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Aircraft Fire Extinguishment

Part V

Preliminary Report on High-Rate-Discharge Fire-Extinguishing Systems for Aircraft Power Plants

by

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AIRCRAFT FIRE EXTINGUISHMENT

PART V

PRELIMINARY REPORT ON HIGH-RATE-DISCHARGE FIRE-EXTINGUISHING SYSTEMS FOR AIRCRAFT POWER PLANTS*

SUMMARY

In this report provisional formulas based on data obtained during fire tests of XR60-1 nd XB-45 aircraft power plants are derived for the design of adequate high-rate-discharge fire-extinguishing systems in potential fire zones These formulas apply to zones through which there is high airflow and in which the internal surfaces are smooth, and to zones through which there is very little or no airflow and the internal surfaces are rough to any gree

Tests have shown that zones of high airflow with uneven internal surfaces require quantities of extinguishing agent far in excess of quantities required for zones of equally high irflow but with smooth internal surfaces, the difference being as much as 200 per cent Because of insufficient data on the effects of various degrees of surface unevenness on extinguishing-agent requirements, the important "turbulence factor" is not established in report.

The information presented in this report was obtained in tests of only one piston-engine er plant and one jet power plant Accordingly, much still remains to be learned regarding he precise requirements for either type of installation. The suggested quantities and discharge rates are conservative and may be expected to decrease appreciably as additional a are obtained on other installations

INTRODUCTION

The configurations of conventional fire-extinguishing systems in aircraft are based to e degree on experimental work conducted from 1940 to 1943 at the Technical Development nd Evaluation Center of the Civil Aeronautics Administration. The formulas resulting from t work originally were contained in a published note,[1] and they have been modified over years as a result of tests by other government agencies and industry. The systems developed originally were extremely complex, primarily because the available equipment could not produce sufficiently high discharge rates Agent distribution could be accomplished only by intricate systems of tubing It is probable that much of the resistance to use of those systems stemmed from their complexity and the associated design, testing, inspection, and maintenance problems

Even the earliest test programs indicated that the agent-discharge rate was a most important factor in the success of an extinguishing system During the simultaneous testing of XR60-1 and XB-45 power plants in 1951 and 1952, efforts were made to provide proper gent distribution throughout potential fire zones by substituting a high rate of agent discharge or perforated-tubing and nozzle systems The term "High-Rate-Discharge" (HRD) was chosen primarily to identify the new development as opposed to conventional systems, and secondarily because the system does provide greater discharge rates. The purposes of this port are

1. To describe the objectives in developing HRD systems
2. To describe successful HRD systems for piston engines and turbojet power plants.
3. To discuss the difficulties encountered with, and the limitations of, HRD systems.

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*Manuscript submitted for publication December 1955.

[1] H. L. Hansberry, "Design Recommendations for Fire Protection of Aircraft Power lant Installations," CAA Technical Development Note No. 31, September 1943.

4. To develop formulas which may be used as guides for building future HRD systems.
5. To define HRD systems as they are understood by test personnel.

OBJECTIVES OF HRD SYSTEMS

The original HRD systems were intended to discharge the agent within potential fire zone with such force that the agent would be distributed throughout the zone in a somewhat explosive manner. It was anticipated that such a system might require more agent than conventional systems but that this would be offset by savings resulting from system simplicity. It also was believed that the agent, discharged at a sufficiently high rate, could completely disrupt airflow and thereby facilitate extinguishment.

The first premise, that the HRD system would require more agent than conventional systems, proved untrue. Ultimately, HRD systems were developed to the point where they required appreciably less agent than conventional systems, probably because of more effective use of all of the available agent. By observation, the second premise appears to be true, that is, rapid agent discharge noticeably disrupts the normal quantity and direction of the airflow.

SUCCESSFUL HRD SYSTEMS

Piston Engines

Figure 1 shows the HRD system developed for the R-4360 engine installation in the XR60-1 airplane for use with liquid extinguishing agents.[2] Figure 2 shows a similar system

TOTAL WEIGHTS AND DISCHARGE RATES IN EACH MAJOR ZONE

ZONE	AIR FLOW OR VOL	WT (LBS)	RATE (LB/SEC)
1	36 LB/SEC	13	23.0
2	60 CU FT	3	4.3
3	48 CU FT	3	4.3
4	*	12	20.0

* AIR FLOW VARIES IN DUCTS AND POCKETS

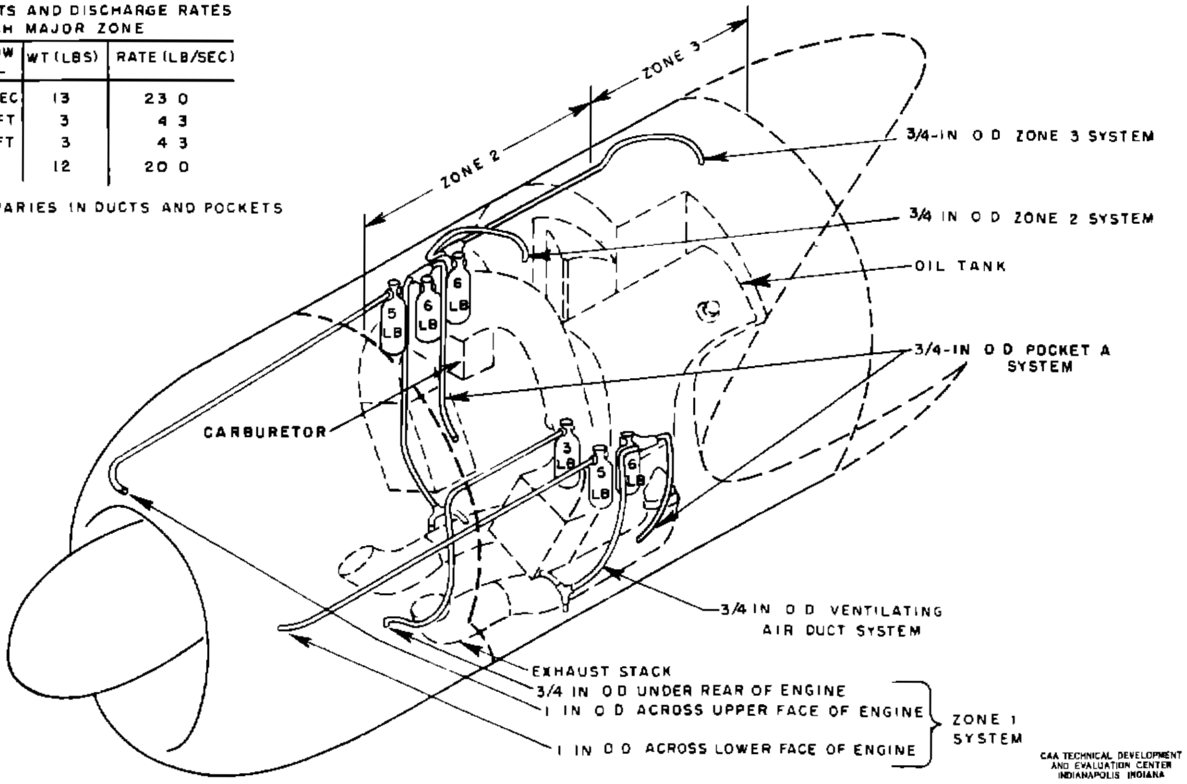

Fig. 1 HRD System for the XR60-1 Nacelle Using Methyl Bromide as the Agent

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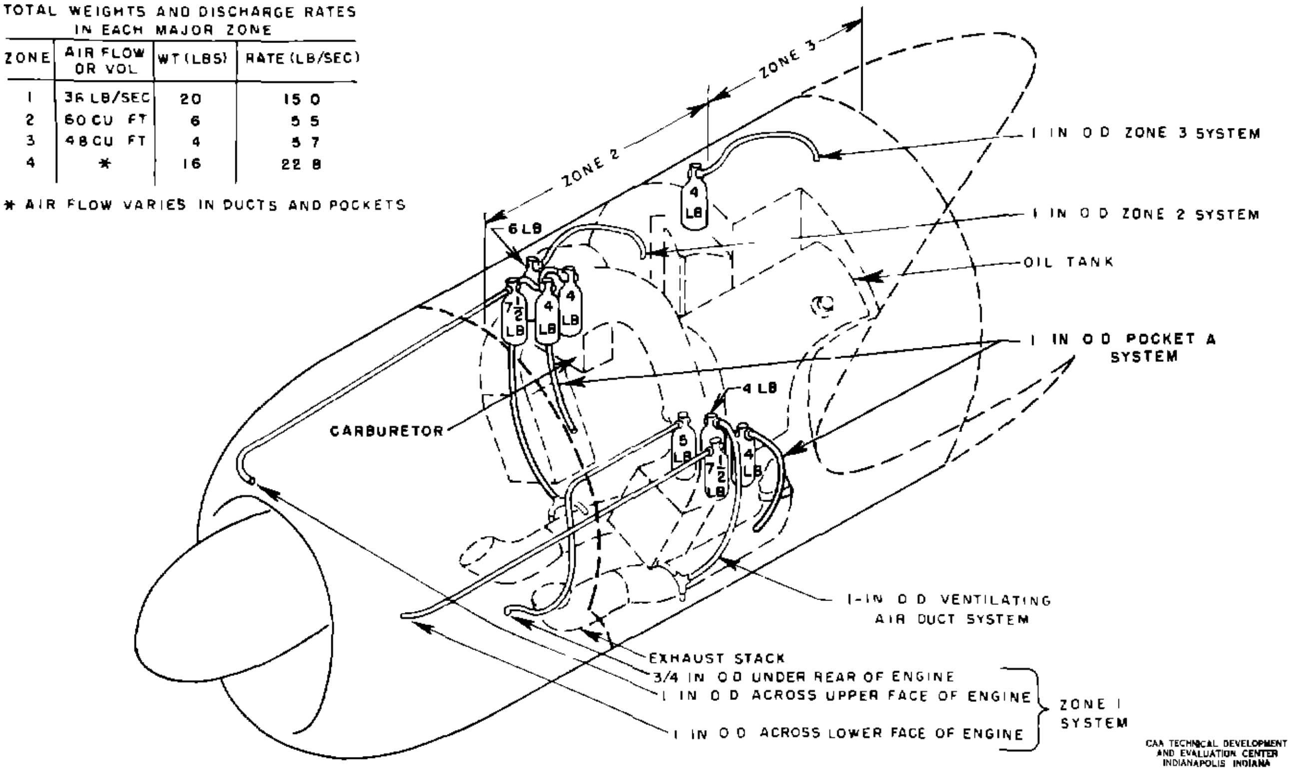
[2] Lyle E. Tarbell, "Determination of Means to Safeguard Aircraft from Power-Plant Fires in Flight, Part V, The Lockheed Constitution (Navy XR60-1)," CAA Technical Development Report No. 198, April 1953.



TOTAL WEIGHTS AND DISCHARGE RATES IN EACH MAJOR ZONE

ZONE	AIR FLOW OR VOL	WT (LBS)	RATE (LB/SEC)
1	36 LB/SEC	20	15 0
2	60 CU FT	6	5 5
3	48 CU FT	4	5 7
4	*	16	22 8

* AIR FLOW VARIES IN DUCTS AND POCKETS

Fig. 2 HRD System for the XR60-1 Nacelle Using Carbon Dioxide as the Agent

developed for use with carbon dioxide. In each figure, the quantities and rates of discharge of the agents are shown for each zone Zone 4 posed a special problem in this power plant because it comprised a number of small isolated volumes of varying airflows This particular zone is not similar to that of any other aircraft and, for this report, will not be considered further. It will be noted from Figs 1 and 2 that the systems in all instances discharge through open-end tubes. For test purposes, no agent container was connected to more than two outlets. The advantages of this arrangement were that the quantities delivered to each zone could be controlled closely and could be altered as necessary without affecting the quantities being delivered to other zones. A minimum number of outlets was one of the test objectives In these systems there were a total of five outlets: one in Zone 3, one in Zone 2, and three in Zone 1 The outlet at the rear of Zone 1 was required because of the configuration, there being no air outlets in the lower rear region The dead space had to be handled separately This third outlet would not be necessary in a conventional Zone 1 with cowl flaps completely around the periphery.

Turbojet Engines

Figure 3 shows the HRD system developed for the aft section of the XB-45 power plant, which incorporated two J-35 engines In this installation it was convenient to conduct fire tests under widely different airflow conditions because the airflow depended primarily upon the power output of the engines [3] Figure 4 indicates the quantities of carbon dioxide required under various test conditions, and Fig. 5 shows requirements for methyl bromide The upper curve in each figure resulted from the use of the original compartment configuration, which incorporated transverse ribs, and the lower curve was obtained after a liner had been added to the lower part of the cowling to provide a smooth inner surface. In general, the condition of the bottom interior surface of the compartment was more important to extinguishing-agent requirements than were the volume and airflow considerations combined

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[3] Charles A. Hughes, "Aircraft Fire Extinguishment, Part II, The Effect of Air Flow on Extinguishing Requirements of a Jet Power-Plant Fire Zone," CAA Technical Development Report No 205, June 1953.

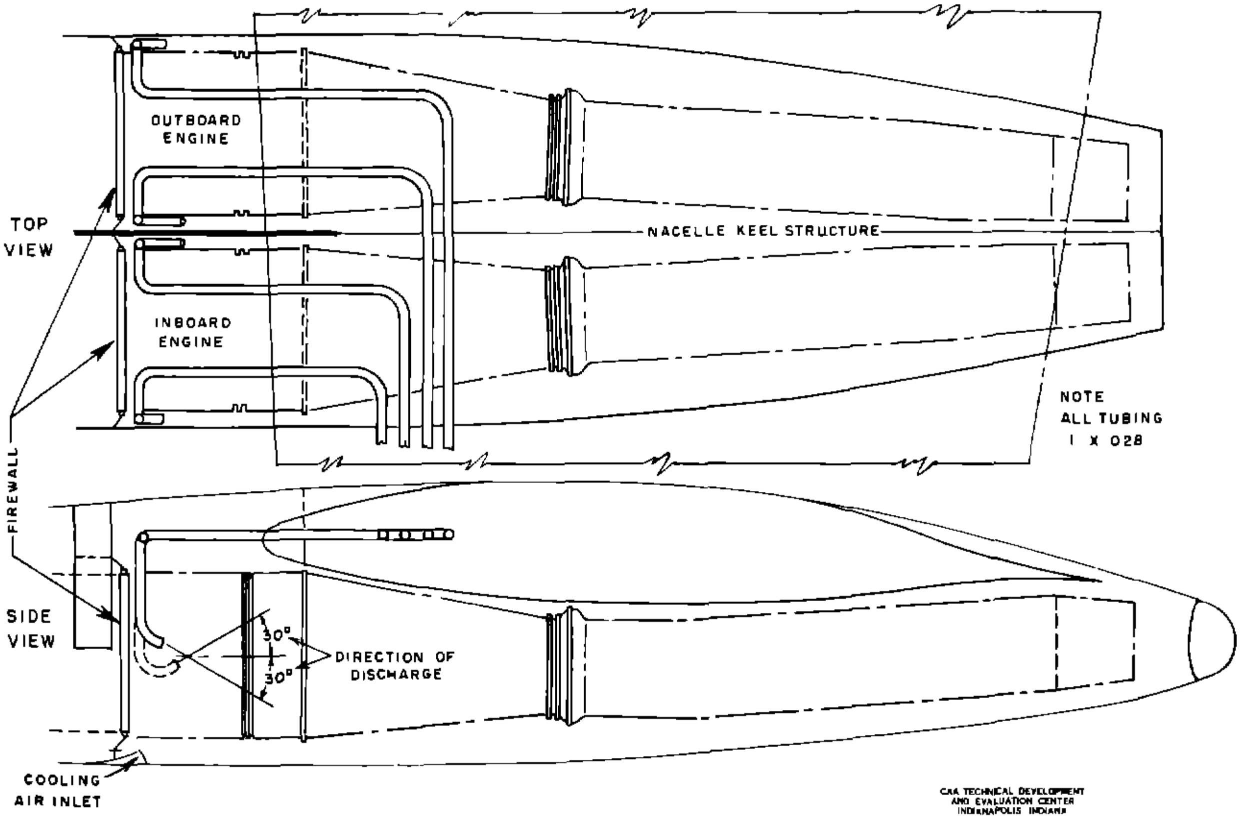

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Fig 3 Experimental HRD Extinguishing System in the Aft Compartment of the XB-45 Nacelle

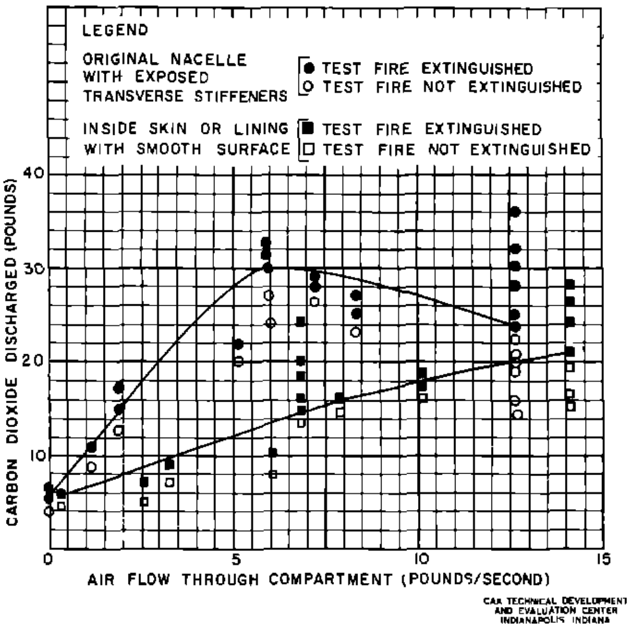

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Fig 4 Carbon Dioxide Required by Experimental HRD System to Extinguish Test Fires Versus Pounds of Air Per Second Flowing Through Fire Zone

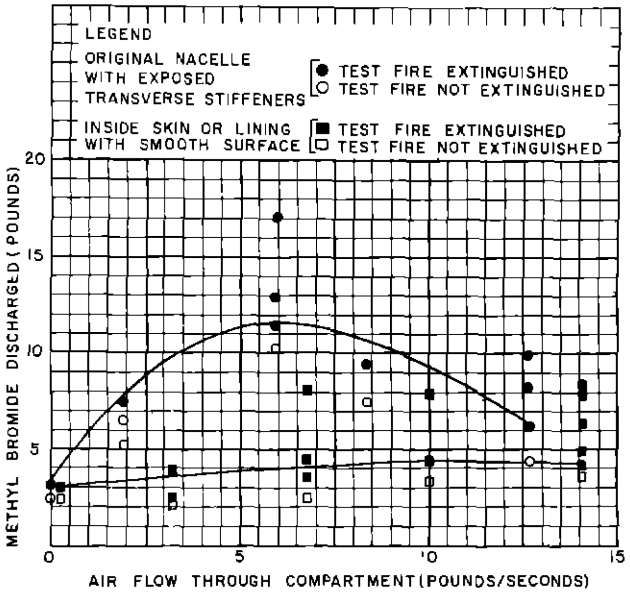

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Fig 5 Methyl Bromide Required by Experimental HRD System to Extinguish Test Fires Versus Pounds of Air Per Second Flowing Through Fire Zone

HRD SYSTEM REQUIREMENTS AND LIMITATIONS

The original concept of the HRD system involved the discharge of agent into a zone at igh rate and in a promiscuous fashion. In general, such undirected discharges proved uate in zones of little or no airflow In zones of high airflow, however, outlet locations nd the directions of the discharges proved very important

Examination of Figs 1, 2, and 3 shows that in zones of high airflow the agent outlets are far forward in the zone as practicable In addition, the outlets are so positioned that a lical agent-spray pattern is provided In the case of Figs 1 and 2, the swirl is opposite to t produced by the propeller In Fig 3, it can be seen that the swirl patterns produced round the two engines are of the opposite hand, clockwise around the right-hand engine and unterclockwise around the left-hand engine Discharges parallel to the nacelle centerline, r perpendicular to it, were not effective

The feed lines between the agent containers and the outlets were made as short and as ct as possible In attempting to provide a high rate of agent discharge, the need for short, irect feed lines is obvious Minimum line lengths, number of fittings, and number of turns n the feed lines are essential in an HRD system

Also essential to the effectiveness of the HRD system is sufficient agent pressurization n most existing liquid-agent systems a fill ratio of 50 per cent is used, which means that one-lf the volume of the container is liquid agent and one-half is the pressurizing gas The ntity of propelling gas required for an agent is a function of the system volume, not a unction of the volume of the agent container The ratio of original gas volume to the volume f the entire extinguishing system (including the agent container) has been termed "volumetric fficiency " This discussion of volumetric efficiency is based on a pressurization of 400 psi cause that is the pressure presently used in liquid-agent containers Figure 6 shows the olumetric efficiencies of a number of extinguishing systems for which data are given in able I Successful systems show volumetric efficiencies greater than 0 5, whereas systems ith volumetric efficiencies of less than 0 5 are either marginal or completely unsuccessful riefly, the minimum volume of propelling gas at 400 psi in an agent container should be equal o or greater than one-half the volume of the entire system, including that of the agent conner Preliminary tests have shown that the effectiveness of a system with a low volumetric fficiency can be improved by increasing the pressurization in the agent container A study in progress to determine the effect of container pressurization on discharge rate for iquid extinguishing agents

The effect of reducing the fill ratio of unwinterized carbon-dioxide cylinders was not nvestigated specifically, but evidence was obtained which shows that reduced fill ratios have an verse effect on carbon-dioxide-discharge rates Winterized carbon-dioxide cylinders were ot used in this work

TABLE I

VOLUMETRIC EFFICIENCIES OF TYPICAL EXTINGUISHING SYSTEMS*

Test No.	Zone Volume (cubic feet)	Zone Air (pounds per second)	Fluid***		Cylinder Volume (cubic inches)	Fluid Volume (cubic inches)	Line Volume (cubic inches)	Gas Volume** (cubic inches)	System Volume** (cubic inches)	Volumetric Efficiency**
			(agent)	(pounds)						
1		36	CH_3Br	13	615	209	116	406	660	0 62
2	190		CH_3Br	6	205	231	27	109	232	0.47
3		36	CH_3Br	40	1292	640	437	652	1729	0 38
4		36	CH_3Br	40	1292	640	160	652	1452	0.45
5		36	CH_3Br	60	1938	960	854	978	2792	0.35
6		36	CH_3Br	40	1292	640	854	652	2146	0.30
7		36	CBr_2F_2	13	615	231	116	384	660	0.58
8	28		$CBrF_3$	3.6	385	64	227	321	612	0 52
9	109		$CBrF_3$	2.3	646	41	290	605	936	0.65
10****	28		$CBrF_3$	1.0	345	18	68	367	453	0 81
11		36	CH_2BrCl	19	615	275	116	340	731	0 46
12	109		CH_2BrCl	22 5	646	325	290	321	936	0 34
13	109		CH_2BrCl	4	646	58	290	588	936	0.63
14	28		CH_2BrCl	4	385	58	227	327	612	0.53
15****	28		CH_2BrCl	1.1	385	20	68	365	453	0.79

* See Fig. 6

** Gas volume = cylinder volume - fluid volume. System volume = cylinder volume + line volume. Volumetric efficiency = $\frac{\text{gas volume}}{\text{system volume}}$.

*** CH_3Br = methyl bromide, CBr_2F_2 = dibromodifluoromethane, $CBrF_3$ = bromotrifluoromethane, and CH_2BrCl = bromochloromethane.

****These tests were conducted using an HRD system. All other tests were made using perforated-tubing systems.

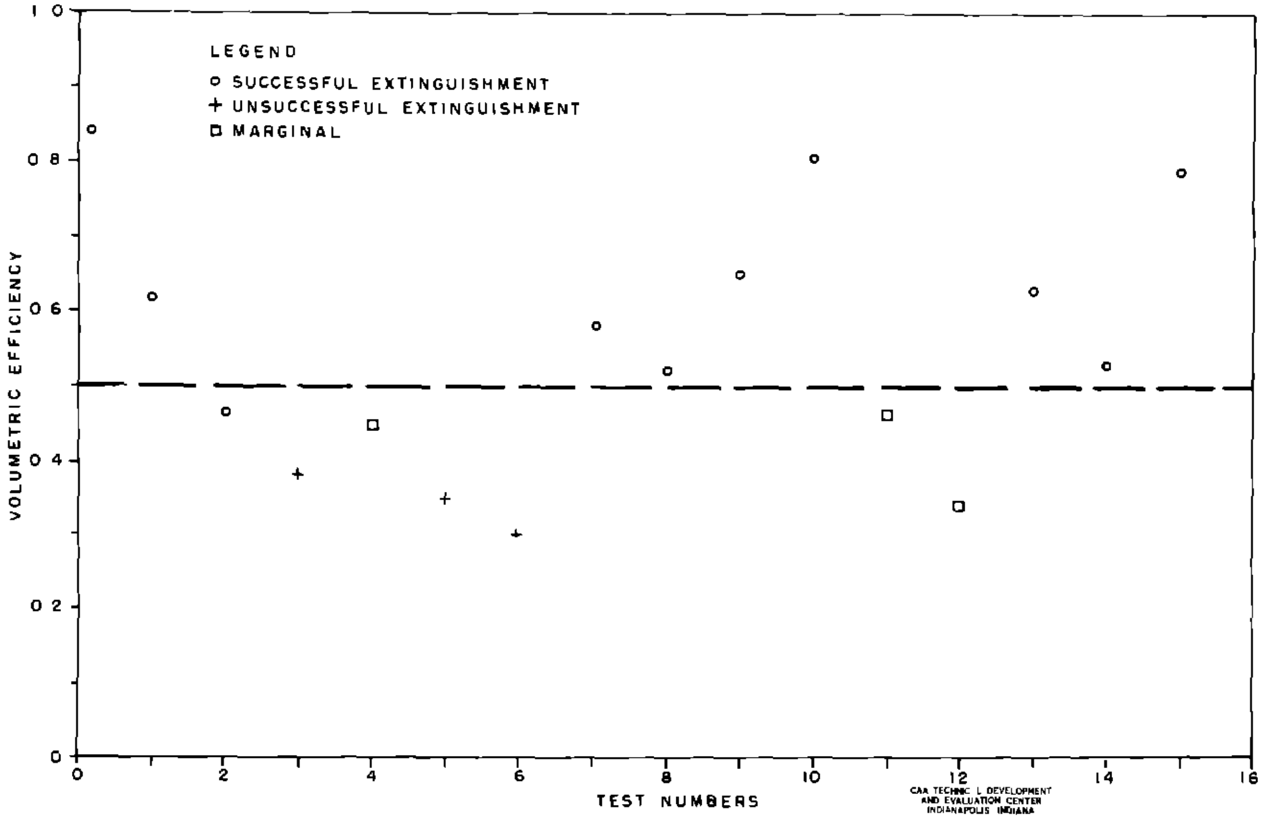

Fig 6 Effect of Volumetric Efficiency on Extinguishing-System Effectiveness (Agent Containers Pressurized to 400 psi)

The requirement for smooth inner surfaces in the lower regions of zones of high airflow not peculiar to the HRD extinguishing system. Figure 7 indicates the quantities of liquid gent required in the rear section of the XB-45 when the original conventional extinguishing ystem was used. Figure 5 indicates liquid-agent quantities required under the same condi- using the newly developed HRD system In each figure the upper curve was obtained ing the original nacelle configuration with transverse ribs, and the lower curve was obtained using a smooth liner over the ribs in the bottom section It may be seen that both curves for the HRD system are lower than comparable curves for the conventional system It also can be seen that, under many airflow conditions, the ribbed inner surface required a reater quantity of agent than is required by volume plus airflow considerations. Unfortu- ly, similar curves for the XR60-1 power plant are not available because the original conventional system used was unsuccessful with the ribbed interior and the HRD development s not initiated until after the liner had been added

The upper curves of Figs. 5 and 7 show that the turbulence factor varies with the airflow, increasing up to an approximate airflow of six pounds per second in the XB-45 and then decreasing. Undoubtedly, this peak would occur at different flow rates in different configura- . As a result it is impossible, at present, to define the turbulence factor for any installation other than the XB-45 tested. Obviously, the condition which creates the turbulence-factor penalty should be eliminated by increasing surface smoothness and improving ventilation and drainage

DEVELOPMENT OF FORMULAS FOR FUTURE HRD SYSTEMS

The formulas derived for the quantities of the various extinguishing agents required in different types of zones by HRD systems are given in Table II. In general, the agent quantities and the agent-discharge rates resulting from these formulas will be conservative. It is probable that future experience and data will make possible reductions in the quantities required as more refinements are introduced into the testing.

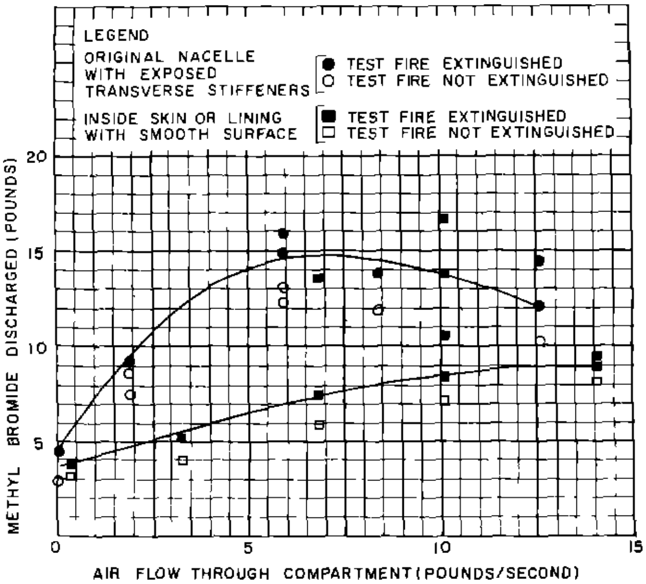

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Fig. 7 Methyl Bromide Required by Perforated-Tubing System to Extinguish Test Fires Versus Pounds of Air Per Second Flowing Through Fire Zone

Of the three so-called liquid agents, most experience has been gained using methyl bromide. Also available is a reasonable amount of data to indicate that dibromodifluoromethane and methyl bromide are approximately equal in their extinguishing abilities. Very few data have been obtained using bromotrifluoromethane, but it does appear equal to the other two agents on a weight basis. Future work should make possible differentiations among the three liquid agents but, in all instances, it is expected that the requirements will be reduced. Bromochloromethane did not match the other three agents in HRD applications, probably because it is appreciably less volatile than the others. The extinguishing ability of carbon dioxide was improved by the HRD application, but even so, it still is inferior to that of the liquid agents.

In the tests which formed the bases for Table II, the quantities of liquid agents specified were discharged within one second The minimum duration of discharge was 0.50 second and the maximum was 0.90 second. The duration of discharge of carbon dioxide varied between 1.25 and 1.35 seconds.

TABLE II

WEIGHT OF EXTINGUISHING AGENTS REQUIRED BY HRD SYSTEMS

Agent*	Zone Classification		
	A and B (High Airflow) Smooth Zone** (cubic feet) (pounds)	C (Low Airflow) Smooth or Rough Zone (cubic feet)	D (No Airflow) Smooth or Rough Zone (cubic feet)
CH_3Br	0.02V + 0.25Wa	0.05V	0.02V
$CBrF_2$	0.02V + 0.25Wa	0.05V	0.02V
$CBrF_3$	0.02V + 0 25Wa	0.05V	0.02V
CH_2BrCl	0.025V + 0.4Wa	0 06V	0.025V
CO_2	0.03V + 0.5Wa	0.07V	0.03V

• CH_3Br = methyl bromide, CBr_2F_2 = dibromodifluoromethane, $CBrF_3$ = bromotrifluoromethane, CH_2BrCl = bromochloromethane, and CO_2 = carbon dioxide.

**V = net volume of the zone in cubic feet. Wa = pounds of air per second passing through the zone at cruising speed.

HRD SYSTEM DEFINITION

As stated previously, the term HRD was chosen because it distinguishes this development rom conventional extinguishing systems and because it obviously provides agent discharges t higher rates than do conventional systems. Accordingly, the following characteristics are intended both as recommendations for, and definitions of, HRD fire-extinguishing systems for ircraft power plants

1 Feed lines should be as short as possible, requiring that the agent containers be as lose as possible to the zones to be protected
2. Feed lines should be direct The fewer fittings and turns, the better. Expansions and restrictions have adverse effects on rate, it is probable that in a feed line with many changes of direction, quantities of propelling gas can get past a liquid agent, thus reducing the discharge rate and making the discharge sporadic and ineffective
3 Feed lines should be open No nozzles or series of perforations are required. The unrestricted release of the more volatile liquid agents, as well as carbon dioxide, can be lied upon for adequate distribution, provided the outlets are located properly.
4 Feed-line cross-sectional areas are dependent upon the rates desired and upon system-lume considerations. The minimum diameter of the feed line is established by the required ate, and the maximum diameter is limited by the need for keeping the system volume at a minimum
5 The volumetric efficiency of an HRD system should be at least 0.5, that is, the original volume of the propelling gas in a system pressurized to 400 psi should be at least one-half he volume of the entire system, including that of the agent container.
6. The locations of the agent-outlet openings in zones of little or no airflow are not critical. A satisfactory location is at the center of the top of the zone, with the agent directed downward.
7. Agent-outlet locations in zones of high airflow are critical. Such outlets should be located as far upstream as practicable The discharge should be directed across the air-tream and slightly downstream in such a fashion that a helical spray pattern is produced. or piston-engine installations, developments to date have been with this swirl directed ounter to that produced by the propeller
8. Agent quantities for particular zones should be calculated as shown in Table II. In zones of little or no airflow, regardless of the configuration, the required agent quantity is dependent upon the zone volume In zones of high airflow with smooth inner surfaces in the lower ctions, the quantity of agent required is dependent upon volume and airflow. In zones of igh airflow with transverse ribs and other flame holders in the lower sections, the quantity of agent required is dependent upon the volume, the airflow, and the turbulence factor produced y the rough interior This turbulence factor is normally much more important than the irflow and the volume considerations combined[4] and, at present, it has not been determined or general application
9. The quantities of liquid agents referred to in item 8 should be discharged in less than ne second, varying between 0.5 and 0 9 second The minimum discharge duration of 0.5 cond undoubtedly could be reduced safely, with a resultant improvement in the system ffectiveness When existing equipment is used, however, a duration of 0.5 second is the ninimum that can be expected In the case of carbon dioxide, the discharge duration should e between 1.25 and 1 35 seconds
10. Quantities of agents, rate of agent discharge, and durations of agent discharge which are alculated for conventional systems do not apply to HRD systems Conversely, quantities, , and durations of agent discharge calculated for HRD systems do not necessarily apply o conventional systems
11 The mere addition of extinguishing-agent quantity to the quantities required does not a safety factor and may result in reducing the safety factor An increase in safety an result from an increase in the rate of agent discharge.

It should be emphasized that the quantities of agent, the two-second-discharge duration, nd the rates of agent discharge which were required for the conventional perforated-tube nd nozzle systems are in no sense changed by this report. Quantities, rates, and duration equirements of conventional and HRD systems are completely different. Accordingly, when conventional system is designed, the particular factor for such systems should be used. hen an HRD system is designed, pertinent HRD factors are needed.

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[4] Ibid.

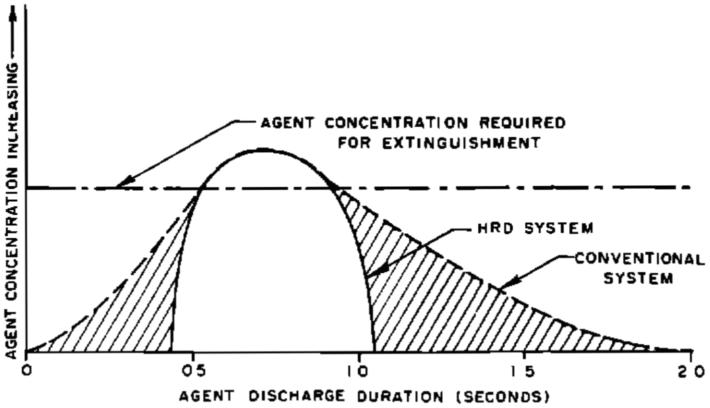

Fig 8 Theoretical Comparison of Extinguishing-Agent Concentrations Produced by HRD and Conventional Systems

Questions have been raised concerning the differences in duration of agent discharge as required by the two systems There is evidence that the two seconds needed by conventional systems resulted from the time required to reach a concentration sufficient to extinguish a fire and the time during which the discharge receded In Fig 8, the solid line indicates agent concentrations produced by the short blast of an HRD system, and the dotted line indicates the agent concentrations produced by a relatively low rate, conventional system discharge The period required for sufficient concentration for extinguishment produced by both systems is the same, but in the case of the conventional system the agent required during the periods of increasing and decreasing concentrations is much greater th in the case of the HRD system The quantity of agent discharged over the period of the cro hatched areas would indicate the difference in extinguishing-agent requirements