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Extinguisher Agent Behavior in A Ventilated Small Aircraft

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Final Report

U.S. Department of Transportation
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Technical Center
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16. Abstract

Hand-held Halon 1211 fire extinguishers were evaluated in a four-place Cessna Model 210C aircraft. The aircraft was operated in an airflow facility under simulated flight conditions. Extinguishers of 2.5 pound capacity were discharged to determine the dissipation rate and toxicity levels of Halon 1211 extinguishing agents.

Agent concentrations dissipated rapidly. Analysis of dose calculations demonstrated that 2.5 pound Halon 1211 extinguishers were safe in the four-passenger test aircraft. Dose calculations for the pilot were only 25 percent of the limit for Halon 1211. Ventilation airflow produced air changes in the cabin of 1.16 minutes at 120 miles per hour airspeed and 1 minute at 140 miles per hour. The high cabin ventilation rates together with the effects of agent stratification resulted in safe conditions. The effective air change time found in analysis was of the order of one-third of a minute. This quantity used in the procedures outlined in Advisory Circular AC-20-42B leads to the conclusion that discharge of Halon 1211 weights of 6 pounds can be safely withstood in the C120 under flight conditions.

Discharge of a 2.5 pound chemical powder extinguisher adversely affected visibility for over 22 seconds.

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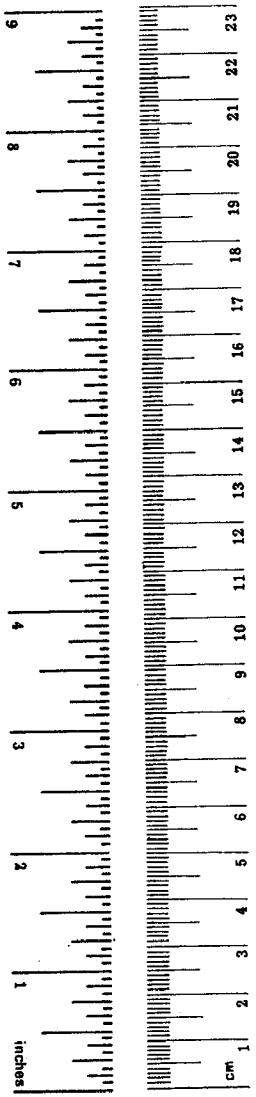
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

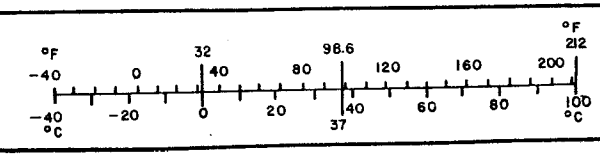
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

Testing of Halon 1211 hand fire extinguishers was conducted in a Cessna Model 210C airplane mounted in an airflow facility. The facility was operated at an airspeed of 120 miles per hour for evaluation of extinguisher performance. Additional testing included measurement of ventilation airflow in the cabin and investigation of free-stream airspeed on extinguisher agent dissipation.

Extinguishers of 2.5-pound capacity were discharged to determine the dissipation rate and toxicity levels of Halon 1211 extinguishing agents. These tests were conducted without fire, and involved the continuous sampling of neat Halon 1211 agents from two locations. Agent concentration was measured at the pilot's nose height and at locations in proximity to discharge of the extinguishers. Air temperature was measured at both sample locations. Extinguisher discharge and associated testing were conducted remotely and observed and recorded by video systems.

Available general aviation fire statistics show that 87 percent of cabin fires are electric in origin. This problem is for the most part located under the instrument panel and was addressed by directing eight extinguisher discharges into this area. A total of 28 tests was completed with the primary variables being agent discharge location and ventilation conditions. Extinguishers were discharged under the instrument panel, and at the fuel and hydraulic selector valves, copilot's seat, rear passenger's seat, and baggage compartment. Ventilation was varied by adjusting the overhead ports and by opening the auxiliary vents.

Ventilation airflow into the cabin was higher than previously thought possible. Time for a cabin air change at an airspeed of 120 miles per hour was 1.16 minutes and 1 minute at 140 miles per hour.

The significant result from this investigation was that 2.5-pound Halon 1211 extinguishers were safe for use in aircraft comparable to Cessna Model 210C. Dose calculation for the pilot's nose height was only 25 percent of the recommended maximum. Cabin ventilation airflow, together with agent stratification, produced safe conditions throughout the cabin because stratification tripled the time for effective air change over the amounts measured exclusively from airflow. This effective air change rate, used in conjunction with the nomographs in AC-20-42C, shows that as much as 6 pounds of Halon 1211 could be safely discharged under the conditions tested in this study.

Discharge of a chemical powder extinguisher obscured visibility for over 22 seconds. This one test confirms precautions contained in Advisory Circular, No. 20-42B, pertaining to loss in visibility created by dry chemical discharge.

INTRODUCTION

PURPOSE.

The purpose of this project was to investigate hand-held fire extinguishers for use in nonpressurized general aviation aircraft and to determine the dissipation rate and toxicity levels of neat extinguishing agent.

BACKGROUND.

General aviation aircraft of two- to six-passenger capacity are not required by the Federal Aviation Administration (FAA) to have fire extinguishers aboard. In view of the limited volume of the cabins and unknown ventilation rates, existing selection information is not currently useful. However, numerous owners are requesting installation of fire extinguishers by the aircraft manufacturers, and some owners are installing extinguishers of their own selection. The aircraft size or cabin volume and ventilation rate have a great effect on the quantity of fire extinguishing agents that can be dischared without exceeding toxicity levels or limits. Reference 1, Advisory Circular (AC) 20-42B states: "When practical, extinguisher size selection should consider the volume and ventilation air-change time of the compartment in which the extinguisher is to be used." The issue becomes critical when an attempt is made to select safe amounts of agent in small aircraft on a volume basis alone. The cabin volumes and calculated concentrations resulting from discharge of 2.5 pounds of Halon 1211 without benefit of ventilation for various aircraft are tabulated in tables 1, 2, 3, and 4.

TABLE 1. SINGLE ENGINE AIRCRAFT (CESSNA AIRCRAFT COMPANY) — 2.5 POUNDS HALON 1211 DISCHARGED AT 70° F

Aircraft Model	Volume ($Ft.^3$)	Concentration (Percent)
152	77	7.3
172	116.1	4.8
172RG	116.1	4.8
TU182	132.4	4.2
TU182RG	130.16	4.3
TU206	144.6	3.9
207	192.1	2.9
C210	139.9	4.0
T210	139.9	4.0
210 Pressurized	141	4.0

TABLE 2. TWIN ENGINE AIRCRAFT (CESSNA AIRCRAFT COMPANY) — 2.5 POUNDS HALON 1211 DISCHARGED AT 70° F

Aircraft Model	Volume ($Ft.^3$)	Concentration (Percent)
310 and 320	143	3.9
340	162	3.5
401 and 402	233	2.4
414 and 427	226	2.5
404	317	1.8
Citation 1	300	1.9
Citation 2	350	1.6
440	441	1.3

TABLE 3. SINGLE ENGINE AIRCRAFT (PIPER AIRCRAFT COMPANY) — 2.5 POUND HALON 1211 DISCHARGED AT 70° F

Aircraft Model	Volume ($Ft.^3$)	Concentration (Percent)
PA-38-112	80	7.0
PA-28-161	130	4.3
PA-28-T200	132	4.3
PA-28-236	132.4	4.2
PA-32-201T	204.6	2.8
PA-32R-301T	209.2	2.7
PA-32R-301SP	212.6	2.6

TABLE 4. OTHER AIRCRAFT — 2.5 POUNDS HALON 1211 DISCHARGED AT 70° F

Aircraft Model	Volume ($Ft.^3$)	Concentration (Percent)
Mooney 201	123.5	4.6
Mooney Turbo 231	123.5	4.6
Beech Bonanza A-36	170.6	3.3
Beech C-24R200	131.3	4.3

For unventilated compartments, the Underwriters' Laboratories standard specifies that a 2.5 pound size Halon 1211 fire extinguisher should not be used in enclosures with volumes less than 312 cubic feet. This limitation would preclude use of Halon 1211 extinguisher agents in all aircraft except twin engine aircraft with large cabins. In this vein, reference 1, Advisory Circular No. 20-42B states: "Inhalation of air containing 4 to 5 percent concentration of Halon 1211 for 1 minute is the maximum that can be safely tolerated by human subjects." When ventilation is considered, safe selection criteria can be based on the total dosage sustained. This is the product of the concentration times the time of exposure. In this manner, increasing ventilation will lower the concentration and thereby lower the dosage of exposure. The high concentration of Halon 1211 in tables 1 through 4 may be tempered somewhat by the introduction of air ventilation such as opening the vents and windows once the fire has been extinguished. Further consideration involves stratification of the halogenated hydrocarbon agents, as they are heavier than air. The molecular weight of Halon 1211 is 165.38 and the

molecular weight of air is 28.97. Dividing the molecular weight of Halon 1211 by the molecular weight of air show Halon 5.7 times heavier than air. Thus, when agent stratification is considered, the pilot's head or breathing location could have significantly lower concentration of Halon 1211 than that near the cabin floor. If there was no ventilation, the behavior that might be expected from discharge of hand-held fire extinguishers in small general aviation aircraft is depicted in figure 1 (reference 2). Although these measurements were recorded in a truck cab, the volume is similar to small aircraft cabins, and the extinguishing agent was Halon 1211. Stratification of the fire extinguishing agent is shown, with only 2 percent initially at the driver's nose and decreasing with time, and 8 percent initially at the floor and also decreasing with time. The dosage experienced by the driver would be the area under the lower curve.

The United States (U.S.) Army Corps of Engineers established a logical series of numbers (1211, 1301, etc.) for quick and convenient identification of the halogenated extinguishing agents. The first digit is the number of carbon atoms in the molecule, the second is the number of fluorine atoms, the third is the number of chlorine atoms, the fourth is the number of bromine atoms, and the fifth digit is the number of iodine atoms (reference 3).

The two major Halon extinguishing agents used in hand fire extinguishers are:

(1) Halon 1211, bromochlorodifluoromethane $CBrClF_2$

(2) Halon 1301, bromotrifluoromethane $CBrF_3$

Halon is a short derivation of halogenated hydrocarbon, which is hydrocarbon that has had the hydrogen atoms replaced with atoms from the halogen series: fluorine, chlorine, bromine, and iodine.

EXPERIMENTAL OBJECTIVES.

The objectives of these tests of neat Halon extinguishing agent discharge in a cabin under flight conditions were to: (1) measure air ventilation rates in the cabin, (2) determine fire extinguisher agent stratification, and (3) measure agent levels continuously with time to determine the dissipation rate of agents discharged from hand-held fire extinguishers.

DISCUSSION

DESCRIPTION OF FACILITY.

A 10-foot-diameter by 24-foot-long airflow facility was designed and constructed from flat 4-foot by 8-foot sheets of low carbon steel. The cross section, figure 2, is octagonal in shape. The entrance is a bellmouth designed to a 5-foot radius. The 10-foot extension is attached to an existing 5-foot-diameter airflow facility, figure 3. Performance of the 5-foot facility is near Mach 1 airspeed or can be choked at 10,000-foot altitude. Two J57 turbojet engines provide power to drive the facility by ejector action. The 10-foot diameter extension was designed for a minimum airspeed of 100 knots. Measurements with a Cessna 210C aircraft installed has indicated that airspeeds of 140 to 150 miles per hour (120 to 130 knots) are achievable. The increase over design performance is attributed to the propeller supercharging action, to increased local airspeed resulting from decrease in tunnel cross section resulting from the frontal areas of the installed Cessna 210C aircraft, and to improved contour development of the wind tunnel walls.

DESCRIPTION OF AIRCRAFT.

The test article is a 1963 model Cessna 210C with retractable landing gear (figure 3). The airplane is a four-place high-wing monoplane, powered by a single six-cylinder, horizontally-opposed fuel injection Continental I0470 engine. For installation in the facility, mounts were designed, fabricated, and installed at the wing spar attachment points and at the wing strut attachment points. The fuselage was installed in the tunnel with 3/4-inch high carbon steel rods connected to the mounts and to the tunnel walls. The wings were cut at a 32-inch root section and were then installed on the fuselage in the tunnel. The sections were installed to provide the cabin ventilation air inlet ports located in the wings. It was necessary to move the ports inboard for inclusion in the 32-inch wing root sections.

MEASUREMENT OF EXTINGUISHING AGENTS.

An enviromentally controlled trailer was utilized for measurement of fire extinguishing agents. The agent of primary interest, Halon 1211, was measured with two Beckman model 865 gas analyzers, modified by changing the water vapor detector to a fluorine detector purchased from Beckman Instruments Company. In addition, an optical filter was added to eliminate sensitivity to water vapor. Calibration gases of Halon 1211 at concentrations of 2 percent, 4 percent, and 6 percent by volume were utilized. Ancillary components utilized were sample transport lines, sample pumps, and sample flow controls.

AIRSPEED CALIBRATION.

Measurement of aircraft airspeed was required in this project for simulation of flight conditions. Aircraft flight speed was required to produce realistic ventilation airflow in the cabin. Opening vents and windows to dissipate extinguishing agents will produce realistic conditions in the cabin which could increase the ventilation.

Pitot-static tubes were utilized to calibrate the aircraft airspeed indicator system. The aircraft airspeed instrument was utilized for establishing test conditions and was monitored by a television camera. These airspeed calibrations were accomplished under a range of engine and facility conditions.

CABIN VENTILATION AIRFLOW.

Airflow in the cabin was visualized and defined as to direction by artificial smoke introduced from the cabin ventilation ports located in the wing-leading edge. Instrumentation consisted of tuffs recorded on video tapes. Pitot-static probes were employed to measure the ventilation airflow as determined by smoke visualization. Additionally, the rate of decay of agent allowed computation of an effective time for an air change. This was the time for the agent concentration to drop 63 percent from its peak value.

DOCUMENTED FIRE LOCATIONS.

Table 5 was excerpted from report DOT/FAA/CT-82-42 (reference 4). The information is from the FAA Service Difficulty Program. Table 5 shows that 86.7 percent of cabin fires in general aviation aircraft are electric or electronic in origin.

TABLE 5. CABIN FIRE STATISTICS

(Involving Smoking Materials, Electical Origin, Hand-Held Extinguishers)

Year	Incidents No.	Smoking Materials No. (%)	Electrical Origin No. (%)	Hand-Held Use No. (%)
1976	15	--	14 (93.3)	--
1977	10	1 (10.0)	9 (81.8)	--
1978	8	1 (12.5)	7 (87.5)	--
1979	23	3 (13.0)	21 (91.3)	--
1980	19	--	16 (78.9)	--
1981	8	--	7 (87.5)	--
TOTAL	83	5 (6.0)	72 (86.7)	none recorded

The electrical and electronic components are located in and under the instrument panel. The instrument panel for the test aircraft (Cessna 210C) is shown in figure 4. Identification of the equipment is also listed. Electrical power for the aircraft is supplied by a 12-volt direct current, negative ground electrical system. A single 12-volt battery supplies power for starting and provides reserve in the event of generator or alternator failure. On the extreme left side of the instrument panel, one item that could be involved in a fire is the master switch. The operation of the battery and generator systems is controlled by this switch. Operation of the switch connects the battery solenoid coil and the generator field coil to ground, thereby activating the power systems.

The ignition start switch is utilized to check the magnetos and is also used to engage the starter through the starter solenoid. The auxiliary fuel pump switch operates two electric fuel pumps connected in series which are located in the nose-gear well.

Additional electrical units located in the left-hand side instrument panel include a number of circuit breakers, instrument and radio light rheostats, radio switch, oil dilution switch, pitot heater switch, navigation light switch, rotating beacon switch, landing light switch, gear up indicator light, gear down indicator light, and electric clock.

Electronic components are installed in the center panel between the pilot's and copilot's location. A stack of three radios and/or radio direction finder equipment is installed in this area. Located under the radios is a Nav-o-matic control auto pilot.

Electrical units on the right or copilot's side of the instrument panel are (1) a transponder control located on extreme right; (2) an ammeter, and (3) additional electrical units including cylinder head temperature gauge, oil temperature gauge and cigar/cigarette lighter.

In combination with these potential electrical ignition sources, are fuel and oil sensor lines brought to the instrument panel for oil pressure and fuel-flow indication. Additionally, fuel flows through the cabin from the overhead wing tanks to tank selector valves located on the floor below the instrument panel. The fuel lines are located behind the side panel walls.

TEST RESULTS

Extinguisher discharge and related testing were accomplished remotely and the results were observed and recorded with video systems. In general, testing was conducted at an airspeed of 120 miles per hour as this condition was achievable by operating the two turbo-jet drive engines and the Cessna 210 piston engine at cruise power. Exceptions to those conditions were: airspeed effects investigation run at 0 to 140 miles per hour, and ventilation studies at airspeeds of 120 miles per hour and 140 miles per hour. Results of the airspeed calibration, using pitot-static probes, disclosed that the aircraft airspeed indicator was accurate above 100 miles per hour in the airflow facility installation.

The cabin ventilation airflow visualization studies showed that with the overhead front vents open and directed toward the pilot's and copilot's faces, direction of the flow was diagonal across the side windows and toward the rear of the aircraft. All flow direction components appear to be comparable downward and rearward. The smoke visualization indicated that the flow was moving at a fast air ventilation rate.

The flow exiting the overhead ventilators was measured with pitot-static probes at airspeeds of 120 miles per hour and 140 miles per hour. Airflow through each of the front vents was 32 ft^3/min and 39 ft^3/min at the noted speeds, respectively. Flow through each of the rear vents was 28 ft^3/min and 29 ft^3/min at 120 miles per hour and 140 miles per hour, respectively. Total flow was 121 ft^3/min and 138 ft^3/min. Since the volume of the 210 aircraft is 139.9 ft^3 the time for an air change in the cabin is 1.16 minutes at 120 miles per hour and 1 minute at 140 miles per hour airspeed. Cabin ventilation flows were significantly higher than previously thought possible. The actual volumetric flow in each port was calculated as the product of the measured exit velocity and the area of the port. The explanation for these high ventilation rates lies in the fact that the leading edge stagnation pressure is high at flight speeds. Since the cockpit of a non-pressurized aircraft is usually close to the static pressure at any altitude, there will be a large pressure differential between the leading edge port and the cabin interior. This causes large ventilation airflows.

DISCHARGE UNDER INSTRUMENT PANEL.

As noted in table 5, 86.7 percent of in-flight fires in general aviation aircraft are electric or electronic in origin. This potential fire area is located for the most part under the instrument panel. The problem was addressed by conducting eight tests with discharge of Halon 1211 agent under the instrument panel. Four 2.5 pound Halon 1211 extinguishers were directed under the instrument panel on the copilot's side and four simular tests were completed by discharging 2.5 pound 1211 extinguishers under the instrument panel on the pilot's side. Two tests at each location were with the overhead vents open and one test at each discharge location was with all the vents open including two auxiliary vent doors located on

the lower fuselage behind the engine. This ventilating airflow is introduced through the cabin heat and defrost system. The last pair of tests was with all the vents closed.

The Halon 1211 measurements during the tests with discharge under the instrument panel were plotted against time in seconds and are presented on figures 5 through 12. Discrete points were taken off a strip chart for analysis. The overall shape of the continuous strip chart readings was presented in the graphs shown in the figures. Peak Halon concentrations behind the instrument panel ranged from 9.60 percent to 3.3 percent with a mean of 7.25 percent. Peak Halon 1211 concentrations at the pilot's nose height was only 2.10 percent maximum with a mean of 1.91 percent. The significant finding is that the Halon concentrations decrease rapidly, within one minute the concentration was 0.50 percent or less. Reference 5 defines the effective air change time when the decay or dissipation curve of the agent is exponential. From the maximum concentration after discharge, the concentration will decay to 37 percent of the maximum after one air change, to 5 percent of the maximum after 3 air changes, etc. Examination of the curves in this report discloses that decay of the agent tends to follow an exponential relationship. The maximum recommended dose is also defined in references 1 and 5 as 4 percent minutes; i.e., exposure to 4 percent Halon 1211 for 1 minute or exposure to one percent for 4 minutes. Dose is defined in reference 5 as Dose=C_o , where C_o is the maximum concentration and τ is the time for one air change. τ may also be defined as the time for an effective air change which includes agents that could be settling out or stratifying.

Dose was calculated for all of the Halon 1211 concentration measurements which were recorded. The discrete measurements decayed in an exponential relationship, however, there was an initial rise time and in some instances after the rise, concentrations remain relatively constant for up to 10 seconds prior to the exponential decay. The excursions were calculated separately then added to the dose calculation. Dose calculations for the pilot's nose height were low and approximately 25 percent of the maximum dose of 4 percent minutes. With the overhead vents open, the dose ranged from 0.82 to 1.11 percent minutes with an average of 0.95 percent minutes for 4 measurements. When all of the vents were opened, the dose was 0.59 and 0.92 for the two tests. When the ventilators were all closed, the dose was 1.04 and 1.68 for the two tests. For this condition, shown in figures 8 and 12, the Halon concentations in some cases were less but the time for an effective air change was greater resulting in similar or greater doses with tunnel operating at 120 miles per hour.

DISCHARGE TO FUEL AND HYDRAULIC SELECTOR VALVES.

The second series of tests involved the extinguisher being directed at the fuel selector valves and hydraulic selector valves on a console raised approximately 6 inches from the floor, located between the pilot and copilot. Four 2.5 pound Halon 1211 extinguishers were discharged in these tests. The cabin ventilation and airspeed were as previously described. The measurements are plotted in figures 13 through 16. Dose for the pilot was low and similar to the levels previously discussed. The range was 0.74 percent minute to 1.17 percent minutes, with an average of 0.93 percent minute. Maximum concentrations in vicinity of the fuel and hydraulic selector valves were less in these tests than maximum concentrations when the agent was discharged and measured beneath the instrument panel.

DISCHARGE TO COPILOT'S SEAT.

Four Halon 1211 extinguishers of 2.5 pounds capacity were directed to the copilot's seat. Impact of the extinguishers was approximately 3 inches up on the back support of the seat. Figures 17 through 20 show the concentrations at the pilot's nose height and at the copilots seat. Maximum concentrations at the copilot's seat ranged from 6.9 percent to 8.8 percent with a mean of 7.8 percent. Peak concentrations at the pilot's nose height varied from 1.6 percent to 2.7 percent, and the four measurements averaged 2.16 percent. The pilot's dose was 1.14 and 1.15 percent minutes with the overhead vents open; 0.61 percent minute with all the vents open; and 1.14 percent minutes with all the vents closed. The latter conditions result in lower concentrations at the nose height but dissipation was slower with an increased τ which effects the dose.

DISCHARGE TO REAR SEAT.

Four 2.5 pound Halon 1211 extinguishers were discharged on the rear passenger's seat located directly behind the pilot at an airspeed of 120 miles per hour. The Halon concentrations measurements versus time are shown in figures 21 through 24. Dose calculated for the pilot's nose height was 0.55 and 0.62 percent minutes with the overhead vents open, 0.36 percent minutes with all the vents open, and 0.88 percent minutes with all the vents closed. The dose was lower than during extinguisher discharge at the locations previously described.

DISCHARGE TO BAGGAGE COMPARTMENT.

Extinguisher agents were also directed to the baggage compartment. Four tests were completed by placing the extinguisher at the pilot's location and directing the exhaust stream to the center of the baggage area. Test measurements are shown in figures 25 through 28. Dose calculations for the pilot's nose height were 0.71 and 0.88 percent minute with the overhead vents open, 0.68 percent minute with all vents open and 1.18 percent minutes with all the vents closed. The Halon concentrations at the pilot's nose height were somewhat higher in these tests than those found during tests on the rear seats. This may indicate some recirculatory flow patterns within the aircraft cabin.

AIRSPEED EFFECTS.

A limited investigation was conducted on the effects of airspeed on Halon concentrations and dose calculations. The area selected for these tests was the copilot's seat. Two Halon 1211 extinguishers of 2.5 pound capacity were discharged at the seat at zero airspeed, figures 29 and 30. Figure 29 is a plot of the results with the vents closed; Halon concentrations at the pilot's nose height did not drop by 63 percent during the 19 minutes duration of the test. The dose calculation was 27.8 percent minutes over this interval, which is extremely hazardous. Figure 30 is a plot of the results with all the vents open, and the dose calculation was approximately 5 percent minutes, which exceeds the recommended dose of 4 percent minutes. The test results at zero airspeed were similar to results shown in figure 1 for discharge of Halon 1211 in a truck cab.

Testing presented in figure 31 was conducted at an airspeed of 40 miles per hour; the dose calculation was 1.58 percent minutes. The tunnel was operated at 80 miles per hour for the measurements depicted in figure 32, and the dose calculated for the pilot's nose height was 1.29 percent minutes. Figures 17 and 18 may be

utilized for airspeeds of 120 miles per hour, the dose was 1.14 and 1.15 percent minutes at this speed. Test results at 140 miles per hour are shown in figure 33, the dose dropped to 0.66 percent minute. The calculated dose is plotted against airspeed in figure 34. Figure 34 clearly shows the effect of airspeed on agent dissipation. Neat state toxicity problems are non-existent at cruise flight speeds, but potentially hazardous while the aircraft is stationary on the ground or taxiing.

TABLE OF RESULTS.

A summary of neat Halon 1211 extinguisher results are contained in table 6. The first two columns give the relevant figure identification and discharge location for cross reference purposes. The third column lists the weight of the agent discharged. The nominal 2.5 pound Halon 1211 extinguisher charge actually varied from 2.40 pounds to 3.65 pounds, with mean agent weight of 2.85 pounds and standard deviation of 0.33. Agent discharge time was determined where possible, and the average was 11.3 seconds, with a standard deviation of 1.97. Further columns define the ventilation conditions, maximum concentration at the test location and maximum concentration at the pilot's nose height. With the overhead vents open, the average maximum concentrations of agent near discharge of the extinguisher was 6.15 percent. With all vents open, it was 6.7 percent.

Halon 1211 extinguishing agent maximum concentrations at the pilot's nose height averaged 1.94 percent with the overhead ports open, 1.84 percent with all vents open, and 1.53 percent with all vents closed. Average dose for the pilot's nose height was 0.90 percent minute with the overhead vents open, 0.65 percent minute with all vents open, and 1.14 percent minutes with all vents closed. These results are tabulated in table 7.

In tests where the agent was discharged under the instrument panel, the air temperature drop behind the instrument panel was 99° F. When the extinguishers were discharged, the significant temperature drop did not cause a malfunction or defect as noted by continued operation of the engine and by video coverage and recordings of instrument operation.

Temperature differential at the pilot's nose was negligible during most tests. Maximum temperature differential at other test locations ranged from 2.6° F to 53.8° F in proximity to discharge of the extinguisher.

One 2.5 pound dry powder test was conducted by discharging the extinguisher on the copilot's seat. The extinguisher was a multi-purpose (ABC) dry chemical charged with the basic agent, ammonium phosphate. This test was significant as video coverage of the test was immediately blacked out for a total of 22.6 seconds. A spotmeter was utilized to measure lumination and/or transmission. The measurements are plotted in figure 35. Light sensed by the spotmeter dropped immediately upon discharge from 100 percent to 28 percent. When objects became visible, although hazy and indistinct as noted by video coverage (22.6 seconds), the spotmeter showed light readings changed to 68 percent of the initial readings.

TABLE 6. DATA SUMMARY

FIG.	TEST LOCATION	AGENT DISCH WT (LBS)	DISCH. TIME SEC.	VENTILATION: OVERHEAD VENTS OPEN	VENTILATION: ALL VENTS OPEN	VENTILATION: ALL VENTS CLOSED	MAX CONC. TEST LOCATION	MAX CONC. PILOT'S NOSE	DOSE PILOT (% MIN)	AIR TEMP °F	MAX ΔT °F	REL HUM. %	AIR SPEED MPH	TEST NO.
5	Under instrument panel copilot's side	3.65		X			7.35	1.95	1.11	67.2	99.6	87	120	3
6	Under instrument panel copilot's side	2.65	-	X			7.25	2.05	0.94	68.1	12.6	78	120	4
7	Under instrument panel copilot's side	2.90	11.0		X		8.00	1.90	0.59	60.2	31.1	45	120	7
8	Under instrument panel copilot's side	2.95	11.5			X	6.10	1.05	1.04	70.8	111.2	78	120	6
9	Under instrument panel pilot's side	3.10	10.0	X			9.05	2.05	0.91	60.9	101.3	45	120	8
10	Under instrument panel pilot's side	2.80	11.0	X			7.45	2.10	0.82	51.3	97.2	29	120	9
11	Under instrument panel pilot's side	2.85	-		X		9.60	2.00	0.92	54.4	99.5	29	120	11
12	Under instrument panel pilot's side	2.90	10.0			X	3.30	2.00	1.68	55.3	99.6	29	120	10
13	Fuel and Hydraulic Selector Valves	2.95		X			4.00	2.45	1.17	43.5	3.0	93	120	12
*14	Fuel and Hydraulic Selector Valves	3.10		X			3.40	1.65	0.86	41.8	7.0	93	120	*13
15	Fuel and Hydraulic Selector Valves	2.65			X		4.25	2.05	0.74	78.8	5.0		120	16
16	Fuel and Hydraulic Selector Valves	3.25				X	4.60	0.85	0.94	78.5	2.6		120	15
17	Copilot's Seat	3.05		X			6.85	2.20	1.14	75.2	24.3	64	120	17
18	Copilot's Seat	3.25	15.9	X			8.80	2.75	1.15	80.3	53.8	64	120	18
19	Copilot's Seat	2.55	11.0		X		7.25	2.10	0.61	81.8	34.5		120	20
20	Copilot's Seat	3.15	14.9			X	8.30	1.60	1.14	80.8	42.4	64	120	19
21	Rear Seat Behind Pilot	2.65	10.5	X			3.95	1.35	0.55	61.9	13.8		120	26
22	Rear Seat Behind Pilot	2.45	12.4	X			3.80	1.45	0.62	60.3	10.2	36	120	27
23	Rear Seat Behind Pilot	2.85	10.7		X		3.75	1.45	0.36	60.0	12.4	36	120	29
24	Rear Seat Behind Pilot	2.25				X	3.45	1.45	0.88	61.2	7.2	36	120	28
25	Center of Baggage Compart.	2.85	-	X			5.15	1.60	0.71	58.9	28.3		120	30
26	Center of Baggage Compart.	3.05	-	X			6.75	1.65	0.84	60.0	22.5		120	31
27	Center of Baggage Compart.	3.20	-		X		7.35	1.55	0.68	61.2	22.8		120	33
28	Center of Baggage Compartment	3.15	-			X	6.40	2.20	1.18	75.5	43.1		120	32
29	Copilot's Seat, Air-Speed Test	2.45				X	8.55	1.20	22.8	76.1	28.1		0	22
30	Copilot's Seat, Air-Speed Test	2.85	10.1		X		5.80	1.95	4.97	75.0	31.3		0	21
31	Copilot's Seat, Air-Speed Test	2.35	10.2	X			3.85	2.10	1.58	71.4	32.4	38	40	23
32	Copilot's Seat, Air-Speed Test	2.40	9.2	X			7.75	2.00	1.29	76.9	47.0	28	80	24
33	Copilot's Seat, Air-Speed Test	2.35		X			7.25	2.00	0.66	74.2	32.0	28	140	25
34	Copilot's Seat, Chemical Powder			X			-	-	-	-	-	-	120	36

* Piston engine not running

TABLE 7. VENTILATION RESULTS

EXTINGUISHER DISCHARGE		CONCENTRATION	
	N	$\bar{X}$ %	S
Overhead Vents Open	12	6.15	2.0
All Vents Open	6	6.70	2.25
All Vents Closed	6	5.35	1.94
PILOT'S NOSE HEIGHT		CONCENTRATION	
Overhead Vents Open	12	1.94	0.42
All Vents Open	6	1.84	0.27
All Vents Closed	6	1.53	0.52
PILOT'S NOSE HEIGHT		DOSE	
Overhead Vents Open	12	0.90	0.21
All Vents Open	6	0.65	0.19
All Vents Closed	6	1.14	0.29

Reference 1 states "When dry chemical fire extinguishers are discharged in crew compartments or confined areas, serious impairment to visibility will occur." This one test confirms this statement. Large quantities of powder residue settled throughout the cabin which required extensive cleanup. In addition, the literature points out that the chemical powder is corrosive, particulary to electronic units.

SUMMARY OF RESULTS

Hand-held fire extinguishers of 2.5 pound capacity were tested and evaluated in a Cessna Model 210C aircraft installed in an airflow facility. These tests were conducted without fires and involved the continuous sampling of neat Halon 1211 agents from two locations. The agent was sampled and measured from the pilot's nose height for toxicity determination and sampled and measured from locations in proximity to discharge of the extinguishers. Air temperatures were measured at both of the gas sampling locations.

Maximum agent concentrations near the point of extinguisher discharge averaged up to 6.7 percent at cruise airspeed. Agent concentrations at the pilot's nose

height averaged between 1.53 percent to 1.94 percent, depending on extinguisher discharge location relative to the pilot. The neat Halon concentration dissipated rapidly; after 1-minute concentrations were less than 0.5 percent. Dose was calculated for the pilot's nose height. Reference 1 and reference 5 defines dose for Halon 1211 as "exposure to 4 percent for 1 minute or 2 percent for 2 minutes."

Dose calculations for the pilot were approximately 1 percent minute. This is considered very safe as the dose was only 25 percent of the recommended limit of 4 percent minutes.

In an exploratory test, a 2.5 pound dry chemical extinguisher was discharged on the copilot's seat. Test results were negative as video coverage was blacked out for over 22 seconds by the cloud of agent in the cabin. This result confirms cautions in Section 7.C of reference 1, "When dry chemical fire extinguishers are discharged in crew compartments or confined areas, serious impairment to visibility will occur." This one test confirms this precaution.

Figures 5 through 28 clearly show that the dose at the pilot's nose is always well below recommended limits for discharge of 2.5 pounds of Halon 1211 under simulated C210 flight conditions. The Underwriter's Laboratory Standards, cited in reference 5, would preclude use of a 2.5 pound Halon 1211 in the C210. Furthermore, the nomographs of AC-20-42B and reference 5 would also preclude use of this extinguisher if the air change time measured from pitot tubes were used. The air change rate of once a minute at 140 mph would allow a Halon weight of approximately 1.6 pounds. However, the experimental procedure in reference 5 is based on evaluation of an effective time for an air change that would include stratification effects as well as air addition through the vent ports of the aircraft. The effective time for an air change in figures 5 through 28 is typically one-third minute.

The effective time for a air change can be used to judge the safety margin throughout the cabin of the C210 and is, in fact, the prime piece of data for generalizing the test results. Agent stratification effects, in effect, triple the ventilation rates in clearing the cabin of agent. Because of this strong effect, proper use of the Halon 1211 selector nomograph in AC-20-42B would allow use of agent weight in excess of 6 pounds. Thus, by including effects of aircraft ventilation augmented by stratification effects, the safety of commercially available halogenated agents in an aircraft like the C210 can be clearly proven. Without such a combination of experiment and analysis on a small aircraft, reliance on existing codes and standards would preclude use of any agent other than water.

CONCLUSIONS

1. Halon 1211 extinguishers of 2.5 pound capacity were shown safe for use in general aviation aircraft of high cabin ventilation rates.

2. Dose calculations for neat Halon 1211 agent for the pilot were only 25 percent of the recommended human exposure limit.

3. Cabin ventilation airflow in non-pressurized aircraft can result in air change rates of the order of one a minute at cruise speeds.

4. The effective ventilation rate including stratification effects resulted in an air change rate of the order of one-third of a minute for use in the selector nomographs of AC-20-42B.

5. Discharge of chemical powder extinguisher in a small cockpit can seriously hamper visibility.

REFERENCES

1. Hand Fire Extinguisher for Use in Aircraft, Advisory Circular, AC No: 20-42B, U.S. Department of Transportation, Federal Aviation Administration, 1982.

2. The Discharge of BCF (Halon 1211) Hand Extinguishers in Confined Spaces, Imperial Chemical Industries Limited, Mond Division.

3. NFPA 12A Halon 1301 Fire Extinguishing Systems and NFPA 12B Halon 1211 Fire Extinguishing Systems, National Fire Protection Administration.

4. Krasner, L. M., Study of Hand-Held Fire Extinguishers Aboard Civil Aviation Aircraft, FAA Technical Report, DOT/FAA/CT-82/42, July 1982.

5. Eklund, T. I., Analysis of Dissipation of Gaseous Extinguisher Agents in Ventilated Compartments, FAA Technical Report DOT/FAA/CT-83/1, May 1983.

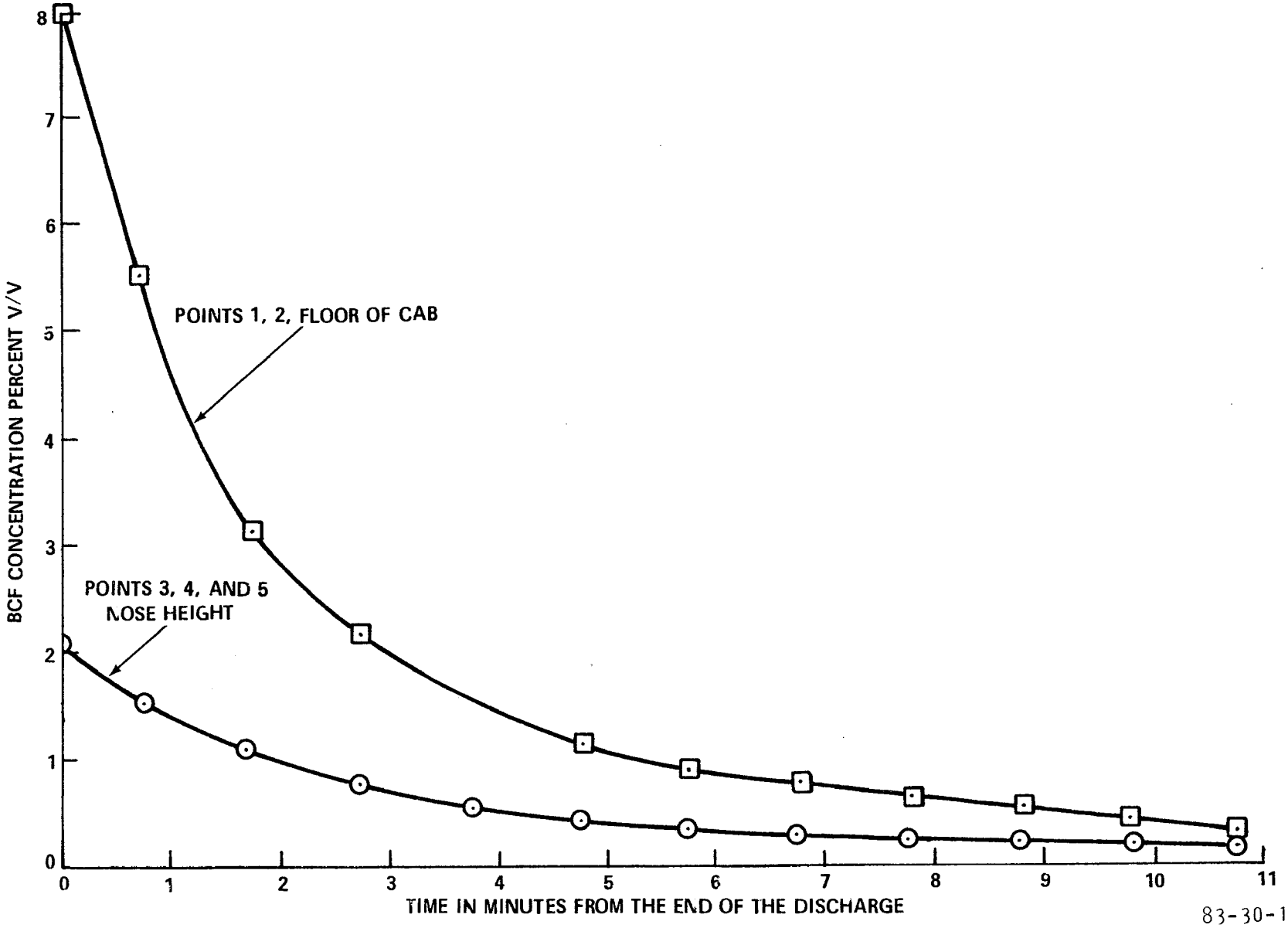


FIGURE 1. "BCF" CONCENTRATIONS - LORRY CAB, RUNS 1 AND 2, 3-lb (1.4 Kg) EXTINGUISHER (EXCERPTED FROM REFERENCE 2)

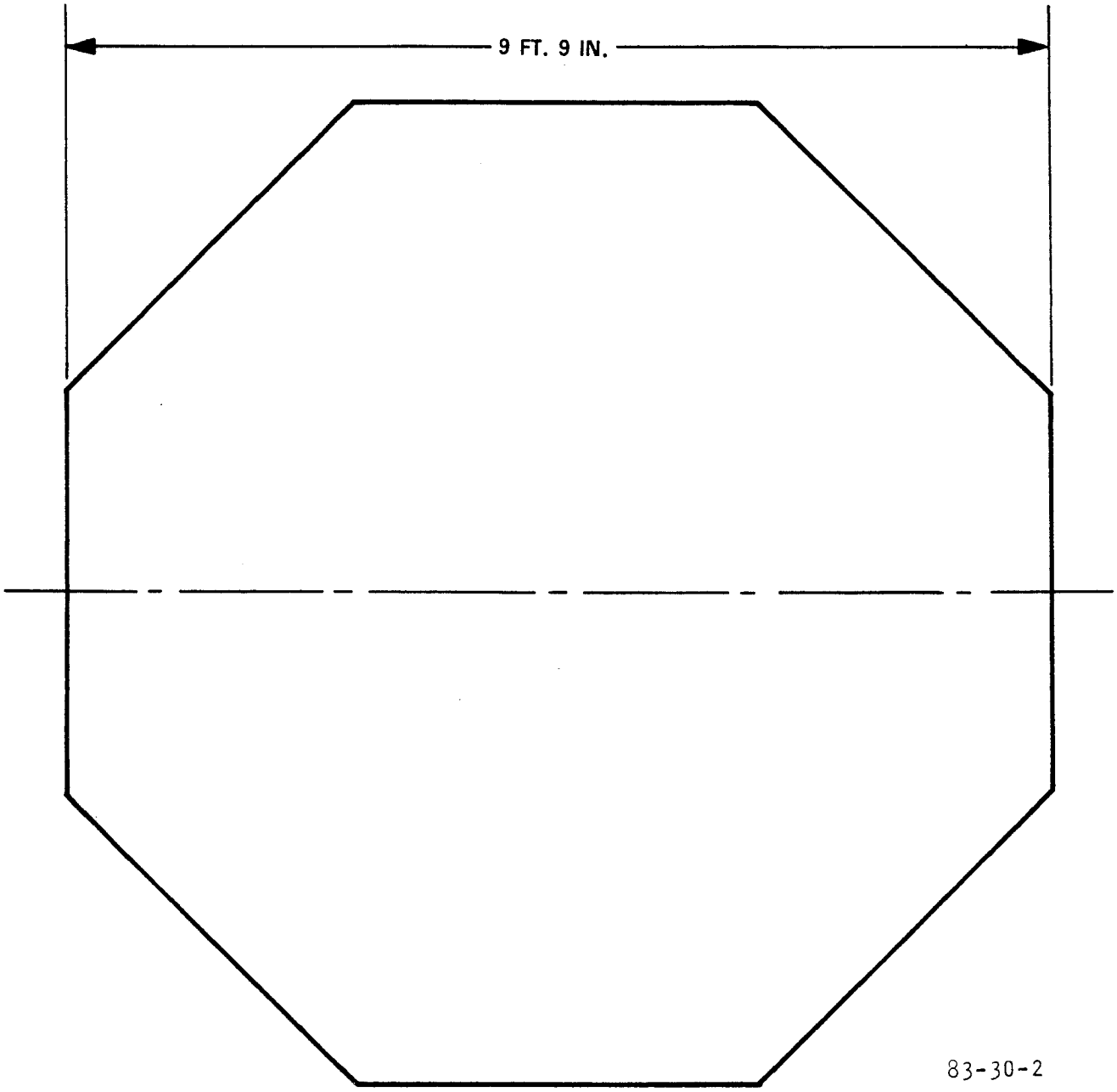


FIGURE 2. GENERAL AVIATION WIND TUNNEL - CROSS SECTION

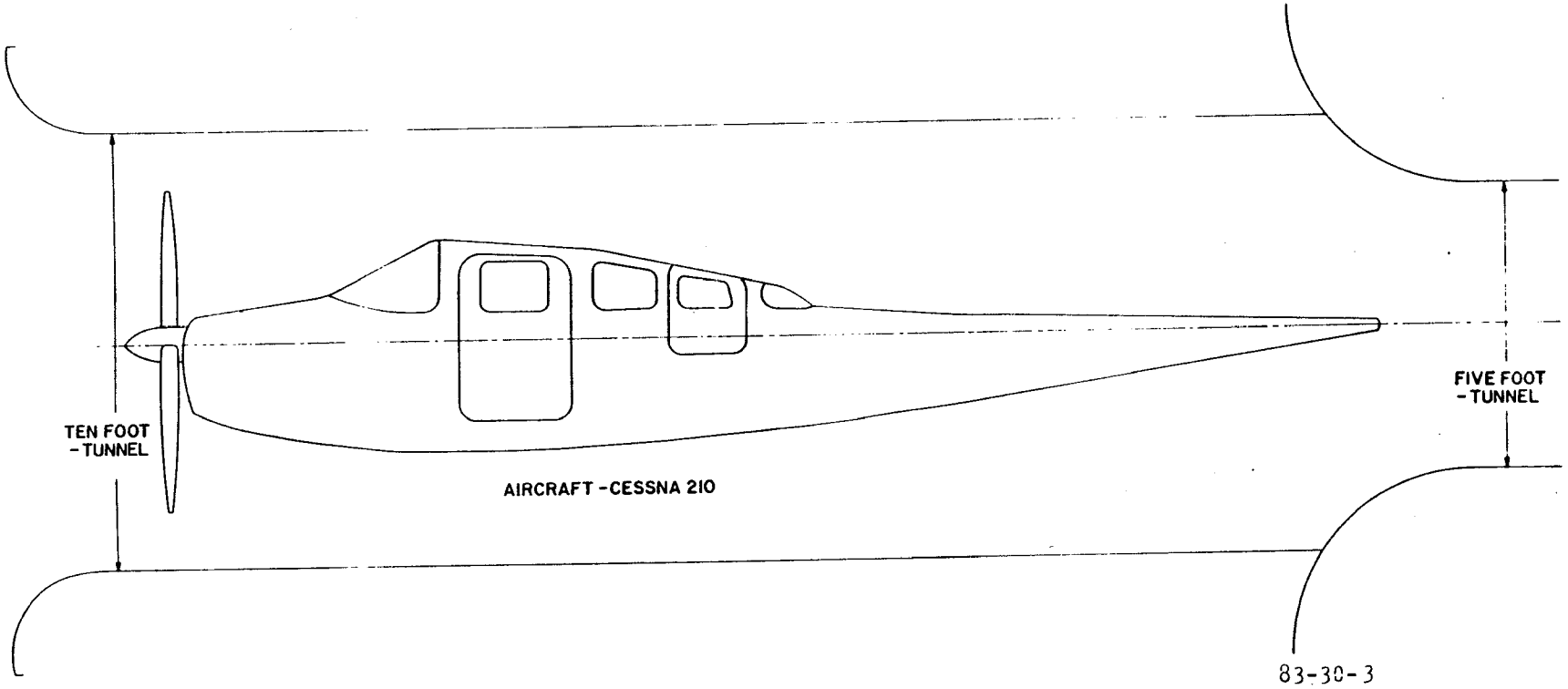
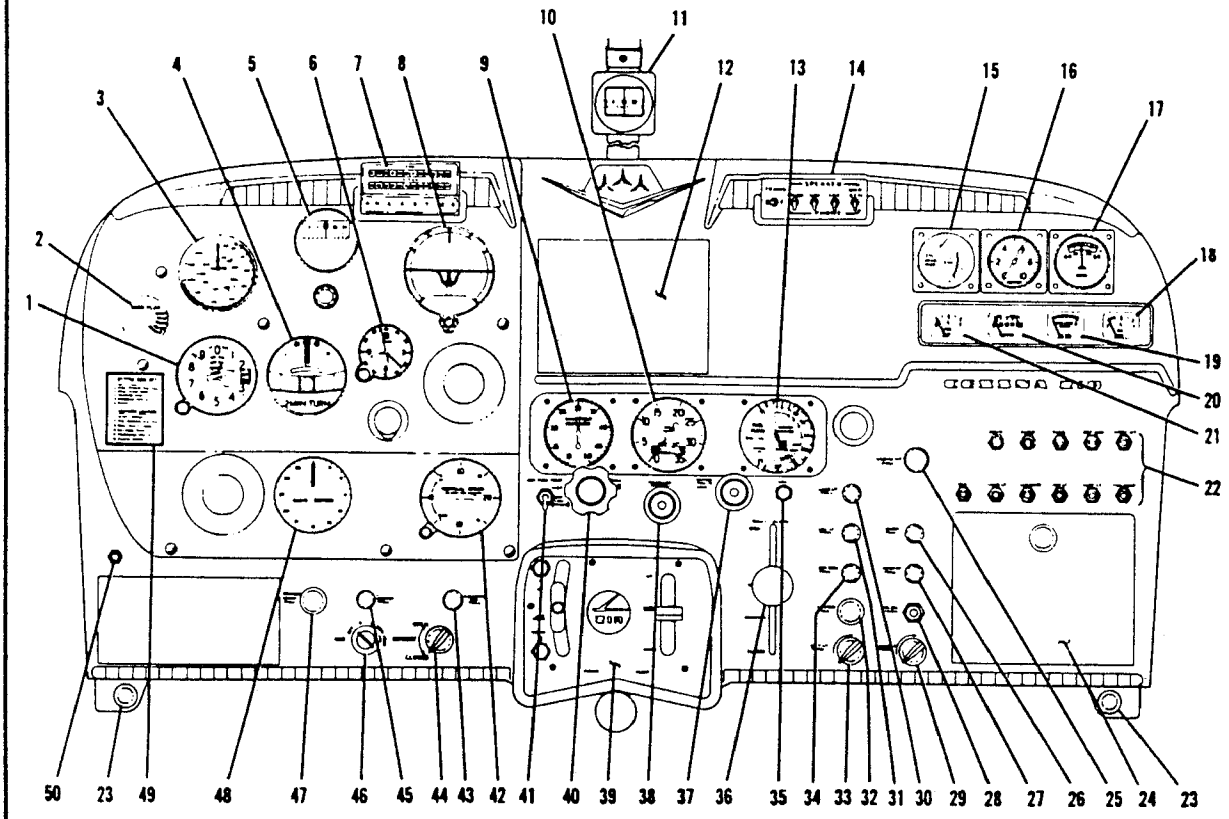
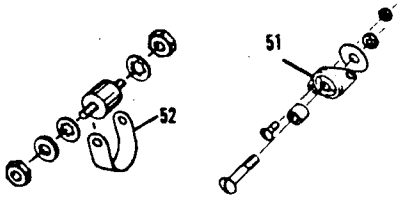


FIGURE 3. GENERAL AVIATION WIND TUNNEL - PROFILE



NOTE

If shockmount has unequal thread length, install shorter threads through stationary panel.



NOTE

The 210 and 210A instrument panels are identical except for minor styling changes and switch relocations.

1. Altimeter
2. Wing Flap Position Indicator
3. Airspeed Indicator
4. Turn-and-Bank Indicator
5. Directional Gyro
6. Clock
7. Compass Correction Card
8. Gyro Horizon
9. Manifold Pressure Gage
10. Tachometer
11. Magnetic Compass
12. Radio Space
13. Fuel Flow Indicator
14. Radio Selector Switches
15. Cylinder Head Temp. Gage
16. Suction Gage
17. Ammeter
18. Fuel Quantity Indicator
19. Oil Temperature Gage
20. Oil Pressure Gage
21. Fuel Quantity Indicator
22. Circuit Breakers
23. Cabin Air Knob
24. Map Compartment
25. Cabin Heat Knob
26. Radio Switch
27. Pitot Heater Switch
28. Oil Dilution Switch
29. Radio Light Rheostat
30. Landing Light Switch
31. Navigation Light Switch
32. Cigar Lighter
33. Instrument Light Rheostat
35. Generator Warning Light
36. Cowl Flap Lever
37. Mixture Control
38. Propeller Control
39. Power Pack (See Section 5)
40. Throttle
41. Auxiliary Fuel Pump Switch
42. Vertical Speed Indicator
43. Induction Hot Air Knob
44. Defrost Knob
45. Master Switch
46. Ignition - Start Switch
47. Fuel Strainer Drain Knob
48. Radio Compass
49. Check List
50. Microphone Jack
51. Shock Mount
52. Ground Strap

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FIGURE 4. INSTRUMENT PANEL - CESSNA MODEL 210C AIRPLANE

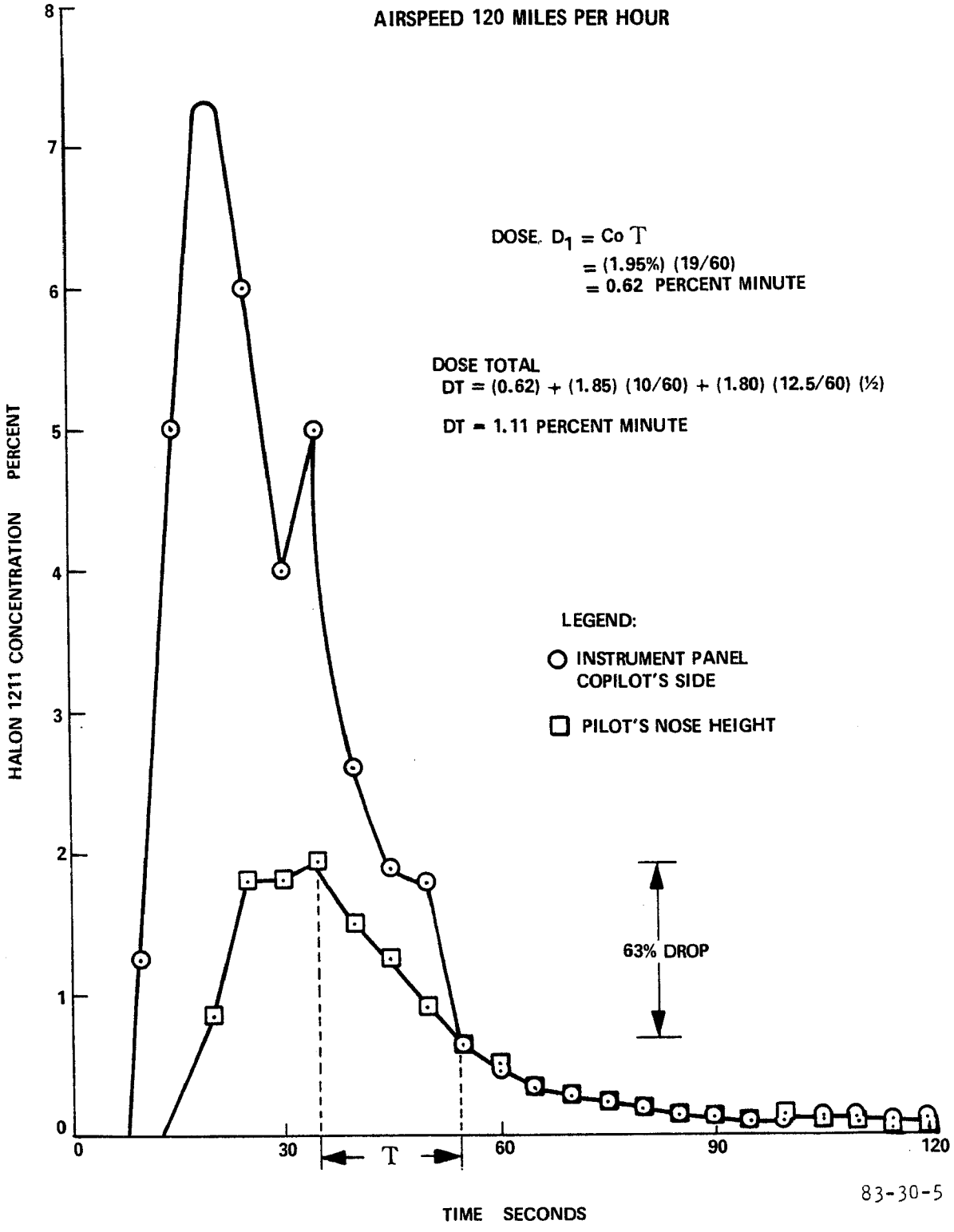

FIGURE 5. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED UNDER INSTRUMENT PANEL - COPILOT'S SIDE - OVERHEAD VENTS OPEN (DOSE TOTAL 1.11 PERCENT MINUTE)

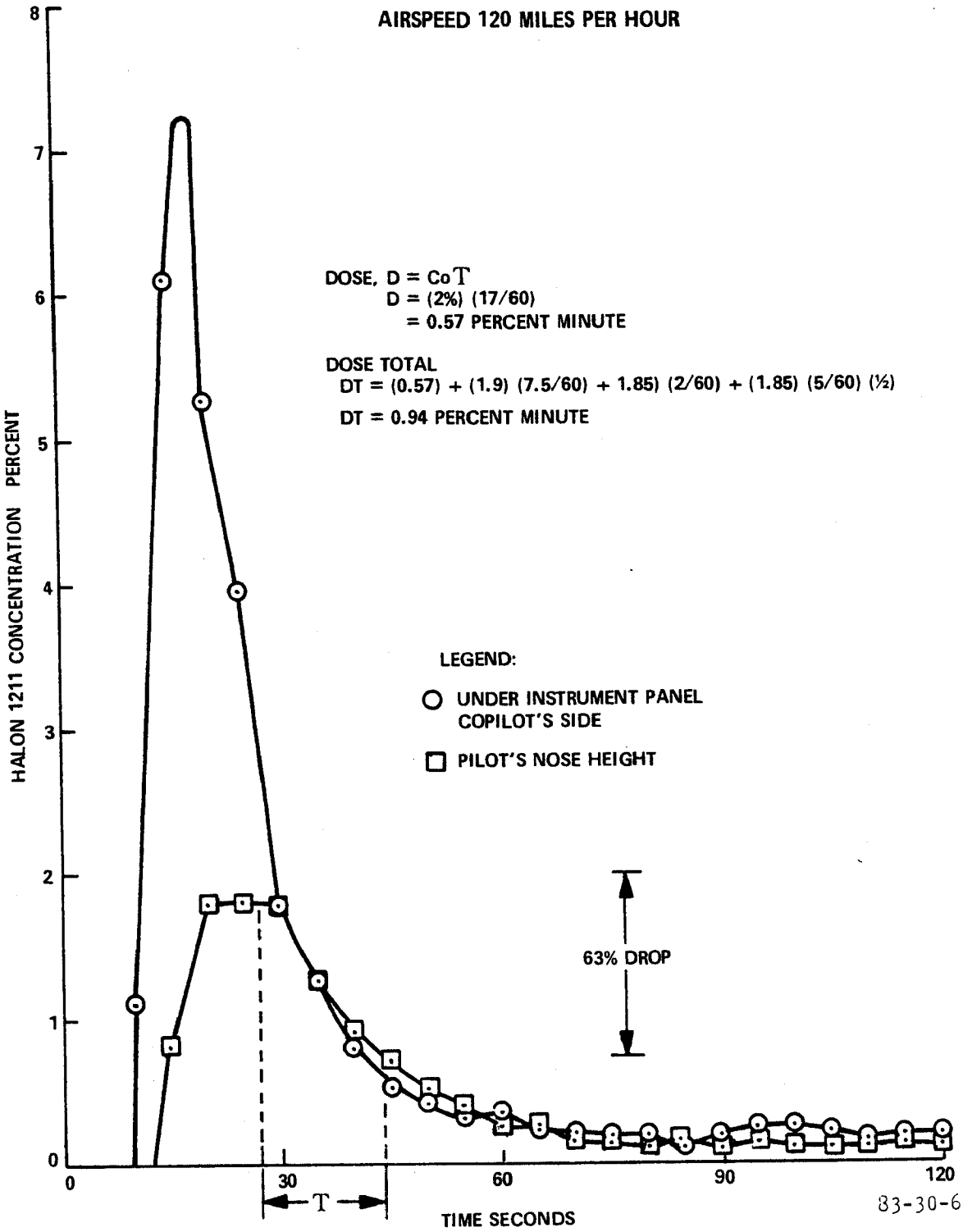

FIGURE 6. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED UNDER INSTRUMENT PANEL - COPILOT's SIDE - OVERHEAD VENTS OPEN (DOSE TOTAL 0.94 PERCENT MINUTE)

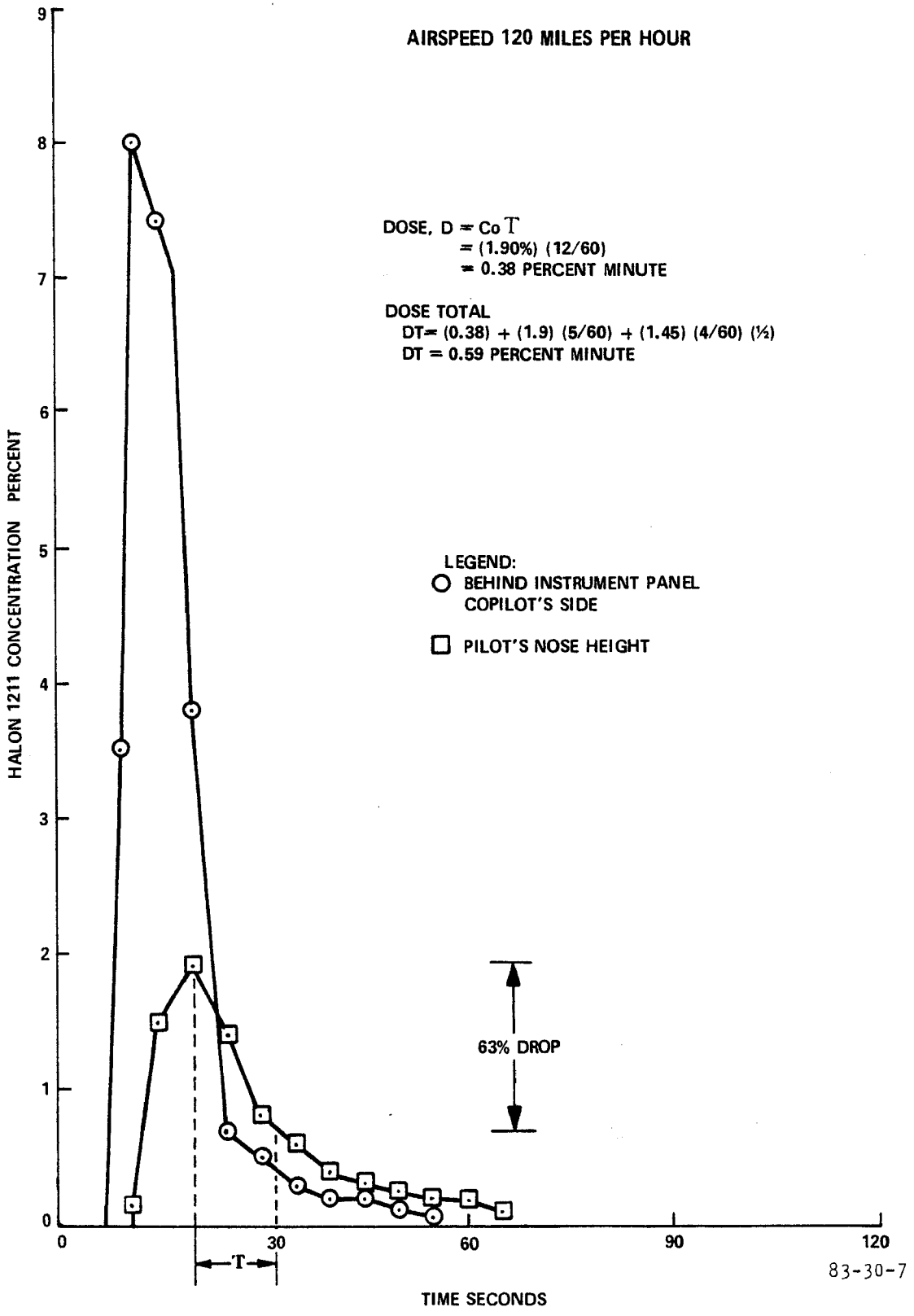

FIGURE 7. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED UNDER INSTRUMENT PANEL - COPILOT'S SIDE - ALL VENTS OPEN

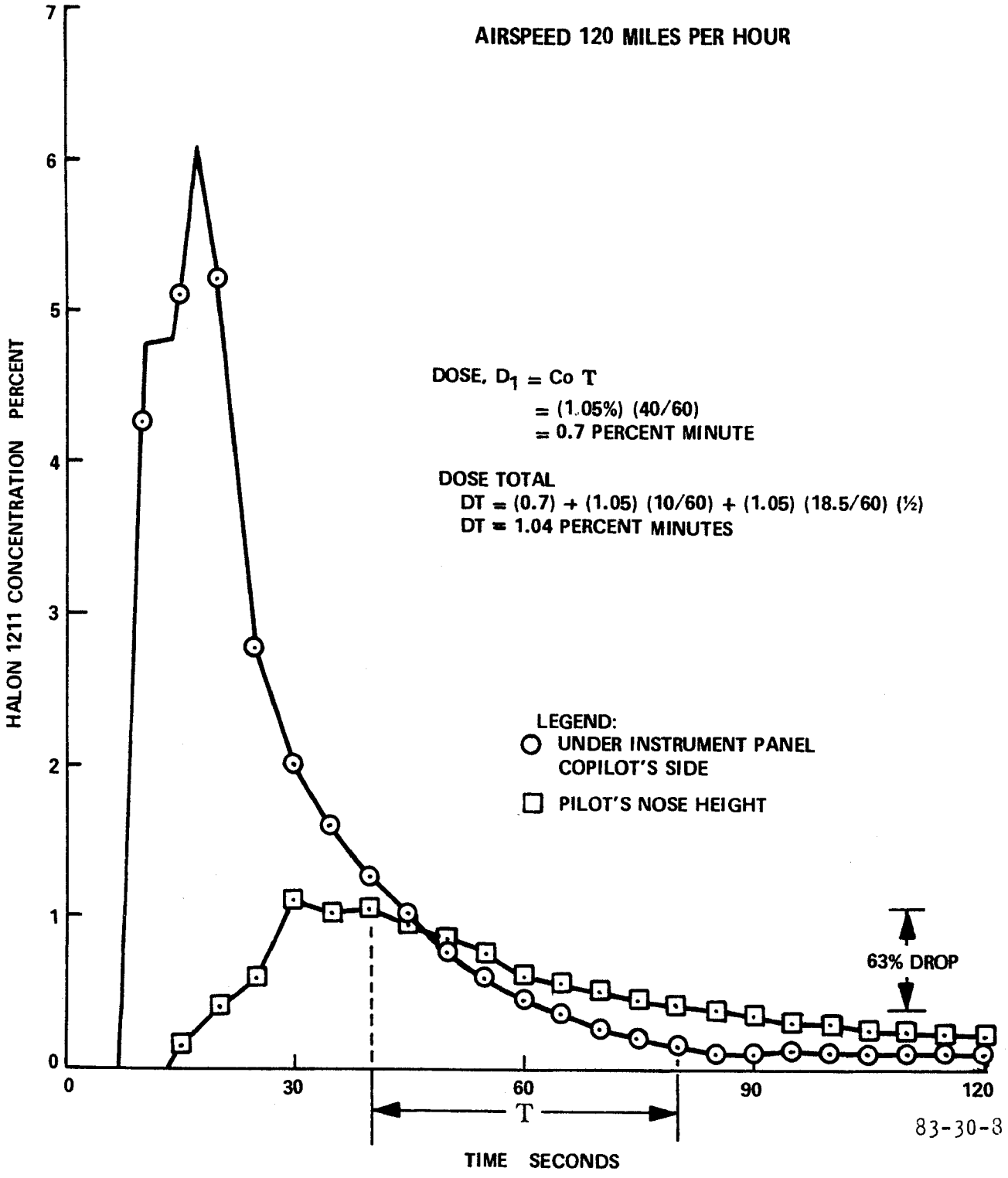

FIGURE 8. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED UNDER INSTRUMENT PANEL - COPILOT'S SIDE - ALL VENTS CLOSED

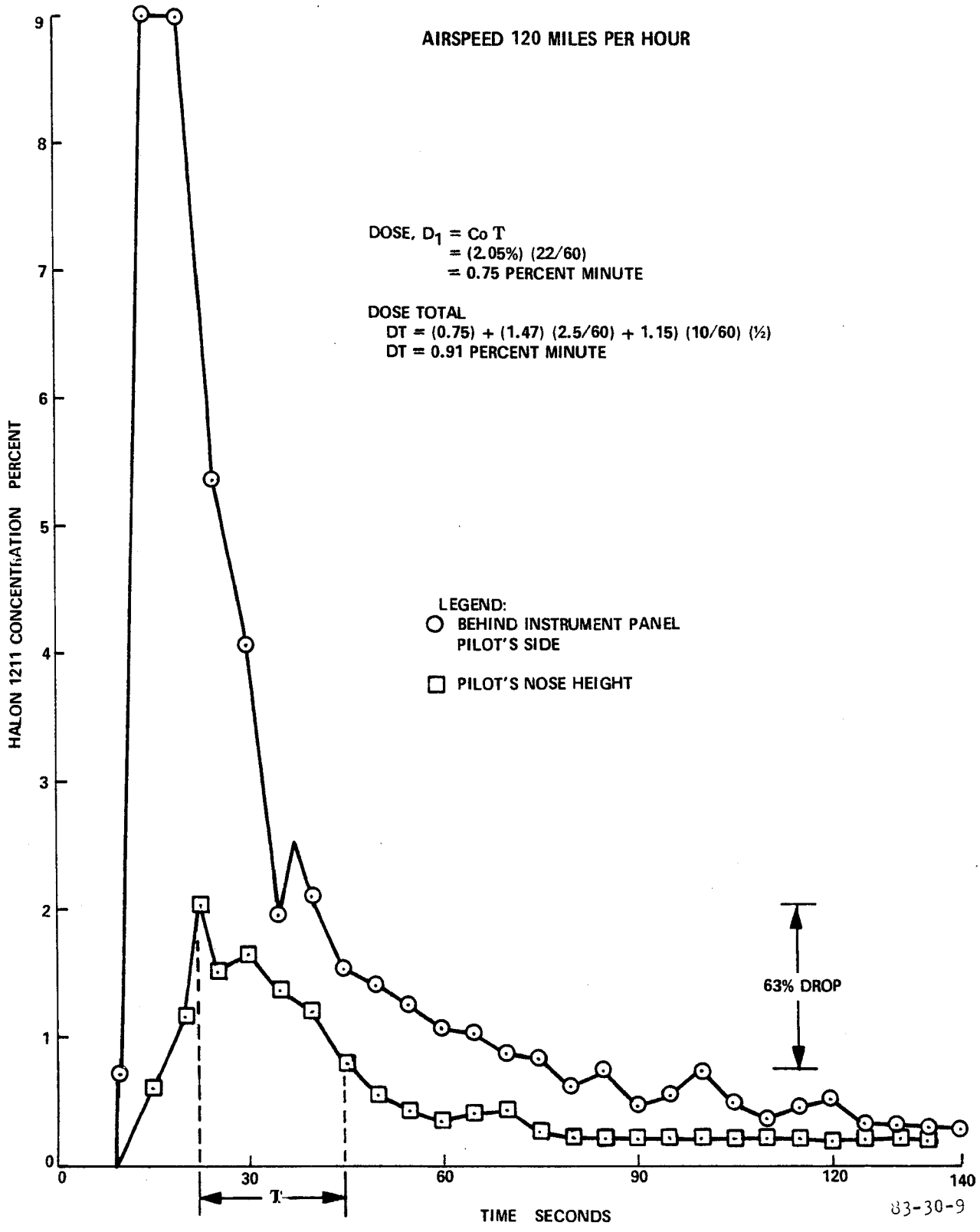

FIGURE 9. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED UNDER INSTRUMENT PANEL - PILOT'S SIDE - OVERHEAD VENTS OPEN (DOSE TOTAL 0.91 PERCENT MINUTE)

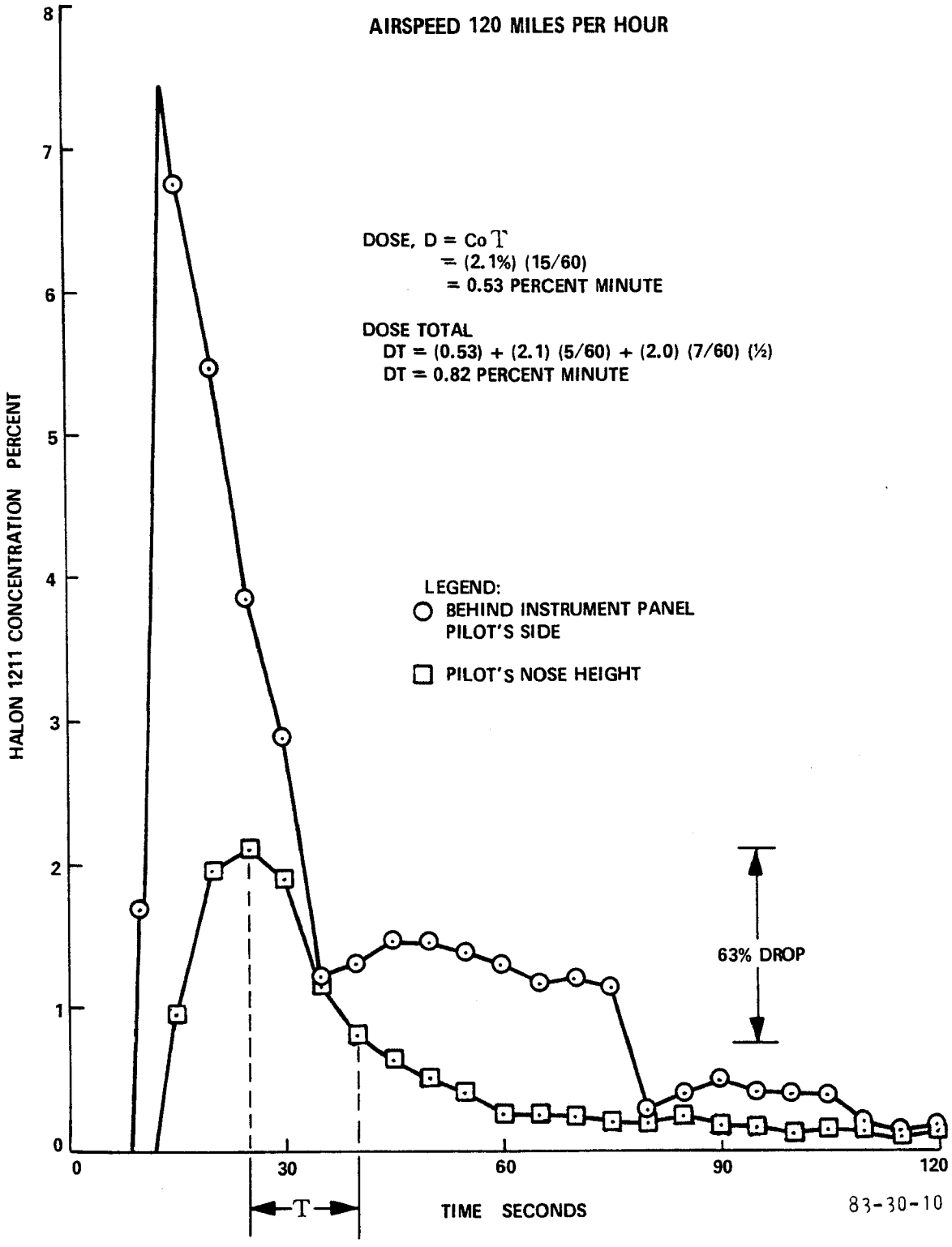

FIGURE 10. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED UNDER INSTRUMENT PANEL - PILOT'S SIDE - OVERHEAD VENTS OPEN (DOSE TOTAL 0.82 PERCENT MINUTE)

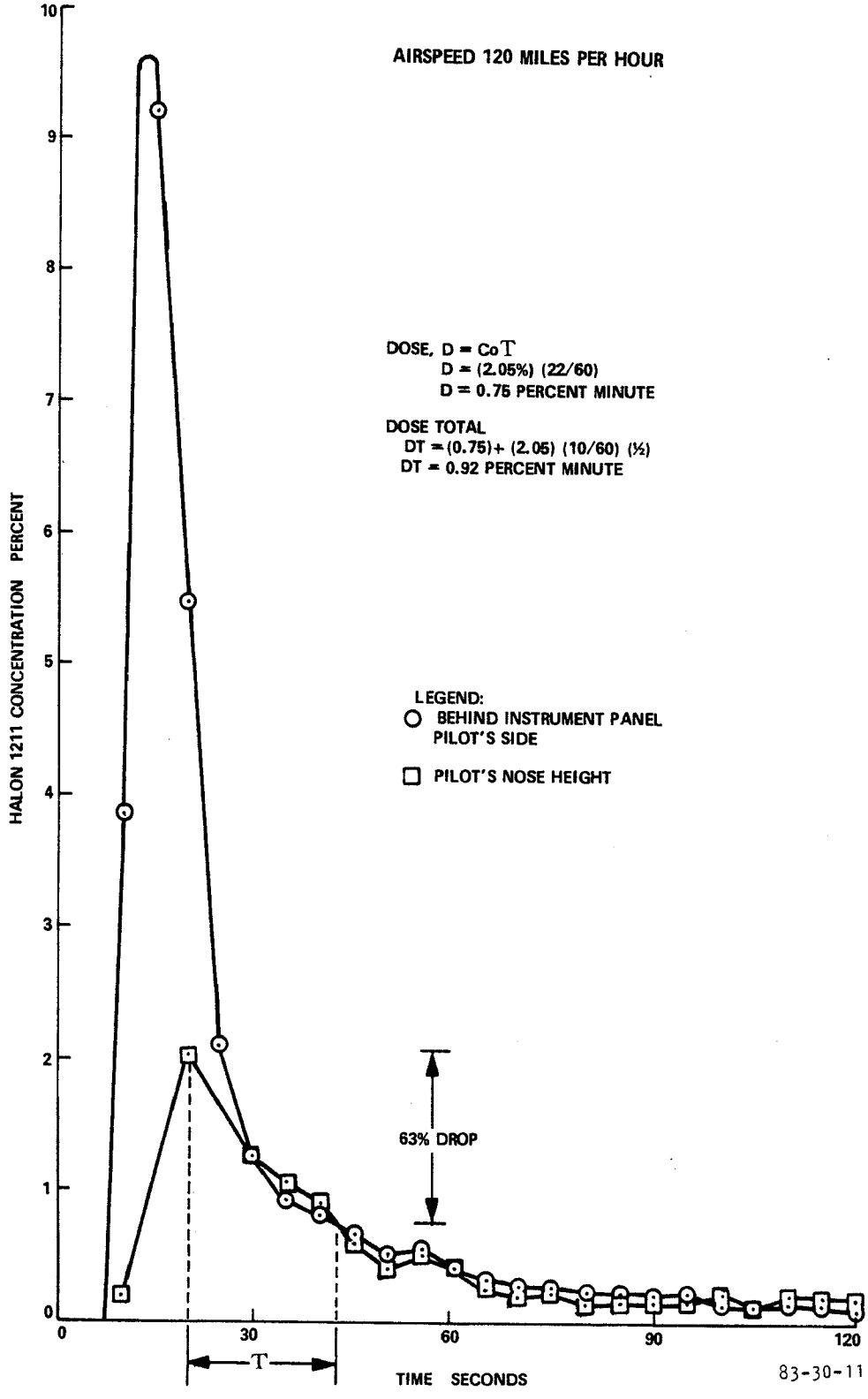

FIGURE 11. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED UNDER INSTRUMENT PANEL - PILOT'S SIDE - ALL VENTS OPEN

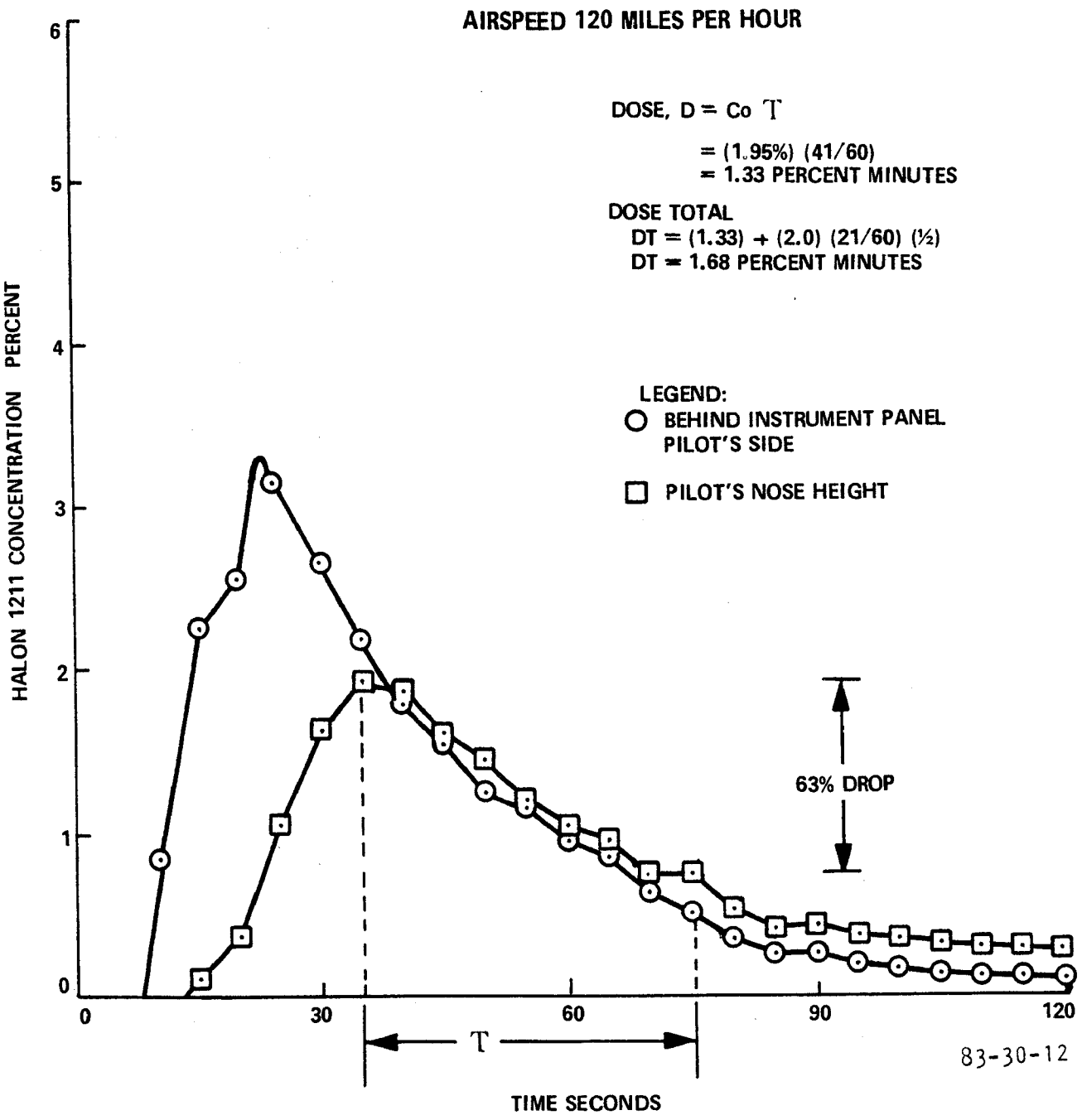

FIGURE 12. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED UNDER INSTRUMENT PANEL - PILOT'S SIDE - ALL VENTS CLOSED

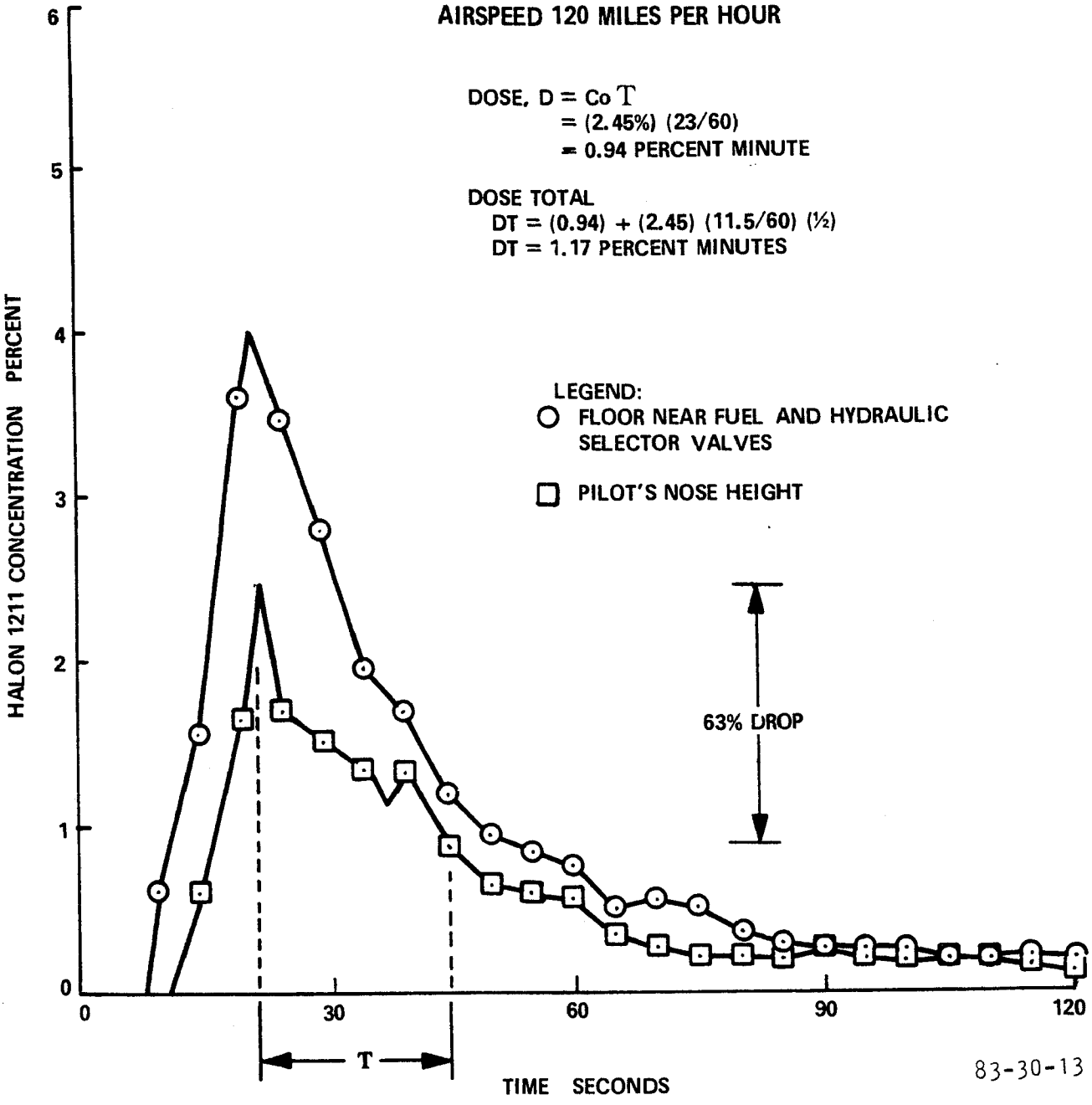

FIGURE 13. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE FUEL AND HYDRAULIC SELECTOR VALVES - OVERHEAD VENTS OPEN (DOSE TOTAL 1.17 PERCENT MINUTE)

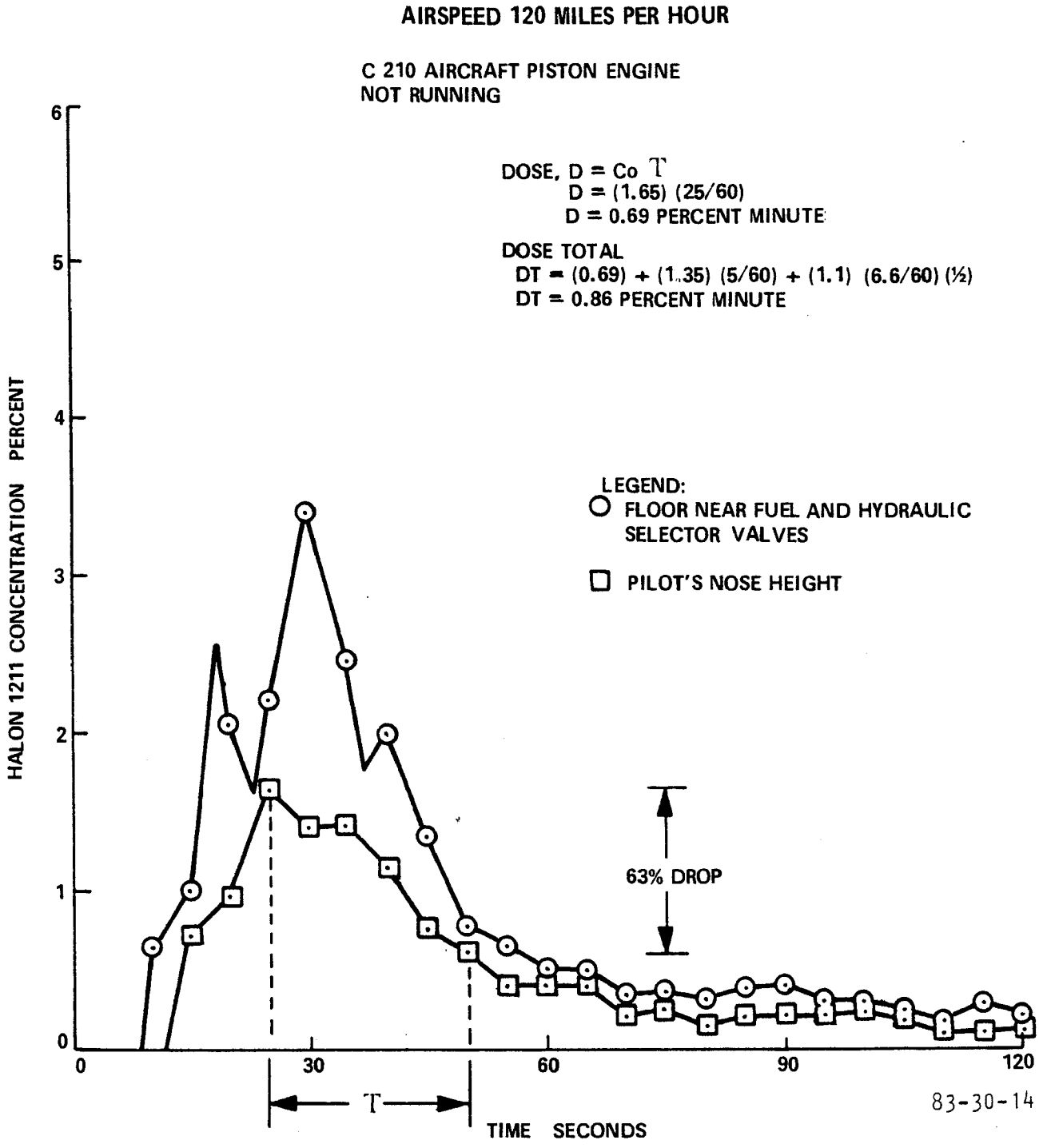

FIGURE 14. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE FUEL AND HYDRAULIC SELECTOR VALVES - OVERHEAD VENTS OPEN (DOSE TOTAL 0.86 PERCENT MINUTE)

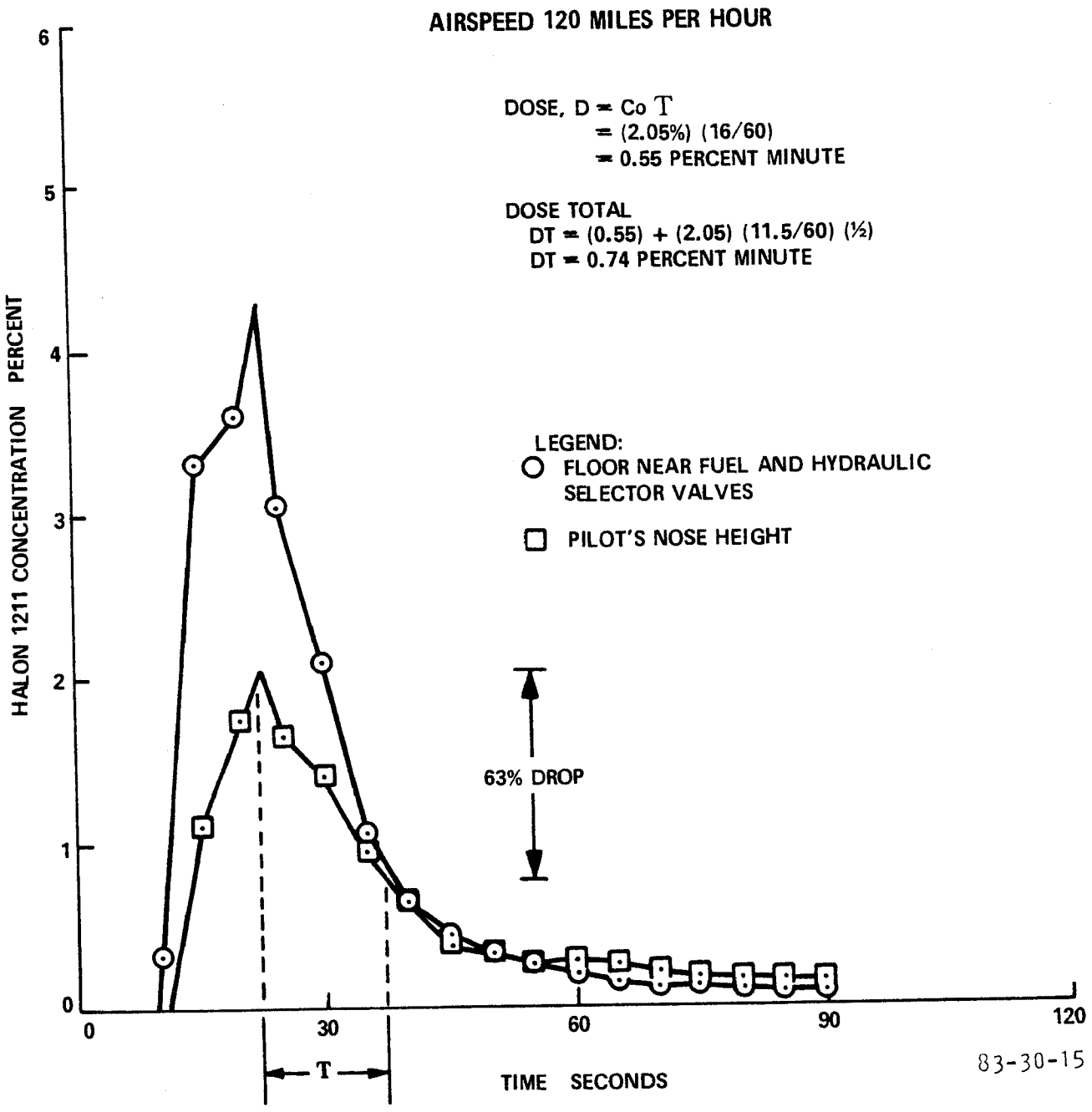

FIGURE 15. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE FUEL AND HYDRAULIC SELECTOR VALVES - ALL VENTS OPEN

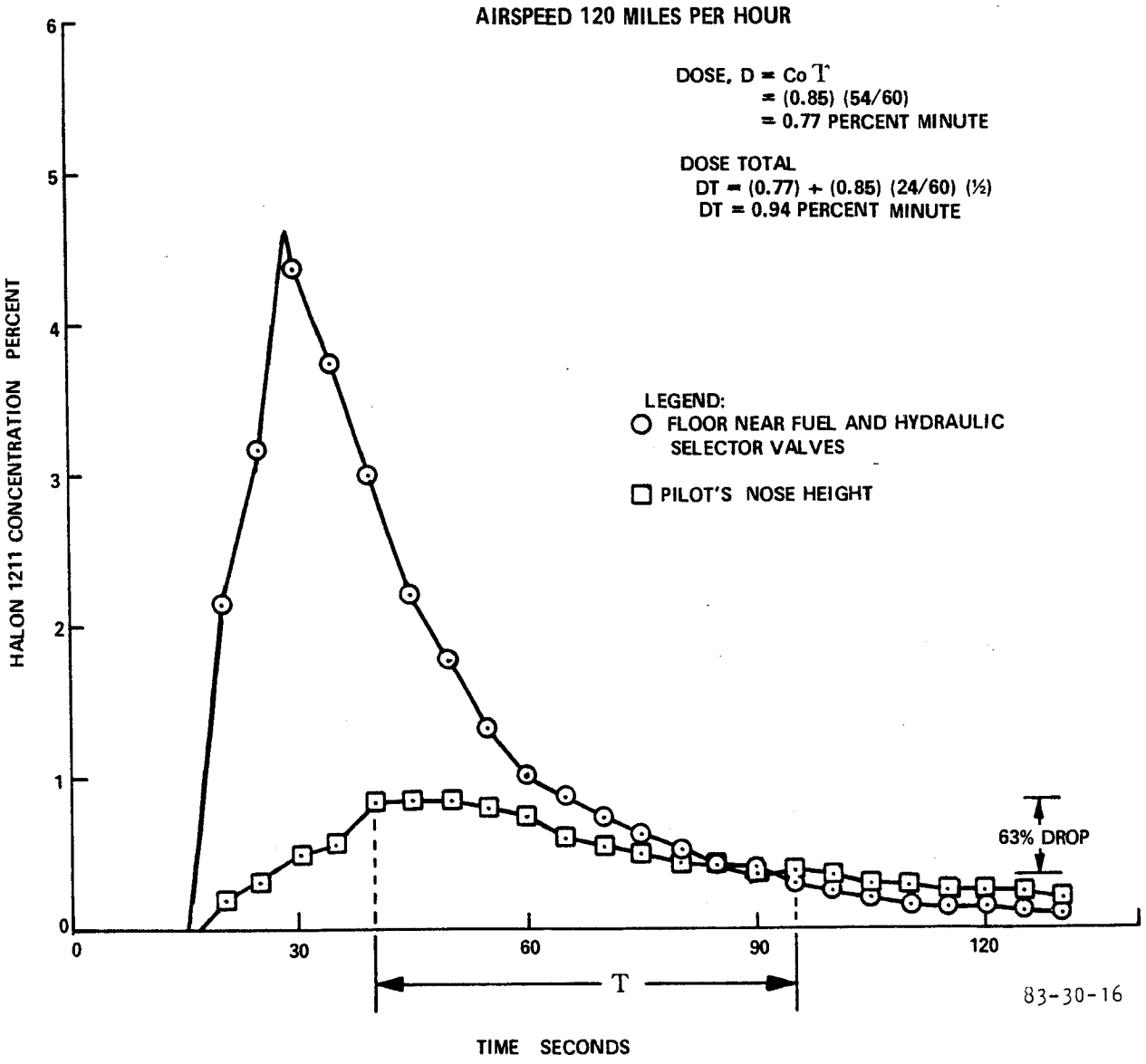

FIGURE 16. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE FUEL AND HYDRAULIC SELECTOR VALVES - ALL VENTS CLOSED

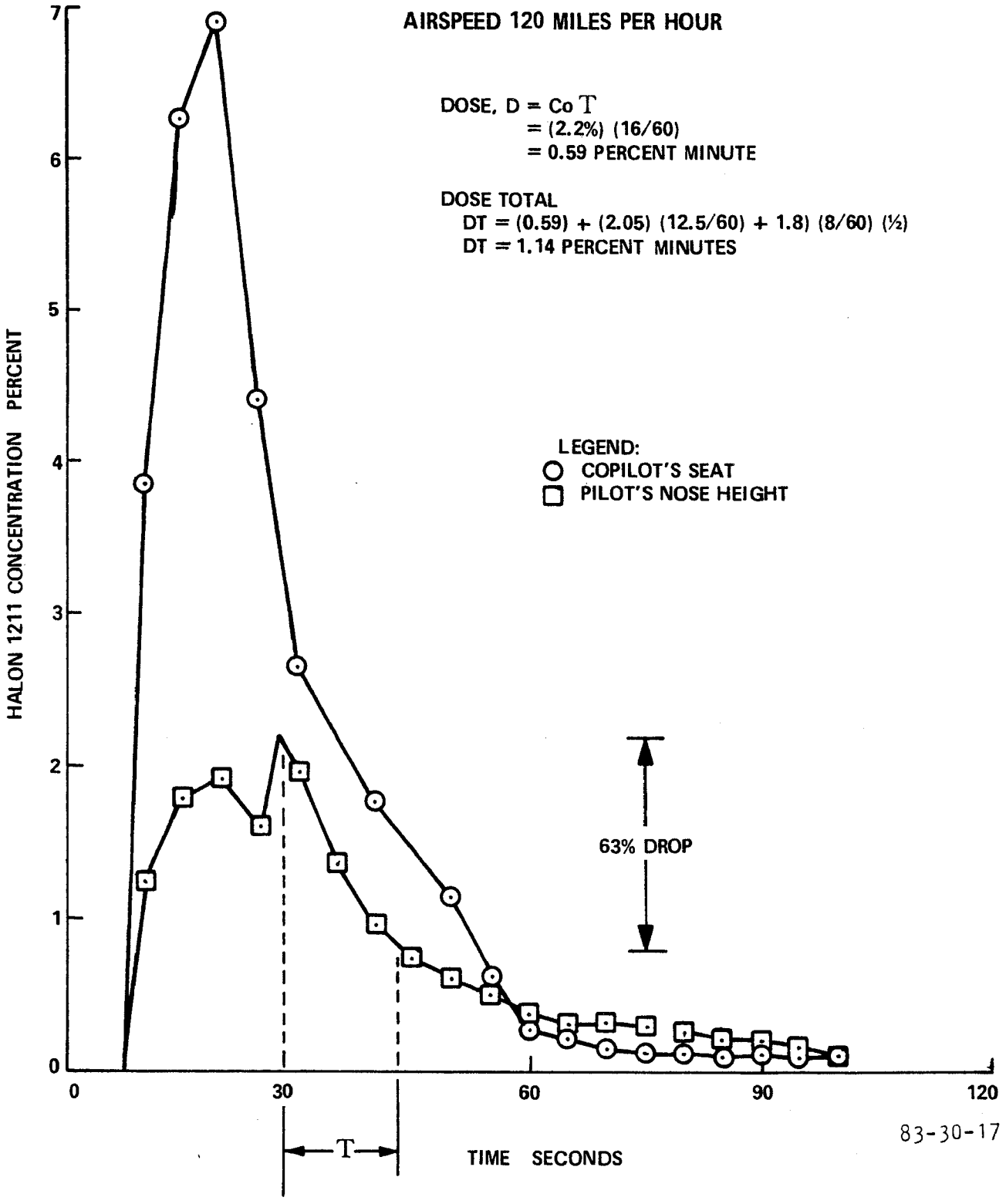

FIGURE 17. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE COPILOT'S SEAT - OVERHEAD VENTS OPEN (DOSE TOTAL 1.14 PERCENT MINUTE)

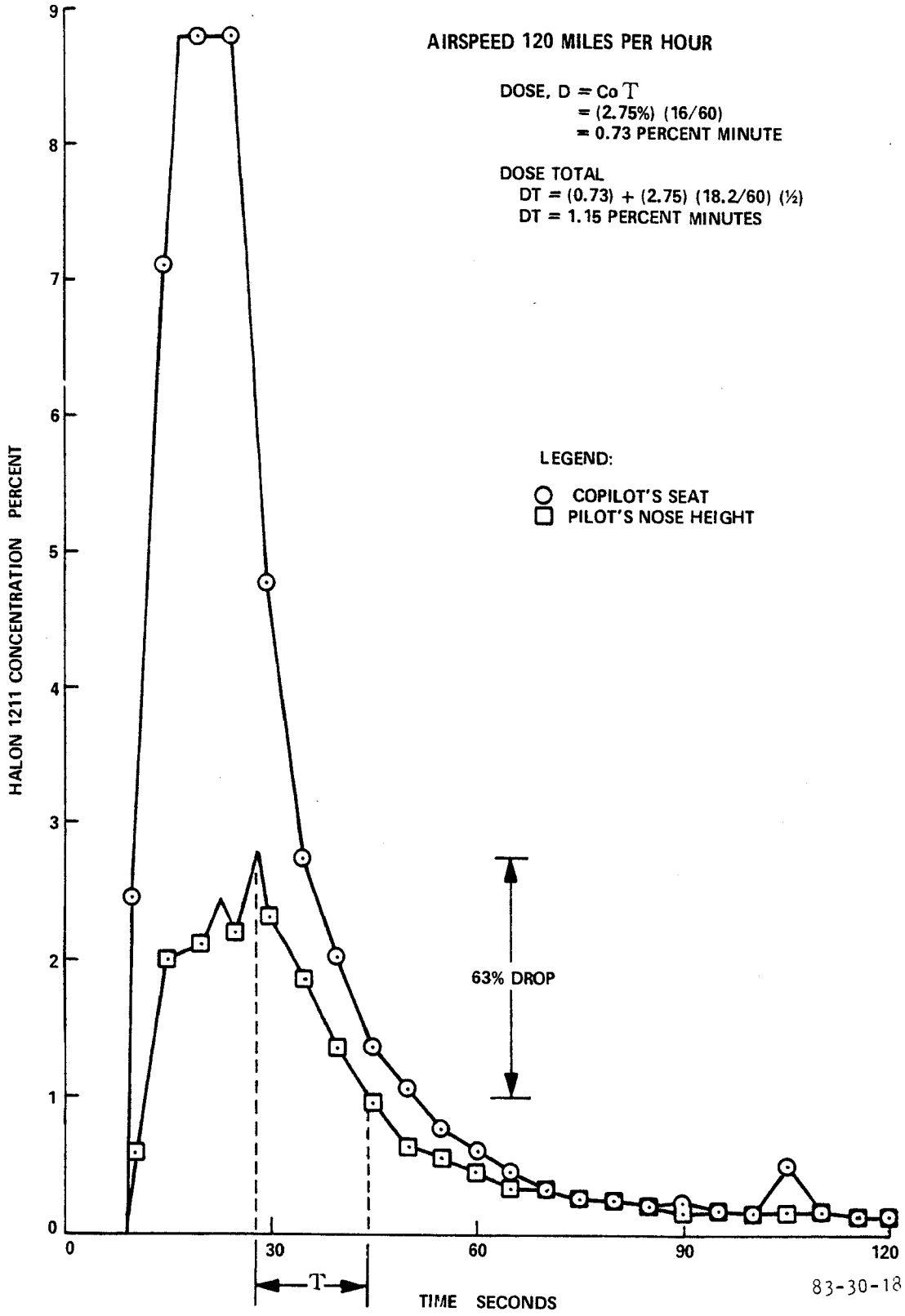

FIGURE 18. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE COPILOTS'S SEAT - OVERHEAD VENTS OPEN (DOSE TOTAL 1.15 PERCENT MINUTE)

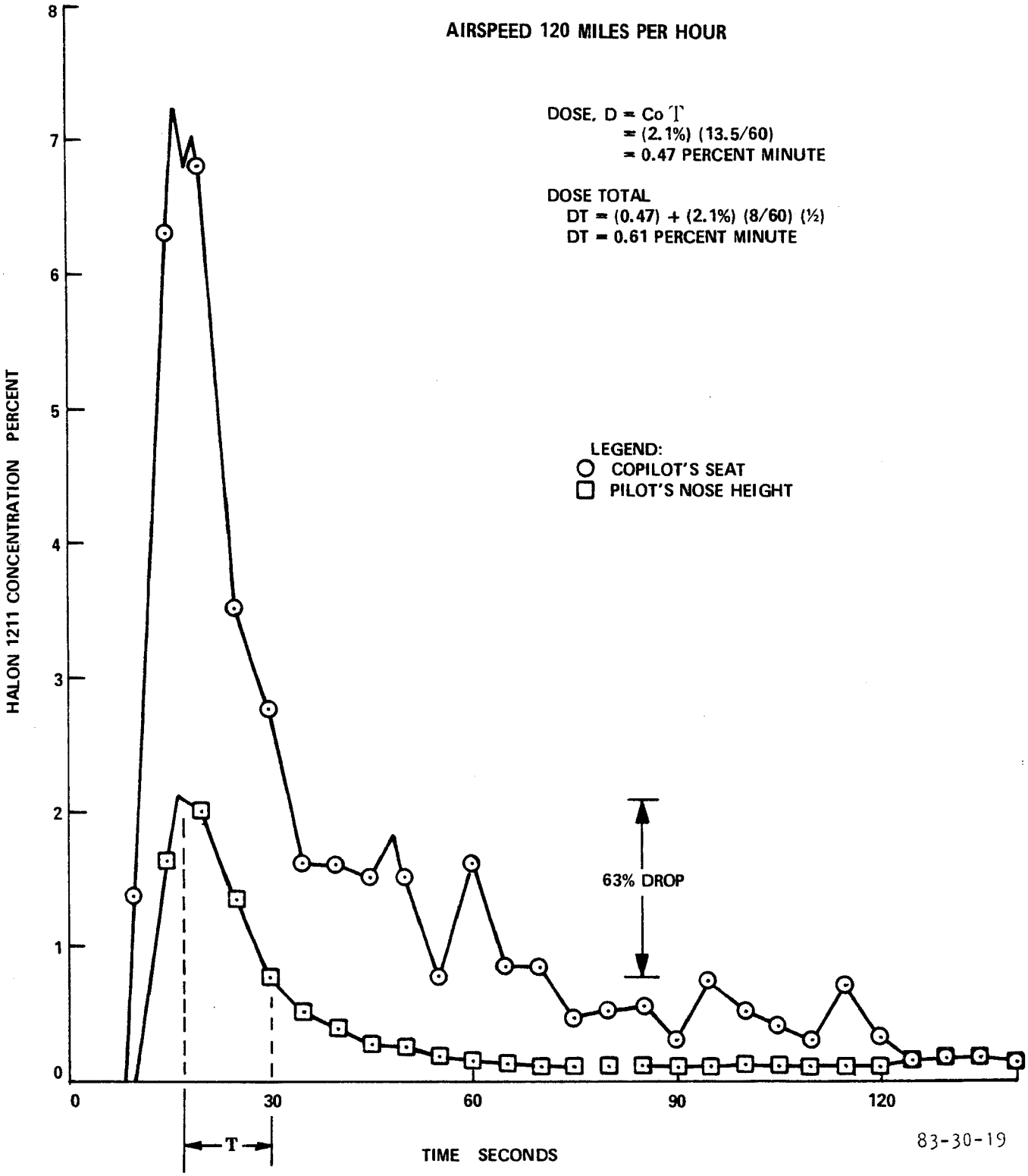

FIGURE 19. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE COPILOT'S SEAT - ALL VENTS OPEN

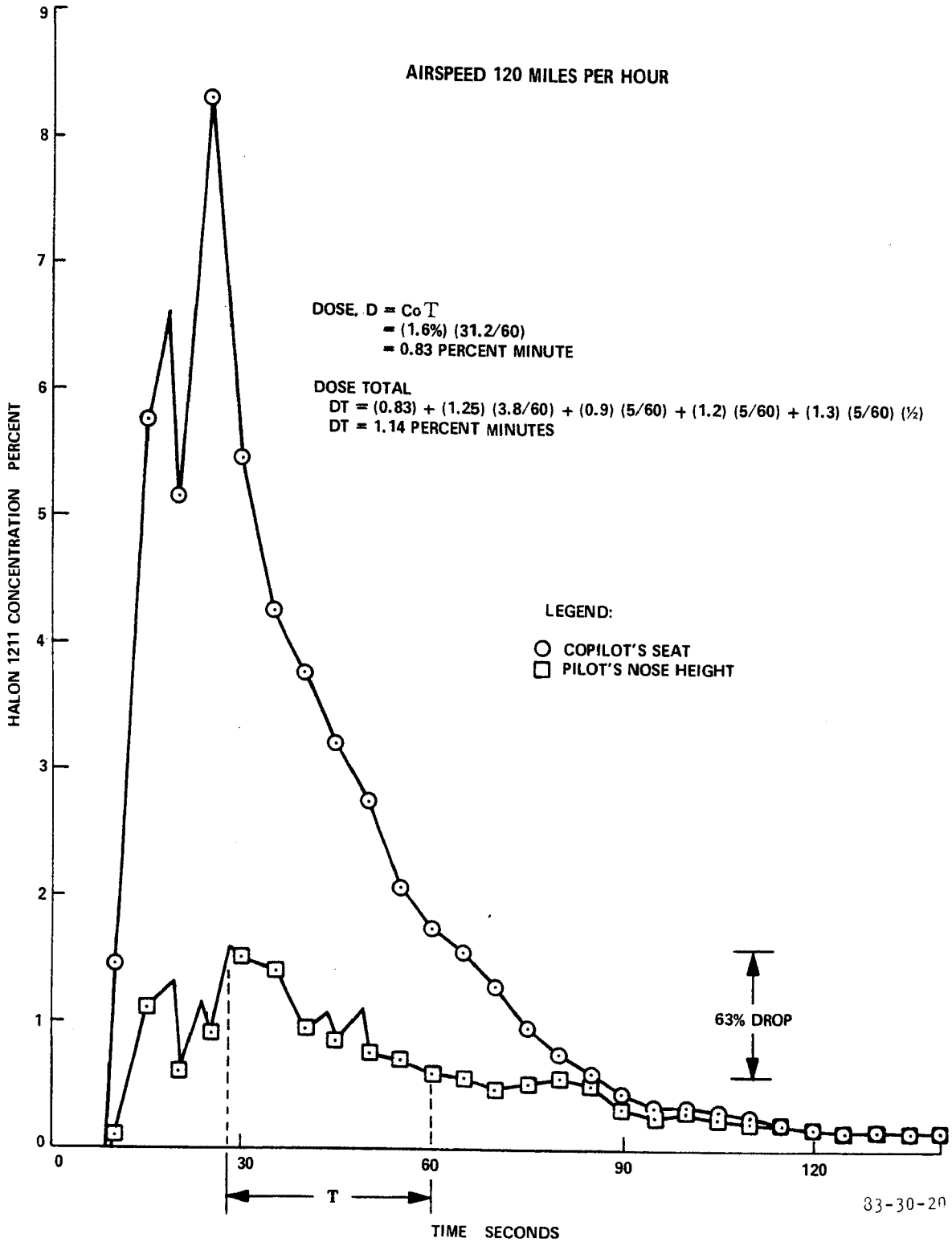

FIGURE 20. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE COPILOT'S SEAT - ALL VENTS CLOSED

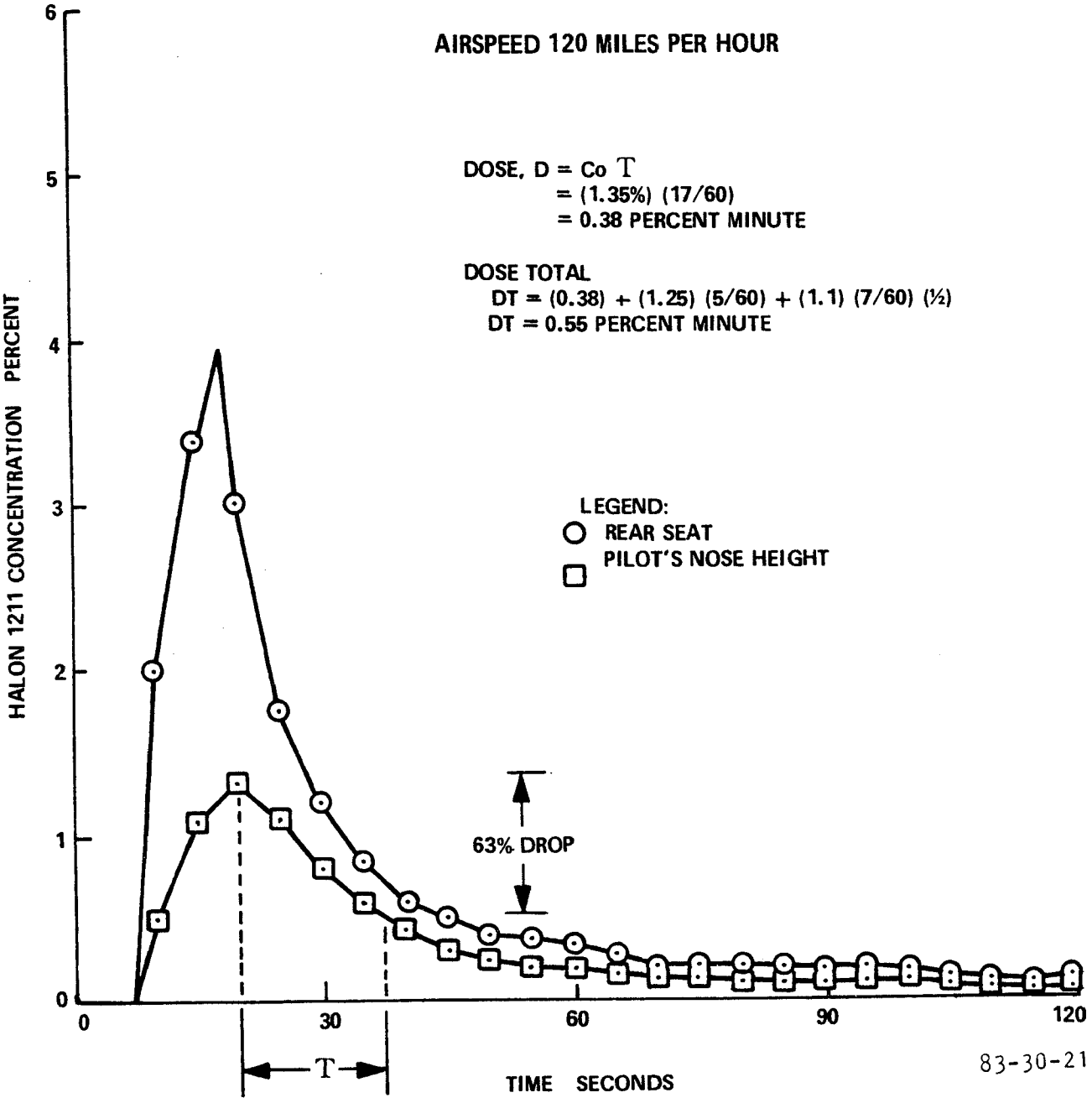

FIGURE 21. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE REAR SEAT BEHIND PILOT - OVERHEAD VENTS OPEN (DOSE TOTAL 0.55 PERCENT MINUTE)

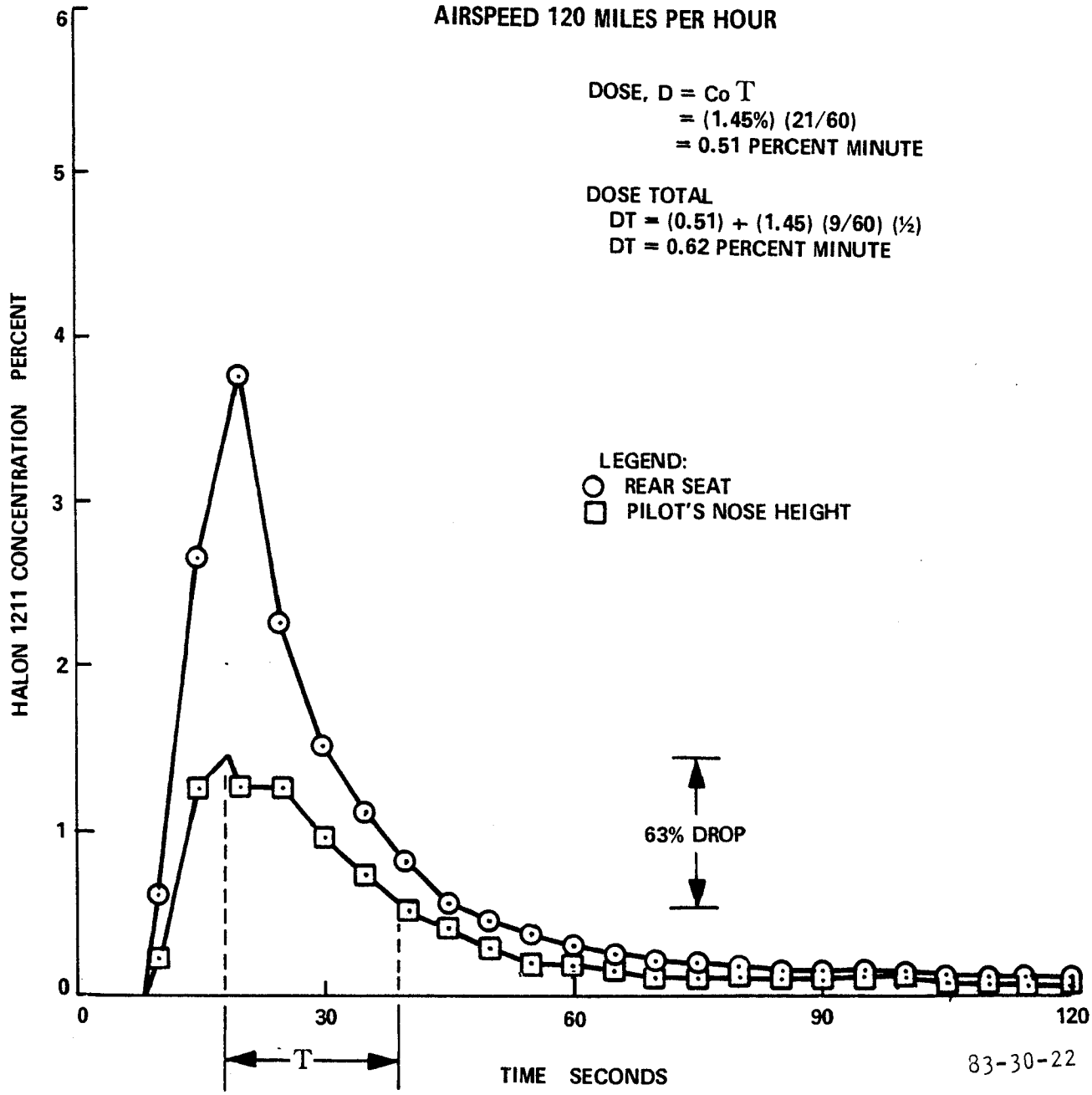

FIGURE 22. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE REAR SEAT BEHIND PILOT - OVERHEAD VENTS OPEN (DOSE TOTAL 0.62 PERCENT MINUTE)

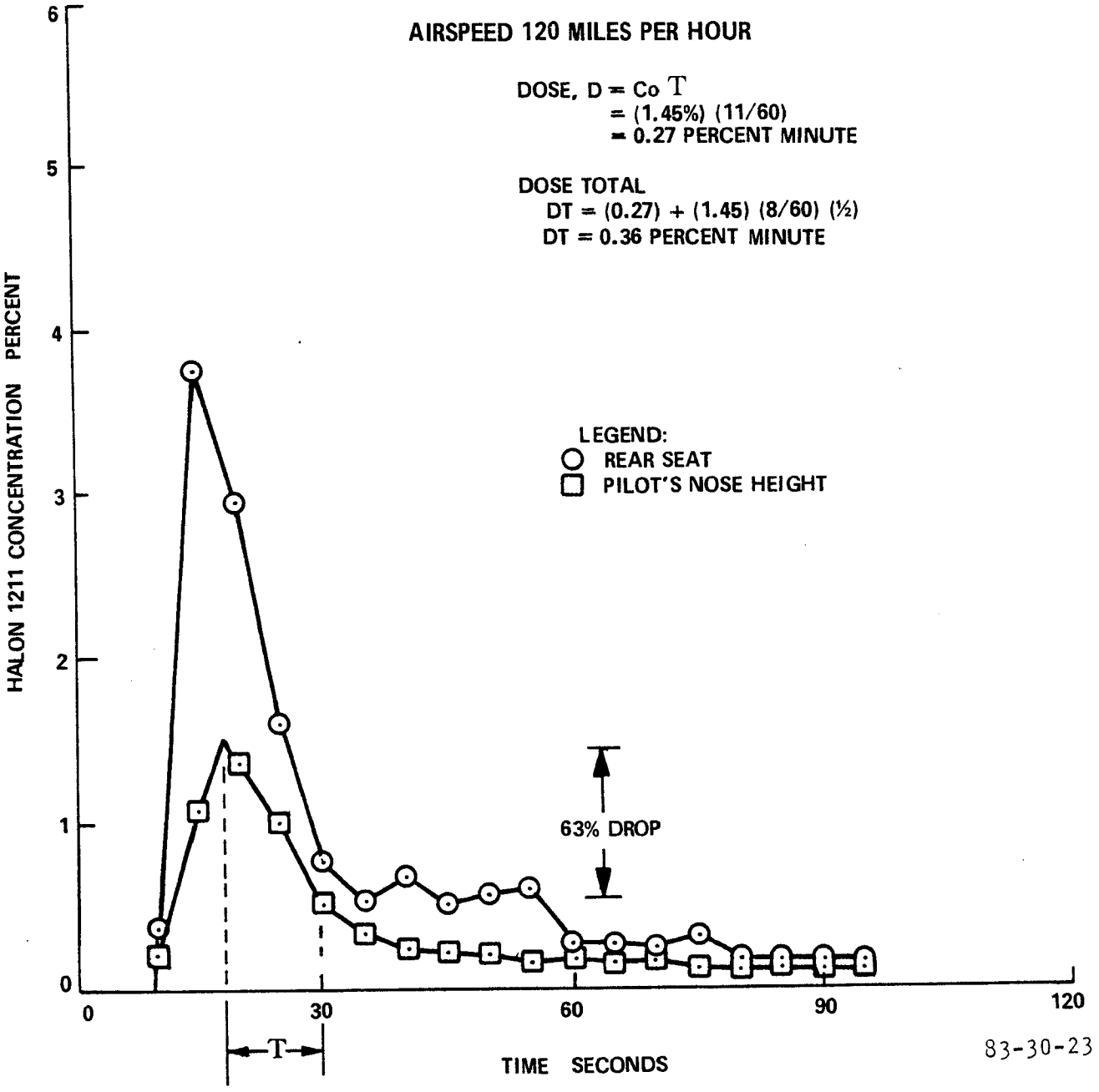

FIGURE 23. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE REAR SEAT BEHIND PILOT - ALL VENTS OPEN

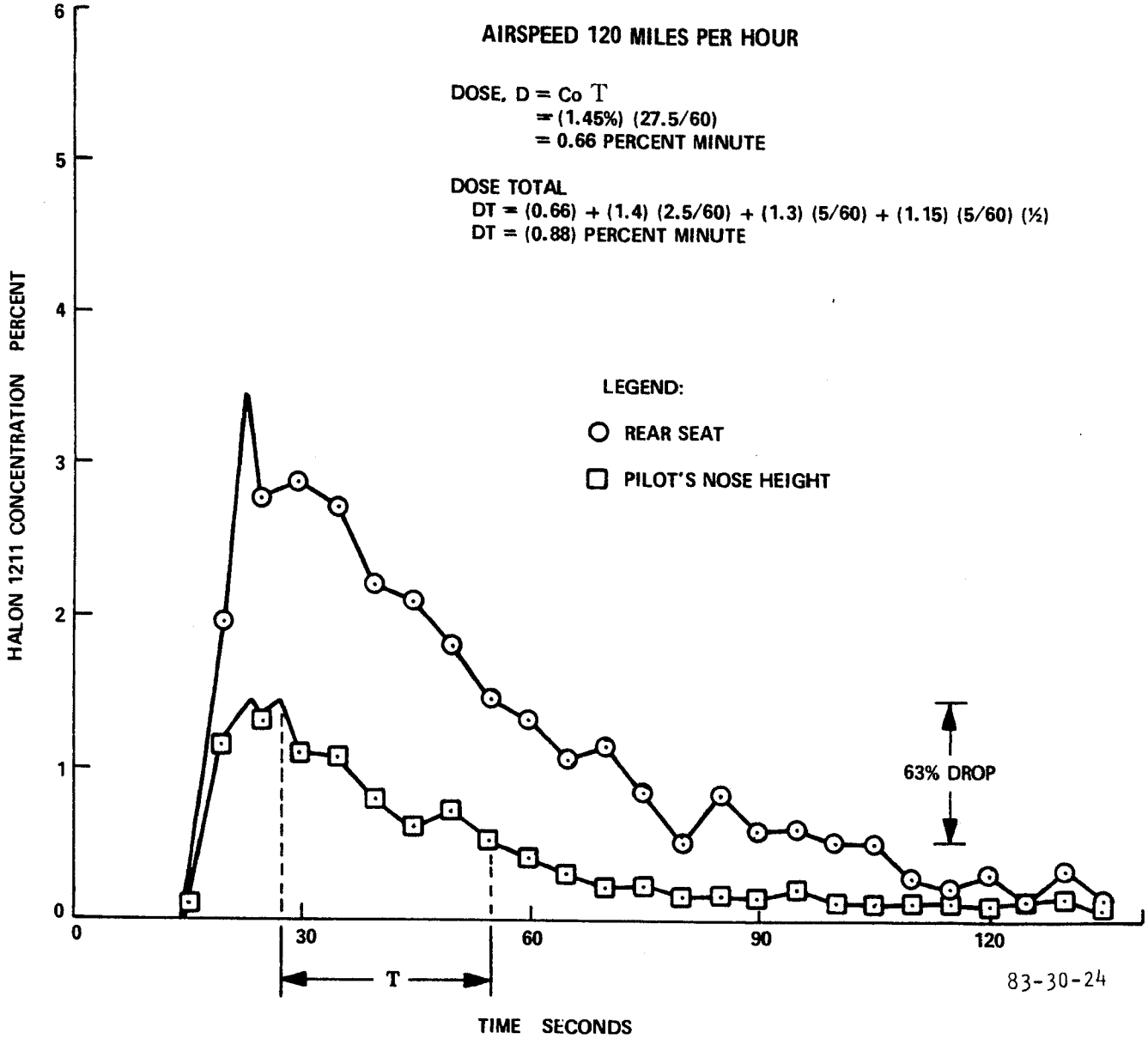

FIGURE 24. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE REAR SEAT BEHIND PILOT - ALL VENTS CLOSED

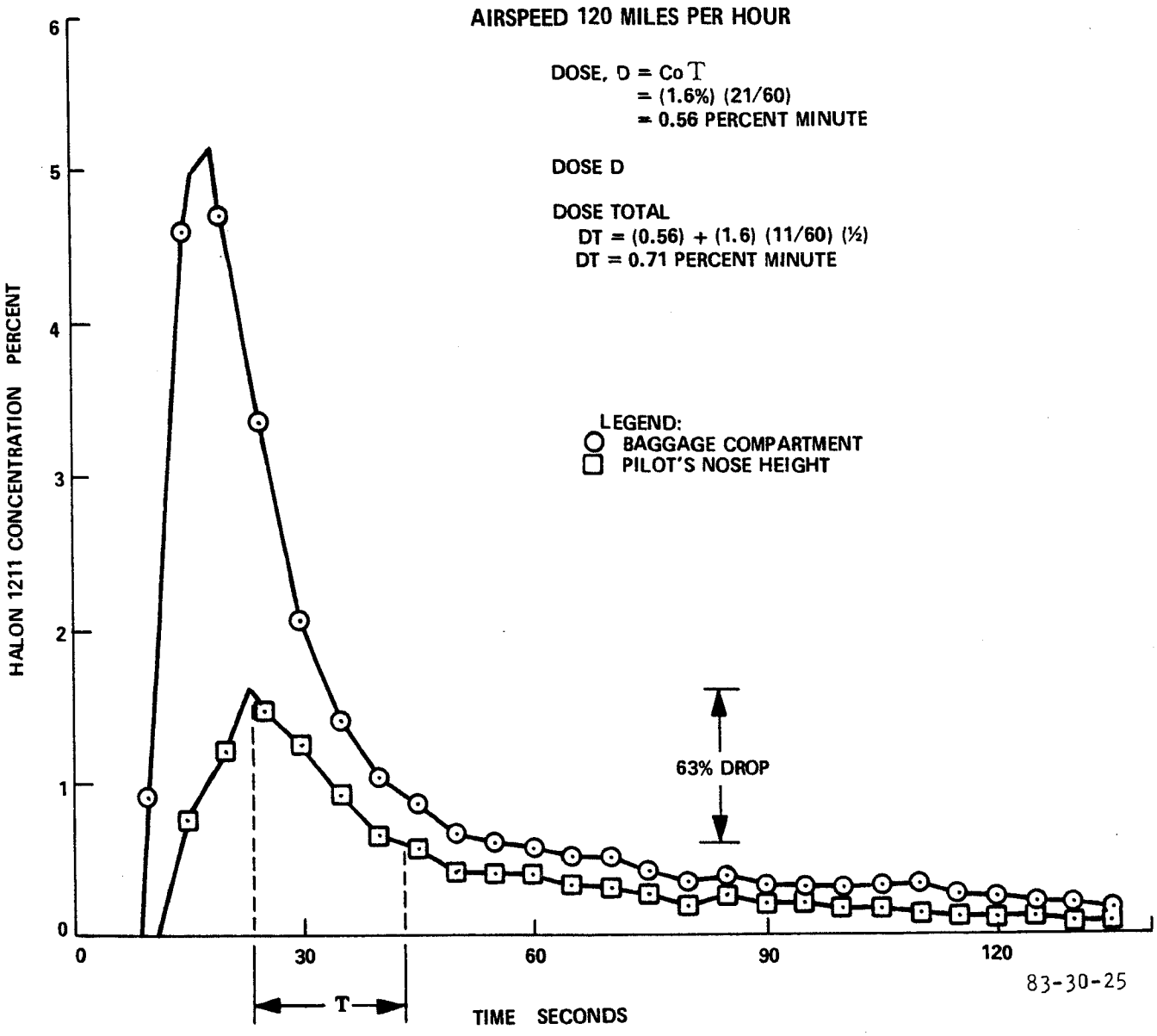

FIGURE 25. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE BAGGAGE COMPARTMENT - OVERHEAD VENTS OPEN (DOSE TOTAL 0.71 PERCENT MINUTE)

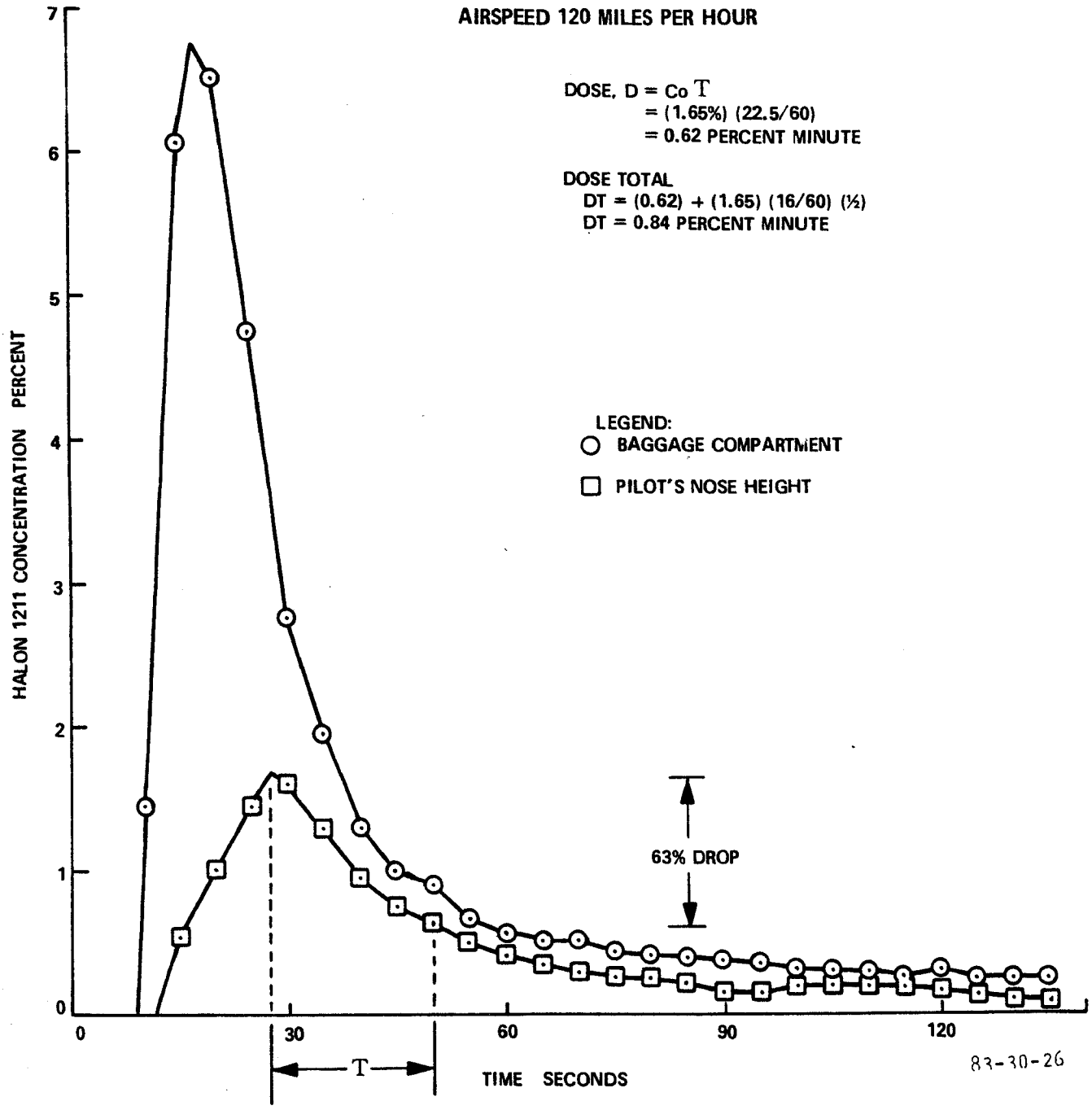

FIGURE 26. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE BAGGAGE COMPARTMENT - OVERHEAD VENTS OPEN (DOSE TOTAL 0.84 PERCENT MINUTE)

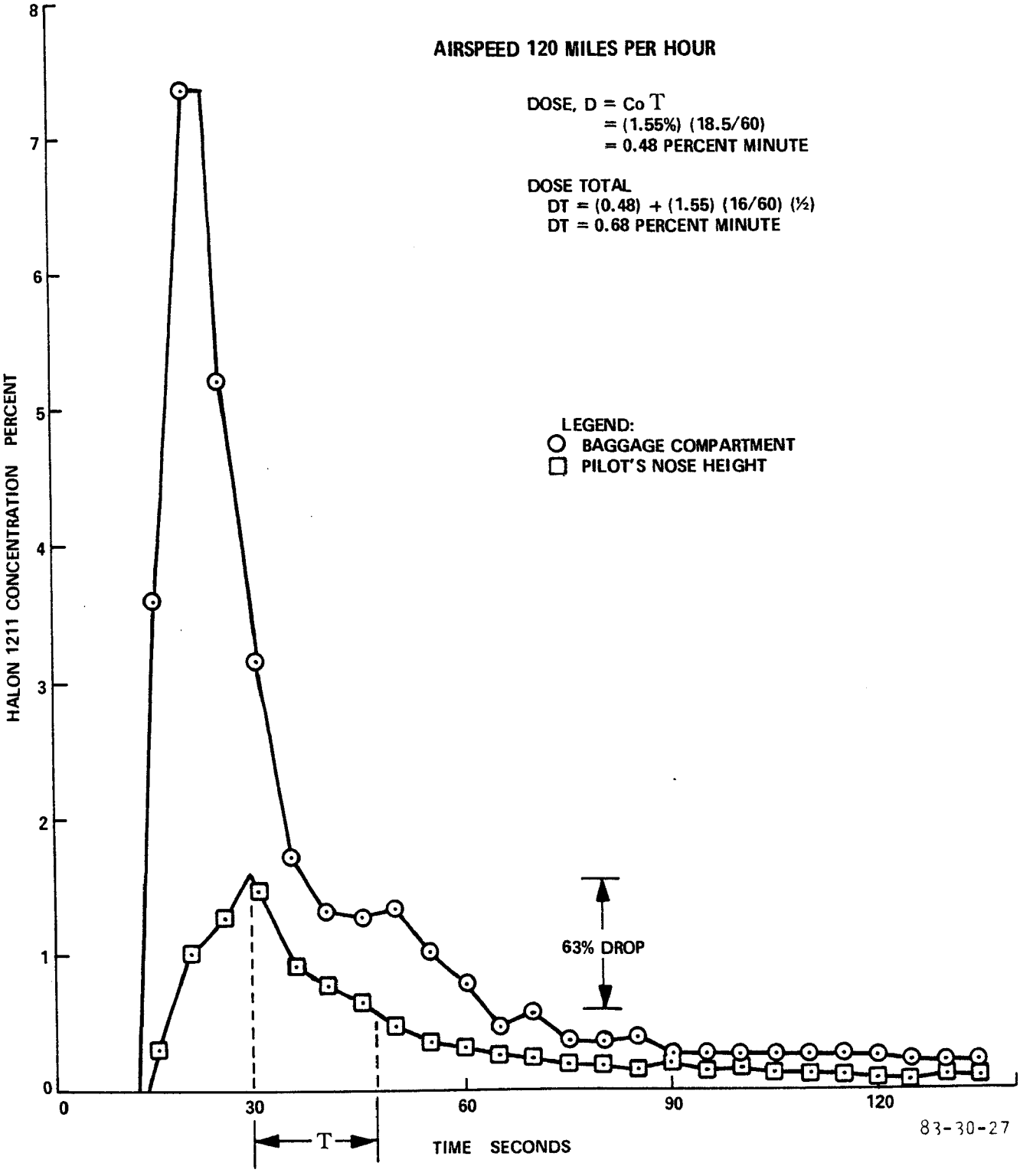

FIGURE 27. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE BAGGAGE COMPARTMENT - ALL VENTS OPEN

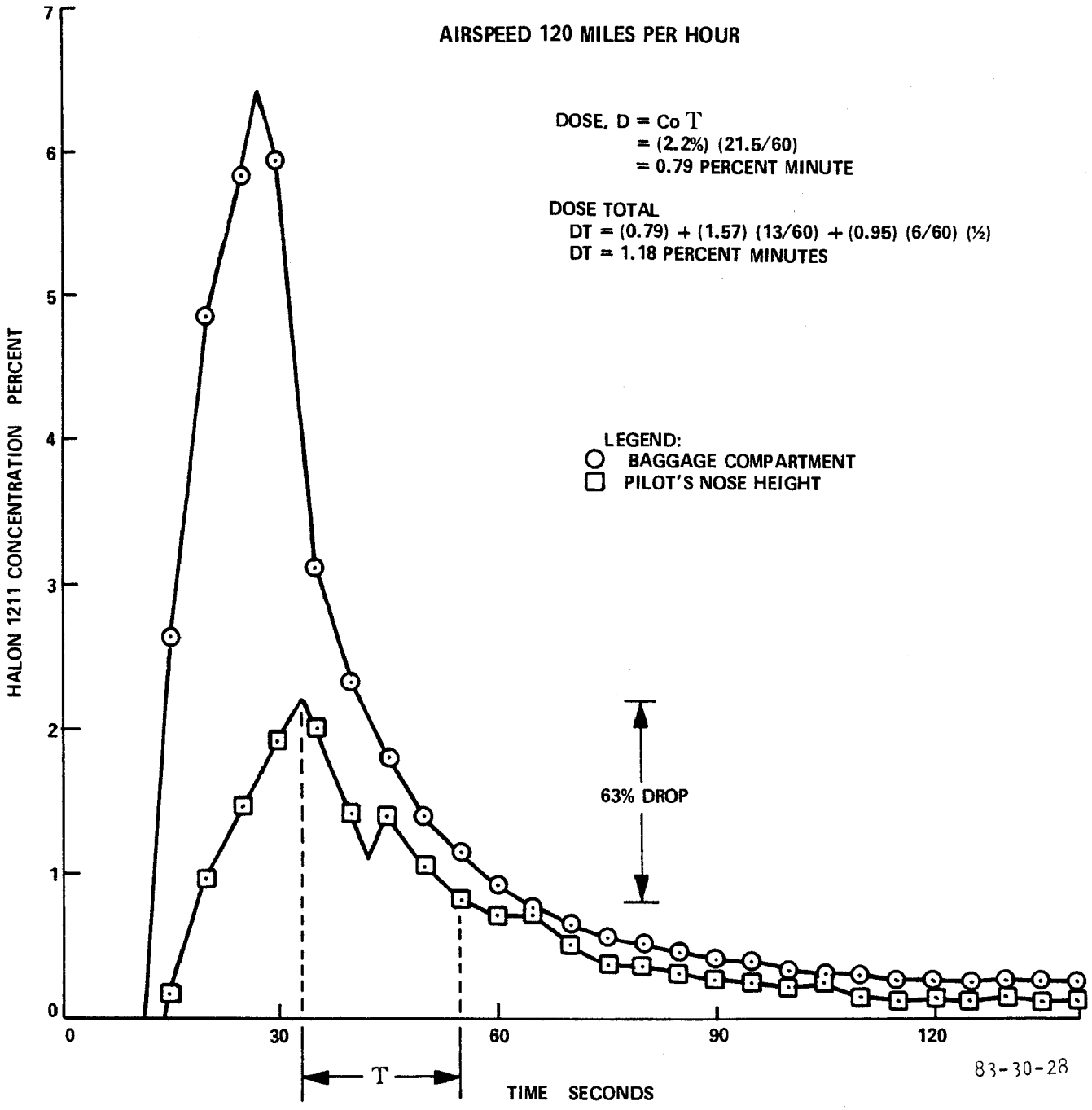

FIGURE 28. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE BAGGAGE COMPARTMENT - ALL VENTS CLOSED

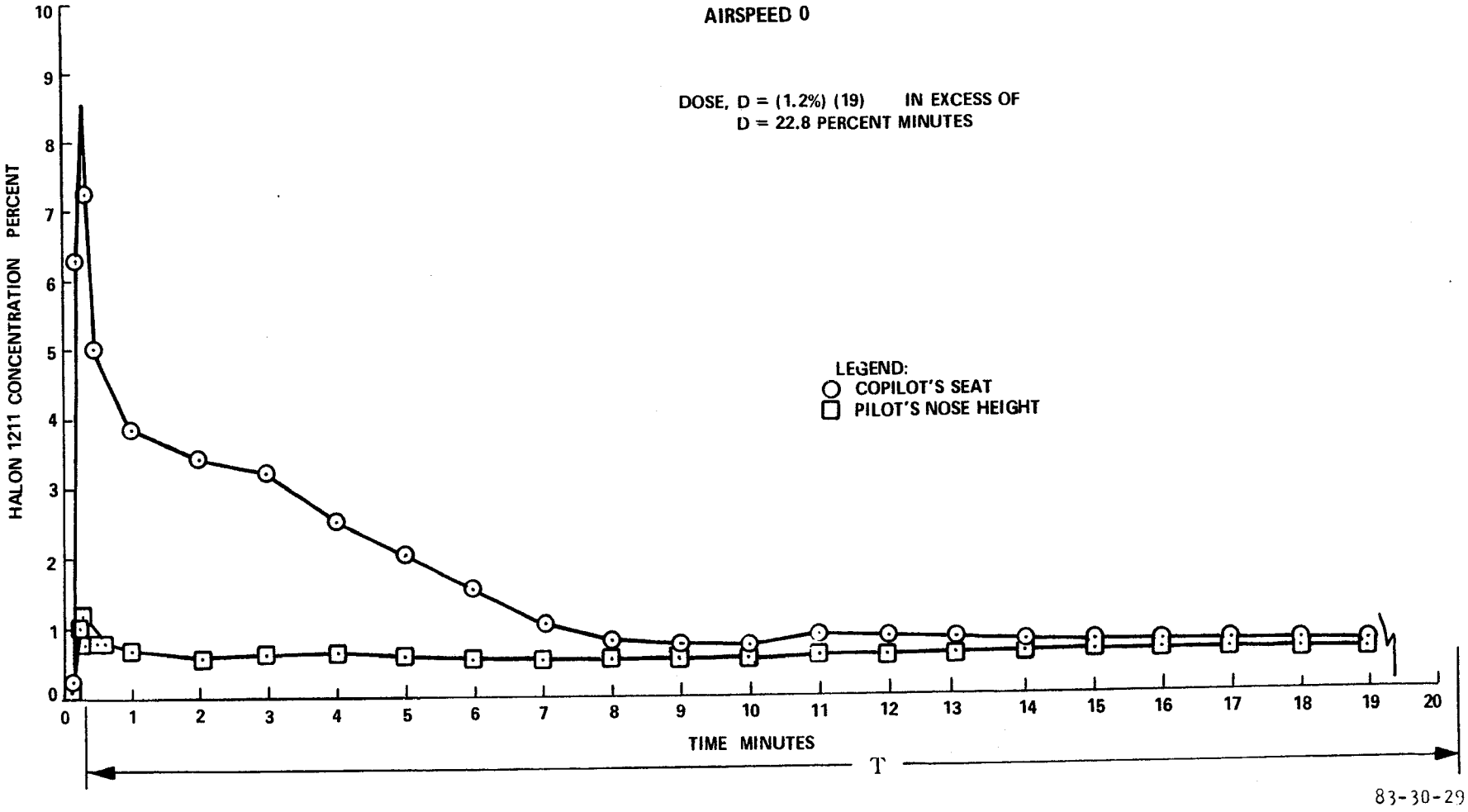

FIGURE 29. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE COPILOT'S SEAT - AIRSPEED 0 - ALL VENTS CLOSED

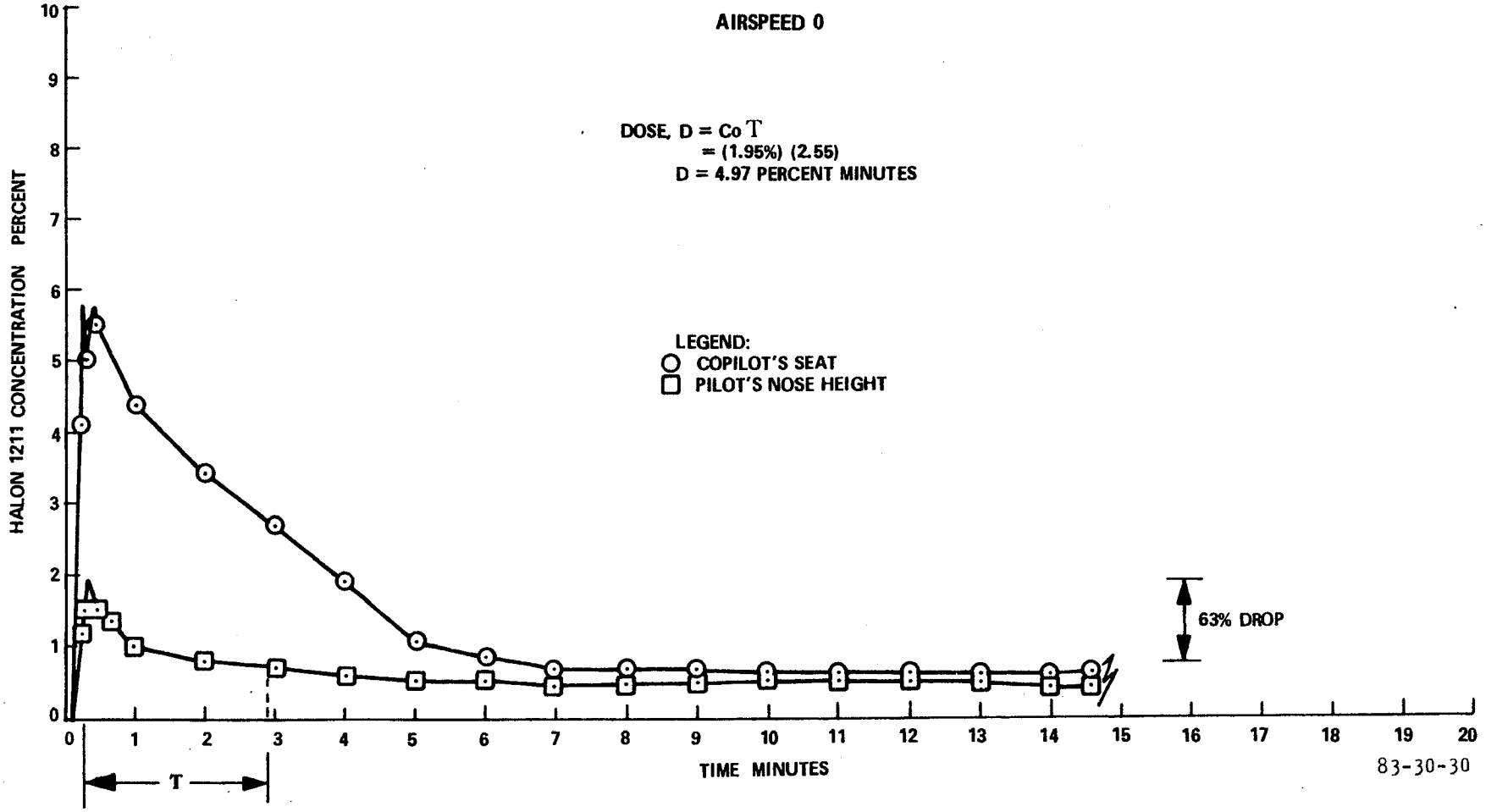

FIGURE 30. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE COPILOT'S SEAT - AIRSPEED 0 - ALL VENTS OPEN

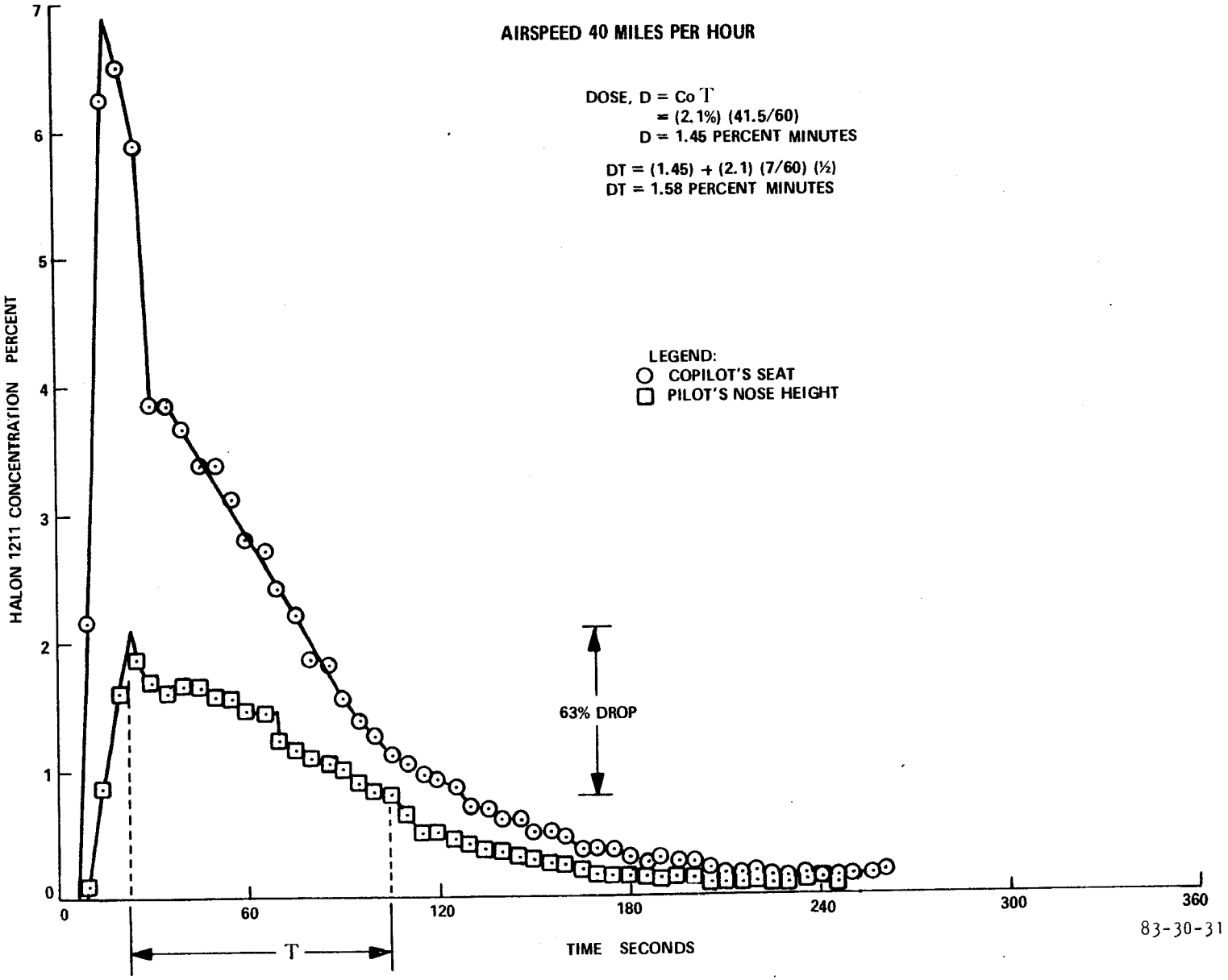

FIGURE 31. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE COPILOT'S SEAT - AIRSPEED 40 MPH - OVERHEAD VENTS OPEN

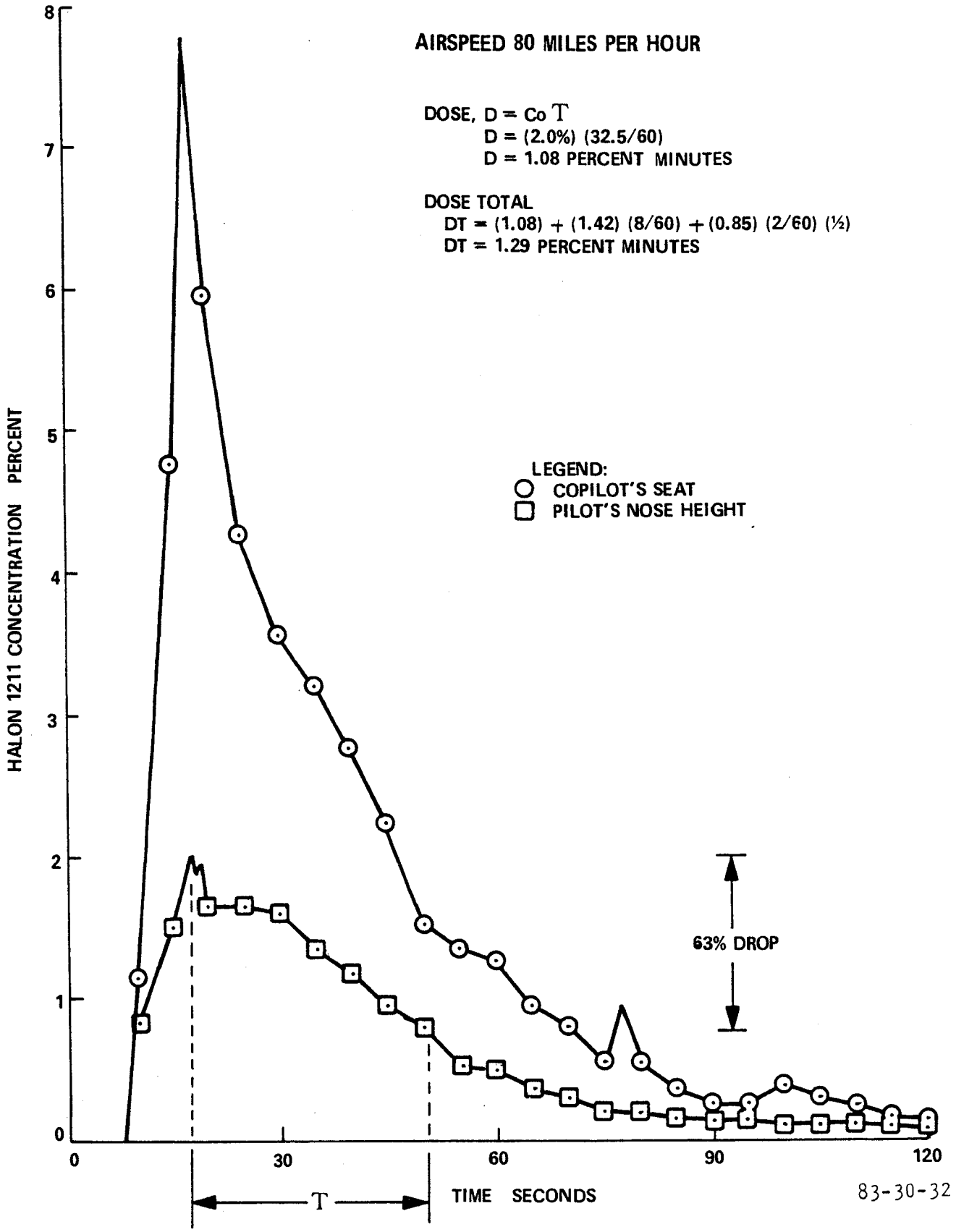

FIGURE 32. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE COPILOT'S SEAT - AIRSPEED 80 MPH - OVERHEAD VENTS OPEN

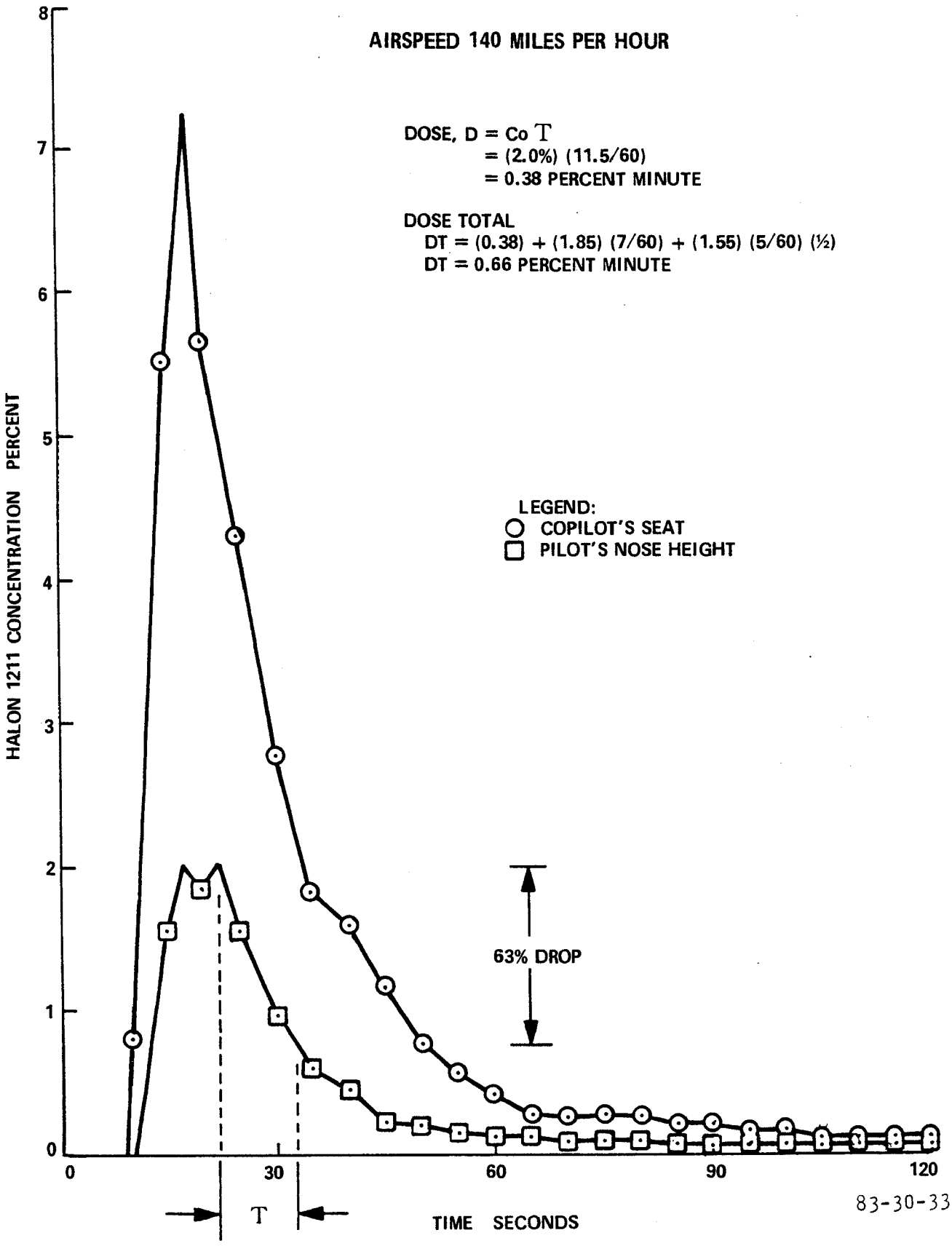

FIGURE 33. HALON 1211 CONCENTRATIONS - 2.5 POUND EXTINGUISHER DIRECTED TO THE COPILOT'S SEAT - AIRSPEED 140 MPH - OVERHEAD VENTS OPEN

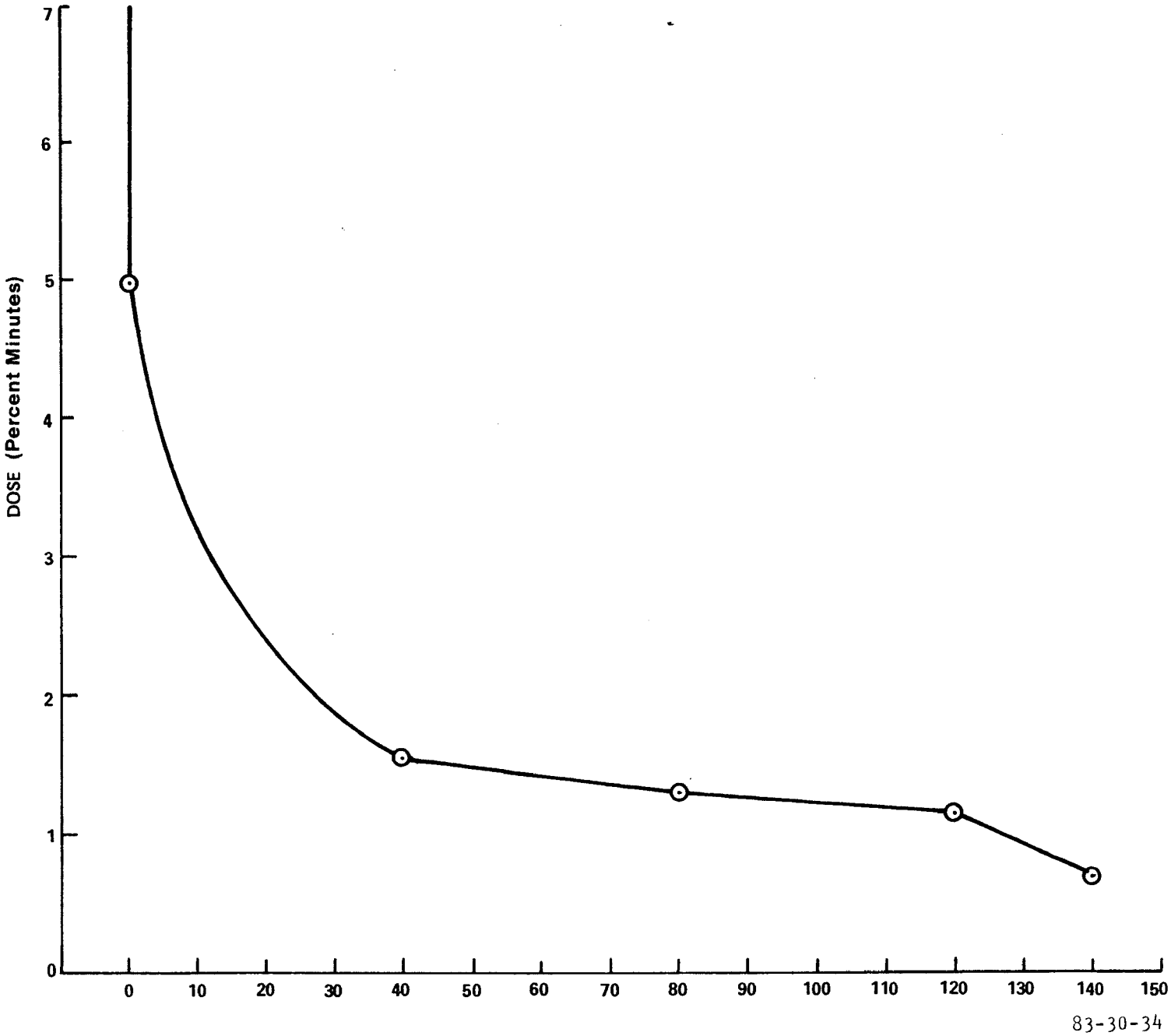

FIGURE 34. EFFECT OF AIRSPEED AND DOSE

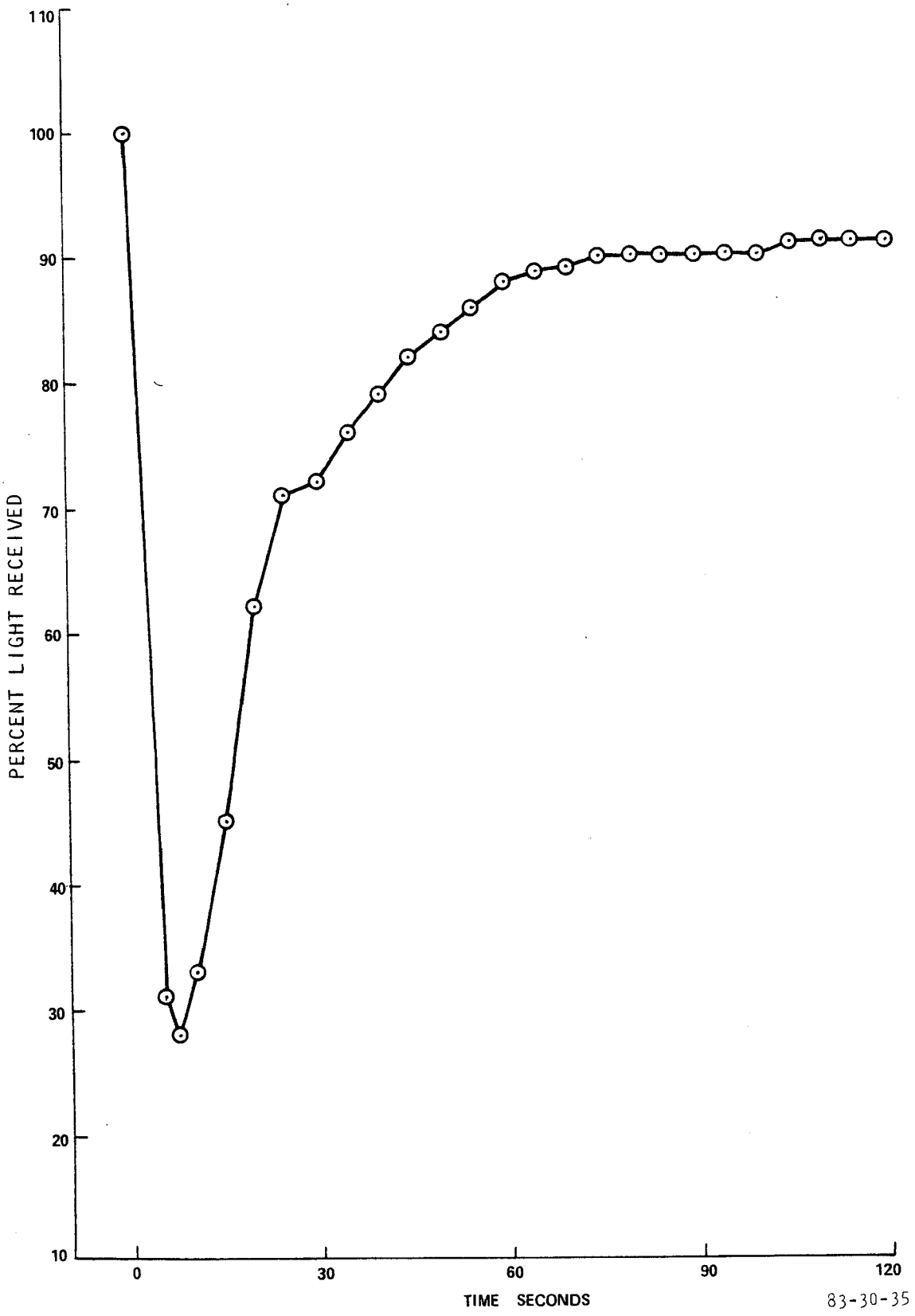

FIGURE 35. SPOTMETER MEASUREMENTS - 2.5 POUND CHEMICAL POWDER EXTINGUISHER DIRECTED TO THE COPILOT'S SEAT