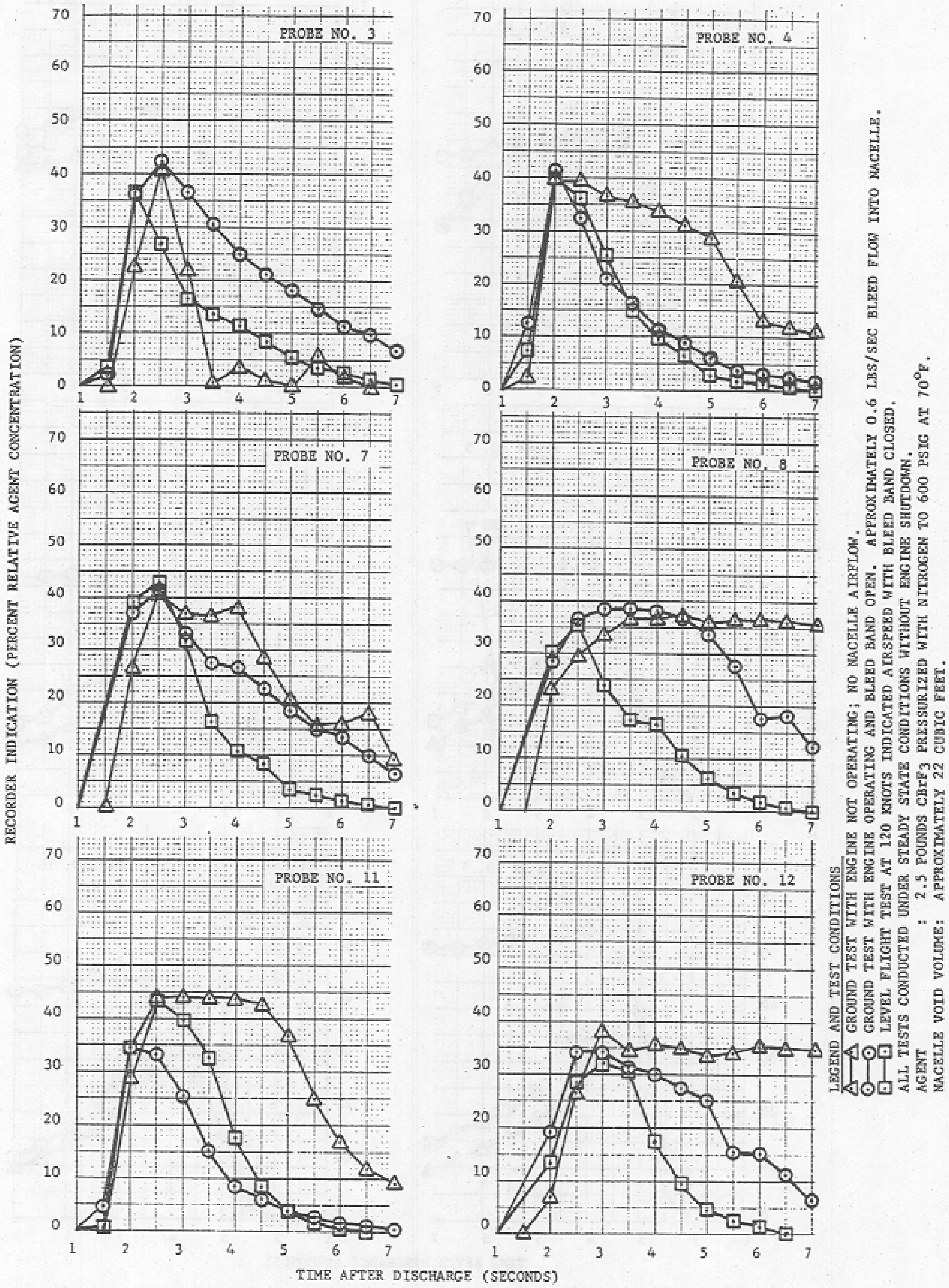


FIG. 16 (CONTINUED)

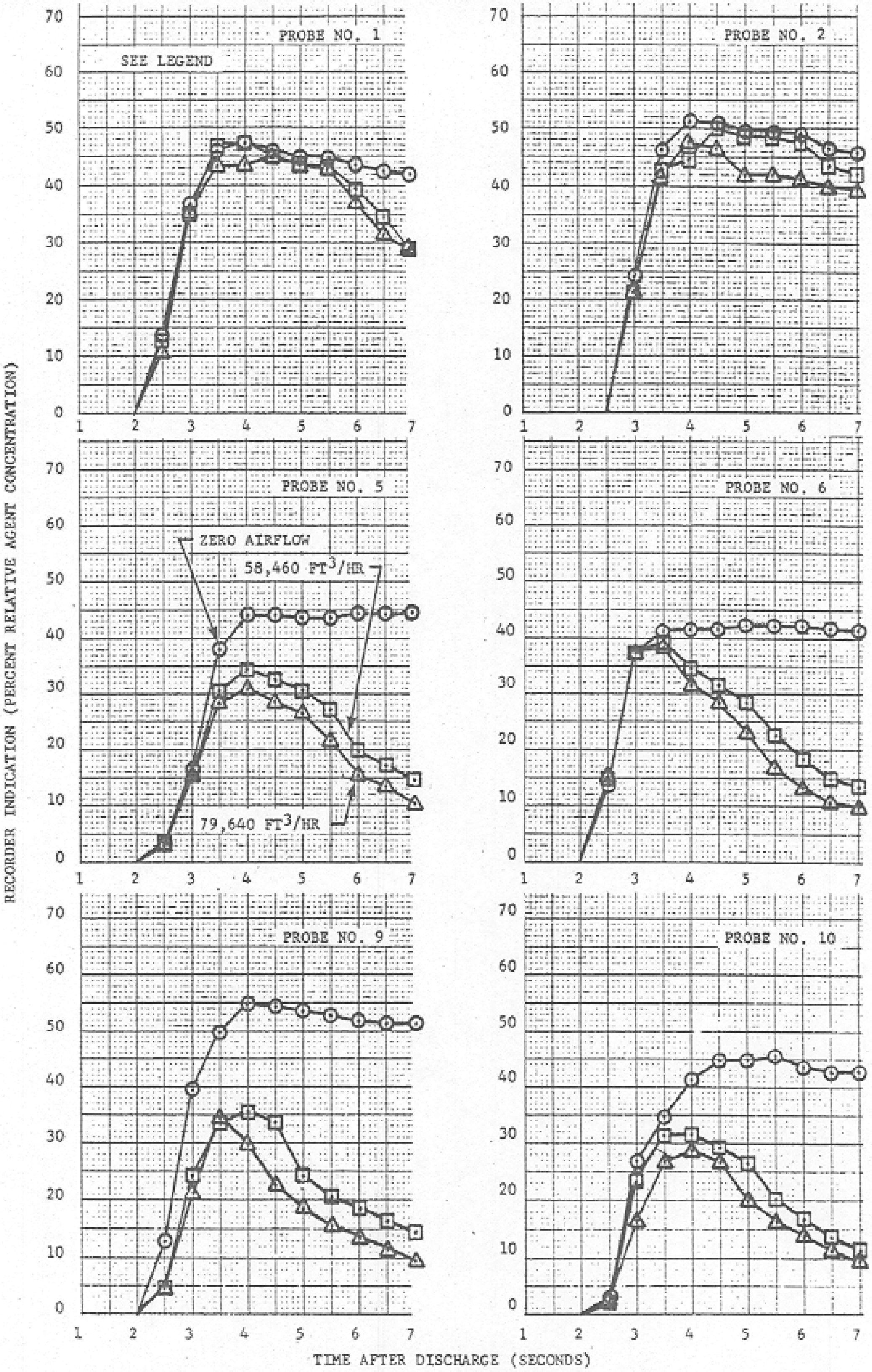
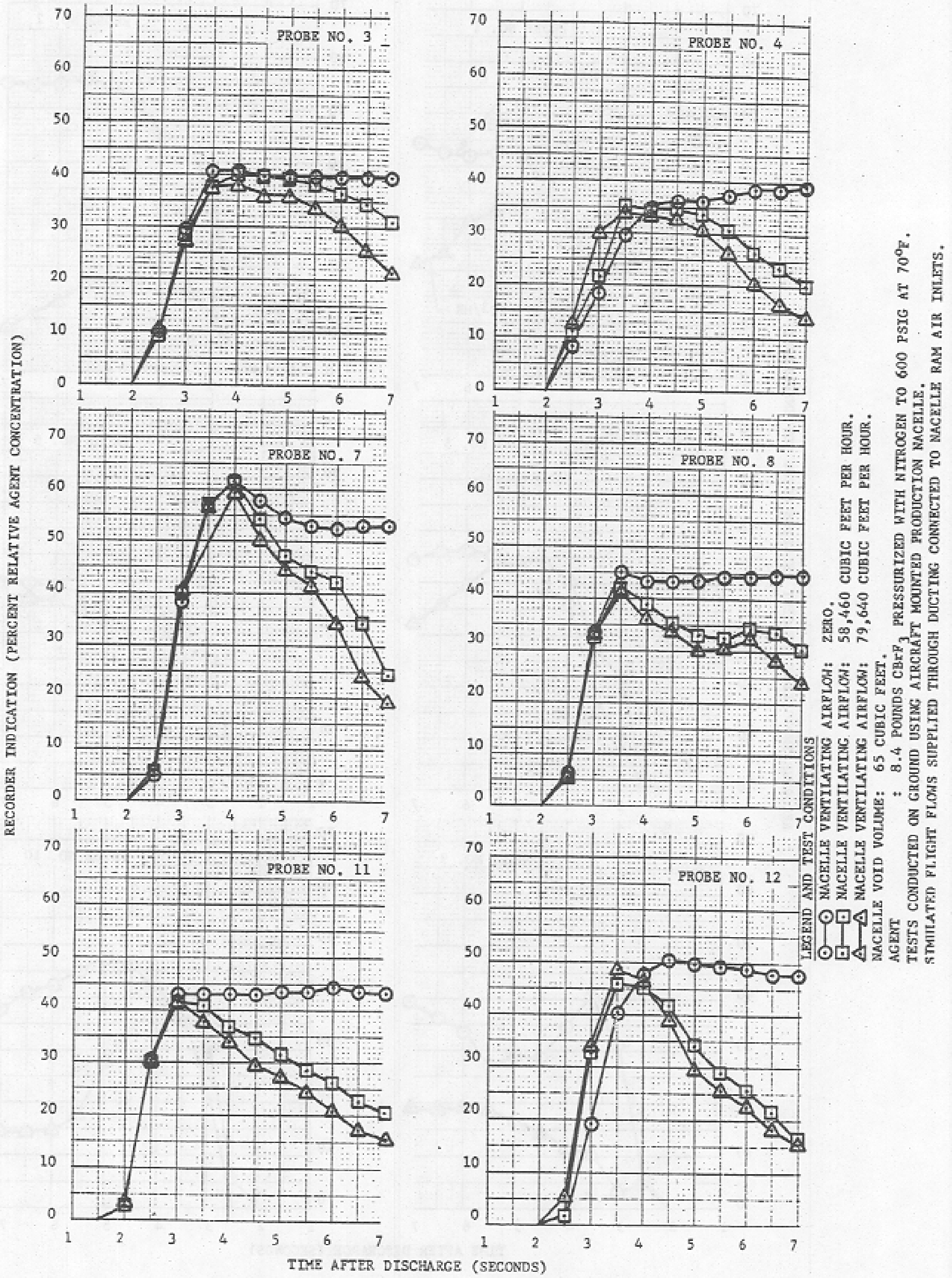


FIG. 17 COMPARATIVE EFFECT OF SIMULATED INTERNAL NACELLE FLIGHT FLOWS ON THE PERFORMANCE OF AN AIRCRAFT POWERPLANT FIRE EXTINGUISHING SYSTEM



LEGEND AND TEST CONDITIONS

⊙—⊙ NACELLE VENTILATING AIRFLOW: ZERO.

⊡—⊡ NACELLE VENTILATING AIRFLOW: 58,460 CUBIC FEET PER HOUR.

△—△ NACELLE VENTILATING AIRFLOW: 79,640 CUBIC FEET PER HOUR.

NACELLE VOID VOLUME: 65 CUBIC FEET.

AGENT : 8.4 POUNDS $CBrF_3$ PRESSURIZED WITH NITROGEN TO 600 PSIG AT 70°F.

TESTS CONDUCTED ON GROUND USING AIRCRAFT MOUNTED PRODUCTION NACELLE.

SIMULATED FLIGHT FLOWS SUPPLIED THROUGH DUCTING CONNECTED TO NACELLE RAM AIR INLETS.

FIG. 17 (CONTINUED)

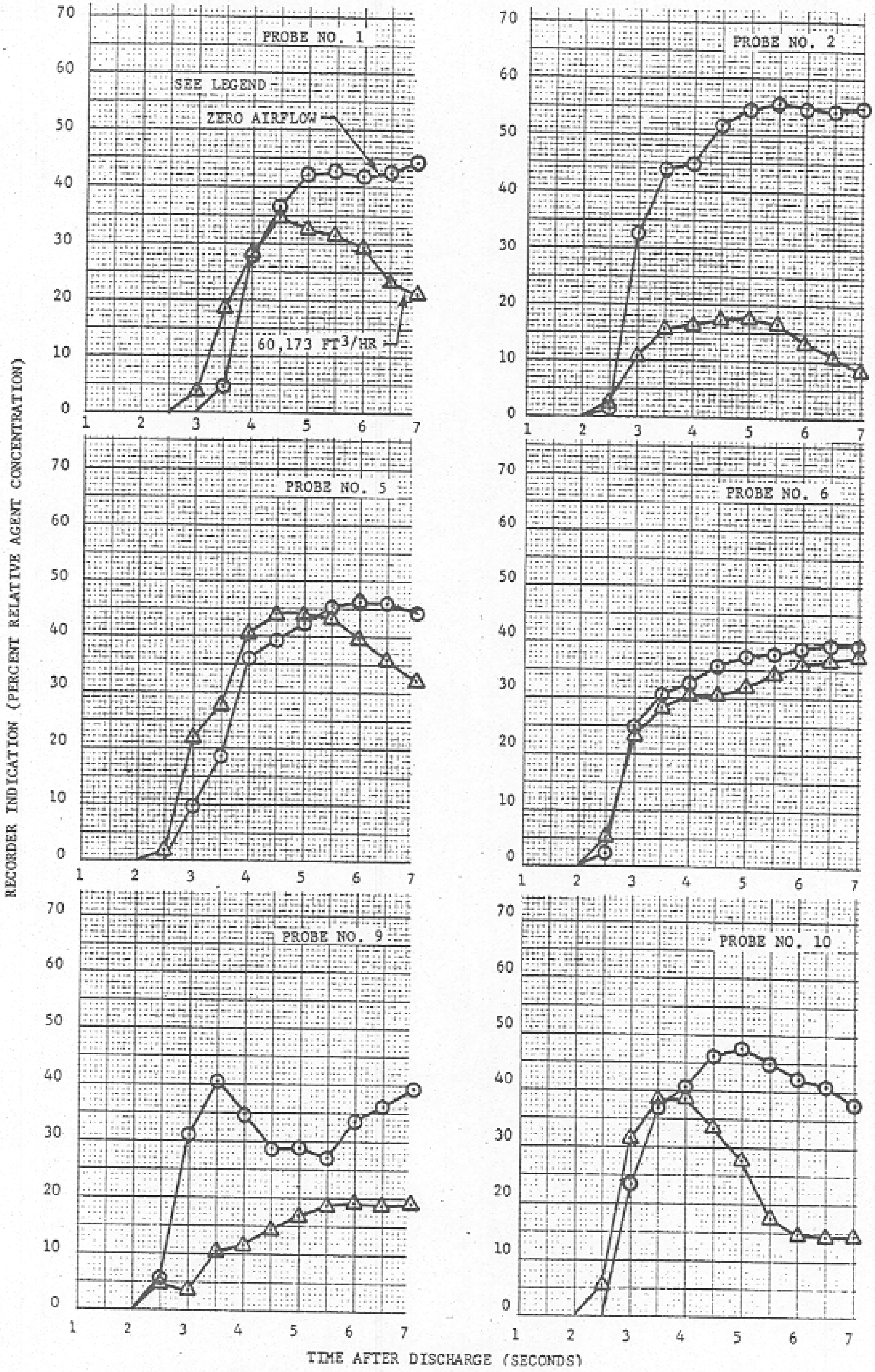


FIG. 18 COMPARATIVE EFFECT OF SIMULATED INTERNAL NACELLE FLIGHT FLOWS ON THE PERFORMANCE OF AN AIRCRAFT POWERPLANT FIRE EXTINGUISHING SYSTEM

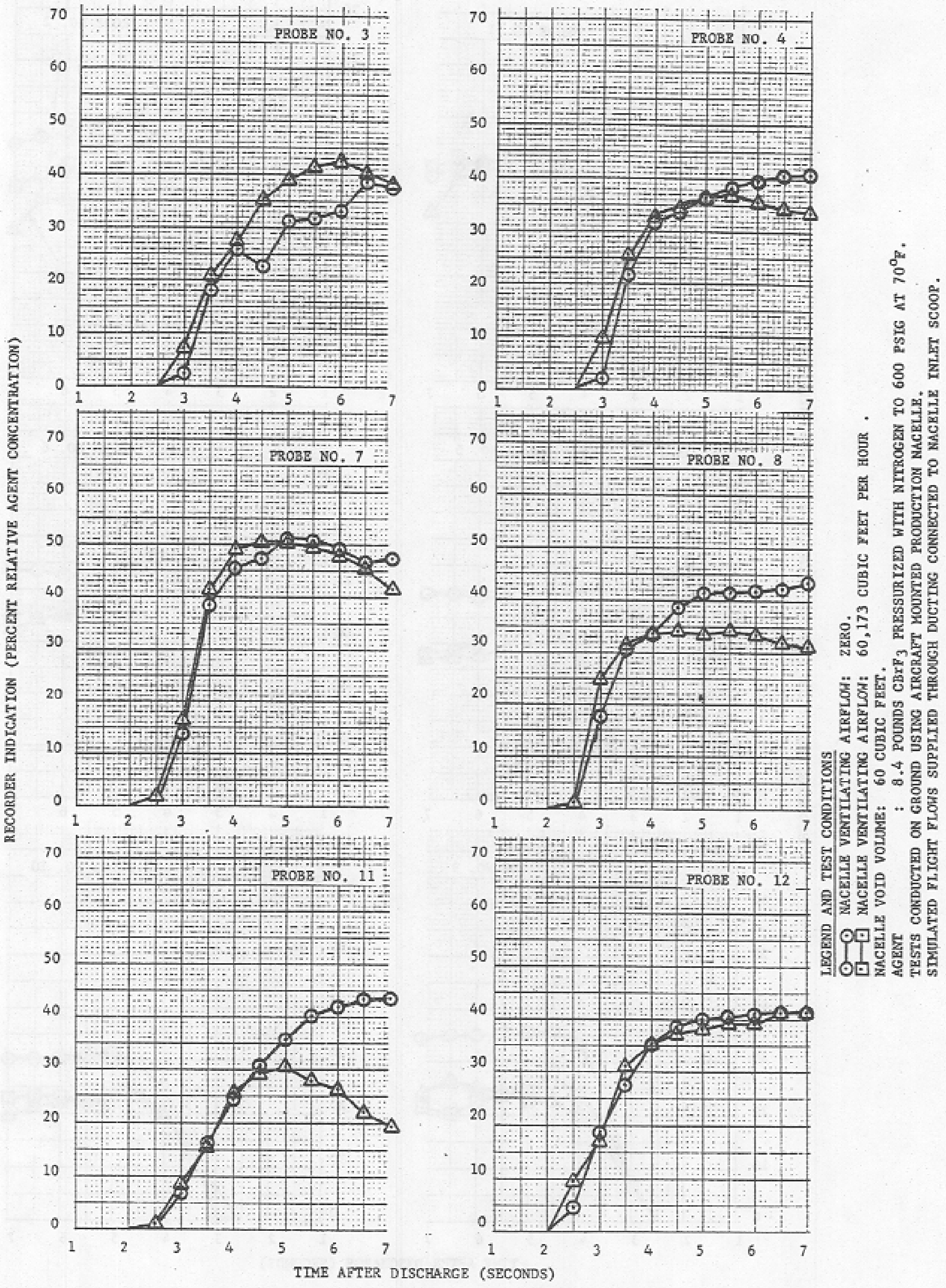


FIG. 18 (CONTINUED)

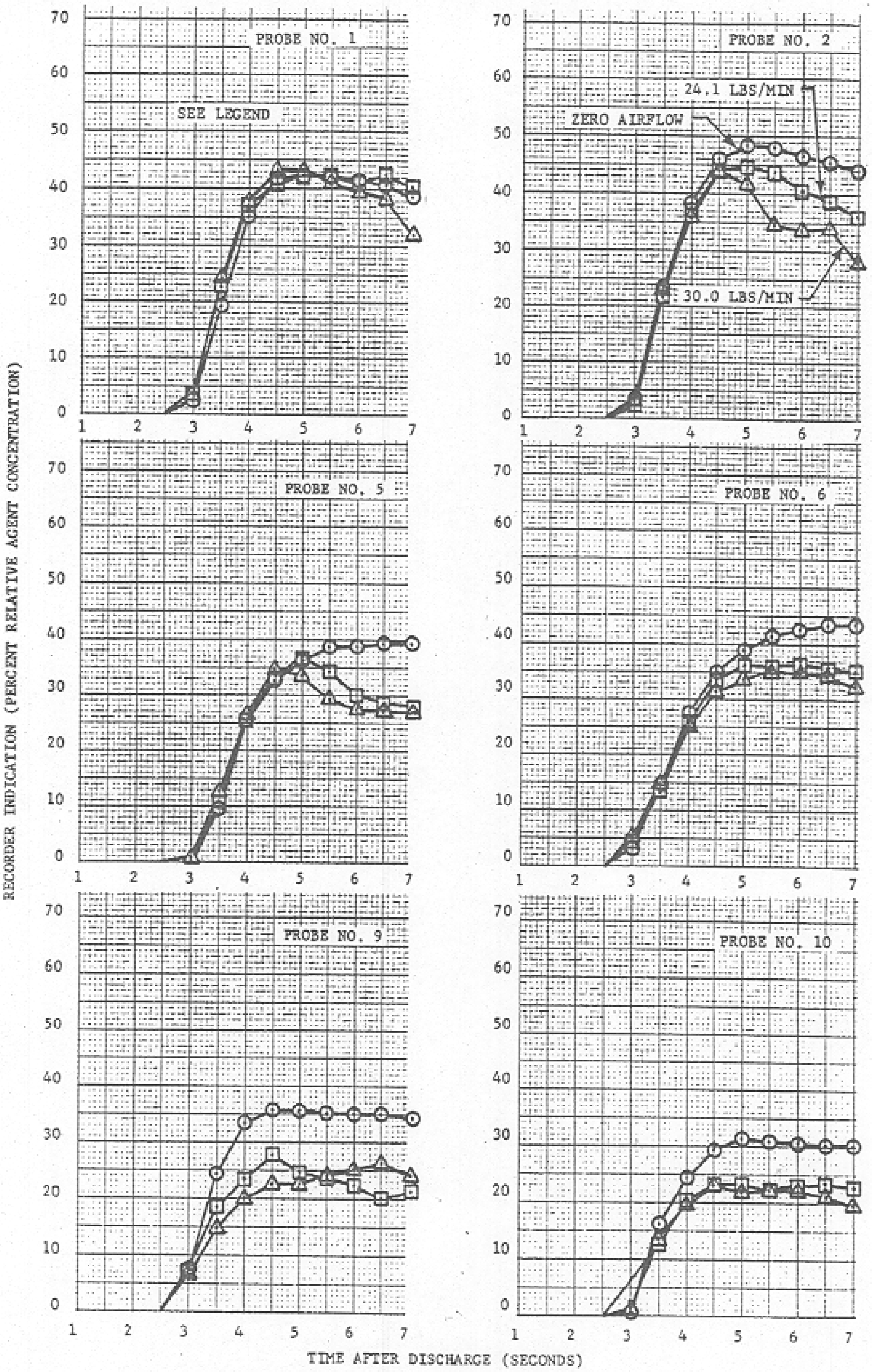


FIG. 19 COMPARATIVE EFFECT OF SIMULATED INTERNAL NACELLE FLIGHT FLOWS ON THE PERFORMANCE OF AN AIRCRAFT POWERPLANT FIRE EXTINGUISHING SYSTEM

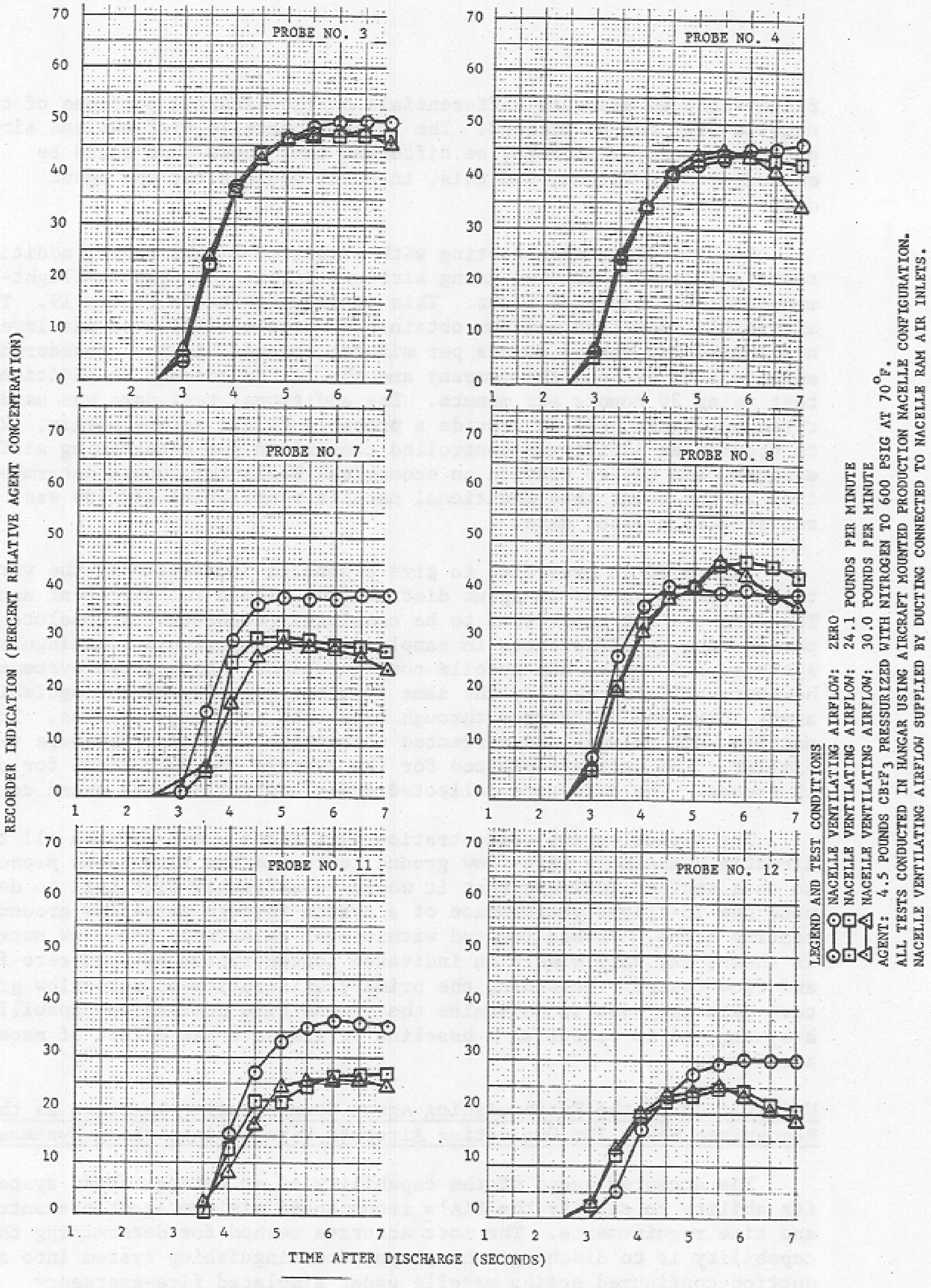


FIG. 19 (CONTINUED)

flight-induced pressure differentials on the external portions of the nacelle will not be present. The internal nacelle airflows and airflow patterns could, therefore, be different than those that would be encountered in flight, and this, in turn, could alter the agent distribution.

Specifically, when testing with simulated flight flows, additional tests are often conducted using airflows higher than the in-flight-measured or calculated flows. This is illustrated in Figure 19. The aircraft's specified maximum obtainable nacelle airflow at sea level on a standard day was 24 pounds per minute; however, it was considered advantageous by both the company and the FAA to conduct an additional test using 30 pounds per minute. The additional test data was used for three purposes: (1) to provide a probable flight safety margin, (2) to provide an additional controlled comparison for determining airflow effects, and (3) to provide an economical basis for future determination in the event that additional nacelle ventilating airflow was required at a later date.

Figure 20 is presented to give a general indication of the variations that may occur in agent distribution within two different nacelles. The data are not considered to be completely accurate for absolute comparison due to differences in sampling probe positioning, extinguishing systems, and engine and nacelle configurations. Both these systems, however, utilized exactly the same type and quantity of extinguishing agent which was discharged through high-rate discharge systems. The nacelle void volumes and corrected volumetric airflow rates were very similar. The data are plotted for the average concentrations for all 12 probes. The data were collected under controlled test stand conditions.

The typical agent concentration variations shown between all the directly comparable zero-flow ground tests and the flow tests presented in this section indicate that it would be extremely difficult to determine the in-flight performance of a system through zero-flow ground testing alone. Probes located within even relatively low-flow nacelles, as shown, may vary widely in indicated concentration between zero-flow and flow tests. Therefore, the primary utilization of zero-flow ground test data has been to determine the ground fire protection capability of a system and to establish a baseline to indicate the effect of nacelle air flows.

Utilization of the Extinguishing Agent Concentration Recorder as the Recognized Means for Evaluating Aircraft Fire-Extinguishing Systems

The accepted gauge of the capability of an extinguishing system is its ability to satisfy the FAA's recommended minimum agent concentration and time requirements. The most accurate method for determining this capability is to discharge the proposed extinguishing system into a production-configured engine nacelle under simulated fire-emergency conditions, and to measure and record the resulting agent distribution.

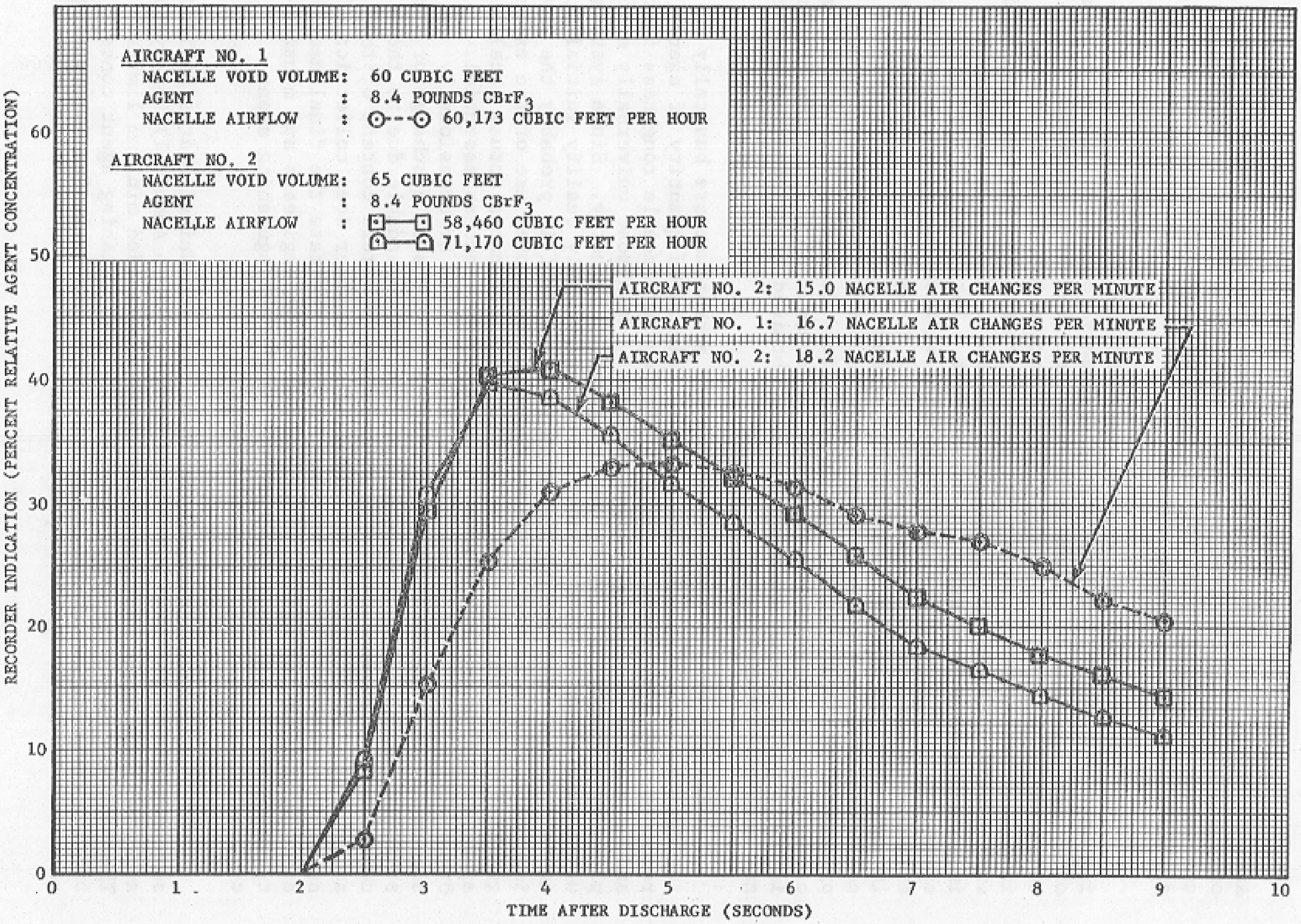


FIG. 20 EFFECT OF EXTINGUISHING AGENT DISTRIBUTION SYSTEM AND VENTILATING AIRFLOW PATTERNS ON SYSTEM PERFORMANCE OF TWO AIRCRAFT NACELLES HAVING SIMILAR VENTILATING RATES AND AGENT QUANTITIES

And, to date, the extinguishing agent concentration recorder is the only aircraft-oriented test equipment that can efficiently provide a continuous time history of the distribution characteristics of an aircraft fire-extinguishing system.

Past experience has indicated that utilization of the extinguishing agent concentration recorder is necessary for proper determination of system performance. This is best illustrated by considering the total number of aircraft systems tested versus the number that were initially acceptable. During the past 14 years, the FAA has evaluated extinguishing systems on 51 separate aircraft. This number does not include the same type aircraft retested at a later date due to minor system or nacelle changes, but represents 51 distinct programs using essentially untested systems. Of these 51 systems tested, no more than 10 were found to meet the recommended minimum limits in their initial configuration. A number of these have required extensive development programs. The FAA's experience in this field indicates that the majority of programs are highly developmental in nature, and that system design is based primarily on experimental data obtained by utilization of the gas analyzer equipment.

Other criteria for system design and acceptance are basically inadequate. For instance, the standard calculated quantity of agent required, which is based on nacelle airflow and nacelle roughness factor, and is used as an initial design parameter, is almost universally multiplied by a factor of 2 by system designers in industry. Since systems using even these doubled quantities of agent rarely qualify initially, it is apparent that the distribution system itself is probably the most important single factor in system design. Therefore, use of the extinguishing agent concentration recorder, which indicates actual nacelle agent distribution once discharge has occurred, becomes essential. Other acceptance methods which have been utilized or occasionally suggested, such as observation of visible products of discharge or substitution of a colored indicator dye, are not dependable due to their dependence on ambient pressure, temperature, moisture content of the ambient air, or density of the substitute. Neither does collection of agent in containers at the discharge nozzles indicate the final nacelle distribution of the agent. Thus, system design engineers and manufacturers have relied almost exclusively on the extinguishing agent concentration recorder in recent years.

Of significance, also, is the fact that the United States military services have established a standard (MIL-E-22285 & Amend -1) for system acceptance which is based upon the FAA's recommended minimum limits. The military have also indicated that the extinguishing agent concentration recorder is currently the best means available for determining adherence to their system requirements.

CONCLUSIONS

Based on the overall program of evaluating aircraft fire-extinguishing systems, it is concluded that:

1. Utilization of the extinguishing agent concentration recorder provides the most comprehensive and practical means presently available for the determination of aircraft fire-extinguishing system performance.

2. The acceptability of an aircraft fire-extinguishing system can be determined by proper utilization of the described recorder.

3. Reliable evaluation testing of in-flight fire-extinguishing systems by use of the agent concentration recorder requires that such tests be conducted under nacelle airflow and pressure conditions existing in flight. Results obtained under ground static conditions may be unrelated to those under flight conditions. Results obtained under ground simulation of in-flight airflows may produce results that differ significantly from in-flight tests unless nacelle airflows are simulated in all respects.

4. Due to the wide variety of aircraft fire-extinguishing systems, engine and nacelle combinations, and aircraft flight envelopes, complete standardization of equipment utilization and test methods is not possible, and each test program requires special adaptation and application of the generalized information presented within this report.

5. Static ground test results cannot be usefully extrapolated to provide in-flight results.

6. The adequacy of a halogenated extinguishing agent system using gaseous nitrogen as a propellant is influenced by the temperature of the agent container. Effectiveness may be decreased by temperature variations higher or lower than those under which the system evaluation tests were conducted.

TABLE 1-I (CONTINUED)

COMPUTED AIR DEFLECTION CALCULATIONS FOR $CBrF_3$ USING 0.401 CALIBRATION RATIO

N	N x 0.599	1/(N x 0.599)
4.00	2.39600	.41736
4.01	2.40199	.41632
4.02	2.40798	.41529
4.03	2.41397	.41426
4.04	2.41996	.41323
4.05	2.42595	.41221
4.06	2.43194	.41119
4.07	2.43793	.41018
4.08	2.44392	.40918
4.09	2.44991	.40818
4.10	2.45590	.40718
4.11	2.46189	.40619
4.12	2.46788	.40521
4.13	2.47387	.40422
4.14	2.47986	.40325
4.15	2.48585	.40228
4.16	2.49184	.40131
4.17	2.49783	.40035
4.18	2.50382	.39939
4.19	2.50981	.39844
4.20	2.51580	.39749
4.21	2.52179	.39654
4.22	2.52778	.39560
4.23	2.53377	.39467
4.24	2.53976	.39374
4.25	2.54575	.39281
4.26	2.55174	.39189
4.27	2.55773	.39097
4.28	2.56372	.39006
4.29	2.56971	.38915
4.30	2.57570	.38824
4.31	2.58169	.38734
4.32	2.58768	.38645
4.33	2.59367	.38555
4.34	2.59966	.38467
4.35	2.60565	.38378
4.36	2.61164	.38290
4.37	2.61763	.38202
4.38	2.62362	.38115
4.39	2.62961	.38028
4.40	2.63560	.37942
4.41	2.64159	.37856
4.42	2.64758	.37770
4.43	2.65357	.37685
4.44	2.65956	.37600
4.45	2.66555	.37516
4.46	2.67154	.37432
4.47	2.67753	.37348
4.48	2.68352	.37264
4.49	2.68951	.37181
4.50	2.69550	.37099
4.51	2.70149	.37017
4.52	2.70748	.36935
4.53	2.71347	.36853
4.54	2.71946	.36772
4.55	2.72545	.36691
4.56	2.73144	.36611
4.57	2.73743	.36531
4.58	2.74342	.36451
4.59	2.74941	.36371
4.60	2.75540	.36292
4.61	2.76139	.36214
4.62	2.76738	.36135
4.63	2.77337	.36057
4.64	2.77936	.35980
4.65	2.78535	.35902
4.66	2.79134	.35825
4.67	2.79733	.35748
4.68	2.80332	.35672
4.69	2.80931	.35596
4.70	2.81530	.35520
4.71	2.82129	.35445
4.72	2.82728	.35370
4.73	2.83327	.35295
4.74	2.83926	.35220
4.75	2.84525	.35146
4.76	2.85124	.35072
4.77	2.85723	.34999
4.78	2.86322	.34926
4.79	2.86921	.34853
4.80	2.87520	.34780
4.81	2.88119	.34708
4.82	2.88718	.34636
4.83	2.89317	.34564
4.84	2.89916	.34493
4.85	2.90515	.34422
4.86	2.91114	.34351
4.87	2.91713	.34280
4.88	2.92312	.34210
4.89	2.92911	.34140
4.90	2.93510	.34070
4.91	2.94109	.34001
4.92	2.94708	.33932
4.93	2.95307	.33863
4.94	2.95906	.33795
4.95	2.96505	.33726
4.96	2.97104	.33658
4.97	2.97703	.33591
4.98	2.98302	.33523
4.99	2.98901	.33456

APPENDIX A

COMPUTED AIR DEFLECTION CALCULATIONS FOR MONOBROMOTRIFLUOROMETHANE ($CBrF_3$)

TABLE 1-I

COMPUTED AIR DEFLECTION CALCULATIONS FOR $CBrF_3$ USING 0.401 CALIBRATION RATIO

N	N x 0.599	1/(N x 0.599)	N	N x 0.599	1/(N x 0.599)
3.00	1.79700	.55648	3.50	2.09650	.47699
3.01	1.80299	.55463	3.51	2.10249	.47563
3.02	1.80898	.55280	3.52	2.10848	.47428
3.03	1.81497	.55097	3.53	2.11447	.47293
3.04	1.82096	.54916	3.54	2.12046	.47160
3.05	1.82695	.54736	3.55	2.12645	.47027
3.06	1.83294	.54557	3.56	2.13244	.46895
3.07	1.83893	.54379	3.57	2.13843	.46763
3.08	1.84492	.54203	3.58	2.14442	.46633
3.09	1.85091	.54027	3.59	2.15041	.46503
3.10	1.85690	.53853	3.60	2.15640	.46374
3.11	1.86289	.53680	3.61	2.16239	.46245
3.12	1.86888	.53508	3.62	2.16838	.46117
3.13	1.87487	.53337	3.63	2.17437	.45990
3.14	1.88086	.53167	3.64	2.18036	.45864
3.15	1.88685	.52998	3.65	2.18635	.45738
3.16	1.89284	.52831	3.66	2.19234	.45613
3.17	1.89883	.52664	3.67	2.19833	.45489
3.18	1.90482	.52498	3.68	2.20432	.45365
3.19	1.91081	.52334	3.69	2.21031	.45243
3.20	1.91680	.52170	3.70	2.21630	.45120
3.21	1.92279	.52008	3.71	2.22229	.44999
3.22	1.92878	.51846	3.72	2.22828	.44878
3.23	1.93477	.51686	3.73	2.23427	.44757
3.24	1.94076	.51526	3.74	2.24026	.44638
3.25	1.94675	.51368	3.75	2.24625	.44519
3.26	1.95274	.51210	3.76	2.25224	.44400
3.27	1.95873	.51053	3.77	2.25823	.44282
3.28	1.96472	.50898	3.78	2.26422	.44165
3.29	1.97071	.50743	3.79	2.27021	.44049
3.30	1.97670	.50589	3.80	2.27620	.43933
3.31	1.98269	.50437	3.81	2.28219	.43818
3.32	1.98868	.50285	3.82	2.28818	.43703
3.33	1.99467	.50134	3.83	2.29417	.43589
3.34	2.00066	.49984	3.84	2.30016	.43475
3.35	2.00665	.49834	3.85	2.30615	.43362
3.36	2.01264	.49686	3.86	2.31214	.43250
3.37	2.01863	.49539	3.87	2.31813	.43138
3.38	2.02462	.49392	3.88	2.32412	.43027
3.39	2.03061	.49246	3.89	2.33011	.42916
3.40	2.03660	.49101	3.90	2.33610	.42806
3.41	2.04259	.48957	3.91	2.34209	.42697
3.42	2.04858	.48814	3.92	2.34808	.42588
3.43	2.05457	.48672	3.93	2.35407	.42480
3.44	2.06056	.48530	3.94	2.36006	.42372
3.45	2.06655	.48390	3.95	2.36605	.42265
3.46	2.07254	.48250	3.96	2.37204	.42158
3.47	2.07853	.48111	3.97	2.37803	.42052
3.48	2.08452	.47973	3.98	2.38402	.41946
3.49	2.09051	.47835	3.99	2.39001	.41841

TABLE 1-I (CONTINUED)

COMPUTED AIR DEFLECTION CALCULATIONS FOR CBrF$_3$ USING 0.401 CALIBRATION RATIO

N	N x 0.599	1/(N x 0.599)
5.00	2.99500	.33389
5.01	3.00099	.33322
5.02	3.00698	.33256
5.03	3.01297	.33190
5.04	3.01896	.33124
5.05	3.02495	.33058
5.06	3.03094	.32993
5.07	3.03693	.32928
5.08	3.04292	.32863
5.09	3.04891	.32799
5.10	3.05490	.32734
5.11	3.06089	.32670
5.12	3.06688	.32606
5.13	3.07287	.32543
5.14	3.07886	.32480
5.15	3.08485	.32416
5.16	3.09084	.32354
5.17	3.09683	.32291
5.18	3.10282	.32229
5.19	3.10881	.32167
5.20	3.11480	.32105
5.21	3.12079	.32043
5.22	3.12678	.31982
5.23	3.13277	.31921
5.24	3.13876	.31860
5.25	3.14475	.31799
5.26	3.15074	.31739
5.27	3.15673	.31678
5.28	3.16272	.31618
5.29	3.16871	.31559
5.30	3.17470	.31499
5.31	3.18069	.31440
5.32	3.18668	.31381
5.33	3.19267	.31322
5.34	3.19866	.31263
5.35	3.20465	.31205
5.36	3.21064	.31146
5.37	3.21663	.31088
5.38	3.22262	.31031
5.39	3.22861	.30973
5.40	3.23460	.30916
5.41	3.24059	.30859
5.42	3.24658	.30802
5.43	3.25257	.30745
5.44	3.25856	.30688
5.45	3.26455	.30632
5.46	3.27054	.30576
5.47	3.27653	.30520
5.48	3.28252	.30464
5.49	3.28851	.30409

N	N x 0.599	1/(N x 0.599)
5.50	3.29450	.30354
5.51	3.30049	.30299
5.52	3.30648	.30244
5.53	3.31247	.30189
5.54	3.31846	.30134
5.55	3.32445	.30080
5.56	3.33044	.30026
5.57	3.33643	.29972
5.58	3.34242	.29918
5.59	3.34841	.29865
5.60	3.35440	.29812
5.61	3.36039	.29758
5.62	3.36638	.29705
5.63	3.37237	.29653
5.64	3.37836	.29600
5.65	3.38435	.29548
5.66	3.39034	.29496
5.67	3.39633	.29444
5.68	3.40232	.29392
5.69	3.40831	.29340
5.70	3.41430	.29289
5.71	3.42029	.29237
5.72	3.42628	.29186
5.73	3.43227	.29135
5.74	3.43826	.29084
5.75	3.44425	.29034
5.76	3.45024	.28983
5.77	3.45623	.28933
5.78	3.46222	.28883
5.79	3.46821	.28833
5.80	3.47420	.28784
5.81	3.48019	.28734
5.82	3.48618	.28685
5.83	3.49217	.28635
5.84	3.49816	.28586
5.85	3.50415	.28538
5.86	3.51014	.28489
5.87	3.51613	.28440
5.88	3.52212	.28392
5.89	3.52811	.28344
5.90	3.53410	.28296
5.91	3.54009	.28248
5.92	3.54608	.28200
5.93	3.55207	.28153
5.94	3.55806	.28105
5.95	3.56405	.28058
5.96	3.57004	.28011
5.97	3.57603	.27964
5.98	3.58202	.27917
5.99	3.58801	.27871

TABLE 1-I (CONTINUED)

COMPUTED AIR DEFLECTION CALCULATIONS FOR $CBrF_3$ USING 0.401 CALIBRATION RATIO

N	N x 0.599	1/(N x 0.599)
6.00	3.59400	.27824
6.01	3.59999	.27778
6.02	3.60598	.27732
6.03	3.61197	.27686
6.04	3.61796	.27640
6.05	3.62395	.27594
6.06	3.62994	.27549
6.07	3.63593	.27503
6.08	3.64192	.27458
6.09	3.64791	.27413
6.10	3.65390	.27368
6.11	3.65989	.27323
6.12	3.66588	.27279
6.13	3.67187	.27234
6.14	3.67786	.27190
6.15	3.68385	.27146
6.16	3.68984	.27101
6.17	3.69583	.27058
6.18	3.70182	.27014
6.19	3.70781	.26970
6.20	3.71380	.26927
6.21	3.71979	.26883
6.22	3.72578	.26840
6.23	3.73177	.26797
6.24	3.73776	.26754
6.25	3.74375	.26711
6.26	3.74974	.26669
6.27	3.75573	.26626
6.28	3.76172	.26584
6.29	3.76771	.26541
6.30	3.77370	.26499
6.31	3.77969	.26457
6.32	3.78568	.26415
6.33	3.79167	.26374
6.34	3.79766	.26332
6.35	3.80365	.26291
6.36	3.80964	.26249
6.37	3.81563	.26208
6.38	3.82162	.26167
6.39	3.82761	.26126
6.40	3.83360	.26085
6.41	3.83959	.26044
6.42	3.84558	.26004
6.43	3.85157	.25963
6.44	3.85756	.25923
6.45	3.86355	.25883
6.46	3.86954	.25843
6.47	3.87553	.25803
6.48	3.88152	.25763
6.49	3.88751	.25723
6.50	3.89350	.25684
6.51	3.89949	.25644
6.52	3.90548	.25605
6.53	3.91147	.25566
6.54	3.91746	.25527
6.55	3.92345	.25488
6.56	3.92944	.25449
6.57	3.93543	.25410
6.58	3.94142	.25372
6.59	3.94741	.25333
6.60	3.95340	.25295
6.61	3.95939	.25256
6.62	3.96538	.25218
6.63	3.97137	.25180
6.64	3.97736	.25142
6.65	3.98335	.25104
6.66	3.98934	.25067
6.67	3.99533	.25029
6.68	4.00132	.24992
6.69	4.00731	.24954
6.70	4.01330	.24917
6.71	4.01929	.24880
6.72	4.02528	.24843
6.73	4.03127	.24806
6.74	4.03726	.24769
6.75	4.04325	.24733
6.76	4.04924	.24696
6.77	4.05523	.24660
6.78	4.06122	.24623
6.79	4.06721	.24587
6.80	4.07320	.24551
6.81	4.07919	.24515
6.82	4.08518	.24479
6.83	4.09117	.24443
6.84	4.09716	.24407
6.85	4.10315	.24372
6.86	4.10914	.24336
6.87	4.11513	.24301
6.88	4.12112	.24265
6.89	4.12711	.24230
6.90	4.13310	.24195
6.91	4.13909	.24160
6.92	4.14508	.24125
6.93	4.15107	.24090
6.94	4.15706	.24055
6.95	4.16305	.24021
6.96	4.16904	.23986
6.97	4.17503	.23952
6.98	4.18102	.23918
6.99	4.18701	.23883

TABLE 1-I (CONTINUED)

COMPUTED AIR DEFLECTION CALCULATIONS FOR $CBrF_3$ USING 0.401 CALIBRATION RATIO

N	N × 0.599	1/(N × 0.599)
7.00	4.19300	.23849
7.01	4.19899	.23815
7.02	4.20498	.23781
7.03	4.21097	.23747
7.04	4.21696	.23714
7.05	4.22295	.23680
7.06	4.22894	.23647
7.07	4.23493	.23613
7.08	4.24092	.23580
7.09	4.24691	.23547
7.10	4.25290	.23513
7.11	4.25889	.23480
7.12	4.26488	.23447
7.13	4.27087	.23414
7.14	4.27686	.23382
7.15	4.28285	.23349
7.16	4.28884	.23316
7.17	4.29483	.23284
7.18	4.30082	.23251
7.19	4.30681	.23219
7.20	4.31280	.23187
7.21	4.31879	.23155
7.22	4.32478	.23123
7.23	4.33077	.23091
7.24	4.33676	.23059
7.25	4.34275	.23027
7.26	4.34874	.22995
7.27	4.35473	.22964
7.28	4.36072	.22932
7.29	4.36671	.22901
7.30	4.37270	.22869
7.31	4.37869	.22838
7.32	4.38468	.22807
7.33	4.39067	.22776
7.34	4.39666	.22745
7.35	4.40265	.22714
7.36	4.40864	.22683
7.37	4.41463	.22652
7.38	4.42062	.22621
7.39	4.42661	.22591
7.40	4.43260	.22560
7.41	4.43859	.22530
7.42	4.44458	.22499
7.43	4.45057	.22469
7.44	4.45656	.22439
7.45	4.46255	.22409
7.46	4.46854	.22379
7.47	4.47453	.22349
7.48	4.48052	.22319
7.49	4.48651	.22289

APPENDIX B

SUGGESTED TABULAR DATA PRESENTATION FORMAT

FAA AGENT CONCENTRATION RECORDER TEST DATA

TEST ARTICLE
TEST NO. 3
DATE 9/25/65
TIME 1630
RECORD NO. 08577

IAS 350 KNOTS
ALT$_P$ 10,000 FT
OAT 30°C
HUMIDITY
STA. PRESS.

AGENT $CBrF_3$
WEIGHT 2.5 lbs.
BOT. PRESS 350 psig.
CONT. SIZE 86 IN^3
CONT. TYPE

GA-2
GA-2A ✓
TEST STAND
FLIGHT ✓ GROUND
TEST CELL

100% AIR	PROBE NO.	Seconds after Discharge																
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
4.59 2.75 0.364	1	0 0	0 0	.67 24.4	1.46 53.1	.29 10.6	.03 1.1	0 0										
	2																	
	3																	
	4																	
	5																	
	6																	
	7																	
	8																	
	9																	
	10																	
	11																	
	12																	

MISC:

NA FORM 6650-1 (2-67)

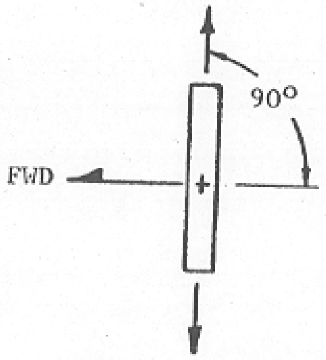
FIG. 2.1 SAMPLE SUGGESTED TABULAR FORMAT FOR BASIC DATA REDUCTION PRESENTATION

FEDERAL AVIATION AGENCY EXTINGUISHING AGENT CONCENTRATION RECORDER DATA

FLIGHT TEST ---------- Level flight at V_{mo}
DATE ----------------- 9/25/65
IAS ------------------ 350 knots
PRESSURE ALTITUDE ---- 10,000 feet
OAT ------------------ 30°C
AGENT ---------------- 2.5 pounds $CBrF_3$ pressurized to 350 psig at 70°F

PERCENT RELATIVE AGENT CONCENTRATION VERSUS TIME

Sampling Probe	Time After Discharge (Seconds)														
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
1	0	0	24.4	53.1	10.6	1.1	0								
2	0	3.0	53.8	33.5	3.9	0.9	0.3	0							
3	0	0	47.3	33.4	2.7	0.4	0								
4	0	0	49.5	48.4	4.2	1.1	0								
5	0	2.1	37.5	14.7	0.3	0									
6	0	11.5	56.4	21.9	1.1	0									
7	0	0	21.8	20.9	4.3	1.3	0.7	0							
8	0	0	6.7	4.2	0.4	0									
9	0	1.3	38.2	13.9	2.5	0.4	0								
10	0	0	17.3	19.9	1.6	0									
11	0	0	36.2	16.5	3.2	0									
12	0	0	42.8	43.2	23.9	14.3	8.5	4.2	2.3	1.5	0.8	0			



NOZZLE ORIENTATION
(Viewed from outboard)

FIG. 2.2 SAMPLE SUGGESTED TABULAR FORMAT FOR FINAL DATA PRESENTATION