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FEASIBILITY AND TRADEOFFS OF A TRANSPORT FUSELAGE FIRE MANAGEMENT SYSTEM

JUNE 1976

FINAL REPORT

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16. Abstract A feasibility investigation and tradeoff analysis was performed on two approaches to increase fire safety for a hypothetical aircraft: (1) an integrated Fire Management System, incorporating fire detection, monitoring, and suppression, and (2) improved non-metallic materials with greater fire retardancy and lower emission of hazardous pyrolysis products. Fire-related accident and incident data over a 10-year period were analyzed. Then the fire safety aspects of the hypothetical aircraft were studied on a zone-by-zone basis. A survey was made of the relevant available technology to upgrade the aircraft fire protection. A fire detection, monitoring, and extinguishing system based on this technology was outlined. Candidate material improvements were identified. The two approaches were defined in terms of performance, economics, and timeliness. Performance and cost factors favored a Fire Management System over improved materials. Unresolved technical problems existed with both approaches, and both involved substantial weight and economic increases. The Fire Management System appeared to have an advantage in timely availability, particularly since some of the qualifying tests for improved materials still need to be developed and accepted. Technology currently exists to provide an effective early-warning fire detection and monitoring system. A safe, effective extinguishing agent suitable for a cabin fire suppression system has yet to be fully demonstrated.

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METRIC CONVERSION FACTORS

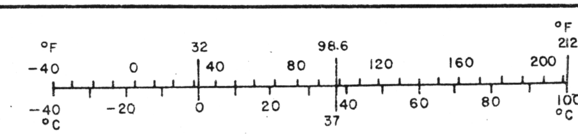
Approximate Conversions to Metric Measures

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



PREFACE

The subject investigation was conducted by the Lockheed-California Company under U. S. Department of Transportation Contract No. DOT-FA75-WA-3657. The program was funded by the Federal Aviation Administration's System Research and Development Service. The study concept and guidelines for the work were developed by Robert C. McGuire who also acted as Technical Monitor during the performance of the contract from June 1975 to April 1976.

The Project Leader for the Lockheed-California Company was Philip S. Starrett. In addition to the listed authors, acknowledgement is made to D. K. Krivec and E. F. Versaw who performed the computer optimization studies given in the Appendix. Appreciation is also expressed to the Lockheed Flight Safety office for providing much of the data for Section 2.

TABLE OF CONTENTS

			PAGE NO.
SECTION	1	INTRODUCTION	1-1
	1.1	BACKGROUND	1-1
	1.2	PROGRAM OBJECTIVES AND REQUIREMENTS	1-2
	1.3	SEQUENTIAL TASKS OF THE INVESTIGATION	1-3
	1.4	BASIS FOR COST DATA	1-5
SECTION	2	FIRE HAZARD SURVEY OF FUSELAGE COMPARTMENT ACCIDENTS/INCIDENTS	2-1
	2.1	DATA COLLECTION AND REVIEW	2-1
	2.2	SUMMARY OF ACCIDENT/INCIDENT DATA	2-4
SECTION	3	FIRE SAFETY ANALYSIS	3-1
	3.1	EQUIPMENTS AND HAZARDS ASSOCIATED WITH EACH ZONE	3-1
	3.2	ZONE VOLUMES AND VENTILATION RATES	3-5
	3.3	ZONE MATERIAL ANALYSIS	3-6
	3.4	REQUIREMENTS FOR IMPROVED FIRE SAFETY	3-8
SECTION	4	FIRE DETECTION AND SUPPRESSION TECHNOLOGY	4-1
	4.1	FIRE DETECTION	4-1
	4.2	FIRE SUPPRESSION TECHNOLOGY	4-19
SECTION	5	FIRE MANAGEMENT SYSTEM CONCEPT	5-1
	5.1	DESIGN REQUIREMENTS	5-1
	5.2	FIRE DETECTION SYSTEM CONCEPT	5-2
	5.3	ZONAL DISTRIBUTION OF DETECTORS	5-10

			PAGE NO.
SECTION 5 - continued			
	5.4	FIRE DETECTOR MONITORING AND DISPLAY SYSTEM CONCEPT	5-13
	5.5	FIRE DETECTION SYSTEM WEIGHT AND COST ANALYSIS	5-18
	5.6	FIRE SUPPRESSION SYSTEM (FSS) CONCEPT	5-20
	5.7	GROUND SUPPLIED FIRE SUPPRESSANT SYSTEM FOR RAMP FIRE PROTECTION	5-36
SECTION	6	IMPROVED FLAME RESISTANT AIRCRAFT INTERIOR MATERIALS	6-1
	6.1	MATERIAL IMPROVEMENT OBJECTIVES	6-1
	6.2	PROGRESS IN MATERIALS	6-3
	6.3	POTENTIAL MATERIAL IMPROVEMENTS FOR EACH ZONE	6-7
SECTION	7	TRADEOFF ANALYSIS	7-1
	7.1	FIRE PROTECTION PERFORMANCE COMPARISON	7-1
	7.2	ECONOMIC COMPARISON	7-3
	7.3	AVAILABILITY COMPARISON	7-5
SECTION	8	CONCLUSIONS	
SECTION	9	REFERENCES	
APPENDIX		OPTIMIZATION OF SUPPRESSANT STORAGE CONFIGURATION	A-1
		INTRODUCTION	A-1
		CALCULATION METHOD	A-2
		RESULTS	A-4
		SUMMARY	A-6

LIST OF FIGURES

Figure		Page
1-1	Designation of Fuselage Zones to be Analyzed	1-6
3-1	Effect of Ventilation Rate on Agent Dilution in a Compartment	3-7
4-1	Particle Size Ranges for Common Aerosols	4-3
4-3	Photoelectric Detector Using Side Scattering	4-8
4-5	Schematic of a Laser Detector	4-12
5-1	Schematic of Conceptual Dual-Detector Assembly	5-6
5-2	Microprocessor Logic for Rate and Concentration Modes	5-15
5-3	FMS Panel Display	5-17
5-4	Weight of Halon 1301 Fire Extinguishing System as a Function of Volume Protected 2.0 Sec. Discharge Time	5-22
5-5	Conceptual Schematic of Optimized Fire Extinguishing System	5-27
5-6	Main Cabin Distribution System - External Supply	5-38
5-7	Fire Suppression Ground Cart	5-39
A-1	Various Phases of Discharge Calculations	A-7
A-2	Extinguishant Bottle Weight Optimization Study	A-8
A-3	Effect of Orifice Diameter on Bottle Design for Halon 1301 Fire Extinguishing System at the Optimum initial Bottle Weight Conditions	A-9
A-4	Fire Extinguishing System using a 5% Halon 1301 Concentration (By Volume) for 1000 cu. ft. Space Minimum Bottle Weight System	A-10
A-5	Weight for a Single Fire Extinguishant Bottle Containing Halon 1301 for a 5% Cabin Concentration	A-11
A-6	Weight of a Single Bottle Halon 1301 Storage and Distribution System	A-12

LIST OF TABLES

Table		Page
2-1	Post-Crash Fires 1964 to 1974	2-7
2-2	Inflight Fires 1964 to 1975	2-9
2-3	RAMP Fires 1964 to 1974	2-11
2-4	Compartment Flame, Smoke and Overheat Incidents January 1968 to February 1975	2-14
2-5	Compartment Flame, Smoke and Overheat Incident Frequency by Zone - January 1968 to February 1975	2-15
2-6	Aircraft Fire Accident/Incident Rate	2-16
3-1	Potential Ignition Sources Associated with Each Zone	3-9
3-2	Typical Volume and Design Ventilation Characteristics of Each Zone	3-12
3-3	Zone Material Breakdown-Flight Station (Zone 1)	3-13
3-4	Zone Material Breakdown-Lavatories (Zones 2 & 6)	3-14
3-5	Zone Material Breakdown-Main Cabin (Zones 3 & 4)	3-15
3-6	Zone Material Breakdown-Attic Area (Zone 5)	3-18
3-7	Zone Material Breakdown-Food Service Lower Galley (Zone 11)	3-19
3-8	Zone Material Breakdown-Cargo Compartments (Zones 9 & 12)	3-20
3-9	Zone Material Breakdown-Equipment Compartments and Service Centers Avionics and Electrical Load Center (Zones 14 & 15)	3-21
4-1	Fire Detector Summary Data	4-18
4-2	Fire Extinguishing Agents Considered for Use in Uninhabited Compartments	4-29
4-3	Fire Extinguishing Agents Considered for Use in Inhabited Compartments	4-30
4-4	Approximate Agent Weight to Protect a 1000 Cu. Ft. Compartment (No Ventilation)	4-31
5-1	FDS Weight, Cost, and Power Requirements by Zone	5-19
5-2	Approximate Cost and Weight for Protecting Each Zone Individually	5-24
5-3	Agent Concentrations Provided by On-board Suppression Systems	5-29

LIST OF TABLES - continued

Table		Page
5-4	Optimized System Function	5-30
5-5	Weight and Cost for the Optimized Fire Suppression System	5-32
5-6	Weight and Cost Totals of Complete On-board Fire Suppression System	5-33
5-7	Fire Detection and Extinguishing System - Estimated Maintenance Cost (excluding Consumable Extinguishing Agent)	5-34
5-8	Fire Detection and Extinguishing System - Estimated Delay Cost	5-35
5-9	Weight and Cost Analysis of a Ground Supplied Cabin Fire Suppression System	5-41
6-1	Materials Analysis by Zones Zone 1 - Flight Station	6-8
6-2	Materials Analysis by Zones Zones 2 and 6	6-9
6-3	Materials Analysis by Zones Zones 3 and 4 - Main Passenger Cabins	6-11
6-4	Materials Analysis by Zones Zone 5 - Attic Area	6-13
6-5	Materials Analysis by Zones Zone 11 - Food Service Lower Galley	6-14
6-6	Materials Analysis by Zones Zones 9 and 12 - Cargo Compartments	6-15
6-7	Materials Analysis by Zones	
	Zones 14 and 15 - Avionics & Electrical Load Center	6-16
	Zones 7, 8, 10 and 13 - Unpressurized Areas	6-16
6-8	Summary of Estimated Cost and Weight Increases per Hypothetical Aircraft with Advanced Materials for Improved Fire Safety	6-17
7-1	Summary Comparison of Two Approaches for Improved Fire Safety	7-6

SECTION 1

INTRODUCTION

1.1 BACKGROUND

Despite continued improvements in aircraft fire safety, a number of fatalities attributable to post crash fire occur in aircraft accidents that could be considered to be otherwise survivable.

Design concepts to further enhance fire safety of an aircraft cabin offer paradoxical choices. For example, flame retardant material may result in increased hazards from pyrolysis products. Improved fire safe materials may not be available in production quantities, or may be prohibitively expensive, or may not have been fully evaluated for production installations. Conversely, if increased safety is sought through the use of fire management systems, problems associated with early warning detection, potentially hazardous extinguishing agents, weight/cost increases and lower dispatch reliability may be involved. Therefore, the goal of increased fuselage compartments fire safety will require:

- o Judicious use of emerging technology on detection, monitoring, and extinguishing systems.
- o Improved materials testing and evaluation techniques.
- o Capability for mathematical and low cost physical fire modeling to assist in tradeoff decisions.
- o Minimization of ignition sources through improved design and maintenance.

National research programs in many of these areas are now in progress. The present study was conducted to provide guidance in the continuing search for increased aircraft fire safety, with respect to the use of fuselage compartment fire detection and fire extinguishing systems and improved materials.

1.2 PROGRAM OBJECTIVES AND REQUIREMENTS

The overall objective of the study is to determine the feasibility and tradeoffs between two basic approaches to improving fire safety in a modern wide-bodied transport fuselage. These two approaches are:

(1) Application of the latest available technologies in early warning fire detection and extinguishing systems.

(2) Application of improved cabin interior materials offering high fire retardancy and low smoke and toxic gas emissions.

The contractual technical requirements of the fire management study may be summarized as:

- o The fuselage compartment fire protection needs shall be identified by a review of aircraft accident/incident records in the period from 1964 through 1974.
- o The study shall use a zone breakdown such as the one shown in Figure 1-1.
- o In-flight, post-crash, and unattended (RAMP)* fires shall all be considered.
- o Fire management provisions for each compartment shall be gauged to the possible hazards of that compartment.
- o Systems concepts shall conform to all pertinent FAA regulations.
- o The status of all national polymeric materials development programs shall be reviewed for relevance to the present study.
- o The fire detector concept should be capable of response to incipient fire conditions. The indication to the flight crew of alarm in one compartment shall be persistent, while

* NOTE: RAMP is used in this report to designate any parked aircraft, whether at the ramp, remotely parked, or in hangar for servicing.

the system continues to monitor the other compartments.

- The fire suppression concept shall use an agent physiologically compatible with crew and passengers. Release of the agent in the cabin during in-flight conditions is an option held open for extreme emergencies only.
- Comparative analysis of approaches should disclose technical, time, and economic advantages, limitations, and tradeoffs.

It is not the intent of this study to evolve and recommend a fire management system design to be incorporated in future aircraft. The study seeks to disclose the feasibility and tradeoffs of the concepts involved, and thus provide guidance for future research and development projects in aircraft fire safety.

1.3 SEQUENTIAL TASKS OF THE INVESTIGATION

The study was broken down into a series of tasks as follows:

a) Define the Aircraft Fire Threat

In order to better understand the problem being dealt with, fire-related aircraft accident and incident data over the last 10 years were analyzed.

b) Analyze Fire Safety Aspects of a Hypothetical Wide-Bodied Transport Fuselage

Using a zone breakdown, the types and amounts of nonmetallic materials used throughout a representative hypothetical fuselage design were defined. Possible ignition hazards, equipment, and typical local ventilation rates are noted. Applicable fire safety regulations are summarized.

c) Survey the Available Technology for Fire Safety Improvements

Current and advanced states-of-the-art were surveyed on potentially applicable detection, extinguishment, and monitoring systems. A similar review was conducted of the national and international efforts on development of materials with greater fire retardancy and lower smoke and toxic gas emission.

d) <u>Analyze the Application of Advanced Fire Safety Concepts to a Hypothetical Wide-Bodied Fuselage</u>

In this phase of the study, the potential technology improvements were brought from the general to the specific in order that feasibility judgements could be made. The impact of fire safety improvements on other systems was assessed. The weights, costs, performance, were defined for both material improvements and fire management systems applicable to each.

e) <u>Perform Tradeoff Analysis</u>

The two basic approaches were compared on the basis of performance, economics, and timely availability.

f) <u>Conclusions</u>

Conclusions drawn from the above tasks were identified and summarized.

In the sections that follow, each of these tasks is treated in detail. A few of the guidelines and constraints adopted for the study should be explained. The hypothetical wide-bodied jet transport chosen for study is approximately the size of the DC-10, L-1011, and the A-300. The interior materials and equipments considered are believed to be representative of modern commercial transport design practice. However, since the analysis is concerned with current aircraft design practice, nothing in this report should be construed as applicable to a particular aircraft nor an endorsement or condemnation of any specific product or equipment manufacturer. The same comments apply to non-metallic interior materials, where, as far as possible, generic designations were used. In some cases, because of the uniqueness of the product, it was impossible to refer

SECTION 2

FIRE HAZARD SURVEY OF FUSELAGE COMPARTMENT ACCIDENTS/INCIDENTS

2.1 DATA COLLECTION AND REVIEW

An analysis was made of all available data relating to aircraft fire accidents and incidents for the period between 1964 and 1974. The survey was limited primarily to U. S. air carrier aircraft, with only a few foreign carriers included where data was readily available. The aircraft types covered are representative of commercial carrier fleets in that time period.

Data were obtained from two main sources: (1) The Lockheed-California Company Flight Safety Office and (2) a Stanford Research Institute study, Reference 1. Data from the Lockheed Flight Safety Office were acquired from all the Armed Services, Flight Safety Foundation (FSF), National Transportation Safety Board (NTSB), International Civil Aviation Organization (ICAO), Federal Aviation Administration (FAA), and other reliable sources. Service Difficulty Reports (SDRs) and Mechanical Reliability Reports (MRRs) were obtained from computer listings provided by the FAA Maintenance Analysis Center (MAC) in Oklahoma City, Oklahoma. For the purposes of this study the data are presented in the following categories:

- Post-Crash Fires
- In-Flight Fires
- RAMP Fires
- Fuselage Compartment Fires (Ref. MRRs and SDRs).

In the discussions that follow a distinction is made between an "Accident" and an "Incident." An "Accident" is an occurrence, associated with the operation of an aircraft, resulting in loss of life, serious injury, and/or substantial damage to the aircraft as specifically defined by the NTSB. An "Incident" is an occurrence, such as in in-flight fire, resulting in minor damage to the aircraft in which reports are required by the NTSB and the FAA.

2.1.1 POST-CRASH FIRES

The most hazardous of all survivable accidents are those where a cabin fire occurs after a survivable landing impact. The data for these cases are summarized in Table 2-1. This table includes survivable accidents where a post-crash fire occurred. The numbers in parenthesis under Fatalities were judged by the accident investigators as deaths primarily attributable to fire. In most cases, a clear cut definition between impact deaths and fire deaths is not possible and the figures given are estimates by official accident investigators. Where reliable data are not available, no entry has been made.

2.1.2 IN-FLIGHT FIRES

In this category, fire was the prime hazard rather than a secondary result of impact. Table 2-2 presents the summary of these accidents/ incidents. The "Incidents" listing from Reference 1 is carried to the beginning of 1968 whereupon the incidents are reported as Service Difficulty Reports (SDRs). The fatalities in parenthesis are judged to be caused primarily by fire, since the prime cause of the crash was an uncontrollable on-board fire. Where the fuselage zone of fire origin can be identified, it is indicated in the table according to the zone breakdown shown in Figure 1-1.

2.1.3 RAMP FIRES

Data are presented in Table 2-3 on ground, ramp and unattended fires for the same 1964-74 period. Information relating to a zone from Figure 1-1 is again indicated where this data was available. Supplementary information is given under "Remarks" where such information is known.

2.1.4 SERVICE DIFFICULTY REPORTS (SDRs)

The bulk of data in this category are service difficulty incidents involving flame, smoke, and overheat occurrences, and recorded from January 1968 to February 1975. These data include Mechanical Reliability Reports (MRRs) from January 1968 to January 1970. A zone analysis of flame, smoke and overheat incidents for this study period is presented in Table 2-4. The same data are presented in order of frequency by aircraft zone in Table 2-5. It should be noted that engine flame, smoke, and overheat incidents are not listed in these tables unless the fuselage compartments were involved. The majority of the fire incidents listed are electrical in origin with the following exceptions: (1) a few incidents of fire initiated in the cabin by passengers, (2) a substantial number of lavatory incidents originated by passengers, such as discarded cigarettes in waste bins, (3) grease and food fires in the galley ovens, and (4) overheated brakes and fires in the fuselage nose or main wheel wells. It is significant that one fact is common to the large number of "controlled" incidents in the flight station, cabins, lavatories, and galleys; they occurred in occupied or accessible areas, where passengers and/or crew could quickly detect and extinguish small fires. A low number of incidents have occurred in the cargo areas. It is also of significance that a large number of incidents in the cabin and flight station areas evolve from overheated electrical lighting ballasts and recirculating air fans. At times, these seemingly small electrical devices can produce disproportionate and alarming amounts of smoke. Similar results can occur from grease or food fires in the galley.

2.2 SUMMARY OF ACCIDENT/INCIDENT DATA

A summary of the data in Tables 2-1, -2, -3, -4, and -5 is presented in Table 2-6 in terms of scheduled departures. Data for the annual number of departures were obtained from a previous study (Ref. 1). In Table 2-6, the total number of aircraft post-crash, in-flight and RAMP fire accidents was calculated as 0.9 per million departures. The rate of incidents was calculated as 15.2 per million departures. These rates for a mass transportation system suggest a good overall fire safety record.

2.2.1 TYPES AND LOCATIONS OF FIRES

The survivable post-crash type of fires occurred with greater frequency than either the in-flight or RAMP fires. Over the period surveyed, 309 fatalities were attributed to post-crash fires while 279 fatalities resulted from in-flight fires. No deaths occurred in any of the RAMP fires.

If an on-board extinguishing system is to improve safety, a question arises as to whether the fuselage will be sufficiently intact to maintain effective extinguishant concentrations. The accidents in Table 2-1 were examined with that question in mind. In seven of the ten accidents where some deaths were attributed specifically to fire by the investigators, there appeared to be sufficient fuselage integrity to permit a cabin fire extinguishant system to be partially effective. The potential for reduction in fatalities was between 116 and 165 out of a total of 309 post-crash fire-related fatalities. While the in-flight fire occurred with less frequency, the hazards of uncontrollable fire were nearly as great. In this case, extinguishment of the fire could prevent crash fatalities.

In those cases where the source of the in-flight fire leading to an accident could be identified (Ref. Table 2-2) the zones involved were:

FIRE ZONE	NUMBER OF CASES INVOLVED
Equipment	3
Lavatory	1
Unidentified	1
	5

The in-flight fire accident data suggests that neither the flight station, the galley, nor the cabin was the location of an uncontrolled fire. Presumably, this indicates both:

(1) The efficiency of the fire retardancy of interior materials when exposed to small ignition sources.

(2) The effectiveness of the occupants in functioning as detectors and fire fighters.

This is highlighted by examination of Table 2-5, which indicates that, despite the hazards involved in the many galley incidents, the fire was safely contained.

Also, the survey further discloses that the greatest danger comes from a fire in an unoccupied area where it may progress to catastrophic proportions before being detected.

It is significant that the cargo compartments did not appear to be a major source of in-flight fire accidents, except in cases involving an incendiary device and hazardous cargo.

RAMP fires, while not incurring any fatalities, have resulted in significant annual property losses. The nature of the RAMP fire, where it may go undetected until extensive damage has occurred, makes it sometimes difficult to establish the point of origin. The data indicate a myriad of reasons, such as solvent (cleaning) catching fire, electrical, oxygen, brakes, chemicals, etc. The high incidence of electrical fires indicates a continuing need for design vigilance in minimizing the hazards from electrical malfunctions.

In summarizing the implications of the survey for the fire management system designer, the following generalized guidelines for improved fire safety are indicated. The system should:

- Prolong emergency evacuation time under post-crash conditions.

- For in-flight fires, place high emphasis on unattended areas where fire can develop unchecked for an extensive period. This should include equipment zones which show a high fire, smoke, and overheat incidence rate.
- Increase protection against undetected development of fires when an aircraft is parked on the RAMP.

TABLE 2-1 POST-CRASH FIRES 1964 to 1974(1)

IMPACT SURVIVABLE ACCIDENTS

Date Accidents	Location	Aircraft	Damage	Fatalities(3)	Fatalities % of Total Occupants	Remarks(2)
11-23-64	Rome, Italy	B707	Total	48(44)	60	T/O Collision w/vehicle
11-08-65	Constance, Ky.	B727	"	58	93	Landing
11-11-65	Salt Lake Cy. Ut.	B727	Substan-tial	43(43)	47	Hard Landing: Rupt. fuel line
12-04-65	Carmel, N.Y.	L1049	Total	4(2)	50	Air Collision
04-22-66	Ardmore, Okla.	L188	"	12(12)	14	Landing
11-20-67	Constance, Ky.	CV880	"	69	84	Landing: Short
08-10-68	Charleston, W.V.	FH227	"	34	94	" "
10-25-68	Hanover, N.H.	"	"	32	76	" "
12-27-68	Chicago, Ill.	CV440	"	27	60	" Roll-out
11-27-70	Anchorage, Al.	DC8	"	47(47)	21	Ditch Collision
12-28-70	St. Thomas, V.I.	B727	"	2(2)	4	Hard Landing
06-07-71	New Haven, Conn.	CV580	"	27(27)	87	Landing: Short
05-18-72	Ft. Lauderdale, Fla.	DC9	"	0	-	Hard Landing

(1) Incomplete data for 1974
(2) From official files
(3) Fatalities in parenthesis indicate deaths attributable to fire itself.

TABLE 2-1 POST-CRASH FIRES 1964 to 1974 (1) - continued

IMPACT SURVIVABLE ACCIDENTS

Date	Location	Aircraft	Damage	Fatalities (3)	Fatalities % of Total Occupants	Remarks (2)
Accidents - cont.						
12-08-72	Chicago, Ill.	B737	Total	43(27)	44	Landing:Stall
12-20-72	Chicago, Ill.	DC9	"	10(10)	25	T/O Collision
10-28-73	Greensboro, N.C.	B737	Substantial	0	-	Landing: Overshoot
11-27-73	Chattanooga, Tenn.	DC9	Substantial	0	-	Landing: Short
01-16-74	Los Angeles, Ca.	B707	Total	0	-	Landing: Hard
01-30-74	Pago Pago, Samoa	B707	"	95(95)	94	Landing: Short
Cargo Accidents						
03-21-68	Chicago, Ill.	B727	"	0	-	T/O Ditch Collision
Incidents						
08-26-64	Dallas, Tex.	DC8	Severe	0	-	Landing
04-26-65	Miami, Fla.	B727	Minor	0	-	Static
06-17-67	Covington, Ky.	DC8	Severe	0	-	Brake locked/landing
12-23-68	Newark, N.J.	DC8	Minor	0	-	Landing
03-28-70	Las Vegas, Nev.	B720	Minor	0	-	Taxi

TABLE 2-2 INFLIGHT FIRES 1964 to 1975[1]

Date	Location	Aircraft	Damage	Fatalities[3] No.	Fatalities[3] % of Occupants	Cause[2]	Zone	Remarks
Accidents								
07-09-64	Parr., Tn.	Viscount 745	Total	39	100	Unknown	-	Inflight fire reported-crashed
06-23-67	Blossburg, Pa.	BAC111	"	34	100	APU duct check valve	8	Loss of tail controls-crashed
07-31-67	Hono., H.I.	Viscount 745	Substantial	0	0	Elect. Panel	15	Cruise Condition
07-26-69	Biskra, Algeria	Caravelle	Total	33	89	Ni-cad. Battery failure	15	O_2 depletion & CO resulted
02-21-70	Zurich, Switz.	CV990	"	47	100	Incend. Device	9	Loss of crew visibility
07-11-73	Orly, France	B707	"	(123)	92	Lav. Fire	6	Progr. fire thru cabin
11-03-73	Boston, Mass.	B707	"	3	100	Hazardous Nitric Acid Bottle(s) leakage	9	Loss of control-crashed
Incidents								
09-22-64	Miami, Fla.	DC8	Minor	0	-	unknown	-	No details
11-05-64	Harrisburg, Pa.	Viscount 745	"	0	-	"	1	Smoke in cockpit
11-25-64	Newark, N.J.	Caravelle	"	0	-	"	4	" " cabin
04-17-66	Charlotte, N.C.	L188	"	0	-	"	12	" " cockpit, fumes in cabin

TABLE 2-2 INFLIGHT FIRES 1964 to 1975 (1) - continued

Date	Location	Aircraft	Damage	Fatalities (3) No.	Fatalities (3) % of Occupants	Cause (2)	Zone	Remarks
Incidents - continued								
09-14-67	Phoenix, Arizona	B707	Minor	0	-	Elect. Wall Htr.	4	Elect. Wall Htr. ignited
1-68 to 2-75	Incidents are additionally covered in the Compartment Fire Incidents - Table 2-4							

(1) Incomplete data for 1974-1975.

(2) From official files.

(3) Fatalities in parenthesis indicate deaths attributable to fire itself.

TABLE 2-3 RAMP FIRES 1964 to 1974

Date	Location	Aircraft	Fuselage Damage	Cause(2)	Zone	Remarks
Accidents						
03-25-65	Albany, N.Y.	CV440	Substantial	Cargo Compt. Light	12	Taxi from landing
07-27-65	Atlanta, Ga.	DC8	"	Ignition of solvent	10	Main Gear Well cleaning
11-25-65	-	DC8	Total	"	4	Cabin cleaning
12-31-66	Long Beach, Ca.	DC8	"	"	4	" "
03-25-67	-	CV440	Substantial	Light ignited cargo	12	
04-11-67	-	CV440	Total	Electr. short	11(U)	
06-13-67	-	B707	Substantial	Oxygen system	12	
06-30-67	Dallas, Tex.	B727	"	Spark from APU ignited cleaning solvent in W/Well	10	
01-25-69	-	B737	"	Oxygen system	4	
01-30-69	Roanoke, Va.	B737	"	Brakes fire	10	
07-29-69	London, England	BAC Trident	"	Arson	3	Gasoline soaked carpet
08-07-69	Phil. Pa.	B720	"	Razor short	6	
04-22-70	Ind., Ind.	B707	"	Cabin light Capacitor	4	

TABLE 2-3 RAMP FIRES 1964 to 1974(1) - continued

Date	Location	Aircraft	Fuselage Damage	Cause(2)	Zone	Remarks
Accidents - continued						
12-31-70	Wash. D.C.	B737	Substantial	O_2 filter element	4	
07-27-71	Oakland, Ca.	L100	"	Cockpit O_2 bottle	1	
08-08-71	Hono., H.I.	Viscount 745	"	Elect. Fail-Battery	10	Taxi - fire
01-25-72	Seattle, Wash.	B720	"	Short Circuit in recirc. fan	4	
04-20-74	Boston, Mass.	L-1011	Total	Several probable sources	4	No single source determined
04-24-74	Jamaica, N.Y.	DC8	Substantial	Fire in wheel Nacelle	10	
Incidents						
11-25-64	New York, N.Y.	DC6	Minor	Cabin fire	4	Taxi
01-09-65	Roanoke, Va.	M404	"	Fire in wheel Nacelle	10	Taxi
03-12-66	Kansas Cty, Mo.	B707	"	Galley Oven	11(U)	
03-23-69	Wash., D. C.	B727	"	Overheated APU ducting	8	
04-12-69	Raleigh, N.C.	B727	"			
01-27-70	Los Angeles, Ca.	DC9	"	Matches in coat pocket - o'head bin	4	Friction between interfolded match packs

TABLE 2-3 RAMP FIRES 1964 to 1974[1] (continued)

Date	Location	Aircraft	Damage	Cause[2]	Zone	Remarks
Incidents - continued						
08-07-70	Jamaica, N.Y.	DC8	Minor "	Left MLG cyl. exploded	10	
08-27-70	" "	DC8	"	Tires blew, fire/Nacelle	10	
12-4-71	Wash.,D.C	DC10	"	Parking Brake Cable binding	10	
05-23-72	Jamaica, N.Y.	B707	"	2 pkgs. chemicals broke open	12	
06-23-73	Spokane, Wash.	DC9	"	Tires blew, fire/Nacelle	10	
04-24-74	Jamaica, N.Y.	DC8	"	"	10	

(1) Incomplete data for 1974

(2) Cause - from official files

(U) Upper Galley

TABLE 2-4 COMPARTMENT FLAME, SMOKE AND OVERHEAT INCIDENTS(1)

January 1968 to February 1975

Zone No.	Zone Description	No. of Incidents	Remarks
1	Flight Station/Cockpit	62	Includes O_2, window deicer overheats, etc.
2	Forward Lavatories	1	Cigarette in waste bin
3	Cabin (First Class)	17	Includes fires in armrests, light overheats
4	Cabin (Coach)	50	" " " "
5	Attic or Overhead	7	Includes in-flight movie equip. and light ballast overheat
6	Aft Lavatories	32	Cigarettes in waste bins, toilet flush motors
7	Engine Equipment	1	Does not include engine incidents
8	APU and other equipment	44	Malfunctioning components
9	Aft Cargo	3	Electrical equipment
10	Main Wheel Well, Hyd. & Other Equip.	88	Overheated brakes, pumps, wiring, etc.
11	Food Service or Galley	133(U) 15(L)	Ovens, coffee makers, etc.
12	Forward Cargo	3	Electrical equipment
13	Nose Wheel Well & ECS Equip.	65	Overheated brakes, electr. and air-conditioning equipment
14	Avionic and Elect. Equip.	9	Electrical boxes, wiring and elect. breakers.

(1) From Service Difficulty Reports in FAA files; occurrences involving minor flame, smoke and overheat service incidents.
(U) Upper Galley
(L) Lower Galley

TABLE 2-5 COMPARTMENT FLAME, SMOKE AND OVERHEAT INCIDENT FREQUENCY BY ZONE(1)

January 1968 to February 1975

Zone No.	Zone Description	No. of Incidents	% Total
11	Food Service or Galley	133(U), 15(L)	28
10	Main Wheel Well, Hyd. and Other Equip.	88	17
13	Nose Wheel Well & ECS Equip.	65	12
1	Flight Station/Cockpit	62	12
4	Cabin (Coach)	50	9
8	APU and Other Equipment	44	8
6	Aft Lavatories	32	5
3	Cabin (First Class)	17	3
14	Avionic and Elect. Equip.	9	2
5	Attic or Overhead	7	1
9	Aft Cargo	3	<1
12	Forward Cargo	3	<1
2	Forward Lavatories	1	<1
7	Engine Equipment	1	<1
	TOTALS	530	100

(1) From Service Difficulty Reports in FAA files; occurrences involving flame, smoke and overheat service incidents.
(U) Upper Galley
(L) Lower Galley

TABLE 2-6 AIRCRAFT FIRE ACCIDENT/INCIDENT RATE

1964 to 1974 (1)

TYPE OF FIRE (2)	NUMBER ACCIDENTS	NUMBER INCIDENTS	PER MILLION DEPARTURES (3) ACCIDENTS	PER MILLION DEPARTURES (3) INCIDENTS
POST-CRASH	22	7	0.4	0.1
IN-FLIGHT	7	535 (4)	0.1	14.9 (4)
RAMP	19	12	0.4	0.2
TOTALS	48	554	0.9	15.2

(1) Incomplete data for 1974
(2) Includes passenger and cargo flights
(3) Based on 5×10^6 departures per year, Ref. 1
(4) See Table 2-2, 2-4 and 2-5.

SECTION 3

FIRE SAFETY ANALYSIS

In this section the hypothetical wide-bodied jet transport (Figure 1-1) chosen for study is defined in terms of equipments and materials affecting fire safety. The baseline configuration discussed herein is intended to be representative of current aircraft design practice. Safety improvements to this configuration in the form of fire detection and suppression systems and advanced fire retardant materials are discussed in later sections.

3.1 EQUIPMENTS AND HAZARDS ASSOCIATED WITH EACH ZONE

While most aircraft components are extensively tested to substantiate their reliability and safety functions, a possibility still exists for electrical short-circuit or overheat, spillage of flammable fluids, or other potential fire hazards. In Table 3-1 a listing is provided of system installations and equipments associated with potential ignition sources which should be considered when performing a fire safety analysis of transport fuselage compartment zones. The probability of a fire can be assessed from the record of fire incidents which have occurred within zones (see Section 2). Explanatory comments relative to the equipment listing in Table 3-1 are as follows:

- Flight Station (Zone 1)

All, or most, airplane systems originate or terminate in the flight station. Although there are extensive electrical and electronic equipments and instrumentation in the flight station, the flight crew, being present during airplane operations, represent excellent fire monitors. However, crew smoking materials and carry-on items, in the form of maps, manuals, clothing, etc., constitute potential combustibles or ignition sources.

- Lavatories (Zones 2 and 6)

A primary hazard in the lavatories has been shown to be the careless disposition of cigarettes into a waste container of combustible paper napkins and towels. Waste container fire safety improvements have been developed in recent years which successfully contain such fires. There are also electrical items, such as lighting, signs, receptacles, heaters, toilet motors, and toilet controls, which may serve as ignition sources.

- Cabin (Zones 3 and 4)

The passenger service assemblies, mounted above the passenger, contain the reading lights, call lights, remote controlled individual air outlets, and supplementary oxygen system. Passenger seats incorporate additional controls, including switches for reading lights, attendant call, individual air outlet, and various modes of the entertainment system.

Electrical controls, wiring and drive motors of the passenger doors may be potential ignition sources.

The multiplexing system is a specialized electrical system incorporated in the more recent transport airplanes. It is integral with the passenger cabins by design and routed to and from the passenger seat controls, through the seat, to the items being controlled. The routing is usually adjacent to the seat tracks, beneath the floor and up the sidewalls into the attic or above ceiling areas. The ceiling lighting extends throughout the main cabin and the fixtures incorporate items representing potential ignition sources. Similar ignition sources are present in the specialized light fixtures contained in the passenger cabins; such as, EXIT, NO SMOKING, FASTEN SEAT BELTS (signs), call system advisory lights, (color coded lights to indicate a passenger call, lavatory call, etc.), work area lights, etc. The temperature sensors for zone control on the environmental control system are also generally in each passenger cabin.

Aircraft configurations which incorporate an underfloor galley also in many cases have a small food service center and galleys in the cabin area. This includes lighting, communication systems, ovens, refrigerators, hot plates, blenders, coffee makers, water coolers, and waste containers. The passenger's smoking materials are an obvious source of ignition, and combustibles which they carry aboard, in the form of luggage and clothing, are uncontrolled.

- Attic (Zone 5)

This zone may contain a motion picture projector. Modern film, although safer than the obsolete and very hazardous cellulose film, is still flammable. Depending on detailed aircraft design, other potential ignition sources contained in this zone are, wiring and connectors, overhead coat compartment electrical drive motors for the coat rods transport, environmental control system cabin zone controls, oxygen lines, if gaseous, or electrical controls, if chemical, passenger services switches and controls, flight control wiring, fuselage mounted engine controls wiring, anti-collision lights, cabin entry door drive motors and controls, if electrically driven, and cabin lighting ballasts/wiring.

- Cargo Compartments (Zones 9 and 12)

The cargo and baggage contents themselves are potential ignition sources, as well as the electrical control circuits of the container transport system, the cargo door controls, and associated compartment lighting. A Federal Air Regulation Class D compartment is a sealed compartment which extinguishes a fire by oxygen starvation. However, if the compartment does not meet the requirements of Class D (Para. FAR 25.857 of Ref. 2) then it must be Class C, with a smoke or fire detector and extinguishing system. Those components may have electrical elements representing potential ignition sources.

- Lower Galley (Zone 11)

  The potential ignition sources of this zone include ovens, oven exhaust system, refrigerators, freezers, food/wrappings, interphone/intercom, oxygen system, lighting, various switches and controls, water heater, and waste compartments. The personnel and cart lifts (elevators) serving the cabins are usually electrically activated and the controls and drive system are potential ignition sources, in the cabin level compartment as well as in the lower galley.

- Equipment Compartments and Service Centers (Zones 7, 8, 10, 13, 14, and 15)

  The afterbody compartment (Zone 7) is unpressurized. It may contain elements of the flight controls system and in some aircraft designs a center engine installation and/or an APU compartment (Zone 8). Because the APU is essentially a small jet engine, the area is classified as a fire zone requiring a fire detection and extinguishing system. In Zone 10, three separate unpressurized compartments may exist. These consist of the right and left main landing gear (MLG) wheel well, and the hydraulic service center. By designer option the hydraulic service center may be incorporated within one or more wheel wells. The hydraulic service center contains electrical elements of landing gear controls, wing flap drives, pumps and other hydraulic power units, instrumentation, and compartment lighting. Potable water system lines may be routed through these compartments. If so, the electrical water line heaters are potential ignition sources. The MLG wells contain the gear itself, with the accompanying hazards which may result from overheated brakes and tires. Zone 13 usually contains several unpressurized compartments, a nose landing gear (NLG) wheel well, and one or two ECS compartments in the adjacent cheek areas. The NLG well contents represents the same hazards as the MLG wells. Potential ignition sources in the ECS compartment include the electrical components of air cycle machine or Freon system controls, heat exchanger door actuators, miscellaneous sensors/control/valves, wiring and connectors, and possibly potable water system line heaters.

Two zones contain primarily electrical and avionic equipment. The Avionic Service Center (Zone 14) typically accommodates the Automatic Flight Control System (autopilot and flight computers), communications, navigation, power conversion, ECS controls and flight station equipment controls. The major potential ignition sources in the electrical service center (Zone 15) compartment are power contactors, circuit breakers, power conversion equipment, aircraft batteries, and heavy duty feeder wires. Other than basic electrical equipment, there may also be items such as radio/radar altimeter components, automatic direction finder components, etc.

The underfloor equipment compartments also contain lengths of hydraulic tubing and bleed air ducting which, of necessity, must pass through the area. While the phosphate-ester-based hydraulic fluids used in modern commercial transports are less flammable than petroleum-based fluids, they will still burn when exposed to a vigorous ignition source. Therefore, any leakage of fluid, especially when absorbed on a wicking material such as thermal insulation, constitutes a hazard. Bleed air ducts are insulated so that the exposed surfaces are typically below 150°F. However, if the insulation barrier is damaged, the bare metal ducting at 450 to 500°F. may be exposed. Air leakage from these ducts at improperly installed joints could cause a local overheat condition. In some aircraft designs, fuel is stored within the fuselage center section wing beam structure or special tankage compartments. Federal Air Regulations require such tanks to possess safety features to minimize potential hazards due to seepage/leaks.

3.2 ZONE VOLUMES AND VENTILATION RATES

For design of a fuselage fire suppression system, it is important to determine the volume and ventilation rate of each zone requiring protection. The volume directly establishes the amount of agent required to achieve effective concentration levels in the zone being designed. The ventilation rate in turn determines the time that the agent will remain at an effective concentration. In Table 3-2, the volume to be protected and ventilation rates are presented for the hypothetical aircraft depicted in Figure 1-1. These figures are believed to be consistent with current aircraft design practice. The effect on the protecting agent caused by dilution through ventilation of the compartment is illustrated in Figure 3-1. When the minimum effective concentration level is 3%, as it is in most cases with Halon 1301, it can be seen that ventilation rates must be maintained below approximately 0.5 air changes per minute to sustain effective suppression levels longer than two minutes. In some cases this may be controlled by manipulation of ventilation valves, etc. However, if the ventilation is a result of compartment leakage and uncontrollable, an additional discharge of the agent (e.g. a second shot) may be required. This situation is considered further in Section 5.

3.3 ZONE MATERIAL ANALYSIS

A materials analysis by zone is provided herein for a typical wide-bodied jet transport. Since the non-metallic materials used in each zone represent potential fuel sources to be considered in any fire threat analysis, an attempt has been made to define the types and quantities of materials used. Tables 3-3 through 3-9 list the various non-metallic materials applied to the fabrication of parts and assemblies of a wide-bodied jet aircraft. The seven tables pertain to the zones previously designated by Figure 1-1. All cargo zones are presented in one table, the lavatory zones in another, and the avionic and electrical load center in one of the remaining tables, since the materials are similar in these zones.

Each table is further categorized by five columns defining, (1) the usage, (2) typical non-metallic materials in current use for each application, (3) an estimate of the surface area of the materials,

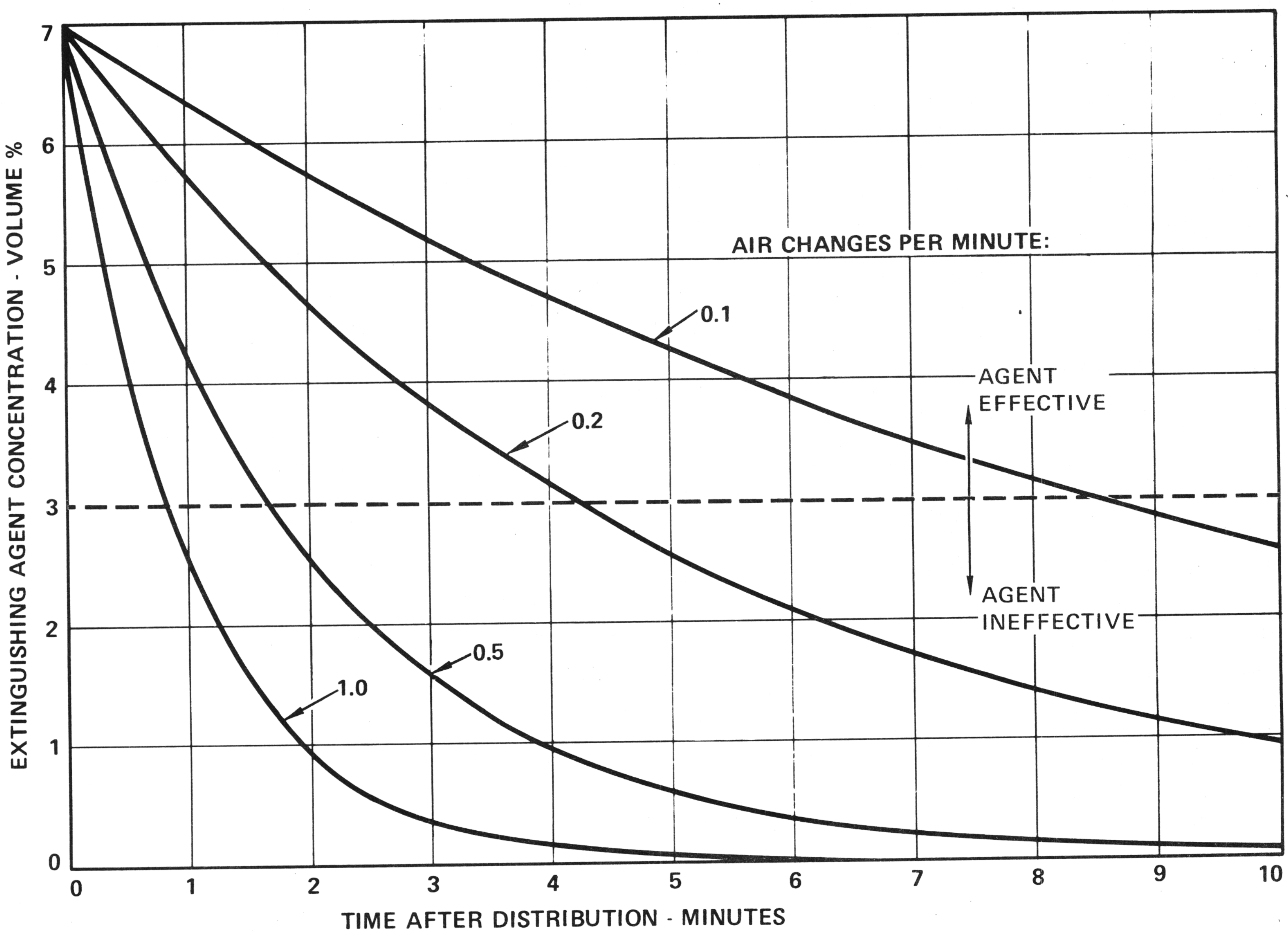


FIGURE 3-1 EFFECT OF VENTILATION RATE ON AGENT DILUTION IN A COMPARTMENT

(4) an approximate estimate of the weight of the materials representing the category listed, and (5) alternate material candidates which might be considered for these zones to improve fire safety. The hypothetical aircraft chosen for study represents a composite of current aircraft design practice. Thus, some materials listed as alternate candidates may already be in service on a particular wide-bodied design.

3.4 REQUIREMENTS FOR IMPROVED FIRE SAFETY

New aircraft designs are currently required to conform to specific fire-related Federal Air Regulations before a type certificate will be issued. Additional regulations are being developed on a continuing basis, to be applied either retroactively or conformed to within an established time period. The present regulations which relate to aircraft fire safety are summarized in Table 3-10. Hence, proposed candidate materials conform to these regulations and anticipate, to the maximum extent, government concerns pertaining to smoke and toxic gas emission. In reviewing the potential hazards (Table 3-1) all of the zones are considered candidates for detection and suppression systems. However, service experience (Section 2) indicates that some zones are much more prone to fire incidents than others. Some zones, with the exception of the equipment zones, may also benefit from upgraded non-metallic materials. In the sections that follow, the technology available to effect fuselage fire safety improvements is reviewed and conceptual designs are developed for further consideration and evaluation in the tradeoff studies.

TABLE 3-1 POTENTIAL IGNITION SOURCES ASSOCIATED WITH EACH ZONE

ZONE 1 FLIGHT STATION

- Electrical/Electronics equipments and instrumentation systems
- Crew oxygen system

ZONE 2 FORWARD LAVATORIES

- Lighting and system
- Return-to-Cabin lighted sign
- Toilet flush motors and controls
- Oxygen system
- Water heater
- Waste container
- Wiring/connectors/system
- Electrical receptacles

ZONE 3 FIRST CLASS CABIN

- Passenger service assemblies
- Passenger seat controls
- Passenger door controls
- Passenger's and carry-on luggage
- Multiplexing system
- Food service center
- Lighting
- Environmental Control System - controls
- Motion picture/ TV system
- Oxygen system
- Power assist coat closet

ZONE 4 COACH CLASS CABIN

- Galley service center
- Same as Zone 3 First Class Cabin

ZONE 5 ATTIC

- Multiplexing system components
- Motion picture projectors
- Overhead coat compartment
- Environmental Control System - cabin zone controls
- Oxygen system/controls
- Passenger services switches/controls
- Flight controls wiring
- Fuselage engine controls wiring, (if located in attic)
- Anti-collision lights
- Entry door drive motors
- Cabin lighting wiring system

TABLE 3-1 POTENTIAL IGNITION SOURCES ASSOCIATED WITH EACH ZONE - continued

ZONE 6 AFT LAVATORIES

- Same as in Zone 2 Fwd. Lavatories

ZONE 7 AFTER BODY, EXCEPT AUXILIARY POWER UNIT (APU)

- Flight controls actuators, etc.
- Service lighting

ZONE 8 AUXILIARY POWER UNIT (APU) COMPARTMENT

- APU
- Self-contained fire detection/ extinguishing systems
- Fuel lines and system
- Lighting

ZONE 9 CARGO COMPARTMENT

- Cargo/baggage
- Container transport mechanism
- Lighting
- Cargo door actuators

ZONE 10 MAIN LANDING GEAR WHEEL WELLS AND HYDRAULIC SERVICE CENTER

- Landing gear controls
- Flap drive
- Motor driven pumps
- Other hydraulic power units
- Potable water system line heaters
- Main landing gear
- Emergency power units
- Instrumentation
- Lighting

ZONE 11 LOWER GALLEY

- Ovens, oven exhaust system
- Refrigerators/Freezers
- Food
- Lift controls
- Interphone/Intercom
- Oxygen
- Lighting
- Environmental Control System controls, fans
- Water heaters
- Waste compartments

ZONE 12 CARGO COMPARTMENT

- Same as Zone 9 cargo compartment

ZONE 13 NOSE LANDING GEAR AND ENVIRONMENTAL CONTROL SYSTEM SERVICE CENTER

- Air cycle machine or Freon system control
- Wiring/ connectors

TABLE 3-1 POTENTIAL IGNITION SOURCES ASSOCIATED WITH EACH ZONE - continued

ZONE 13 NOSE LANDING GEAR AND ENVIRONMENTAL CONTROL SYSTEM SERVICE CENTER (cont.)

- Heat exchanger door actuators
- Misc. sensors/controls/valves
- Lighting
- Potable water system line heaters
- Nose landing gear

ZONE 14 AVIONICS SERVICE CENTER

- Automatic flight control system
  - Autopilot
  - Flight computers
- Communications, navigation
- Fans
- Power conversion equipment
- Flight station equipment controls

ZONE 15 ELECTRICAL SERVICE CENTER

- Power contactors
- Circuit breakers
- Power conversion equipment
- Aircraft batteries
- Fans
- Heavy duty feeder wires
- Radio altimeter
- Automatic direction finder
- Lighting

NOTES: (1) Careless disposition of smoking materials is a common hazard applicable to all occupied compartments.

(2) Crew and passenger carry-on luggage constitute a form of fire load.

TABLE 3-2 TYPICAL VOLUME AND DESIGN VENTILATION CHARACTERISTICS OF EACH ZONE

ZONE	VOL. CU. FT.	NORMAL VENT. RATE, CFM	MINIMUM VENT. RATE, CFM
1 FLIGHT STATION	400	400	250
2 FORWARD LAVATORIES	70 EA	30 EA	30 EA
3 FIRST CLASS CABIN	7000	1500	520
4 COACH CLASS CABIN	10,000	4000	1390
5 ATTIC	4000	0	0
6 AFT LAVATORIES	70 EA	30 EA	30 EA
7 AFTERBODY, EXCEPT APU COMPT.	2100 (a)	2100	2100
8 APU COMPT.	NA (a)	NA	NA
9 CARGO COMPT. (2), AFT	2300 (c)	10 EA	10 EA
10 MLG, HYD. SERV. CNTR.	700 (a)	700	700
11 LOWER GALLEY	1400	400	0 (b)
12 CARGO COMPT., FWD	1600 (c)	10	10
13 NLG, ECS SERV. CNTR.	1000 (a)	0	0
14 AVIONICS SERV. CNTR.	600	1200	0 (b)
15 ELECTRICAL SERV. CNTR.	400	600	0 (b)

(a) Unpressurized
(b) Minimum rate would require closure of exhaust vents
(c) Class D Compartments

TABLE 3-3 ZONE MATERIAL BREAKDOWN-FLIGHT STATION (ZONE 1)

ASSEMBLY	TYPE NON-METALLIC MATERIAL	EXPOSED AREA (ft^2)	WEIGHT (lbs.)	POSSIBLE ALTERNATE MATERIAL CONSIDERATIONS OR REQUIREMENTS
Ceiling Panels (Sandwich Construction)	Epoxy or Polyester/ glass Laminate - urethane paint	100	60	Better fire safety resin systems available for use with fiberglass
Walls & Partitions (Sandwich Construction)	Epoxy or Phenolic/ glass skins - Nomex core-epoxy adhesives, decorative PVC-PVF laminate with pressure sensitive adhesive	23	13	o Phenolic/glass skins o New low smoke adhesive system would be required to lower smoke emission o New decorative film or minimum PVF film over phenolic should be used
Door		13	8	o Burn through capabilities should be considered to separate flight station from cabin
Thermoformed parts for flight Station trim	Modified polyphenylene oxide	200	75	o Modified polysulfone o Need test data on service life and cleaning ability
ECS Ducting overhead	Epoxy or polyester - fiberglass laminate	200	35	o Phenolic/glass laminate
Insulation covering overhead & sides and ducts	PVF/polyamide scrim cloth (heat sealed)	300	1 oz/sq. yd. 2.1 lbs.	o Polyimide film over batts and ducts

TABLE 3-4 ZONE MATERIAL BREAKDOWN-LAVATORIES (ZONES 2 & 6)

ASSEMBLY	TYPE NON-METALLIC MATERIAL	EXPOSED AREA(ft^2)	WEIGHT (lbs.)	POSSIBLE ALTERNATE MATERIAL CONSIDERATIONS OR REQUIREMENTS
Ceiling Panels (Sandwich Construction)	Epoxy or phenolic resin/fiberglass skins. Nomex core. Decorative PVF covering. Pressure sensitive adhesive.	110	35	Panels developed to meet burn through resistance 2000°F. - 15 minutes (NASA development). Probably phenolic resin/fiberglass skins. Develop low smoke adhesive. Develop more flame resistant decorative film or paint.
Wall, backs, door panels (Sandwich Construction)	Epoxy or phenolic resin/fiberglass skins. Nomex core. Decorative PVF-PVC film. Pressure sensitive adhesive.	430	280	Same as ceiling panels
Floors (Sandwich Construction)	Titanium or aluminum or epoxy fiberglass skins. Nomex, foam or balsa core.	40	30	Metal skins. Nomex core.
Floor pans	Vinyl/fiberglass laminate.	100	55	No change recommended
Under sink and cabinet doors (Sandwich Construction)	Epoxy resin/fiberglass skins. Nomex core. Decorative PVC-PVF film.	55	32	Same as ceiling
Service bins and service holders. Injection molded and thermoformed parts	Modified polyphenylene oxide or polycarbonate	55	40	Modified polysulfone for thermoforming and polyether sulfone or polyphenylene sulfide for injection molded parts.

TABLE 3-5 ZONE MATERIAL BREAKDOWN - MAIN CABIN (ZONES 3 & 4)

ASSEMBLY	TYPE NON-METALLIC MATERIAL	EXPOSED AREA (ft^2)	WEIGHT (lbs.)	POSSIBLE ALTERNATE MATERIAL CONSIDERATIONS OR REQUIREMENTS
Ceiling panels Regular type (Sandwich Construction)	Epoxy or phenolic/fiberglass or Kevlar fabric skins. Nomex core. Epoxy adhesive. Decorative PVF film. Pressure sensitive adhesive.	850	365	Phenolic resin/fiberglass skins. Nomex core. Develop low smoke adhesive. Develop more flame resistant decorative film.
Acoustical type (Sandwich Construction)	Epoxy/fiberglass skins. Nomex/glass batt core. Epoxy adhesives. Decorative PVC-PVF film. Heat set adhesive.	450	325	Phenolic/fiberglass. Nomex/glass batt core. Develop low smoke adhesive. Develop more flame resistant decorative film.
Partitions- sidewalls, cabinets, service center walls, clothes closet walls, lift walls, etc. (Sandwich Construction)	Epoxy/figerglass skins. Nomex core. Decorative PVC-PVF film. Pressure sensitive adhesive.	2200	1740	Phenolic/fiberglass skins. Nomex core. Develop low smoke adhesive. Develop more flame resistant decorative film.
Class Dividers (Sandwich Construction)	Aluminum skins/Nomex core. Epoxy adhesive. Decorative PVC-PVF film. Pressure sensitive adhesive.	90	100	Develop more flame resistant decorative film.
Light fixtures and deflectors	Thermoformed Polycarbonate	365	95	Thermoformed mod-polysulfone or mod-polycarbonate.

TABLE 3-5 ZONE MATERIAL BREAKDOWN - MAIN CABIN (ZONES 3 & 4) - continued

ASSEMBLY	TYPE NON-METALLIC MATERIAL	EXPOSED AREA (ft^2)	WEIGHT (lbs.)	POSSIBLE ALTERNATE MATERIAL CONSIDERATIONS OR REQUIREMENTS
Passenger service assemblies. Center row. Outboard row.	Injection molded polycarbonate	80 220	155 400	Polyphenylene sulfide or polyether sulfone.
Complex door surround parts.	PVC/Acrylonitrile-butadiene-styrene co-polymer	580	385	Cl-PVC, Kynar/Mod-polysulfone or Kynar/polycarbonate.
Seat trays, seat backs, and side panels.	Acrylonitrile-butadiene-styrene co-polymer	1100	600	Develop new low smoke emission materials because of volume used.
Soft trim, Foamed seat backs, Arm pads	PVC/fabric Polyurethane foam Dense molded urethane	500 1050 100	200 520 100	Develop new materials
Upholstery Curtain fabrics	FR wool, FR rayon, or Nomex fabric "	3600 400	420 40	Develop new fabrics, e.g. PBI, Kynol, etc.
Seat cushions	Polyurethane (FR) 256 (2.8 ft^2/per seat)	720	600	New foam development or method of preventing cushion burning by FR cover or barrier
Floor Coverings Hard Soft	 PVC/glass laminate Wool rugs-Nomex rugs	 285 1900	 110 750	No change recommended. Develop replacement of high smoking wool rugs. Use of carpet for wall covering should be minimized except for possible kick areas, max. of 12" height, in vertical direction.

TABLE 3-5 ZONE MATERIAL BREAKDOWN - MAIN CABIN (ZONES 3 & 4) - continued

ASSEMBLY	TYPE NON-METALLIC MATERIAL	EXPOSED AREA (ft^2)	WEIGHT (lbs.)	POSSIBLE ALTERNATE MATERIAL CONSIDERATIONS OR REQUIREMENTS
Structural flooring (Sandwich Construction)	° Aluminum or Titanium skins/Nomex core. ° Epoxy-Fiberglass skins/ Balsa core. ° Epoxy-Graphite skins/ Nomex Core ° Epoxy-Fiberglass skins PVC Foam ° Epoxy-Fiberglass skins/ Nomex Core	2300	1600	Develop replacement materials for heavier smoke producing components due to large surface area and weight of material available for consumption in event of large post-crash fire (i.e. PVC Foam)

TABLE 3-6 ZONE MATERIAL BREAKDOWN - ATTIC AREA (ZONE 5)

ASSEMBLY	TYPE NON-METALLIC MATERIAL	EXPOSED AREA(ft^2)	WEIGHT (lbs)	POSSIBLE ALTERNATE MATERIAL CONSIDERATIONS OR REQUIREMENTS
Electric wire and cable harnesses	Kapton or polyarylene or poly-x or teflon insulated conductor	1600	60 Non-metallics	Restrict wire insulation to Kapton, teflon, tefzel or polyarylene for upgraded flame and smoke safety in attic
Convoluted electrical conduit	Teflon or Tefzel tubing	150	35	No change recommended
Environmental Control System rigid air ducting	Epoxy or polyester fiberglass laminate. Epoxy skins and urethane foam core	3260	700	Phenolic/glass laminate only-eliminate use of foam products for sandwich constructions
Rubber/fabric duct connectors	Silicone/polyamide Silicone/fiberglass	140	30	Silicone/Nomex. No change
Insulation	Glass fibers/phenolic resin	7000	80	No change
Insulation covering	PVF/polyamide scrim			Tefzel, Kynar or Kapton film/scrim system

TABLE 3-7 ZONE MATERIAL BREAKDOWN - FOOD SERVICE LOWER GALLEY (ZONE 11)

ASSEMBLY	TYPE NON-METALLIC MATERIAL	EXPOSED AREA(ft^2)	WEIGHT (lbs.)	POSSIBLE ALTERNATE MATERIAL CONSIDERATIONS OR REQUIREMENTS
Ceiling Panels	Epoxy-glass laminate	170	50	Phenolic-glass laminate and film
Sidewalls - Cabinets (Sandwich Constructions)	Epoxy/glass skins Nomex core Decorative PVF/PVC film Pressure sensitive adhesive	425	220	Phenolic/glass skins. Nomex core. Develop low smoke adhesive. Develop more flame resistant decorative film.
Thermoformed parts and under-floor pans	Polycarbonate	150	50	Modified polysulfone
Flooring (Sandwich Construction)	Epoxy/glass skins Nomex core	125	115	No change recommended but could be phenolic/glass skins
Plastic covering	PVC/fiberglass	190	80	No change recommended
Wall rug coverings. Acoustical or service damage	Wool rugs meeting 60-sec. vertical flammability test requirements	90	30	Eliminate use as sidewall covering

TABLE 3-8 ZONE MATERIAL BREAKDOWN - CARGO COMPARTMENTS (ZONES 9 & 12)

ASSEMBLY	TYPE NON-METALLIC MATERIAL	EXPOSED AREA (ft^2)	WEIGHT (lbs)	POSSIBLE ALTERNATE MATERIAL CONSIDERATIONS OR REQUIREMENTS
Ceilings	Polyester/glass or Nomex laminate. Phenolic/glass laminate	1000	200	Phenolic/glass laminate
Sidewalls	Epoxy/Nomex fabric	2000	500	Same as ceiling
Floors	Aluminum Sheet Titanium/crushed Aluminum core sandwich Epoxy/aluminum/Nomex laminate	- -	- -	No change
Injection molded plastic parts, (Light frames). Air grilles	Polycarbonate	18	10	Modified polycarbonate or polyphenylene sulfide.
Aft cargo tie-down straps	Polyamide	- -	- -	No change recommended

TABLE 3-9 ZONE MATERIAL BREAKDOWN - EQUIPMENT COMPARTMENTS AND SERVICE CENTERS

AVIONICS AND ELECTRICAL LOAD CENTER (ZONES 14 & 15)

ASSEMBLY	TYPE NON-METALLIC MATERIAL	EXPOSED AREA (ft^2)	WEIGHT (lbs)	POSSIBLE ALTERNATE MATERIAL CONSIDERATIONS OR REQUIREMENTS
Rigid cooling ducts	Polyester or epoxy fiberglass laminate	870	180	Phenolic/glass laminate
Insulation batt covering	Fiberglass fibers. PVF/polyamide scrim (heat sealer)	- - 450	- - 5	No change recommended Kapton or Tefzel film covering
Insulated wire	Kapton, Teflon, Tefzel, polyarylene or poly-x insulations	- -	- -	Elimination of poly-x and Tefzel for better flame resistance.
UNPRESSURIZED AREAS (ZONES 7, 8, 10, & 13)				
Limited non-metallic areas controlled by other restrictions	- - -	- -	- -	Only material replacements for change are insulation covering material to polyimide film

TABLE 3-10 SUMMARY OF FEDERAL AIR REGULATIONS, PART 25, CONTROLLING FIRE AND SMOKE IN TRANSPORT FUSELAGE COMPARTMENTS

FAR Part 25 Paragraphs on Fire and Smoke
(excluding Powerplant Fire Protection)

25.831 VENTILATION

.831(c) Crew and passenger compartments must be free of harmful or hazardous concentrations of gases or vapors. (referred to, also, in 25.1359 below)

25.851 FIRE EXTINGUISHERS

.851(a) Hand fire extinguishers must be approved, types and quantity of extinguishing agent must be appropriate to kind of fire they are provided for, must be designed to minimize toxic gas concentrations, and readily available.

.851(b) Built-in fire extinguishers capacity in relation to volume of compartment where used and the ventilation rate must be adequate for any fire in that compartment, extinguishing agent must not be hazardous to personnel, and must cause no structural damage.

25.853 COMPARTMENT INTERIORS

.853(a)(b)(b-1)(b-2)(b-3) Flame resistance requirements of cabin materials

.853(c) Ashtrays in smoking compartments, compartments without ashtrays placarded against smoking.

.853(d) Receptacles for towels, paper, or waste must be at least fire resistant and must contain possible fires.

.853(e) One portable fire extinguisher in pilot compartment

.853(f) Specifies minimum number of portable fire extinguishers, conveniently located.

25.855 CARGO AND BAGGAGE COMPARTMENTS

.855(a)(a-1(a-2) Flame resistant requirements of cargo and baggage compartment materials.

.855(b) Any controls, wiring, lines, equipment, or accessories in the compartments either designed so they cannot be damaged or if damaged, breakage or failure must not cause a fire hazard.

.855(c) Cargo or baggage must not interfere with fire-protective features of the compartment

.855(d) Heat sources in the compartment must be shielded or insulated to prevent ignition of cargo.

.855(e) Flight tests required to demonstrate compartment accessibility, prevention of entry of hazardous quantities of extinguishing agent into crew of passenger compartments, and dissipation of extinguishing agent in Class C compartments.

25.857 CARGO COMPARTMENT CLASSIFICATION

.857(a)(b)(c)(d)(e) Specify class of compartment fire protection provisions therefore, and require means to exclude hazardous quantities of smoke, flames, or extinguishing agent from crew or passenger compartments.

25.859 COMBUSTION HEATER FIRE PROTECTION
(Not in general use today)

25.863 FLAMMABLE FLUID FIRE PROTECTION

.863(a) Means must be provided to prevent ignition of leaking flammable fluids or vapors, and to minimize hazards if ignition does occur.

.863(b) Factors to be considered in demonstrating compliance with .863(a).

25.865 FIRE PROTECTION OF FLIGHT CONTROLS, ENGINE MOUNTS, AND OTHER FLIGHT STRUCTURE

These parts and systems, if subjected to the effects of a fire zone, must be made of fireproof materials or shielded from the effects of the fire.

25.867 FIRE PROTECTION: OTHER COMPONENTS

.867(a) Surfaces to the rear of nacelles, within one nacelle diameter of the nacelle centerline, must be at least fire-resistant.

.867(b) Exception for tail surfaces that cannot be readily affected by emanations from a fire zone or engine compartment of a nacelle.

25.1359 ELECTRICAL SYSTEM FIRE AND SMOKE PROTECTION

.1359(A) Electrical system components must meet the requirements of 25.831(c) and 25.863 above.

.1359(b) Electrical cables, terminals, and equipment in designated fire zones, and that are used in emergencies must be at least fire resistant.

.1359(c) Main power cables in the fuselage must be isolated from flammable fluid lines or must be shrouded by conduit.

.1359(d) Electrical wire and cable insulation in the fuselage flame resistance requirements.

25.1451 FIRE PROTECTION FOR OXYGEN EQUIPMENT

.1451(a) Oxygen equipment and lines must not be in any designated fire zones.

.1451(b) Oxygen equipment and lines must be protected from heat emanating from any designated fire zone.

.1451(c) Oxygen equipment and lines must be installed so that escaping oxygen cannot cause ignition of flammables present.

25.1561 SAFETY EQUIPMENT

.1561(b) Lockers or compartments containing fire extinguishers must be marked.

Part 25 APPENDIX F: AN ACCEPTABLE PROCEDURE FOR SHOWING COMPLIANCE WITH 25.853, 25,855, and 25.1359.

SECTION 4

FIRE DETECTION AND SUPPRESSION TECHNOLOGY

The current State-of-Technology applicable to the design of an aircraft fire detection and suppression system is reviewed in this section. Selection and application of a particular conceptual system is deferred to Section 5.

4.1 FIRE DETECTION

4.1.1 FUNDAMENTALS

The presence of fire results in observable changes in the surrounding environment. It is the sensing of these changes that forms the basis for all fire detectors. A fire introduces the following tell-tale indicators into the atmosphere:

- Aerosols
  - Solid Particulates
  - Liquid droplets
- Gases
  - Thermal degradation (pre-ignition)
  - Pyrolysis (post-ignition)
- Energy
  - Ultraviolet radiation
  - Visible light
  - Infrared radiation
  - Heat from exothermic chemical reactions

As the fire develops, it usually progresses from overheat, to smoldering, and finally to flaming combustion. In an aircraft detection system, it becomes especially important to achieve very early detection. The resources to fight the fire are usually limited, and it is much easier and safer to extinguish at an early stage. Also, because rapid egress of the passengers is not always possible, buildup of smoke and noxious gases should be minimized. Thus, the detectors of primary interest are those sensitive to the indicators originating in the pre-ignition or early smoldering phase. Studies have shown that both aerosols and gases are given off in these early stages. The emission of significant amounts of energy is usually delayed until flaming combustion.

4.1.2 AEROSOLS

Sensing the presence of aerosols forms the basis for a number of detector types operating on various principles. The range of aerosol sizes emitted during the pre-ignition and combustion phases is from 5×10^{-4} to 10 micrometres. The heating of materials in the pre-ignition phase results in particles in the size range of 5×10^{-4} to 1×10^{-3} micrometres (Ref. 3). The light scattering efficiency of particles smaller than 0.3 micrometres is very low. Therefore, these particles are invisible, but as time progresses, coagulation, evaporation, and sedimentation tend to stabilize the size distribution in the range of 0.1 to 1.0 micrometres. Some of these particles, even in the pre-ignition phase, are thus in the visible range (larger than 0.3 micrometres) and appear as smoke. As smoldering develops, more particles in the range from 0.5 to 1 micrometre are observed. However, the largest concentration of particles is still in the range below 0.5 micrometre. These particles may be liquid or solid, or they may be liquid droplets condensed around a solid nucleus. The particle size range of several smokes and dusts is shown in Figure 4-1.

Early detection can therefore be based on sensing the presence of invisible particles in the 0.1 to 0.3 micrometre range. At

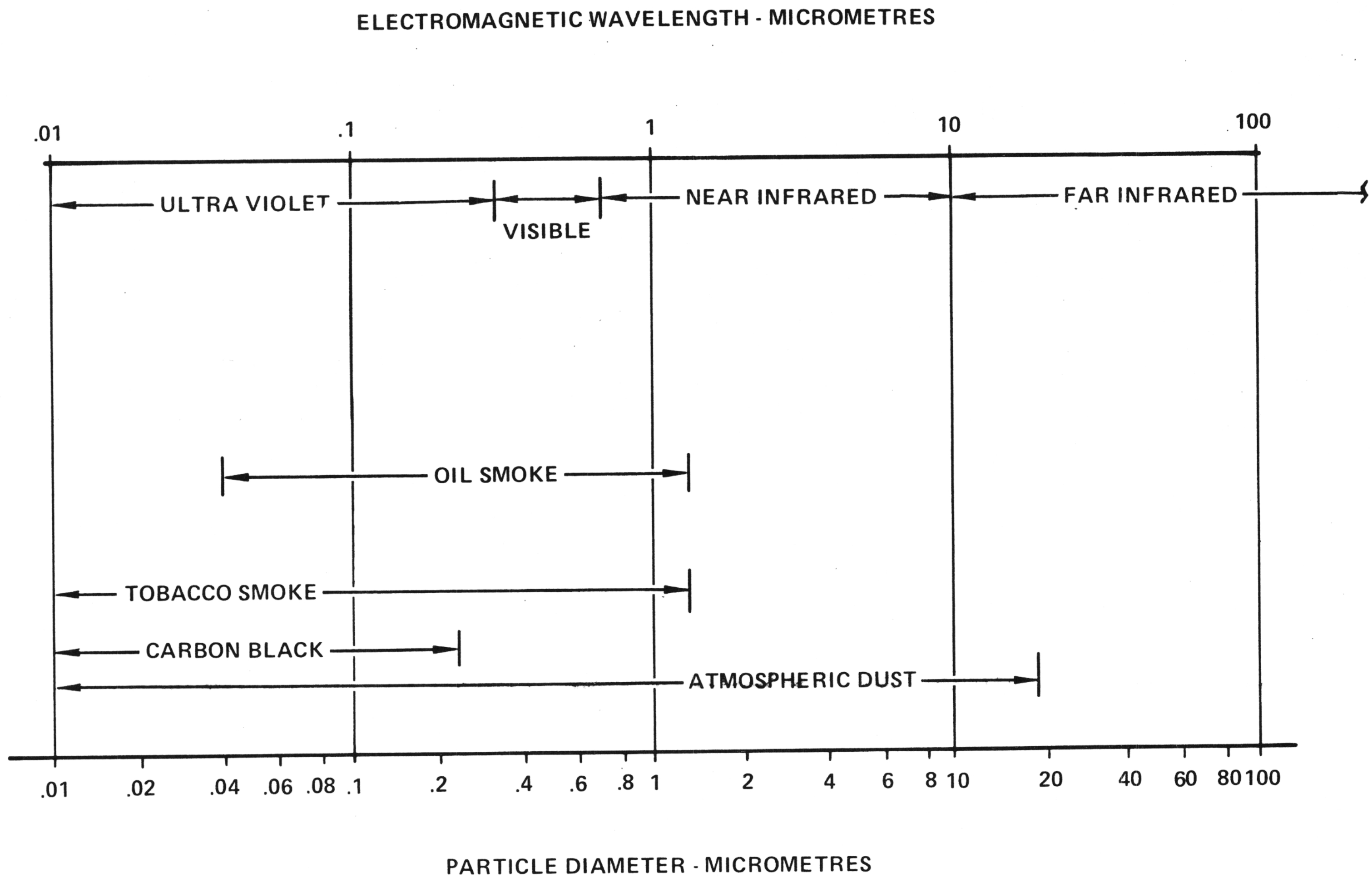


FIGURE 4-1 PARTICLE SIZE RANGES FOR COMMON AEROSOLS

a slightly later stage, as coagulation begins to produce particles in the visible range, sensing of smoke is then possible. Detectors utilizing a variety of principles to sense the presence of these aerosols are discussed subsequently in this section.

4.1.3 GASES

As a material approaches its ignition temperature, thermal degradation results in emission of trace gases. Because these gases depend upon the specific chemical nature of the material and because their concentration in the atmosphere is so low, they have not been found useful in fire detection. However, once ignition takes place, substantial quantities of gases common to many materials are emitted. Gases found present in most fires include water vapor, carbon monoxide, and carbon dioxide. Of these, carbon monoxide is probably the most promising indicator because the background level is so low in normal atmospheres. In some cases, emission of gases specific to known fuels might be sensed. However, the variety of interior materials used in aircraft would appear to preclude such an approach. It should be noted that the presence of detectable quantities of gases tends to lag the emission of aerosols, making this approach less capable of an early warning signal.

4.1.4 ENERGY

Many forms of heat detectors are in common use, both in aircraft and building applications. The water sprinkler system, with its fusible actuation, is a primary example. The aircraft industry has used heat sensitive detectors, such as bimetallic devices and continuous line eutectic metal elements, for many years as overheat and fire detection devices. It is current practice to protect engine nacelles, auxiliary power unit compartments, and some equipment bays with such detectors (Ref. 4). However, since substantial heat must be developed for their actuation, they are not early warning detectors.

Somewhat earlier detection can be accomplished by sensing the radiation of energy from an open flame. Radiation surveillance devices generally detect ultraviolet (UV) or infrared (IR). Various techniques are used to compensate for presence of sunlight and other ambient sources of radiation. An integrated IR-UV system, combined with a continuous element heat sensor has been recently applied to engine fire detection in an effort to achieve high reliability and a low false alarm rate, (Refs. 5 and 6).

The primary disadvantages of radiation sensing are: (1) the requirement that the fire progress to open flaming, and (2) the difficulty of locating a detector that could "see" a flame in any part of a complex compartment.

4.1.5 SIGNAL TRANSMISSION FROM FIRE TO DETECTOR

Another fundamental aspect of the detection problem is the mode of transfer of the signal or fire indication to the detector which usually is some distance away. For energy sensitive devices, this can occur either by heat conduction, convection, or radiation. Heat conduction is only practical for very compact situations, such as equipment protection. Radiation is the most rapid mode of signal transmission, somewhat offsetting the delay resulting from waiting to sense open flaming from an incipient condition. As already pointed out, an unobstructed path is required to view the source either directly or by reflection surfaces.

By far, the most common mode, which is applicable to aerosols, gases and heat, is transmission by free or forced air convection. However, convection is slow and subject to "dead" spaces. Even the induced convection velocities of the aircraft compartment ventilation systems are seldom over one foot per second. Thus, location of detectors relying on either free or forced convection is very critical.

4.1.6 EARLY WARNING DETECTORS

Since a key ingredient in a successful fire management system is early detection, the primary emphasis in this section will be placed on detectors having that potential capability. A discussion of each type of early warning detector will center on the operation principle, accuracies to be expected, ambient environmental effects, reliability of detection, false alarm propensity, weight and approximate cost. The technical and economic aspects to be considered in the design of a successful aircraft early warning fire detection system are:

- Reliability of Detection
- Absolute Minimum of False Alarms
- Functional Throughout the Aircraft Operating Envelope
- Interface Compatibility with other Aircraft Systems
- Maintenance
- Weight
- Cost
- Endurance

The costs quoted in the discussions that follow usually reflect available data on household units. The high reliability and ruggedness required for aircraft applications would increase the price substantially. It is important to point out that rapid advances are taking place in this area of technology and therefore important recent studies in early warning or detector developments may have been inadvertently omitted.

4.1.7 IONIZATION DETECTORS

Early warning sampling detectors based on ionization principles resulted from the early work of a Swiss physicist, Dr. Ernst Meili, who was the developer of the cold cathode tube, Ref. 3. This type of detector is capable of detecting pre-ignition particles primarily in the range of .01 to 1.0 micrometre. This range of particles includes the small invisible aerosols to the large, visible smoke particles. Tobacco combustion aerosols, for example, range between .01 and 1.0 micrometre. The principle of operation of this type of detector is the ionization of air molecules by a radioactive source which establishes a steady state current between an anode electrode and a cathode electrode (Figure 4-2). When aerosols enter the space, many of the negative ions attach themselves to the aerosols. The relatively large aerosol particles move slowly compared to the ions, reducing the current flow and unbalancing the sensing circuit. Various techniques have been utilized for increasing the sensitivity and/or compensating for changes in ambient conditions. These techniques involve geometrical changes such as placement of the radiation source close to the negative electrode (uni-polar) and use of a reference chamber (dual chamber type) for compensation of slow changes in ambient conditions, Ref. 3. Recent advances in solid state circuitry have also reduced the electronics and size, such that these detectors have been increasingly attractive for industrial and residential early warning fire detection usage. By use of a separator, developed during earlier studies on a quartz crystal detector (Ref. 10), aerosols taken into the ionization chamber are limited in size to less than 1.0 micrometre. Thereby ambient contamination from non-fire related sources is minimized. Units are currently undergoing evaluation tests for NASA Space Shuttle Orbiter and Spacelab (ESRO) compartment fire detection applications (Ref. 9). The overall detector including integrated solid-state electronics is compactly designed and weighs approximately 1.5 lbs.

4.1.8 PHOTOELECTRIC DETECTORS

Although this type of detector has not usually been considered

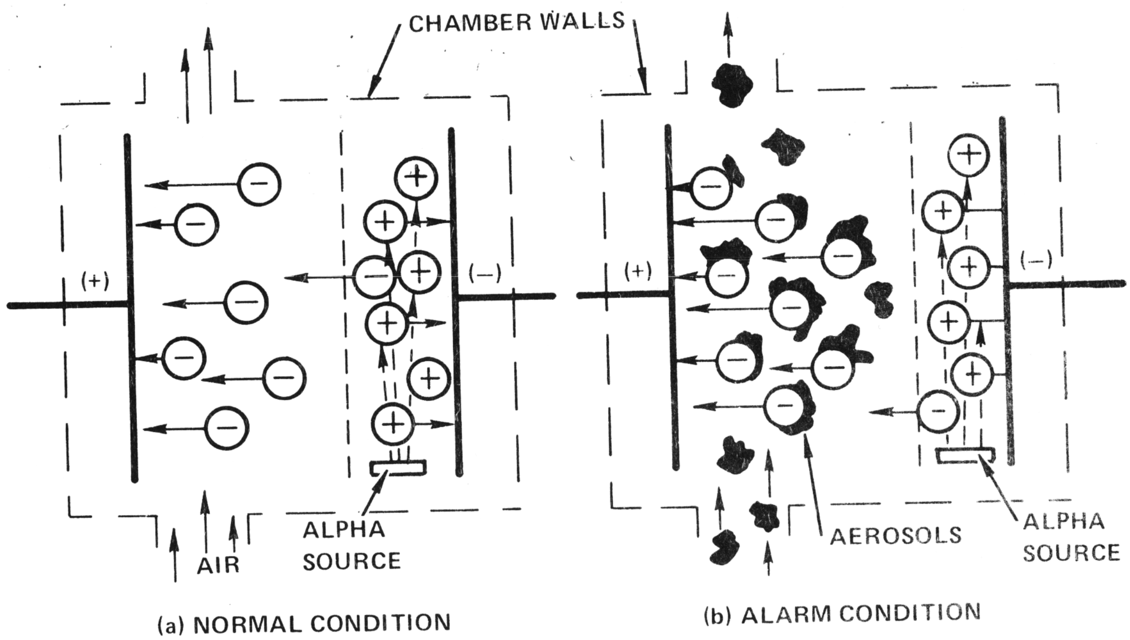


FIGURE 4-2 OPERATION OF AN IONIZATION CHAMBER

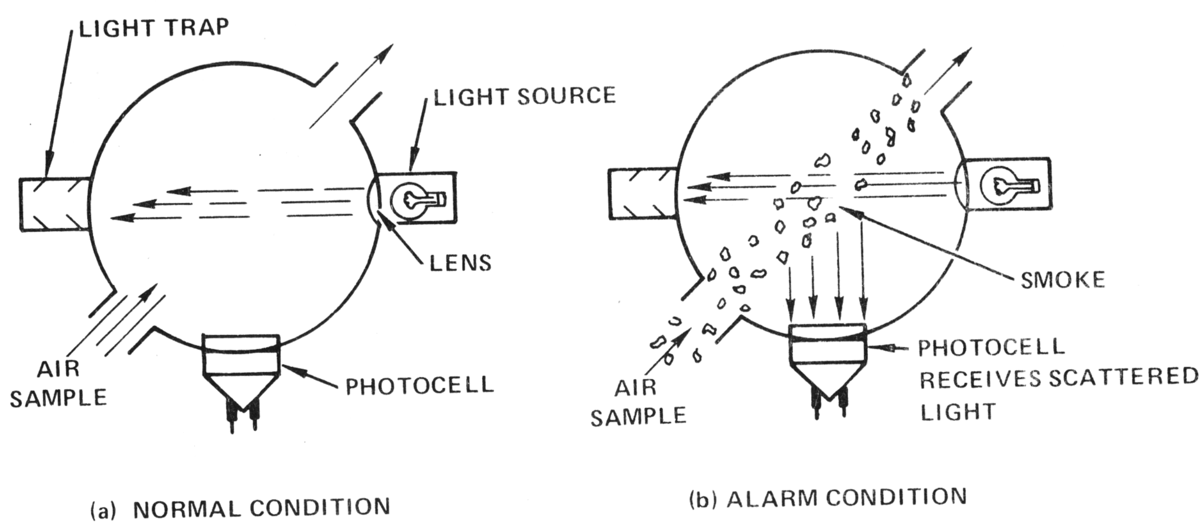


FIGURE 4-3 PHOTOELECTRIC DETECTOR USING SIDE SCATTERING

in the early warning category, it will be described in this section for two reasons; (a) presently, it is the predominant type of compartment smoke detector being used in current commercial aircraft (FAA TSO Cla), and (b) recent improvements in detection chamber designs and application of solid-state electronics technology indicates the potential for early warning detection. The principle of operation of photoelectric detectors is the particle attenuation of a light beam intensity integrated over a beam path length or the scattering of a light beam, either in the forward direction or at various angles to the beam paths, Ref. 3. The first of these is called the "beam" type and the second is called the "Tyndall Effect" type. Both utilize a light source and a photocell receiver. The "beam" type is sensitive to alignment, dust or dirt on the source and/or receiver, and voltage variations. Therefore, it is not extensively used. The "Tyndall Effect" type is more popular and may either use a target to shield the photocell from the beam, or the beam source and photocell may be arranged at some angle, generally 90°. As particles enter the chamber, they scatter the light which is reflected onto the photocell, Figure 4-3, thus providing a current flow for smoke indication. Early models of these detectors were only effective at 8 - 10% light obscuration; however, new detectors are reported effective in the 0.4 to 1.5% light obscuration range. The lifetime of the incandescent lamp light sources is limited on these earlier detectors, especially under vibrating or moving systems. This shortcoming has been improved with light-emitting diodes (LEDs) or, gas-filled flash tubes as light sources with lifetimes in the order of 10 - 20 years. Another important advantage is the low current drain of these new light sources (50 microamps to 50 milliamps). The gas-filled tube light source type, apparently to decrease the propensity of false alarms, requires a smoke concentration duration of 5 to 10 seconds before initiation of an alarm. Suggested improvements in sensitivity of these photoelectric type of detectors are the incorporation of light sources having a major spectral component in the near ultra-violet and bluegreen wavelengths and a matching photo-cell to respond to the larger invisible aerosols, since the best scattering of energy occurs when the particle diameter approaches the wavelength of incident radiation, Ref. 3. Efforts are also being directed at determining the geometrical parameters for effective detector designs in order to predict performance by simple and inexpensive laboratory techniques, since response of these and ionization detectors are very dependent on entrance and chamber design, Ref. 11. Currently, the side scattering design is favored over forward scattering for these detectors. Recent tests conducted by Alvares and McKee, Ref. 12, Custer, Ref. 13 and Bright, Ref. 14, indicate that good photoelectric detectors are comparable in overall performance to ionization detectors. In general, it can be stated that if a fire is a slow, smoldering fire without flame, a good photoelectric detector will be superior to a good ionization detector in detection time. Conversely, if flaming is present, the ionization detector will be faster in response, Refs. 13 and 14. A good photoelectric detector will be less prone to false alarms from cigarette smoke (.01 to 1.0 micrometre) and other aerosols, compared to an ionization detector and is more desirable for detection in water extinguishant sprinkler systems, Ref. 13. Photoelectric "Tyndall Effect" detectors range in cost between $50 and $160. Weight range of these detectors is between 14 oz. to 1.5 lbs.

4.1.9 SEMI-CONDUCTOR GASEOUS DETECTORS

One type of gas detector uses a semi-conductor to sense reducing or combustible gases, such as unburned hydrocarbons, carbon monoxide, and hydrogen sulfide. Some of these detectors employ a heated n-type semiconductor, which is composed of a metallic oxide coating (generally tin dioxide), and were originally developed for combustible gas detection (Ref. 3). In contact with normal atmospheres, oxygen molecules are chemisorbed on the highly porous coating. When a reducing gas comes in contact with the coating, the molecules react with the trapped oxygen, thereby causing a release of electrons and increasing the conductivity of the coating. A requirement for operation is the presence of hydrocarbons or combustibles. However, not all combustion processes release these byproducts, e.g. gasoline burning. Unfortunately, many devices utilizing these n-type semiconductors are being marketed as "Smoke-Fire Detectors." A recent study indicates a detector of this type responded comparably to ionization and photoelectric detectors in small scale smoldering cellulosic fires. However, in twenty-six large scale fires, this type of detector responded only once (Ref. 15). Other problem areas are the propensity for false alarms from commonly present aerosols, humidity changes, and long-term stability (reduced sensitivity). Recent manufacturer's data (Ref. 16), describes a "high sensitivity Carbon Monoxide sensor TGS #711, where several tens ppm of CO can be detected without difficulty." This development is so recent that important parameters such as long-term stability and false alarm propensity have not been fully evaluated. The basic sensor integrated with control and alarm functions is in the $25 to $50 range and weighs approximately 1.5 pounds.

4.1.10 POLYMERIC EARLY WARNING DETECTORS

A relatively new type of sampling early warning or incipient fire detector is the polymeric type of gas detector referred to as "lock and key devices," (Ref. 17). A simple schematic is shown in Figure 4-4. This detection technique exploits the principle of change of electrical properties of selected

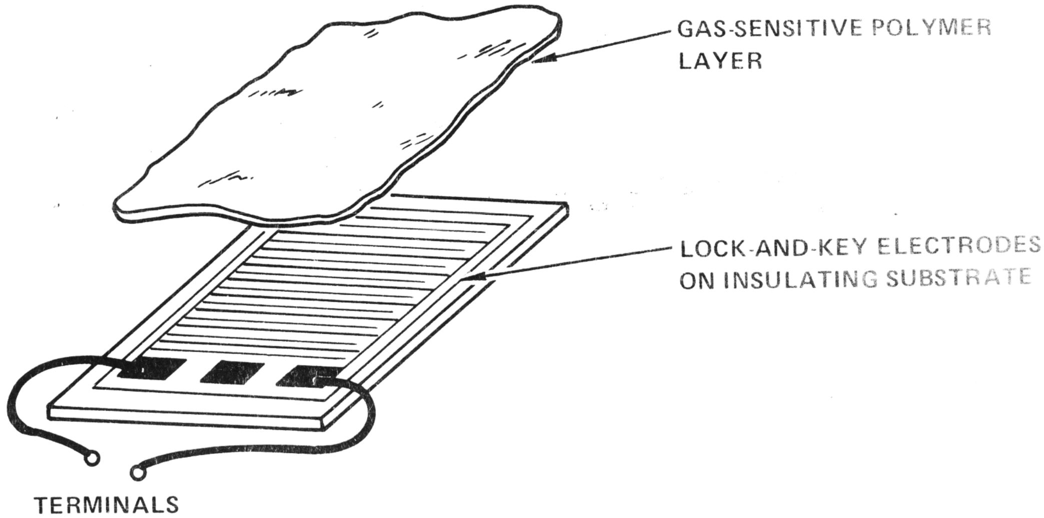


FIGURE 4-4 POLYMERIC DETECTOR

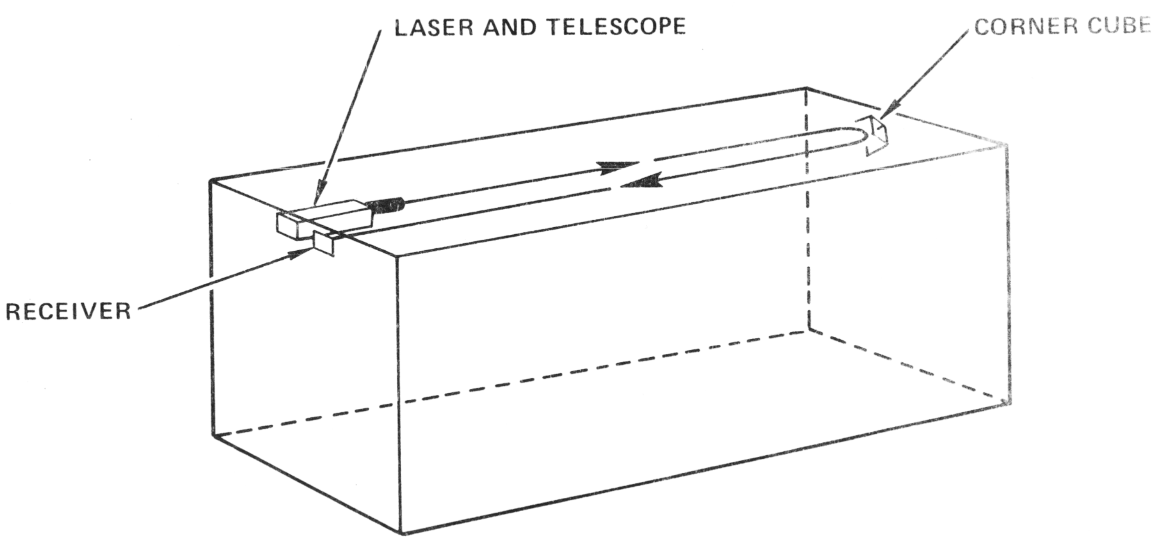


FIGURE 4-5 SCHEMATIC OF A LASER DETECTOR

polymeric compounds in the presence of certain gases. It is postulated that this effect may be the result of complex formation and transfer of charge between the gaseous molecules and the polymer.

Devices have been fabricated from eight polymers and evaluated for performance as a function of temperature, humidity, and combustion by-products response. Polymers have responded to SO_2 in the 10 parts per million (ppm) range and to NH_3 in the 5 ppm range. One of the more promising of these polymers is poly (p-aminophenylacetylene) and devices were fabricated from this polymer for aging under different environmental conditions and subsequently re-evaluated. Tests indicate some degradation of sensitivity, but they were still responsive to pyrolytic products (Ref. 18). Continuing efforts are directed towards improved specificity of response to gases such as CO, decreased sensitivity or compensation for humidity variations, investigation of properties of combined polymers and new polymers, and other techniques for improved, miniaturized, low cost devices. An analytical model has been developed to correlate empirical data to the mechanistic theory of operation and to guide future design efforts, (Ref. 20). Active consideration of these types of detectors for aircraft compartment fire detection awaits further evaluation as to performance under reduced pressure (altitude), long term stability,and other factors.

4.1.11 IR AND UV FIRE DETECTORS

IR, UV, and combinations of these energy detectors operate on a radiation surveillance principle. Although not considered to be of the early warning or incipient type, recent advances and applications of these types of detectors require continued interest. As previously indicated, a flame radiates in the IR, visible, and UV spectrum, and with proper photocells and filters, it is possible to design devices for flame detection. In the

IR type, various approaches have been used to minimize the effects of sunlight and other radiating bodies by utilizing dual filters or dual detection circuits. Similarly, by proper photo-cells or photo-conductive tubes, the UV radiation from a flame can be detected. The operating range of UV detectors is in the 0.17 to 0.30 micrometres region which is out of the range of sunlight or artificial lighting. A recent, important application of a UV sensor for flame detection was on NASA's Skylab Space Vehicle (Ref. 19). Considering all of the spacecraft's operating environment, a UV flame detector was judged to be the best system for volume flame surveillance of all the spaces of the spacecraft. The requirements were for proven volume surveillance reliability, low maintenance, minimum propensity for false alarms, and maximum sensitivity. The photo-conductive tube used to sense UV radiation is of the Geiger-Mueller type. This tube consists of two parallel plate electrodes in a gas-filled, UV transmitting glass envelope. UV radiation incident on the tube releases photoelectrons from the metal electrode, thus triggering an avalanche conduction ionization process. If the UV radiation continues, the conductivity of the tube rises sharply, thus generating voltage pulses at the output. The frequency of these pulses is used to indicate a fire. These detectors have a cone of vision up to 180°; the sensitivity decreasing from 100% straight ahead to 40% at the sides. Reportedly, they can detect a 1-inch high hydrocarbon flame at a distance of 10 feet or a 3/4 inch diameter candle flame at a distance of 10 feet or a 3/4 inch diameter candle flame at a distance of 6 feet. Response times for these detectors range between 5 milliseconds and 3 seconds. Since the detector tube is totally sealed, presumably ambient pressure fluctuations have negligible effects. These detectors can operate at 300°F. and on special applications up to 650°F. Typical weight of a UV detector without microprocessor is approximately 10-12 oz.

Combined IR and UV sensors as an integrated fire detector system have been developed for engine nacelle applications (Ref. 6), and more recently applied to other aircraft compartments (USAF C-5A's) in addition to marine patrol boats (Ref. 20). These systems give an alarm indication when there is a predetermined deviation from the ambient IR-UV balance.

4.1.12 LASER BEAM FIRE DETECTION

This system can be classified as a combined aerosol and energy detection system. A coherent, monochromatic laser beam, where the energy is being propagated in phase, will detect changes in the index of refraction of air when the air molecules are heated by a source of heat. In addition, the laser beam will react similarly to a photoelectric detector upon the attenuation of the beam energy by smoke particles (Ref. 3). Utilizing these principles, a system (Figure 4-5) has been developed which utilizes a laser beam source with a telescope for long projection, a corner cube mirror to compensate for misalignment and vibration, and heat and smoke photocells with appropriate filters. Practical range of the alarm is reported to be 300 feet. Tests of this system reportedly have been performed in an atomic energy plant, an aircraft factory, a coal mine, and a power generating station (Refs. 3 and 21). Reasonable response times of 10 to 20 seconds due to heat from small test fires in a tunnel and 24 seconds response, at low ventilation rates, to smoke appear to make this type of system promising for lengthy spaces such as long, uninterrupted compartments and tunnels. Testing of these systems in the areas of varying environmental conditions, power consumption, false alarms, and endurance needs to be performed for a full evaluation.

4.1.13 CONDENSATION NUCLEI

Large quantities of aerosols are generated from materials at temperatures well below their ignition temperature. The temperature at which submicrometre particles are generated from materials is defined by Van Luik as their thermal particulate point, (Ref. 7). A very early warning type of detector capable of sampling particles in the range of .001 to .1 micrometre is the condensation nuclei type. This device aspirates an air sample into a chamber of 100% humidity. Subsequently, the air is passed through an expansion section, resulting in over 100% humidity. This action condenses water onto the aerosol particles and the resulting fog is subsequently measured by a sensitive photoelectric system (Ref. 3). These very early warning type of detectors, although they are quite sensitive to combustion aerosols, require very careful calibration, repeated change of settings for sensitivity due to changes in ambient conditions, and frequent maintenance care.

4.1.14 RESONANT QUARTZ CRYSTAL DETECTORS

This type of early warning or incipient detector is also of the sampling type such as previously described; however, a somewhat different method of sampling type detection is utilized. These detectors stem from the early efforts of Chuan (Ref. 10) to measure directly the mass of airborne particulate matter. This technique utilizes a specially designed jet forming nozzle to separate particles, 0.7 micrometres or less, from an aspirated sample of air and impact these particles on a quartz piezoelectric crystal. Particles over this size bypass the sampling tube and pass on through the pump unit. As the submicrometre particles impact and are collected on the quartz sensing crystal, the crystal resonant frequency is changed proportionally to the mass change. As mass collects on the sensing crystal, its frequency is lowered, thus increasing the difference between it and the reference crystal. A regenerator is designed in the detector for periodic cleaning of the sensing crystal. The separator concept developed during this work has application to any detector sensing aerosols. By separating out the larger particles and leaving those primarily associated with the presence of fire, the signal-to-noise ratio is improved. As mentioned earlier, an ionization detector has been developed which employs this separator (Ref. 9).

4.1.15 SUMMARY AND CONCLUSIONS OF DETECTORS' CHARACTERISTICS

A summary of the available data on the detectors discussed in this section is presented in Table 4-1 The detectors are classified by at least eight important parameters necessary for the purposes of aircraft application. Additional design objectives related to the purposes of this study will be discussed in Section 5. In Table 4-1, a range of values is given for some of these parameters available from the reference literature. At the time of this study, information is not available in several important areas for these detectors. Early warning detection concepts that appear most promising at this time for the development of an aircraft fire detection system are those based on the ionization and light-scattering principles. The latest modifications of these concepts are the flow-through, dual chamber ionization and the LED photo-electrics. Concepts that may prove promising in the future, pending further developments, are the polymeric and possible semi-conductor gas sensing detectors in addition to the laser detection techniques for long uninterrupted passageways. In special cases, involving early flame detection, the UV, IR or combined systems may offer special advantages.

TABLE 4-1 FIRE DETECTOR SUMMARY DATA

TYPE	SENSITIVITY	TIME RESPONSE (Sec)	POWER REQUIREMENT AC	POWER REQUIREMENT DC	MTBF (1) (Hrs)	(2) BITE	(3) LRU	WEIGHT (Oz)	CURRENT STATUS
Condensation Nuclei	.001 - .1 Micrometre	NA (4)	NA	NA	NA	NA	No	NA	Limited Laboratory Use
Ionization	.01 - 1.0 Micrometre	26-51	.04 Amp 120 V	10^{-9} to .25 Amp 220 to 11V	10^5	Yes	Yes	24-48	In Residential & Industrial Use
Flow-Through Ionization	<.7 Micrometre	10-15	None	.18 Amp 28 V	$2x10^4$ approx.	Yes	Yes	24	Undergoing Qualification Tests
Polymeric	5-10 ppm Gases	NA	None	$5x10^{-10}$ Amp, 50V	NA	NA	NA	<16	In Advanced Development
Semi-Conductor	>50 ppm Gases	36	.03 Amp 115 V	0.5 Amp 12 V	NA	Yes	Yes	24-30	In Residential & Industrial Use
Photoelectric	0.4 to 1.5% Light Obscuration	26-150 (5)	50^{-6} to .04 Amp 220 to 120 V	.08 to .05 Amp 6 - 24V	$8x10^4$ to $1.7x10^5$	Yes	Yes	12-24	In Residential & Industrial Use
Laser Beam	NA	10-20 to heat, 25 to smoke	NA	NA	NA	NA	NA	240 Approx.	In Limited Use (Gr. Britain)
Infra-Red	.65-.85 Micrometre Wave Length Range	.005-6 (to flame)	NA	.01 Amp 12-24 V	NA	Yes	Yes	16-24	In Aircraft Eng. and Marine Use
Ultra-Violet	.17-.30 Micrometre	.005-6 (to flame)	.04 Amp 120 V	.006 to .012 Amp 12-24 V	NA	Yes	Yes	11-16	In Aerospace Use

(1) MTBF, Mean Time Between Failures; (2) Built in Test Equipment
(3) LRU, Line Replaceable Unit; (4) Information not Available; (5) Photoelectric Detectors Response Range.
(Ref. 12)

4.2 FIRE SUPPRESSION TECHNOLOGY

4.2.1 FUNDAMENTALS

Sustained combustion requires fuel, oxygen, and heat. Fire suppression technology is based on disrupting the ongoing interaction of these three key fire ingredients. The literature is replete with descriptions, often conflicting, of the mechanisms of various fire suppressants (Refs. 22, 25, and 46). These action mechanisms can be briefly summarized as:

- Removal of heat (cooling)
- Isolating the fuel (blanketing)
- Removal of oxygen (dilution)
- Chemical interference with the combustion process.

Indeed, some agents perform one or more of these functions and the complete mechanisms are not entirely understood for other agents (Refs. 22, 25).

In the case of ordinary combustibles, removal of heat is one of the most effective means of total extinguishment. This process occurs when the agent absorbs sufficient heat to cool the burning material to a point where it ceases to release enough vapors to maintain a combustible mixture in the fire zone. Extinguishment by water is an example of this action. Another type of heat removal involves the addition of inert gaseous agents which raise the heat capacity of the atmosphere. The absorption of combustion energy by these agents inhibits the requisite preheating of material ahead of the flame front and combustion is not self-sustaining (Ref. 26).

Isolating the fuel from the oxidizing agent by a blanket of non-combustible vapor just above the burning material will cause the fire to go out. It will stay out if the blanket is maintained long enough for the material to cool below its self-ignition temperature. Carbon dioxide is representative of this mode of extinguishment.

Removal of oxygen by dilution with inert gases is an effective fire extinguishing technique. One example of this method is illustrated by the current practice for aircraft cargo compartments. Ventilation is restricted such that any fire quickly consumes most of the available oxygen, replacing it with CO_2 and water vapor, and the fire is then not self-sustaining. A suppression system based on this technique would reduce the oxygen content by displacing it with an inert diluent gas, such as nitrogen.

Extinguishment by chemical action is attributed to the reaction of the pyrolysis products of the halogen compound with the active combustion products within the flame zone. This reaction breaks the chain and flame propagation ceases. For complete extinguishment, the agent concentration must be maintained long enough for the material to cool below its self-ignition temperature.

4.2.2 CHARACTERISTICS OF AGENTS

A variety of extinguishing agents have current usage or have been proposed for use in uninhabited or unoccupied compartments (Table 4-2). Some of these same agents have current or proposed usage in occupied compartments as well, but only in the local application mode with portable extinguishers, where normal air changes can be relied upon to remove the toxic gases due to the agent itself or its pyrolysis by-products. For total flooding systems (automatic or manually actuated suppression) in uninhabited compartments, the problem of agent selection can be resolved on the basis of agent effectiveness and efficiency relative to the concentration required, the weight, the storage volume, distribution requirements, cost, etc. For extinguishant discussions, it is important to differentiate between effectiveness and efficiency. Effectiveness refers to application rate (quantity per unit time) whereas efficiency refers to minimum concentration needed for extinguishing flames. While each application must be considered on its own merits, the evidence suggests that the halogenated hydrocarbons are the most efficient extinguishants and among these the most efficient is Halon 1301 ($CBrF_3$), (Refs. 22, 25, 30, and 43).

In inhabitable compartments, using the total flooding concept, the additional requirement of compatibility with human physiology greatly reduces the list of potential agents which can be seriously considered for application. An agent may have three adverse characteristics, such that it:

- o is toxic in the neat form
- o is toxic in the pyrolyzed form
- o reduces the oxygen content of the air by dilution.

Any one or all of these effects may cause a short-term loss in useful function (Refs. 31, 32, 33, and 40), specifically, inability to exit the burning aircraft.

In the subsections that follow, agents are examined which have been recently considered for use in inhabited areas.

4.2.2.1 Perfluoralkanes

In a program directed at creating life sustaining atmospheres which do not support combustion, Atlantic Research examined a group of agents in the perfluoralkane category (Refs. 34 and 35). These agents, namely CF_4 (carbon tetrafluoride), C_2F_6 (hexafluoroethane) or C_3F_8 (octofluoropropane), when incorporated into the confined atmosphere, act to suppress combustion. The suppression mechanism appears to result from the increase in the heat capacity of the oxidizing atmosphere. The studies indicated that if the heat capacity of the atmosphere exceeds a critical value (50 calories per degree centigrade per mole of oxygen) the atmosphere will not support combustion. While not as efficient as the halogenated compounds, toxicity studies on animals have demonstrated, that in the neat form, these agents are physiologically more inert (Ref. 35). However, in extinguishing on-going fires, C_2F_6 and C_3F_8 decompose appreciably, producing substantial quantities of hydrogen fluoride (exceeding that produced by Halon 1301). CF_4 produces minimal hydrogen fluoride during decomposition, but in the concentration required to extinguish all classes of fire, could result in an oxygen concentration at sea level pressure of approximately 16%. This is equivalent to a physiological effect at sea level similar to an altitude exposure of 7000 feet. If the aircraft cabin pressure altitude was already at 8000 feet, as it normally is during cruise in a modern jet transport, the physiological effect could be similar to a 15,000 foot exposure. Such exposure represents an additional undesirable stress (Ref. 41), in any emergency situation.

The other perfluoralkanes, C_4F_8, C_4F_{10}, and C_7F_{16} are at lesser states of development and do not appear promising. Some of the properties of these agents are indicated, where known, in Table 4-3. In the required concentrations, the agents would result in a substantial weight penalty (Table 4-4) over Halon 1301.

4.2.2.2 Nitrogen

Pressurizing an enclosed volume (e.g., a submarine) with nitrogen while maintaining the partial pressure of oxygen at .21 atmosphere has been studied as a means of creating a habitable atmosphere which will not support combustion (Ref. 37). In these tests burning JP-4 was extinguished in 30 seconds by over-pressurizing the chamber with nitrogen to 1.35 atmospheres. Additional studies (Ref. 38) have shown that at an over-pressure of 1.6 atmospheres paper is self extinguishing, but pressures of 3.5 atmospheres are required to create an inerting condition where combustion of paper will not occur.

In an aircraft the concept of overpressurization has several limiting disadvantages. During an emergency landing, the aircraft must be unpressurized to avoid structural failures on impact and also, so that the doors may be opened as rapidly as possible. Overpressurization in flight is limited by the structural capability of the fuselage. Also, any onboard fire may produce local weakening of primary structure, adding the hazard of explosive decompression.

The alternative is to maintain normal pressures, but dilute the oxygen content by injection of nitrogen. At a pressure of 1 atmosphere, approximately 55% by volume of additional diluting nitrogen is required for hexane flame inerting. This results in an atmosphere containing approximately 88% nitrogen and 12% oxygen with a resultant physiological effect of exposure similar to a fifteen thousand foot altitude. Fire extinguishing tests (Ref. 39) in a 5000 cu. ft. cargo compartment containing a 10% cargo load of Class A combustibles (corrugated boxes filled with excelsior) required nitrogen concentration which reduced the oxygen level to approximately 9% before flame extinguishment was achieved. When the oxygen level increased to approximately 12%, due to natural compartment leakage of 75 cu. ft/min., a flash fire developed, indicating a smoldering condition during the interim period. Thus, to be effective, the oxygen level may need to be held as low as 9%, which is an oxygen partial pressure physiologically equivalent to 21,000 ft. Assuming that it is possible to achieve a rapid and complete mixing (to preclude asphyxiation) of the nitrogen, the effect on human ability to function physically and rationally (Ref. 41) after an almost instantaneous ascent to a 21,000 foot altitude, would be questionable. The temperature effect of discharging this quantity of nitrogen into a confined space would also have to be strongly considered. In the case of nitrogen as well as some of the other gaseous extinguishants under consideration, a decision of cryogenic storage versus storage as a high pressure gas would have to be made. Cryogenic storage presents the complications of a heat source for vaporization and daily service to make up boiloff losses. Storage as a gas, at 3000 psig, is possible but involves large weight penalties and some hazard when a large pressure vessel is exposed to a crash landing.

4.2.2.3 Halon 1301

Currently a large number of commercial air transport aircraft use Halon 1301 extinguishing systems to protect engine nacelles, APU compartments, and to a lesser extent, cargo compartments. As extensive testing has demonstrated, Halon 1301 has a relatively high degree of fire fighting efficiency per unit weight of agent, and is easily stored as a dense liquid. Application of Halon 1301 to deep seated fires will extinguish the flame and control the rate of burning. However, to achieve complete extinguishment, the concentration of agent must be maintained for a period of time sufficient for the burning material to cool below its self-ignition temperature, (Ref. 30). The toxicity of the agent in both the neat form and when pyrolyzed has been an inhibiting factor in applications to inhabited compartments. Concentrations below 7% by volume are considered safe if exposure is limited to five munutes or less, (Refs. 41 through 44). Decomposition products are hazardous and the quantity generated depends to a large extent on the size of the fire, the concentration of the Halon vapor, and the length of time that the agent is in contact with the flame or heated surfaces above a temperature of 900°F. Since Halon 1301 extinguishes flames by chemical interaction, decomposition of the vapor is the essential mechanism of extinguishment. To minimize the volume of decomposition products generated, rapid and total extinguishment is essential, (Ref. 45).

Numerous toxicity studies of Halon 1301 have been conducted. However, these studies, in general, have not been related to real fire scenarios that might be expected in aircraft, making it difficult to relate available toxicity data to the total fire hazard. Whether this toxicity hazard can be quantified with any degree of certainty is the subject of some amount of controversy, (Ref. 46). Experiments which will evaluate the effectiveness and toxicity of the agent in typical cabin interior fires and simulated post-crash fire scenarios where fuselage ruptures, open exits, and ambient winds exist are needed.

Test conducted during the AIA Crashworthiness Development Program in 1966 demonstrated that internal cabin fires could be effectively extinguished by Halon 1301 (Ref. 42). Flames entering a cabin from an external fuel fire were reduced in height, but since interior materials were not installed, the extent to which fire propagation through the fuselage might be reduced was not determined. As indicated in Table 4-4, the weight of Halon 1301 required to inert a given volume is significantly lower than any of the other agents. Research is needed to establish whether the known toxicity hazards are acceptably small relative to the hazards of the fire itself.

4.2.2.4 Water

Water fog has been used effectively to prevent, control, and to extinguish fires in addition to providing exposure protection to equipment and occupants in or near the fire zone.

The primary extinguishing action of water is in cooling the burning material below the point at which it will give off combustible vapors. A secondary, but important, extinguishing action is brought into play if sufficient steam is generated, to the exclusion of oxygen supporting the fire. In the conversion of water from a liquid to a vapor, the volume at ordinary pressures increases 1700 times. This volume of vapor excludes an equal volume of air surrounding the fire and effectively smothers it, (Refs. 24 and 42). Whether a fire can be extinguished or controlled by water depends upon the heat generated by the fire, the rate of application of the water and the total quantity of water available. An additional benefit is derived since wetted surfaces cannot be brought to their ignition temperature until the water has been evaporated, thereby retarding fire propagation. This cooling, wetting, characteristic of water makes it particularly effective against fires of solid combustibles.

Evaluation of water fog system during the AIA Crashworthiness Development Program, (Ref. 42), demonstrated the feasibility of controlling interior fires due to flames entering a rupture. Flow rates of 20 gpm and 8 gpm were used, with less fire damage occurring with the lower flow rate because the discharge lasted longer. However, interior temperatures were also higher by about 200°F. Production of noxious gases was reduced during the water fog test since the fog retarded the burning of interior materials and presumably some of the gases went into aqueous solution with the water droplets as they fell through the air. The advantage of wetting the interior materials was shown since temperatures did not increase for some time after completion of the discharge.

During these tests, a total of 20 gallons of water was discharged into an 850 cu. ft. volume at flow rates of 8 and 20 gallons per minute for a discharge time of 2.5 and 1 minute, respectively. To aid in comparing a water fog system with other extinguishants, at the equivalent lower flow rate, approximately 29 gallons of water (241 lbs.) would have been required to protect a 1000 cu. ft. cabin volume for a 3-minute discharge time. As was previously stated, whether this flow rate could effectively control or extinguish a fire would depend on the size of the fire. In the test, because compartment temperatures rose 200°F during the lower discharge rate, it was concluded that a water fog system at the lower flow rate would not have been effective on a larger fire.

The water fog system has the advantage of no agent toxicity, retarding ignition by wetting combustible materials, cooling the cabin environment, providing exposure protection and is probably less influenced by wind effects in the post-crash fire condition. The disadvantages are that the high weight of water required precludes protecting the entire cabin volume simultaneously, the fog may restrict visibility for escape, and the size of the external fire could render the system ineffective by overtaxing the water supply. Of course, this latter condition is applicable to all extinguishants. Water, alone or in conjunction with corrosive combustion gases, may also cause substantial damage to the aircraft beyond that caused by the fire itself. In a modern wide-bodied transport, about 100 to 200 gallons of potable water are carried to supply drinking and wash water requirements. However, toward the end of the flight, most of this water may be in the waste tanks. Some further consideration of how this water might be used selectively for fire fighting may be merited, but it appears to have many practical limitations.

4.2.3 DECOMPRESSION

One method of fighting an in-flight cabin fire at cruise altitude might be to decompress the airplane. When the partial pressure of oxygen is reduced, the fire tends to be suppressed. In some experiments at Lockheed-California Company (Ref. 47), two aircraft seats were ignited at 8000 foot altitude. When the seats were well involved in fire, the altitude was increased to 38,000 feet. The flames were reduced from several feet in height to several inches, but did not extinguish. An exposure to 50,000 feet extinguished the flames, but reignition took place on descent.

The disadvantages of this technique are: (1) exposure of crew and passengers to low ambient pressures with the accompanying hazards, (2) requirement to redesign the oxygen system and masks which currently do not provide smoke protection, (3) the need to sustain high cabin altitude in an emergency rather than descend, (4) the potential for reignition during descent, and (5) the requirement to be initially at high altitude to be effective. Additional study may be worthwhile of selected situations (e.g. cargo aircraft) where this technique could be used. However, the disadvantages, especially in light of the in-flight fire experience (Section 2), appear to outweigh the advantages.

4.2.4 SUMMARY OF AGENT CHARACTERISTICS

Of all the agents examined, only Halon 1301 appears to be a practical candidate for an on-board fuselage compartment fire extinguishing system. It is clearly superior to other agents for unoccupied zones. While some aircraft and industrial applications of Halon 1301 have been made to inhabited compartments, its unqualified acceptability has yet to be substantiated. Section 5 covers a detailed weight, cost, and performance analysis of a conceptual Halon 1301 suppressant system for fuselage protection.

TABLE 4-2 FIRE EXTINGUISHING AGENTS CONSIDERED FOR USE IN UNINHABITED COMPARTMENTS

COMPOSITION	EFFECTIVE[1] CONC. (%)	TOXIC LEVEL NEAT FORM (%)	TOXIC LEVEL PYROLYZED (%)	STATUS	UL[2] TOXICITY RATING	REFERENCE(S)
H_2O (Water Fog)	>8	None	N/A	N/A	-	22
Methyl Bromide (CH_3Br)	9.7	.5-1	N/A	N/A	2	22
Carbon Tetrachloride (CCl_4)	11.5	2-5	N/A	N/A	3	22
Carbon Dioxide (CO_2)	29.5	7	N/A	In use	5	22
Nitrogen (N_2)	88	-	-	In use	N/A	37, 39
* Halogenated Hydrocarbons						
($CBrF_3$) 1301	6.1	7	1.4	In use	6	36
$CHBr_2F$	6.4	N/A	N/A	N/A	N/A	22
CH_2BrCl(CB)	7.6	N/A	N/A	In use	N/A	22
CH_2BrF_2	8.4	N/A	N/A	N/A	N/A	22
$CBrClF_2$	9.3	N/A	N/A	N/A	N/A	22
* Halogenated Foams						
$CBrF_2$ (2402)	4.9	N/A	N/A	N/A	5	27, 28, 29
$CBrF_3$	6.1	7	1.4	In use	6	27, 28, 29
CH_2BrCl (1011,CB)	7.6	N/A	N/A	N/A	3	27, 28, 29
CF_2BrCl (1211)	9.7	N/A	N/A	N/A	5	27, 28, 29
CF_2Cl_2 (122)	14.9	N/A	N/A	N/A	6	27, 28, 29

(1) Concentration of agent (%) at "Flammability Peak," n-Heptane fire, Ref. NFPA, 13th Edition.
(2) Underwriters Laboratories toxicity rating, 1-Highest.
* Halogenated Hydrocarbons: containing Bromine, Chlorine, Iodine or Fluorine in compounds
N/A Reliable data not available.

TABLE 4-3 FIRE EXTINGUISHING AGENTS CONSIDERED FOR USE IN INHABITED COMPARTMENTS

COMPOSITION	EFFECTIVE (1) CONC. (%)	AGENT STABILITY (2) HF, PPM/SEC	TOXIC(ALC) LEVEL (3) NEAT FORM (%)	PYROLYZED (%)
Perfluoroalkane Compounds				
CF_4	21	0.7	(4)	N/A
C_2F_6	12	28	(4)	N/A
C_3F_8	10	43	N/A	N/A
C_4F_8	18.1	N/A	N/A	N/A
C_4F_{10}	9.8	N/A	(4)	N/A
C_7F_{16}	7.5	N/A	N/A	N/A
Other Agents				
$CBrF_3$	6.1	5	>10	.23 (5)
H_2O (water fog)	>8	N/A	Nil	N/A
N_2 or LN_2	88	N/A	Nil	N/A

(1) References 22, 34, 35, 39
(2) Reference 35, 1.0 ft^2 fire in 1000 ft^3 volume (Class A combustibles)
(3) Approximate Lethal Concentration (ALC), Reference 36, ALC Level, Pyrolyzed - 15 minute exposure
(4) Four hour exposures of mice or rats to 80% CF_4, C_2F_6 and C_4F_{10}, 20% O_2 reported no physiological damage, 20 to 60% CF_4 administration to dogs did not cause cardiac effects, Ref. 35.
(5) From Ref. 48.
N/A Indicates reliable data not available.

TABLE 4-4 APPROXIMATE AGENT WEIGHT TO PROTECT A 1000 CUBIC FOOT COMPARTMENT (No Ventilation)

AGENT	EFFECTIVE CONCENTRATION % BY VOLUME	AGENT WEIGHT LBS.
HALON 1301 ($CBrF_3$)	5	19
Liquid Nitrogen	88	40
CF_4	21	48
C_2F_6	12	43
C_3F_8	10	49
C_4F_8	18	94
C_4F_{10}	9.8	60
C_7F_{16}	7.5	75
Water Fog	>8	- - -

SECTION 5

FIRE MANAGEMENT SYSTEM CONCEPT

In this section, a transport fuselage Fire Management System (FMS) concept is developed in sufficient detail to assess potential performance, cost, and weight. The system is comprised of two subsystems, the Fire Detection System (FDS), and the Fire Suppression System (FSS). The design concepts and equipment selections are based on the hypothetical wide-bodied jet transport in Figure 1-1. However, this same technology could also be considered applicable to other transport fuselages. The system concept has been carried to a degree of definition which permits the subsequent tradeoff analyses in Section 7.

5.1 DESIGN REQUIREMENTS

A design is sought which would provide a major increase in transport fuselage compartment fire safety. The study guidelines (Ref. 49) indicate that the Fire Management System should:

- o Provide substantially increased fire safety for conditions of post-crash fires, in-flight fires, and RAMP fires.
- o Have an economically realistic cost and weight.
- o Use concepts conforming to pertinent FAA regulations.
- o Have a negligible effect on dispatch reliability.
- o Utilize technical concepts which are practical and achievable within current or advanced state-of-the-art.
- o Have no deleterious effects on operation of other aircraft systems.
- o Be compatible with standard airline operating, maintenance

procedures and supply logistics.

The detailed requirements and suggested conceptual designs for the detection and suppression systems are given in the sections that follows.

5.2 FIRE DETECTION SYSTEM CONCEPT

5.2.1 DETECTION REQUIREMENTS

The detection and monitoring portion of the fire management system senses the presence of abnormal smoke and/or gases and provides an alarm to the flight engineer. This subsystem should conceptually:

- o Be based on early-warning detection technology, in order that the fire can be controlled in its incipient stage.
- o Have built-in test equipment (BITE) and line replaceable unit (LRU) features to maximize reliability and maintainability.
- o Have fail-operational philosophy.
- o Have a mean-time-between failure (MTBF) which approximates the life of the aircraft.
- o Have a mean-time-between-false-alarms (MTBFA) which approximates the MTBF.
- o Respond in less than 10 seconds to an out-of-tolerance smoke or gas concentration.
- o Provide the flight engineer with an easily interpretable display of fire location and condition to facilitate rapid execution of fire management procedures.
- o Be capable of alarming on the basis of both a rate-of-change of incipient particle concentration level and absolute particle concentration level.
- o Provide indication of fire situation, i.e. whether extinguishing effort has been successful.
- o Cyclically monitor all zones every 5 seconds, providing

a persistent alarm for any zone out of tolerance while continuing to cyclically monitor all other zones.

- Be insensitive to normal environmental influences of altitude, humidity, lint and dust, sunshine, temperature, fuel and hydraulic oil vapors, cleaning solvents, smoking materials, aerosol sprays, etc.
- Be capable of automatic suppressant dispersal for the parked, unattended condition with appropriate alarm to local fire-fighting personnel.
- Provide, through modern microprocessor technology, maximum flexibility in setting (and altering, if desired) different alarm levels between zones of widely varying volumes and environments, including ventilation shutdown procedures, as necessary.
- Be responsive to the combustion emissions of any of the types of materials to be found in different zones.
- Have a low enough power consumption so that the system can operate for prolonged flight periods on emergency power and battery or ground power unit when parked on RAMP.
- Be sufficiently rugged to sustain aircraft vibration, shock, and maintenance handling.
- Be located, relative to potential hazards, to minimize the response time (e.g., in outflow ventilation paths).
- Provide minimum projection into the occupied areas, thus avoiding accidental mechanical damage and improving the appearance.
- Utilize normal crew and passenger alertness to fire incidents.

5.2.2 EARLY WARNING FIRE DETECTOR(S) SELECTION

To avoid costly and annoying false alarms, a concept was selected for further analysis which utilizes two highly reliable detectors to confirm the existence of a fire situation justifying an alarm. This is similar to design concepts now in use which incorporate two heat detectors in an aircraft engine nacelle. Confirmation from both detectors is required to trip the alarm. For reasons cited in Section 4, an ionization detector and a photoelectric detector were judged to possess the greatest potential for fulfilling the design requirements previously set forth. Both devices are sensitive to incipient fire conditions and will provide an early warning. One of the two detectors selected is a flow-through ionization type proposed for application to the NASA Space Shuttle (Ref. 9). This detector has received the benefit of extensive development for the proposed space application and it incorporates the latest state-of-the-art electronics technology. The second detector is a sensitive photo-electric unit utilizing a Light Emitting Diode (LED) source and the "Tyndall Effect" scattering principle. The ionization detector has a greater sensitivity to open flaming combustion (e.g. burning paper) whereas the photoelectric detector is more responsive to the smoldering or visible smoke conditions (e.g. overheated electrical wire). However, prior analysis suggests that both detectors should be tripped by any typical zone fire well before it becomes a major hazard.

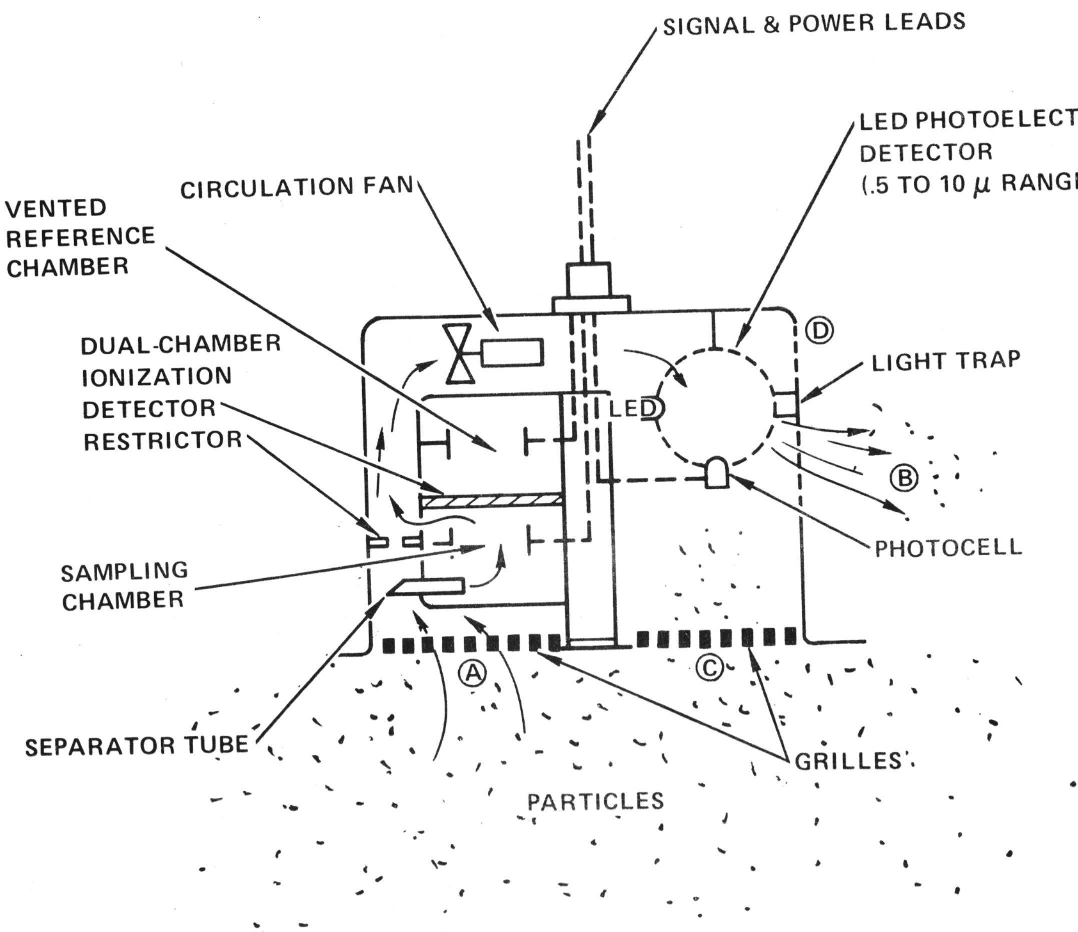
In this concept, a distinction is made between a "warning" and an "alarm." Either detector can signal a "warning," and this could be considered serious enough to merit visual inspection (usually feasible in the cabin, lavatories, galley, electrical load center, attic, and avionics compartment) by the flight crew. However, if both detectors signal a "warning," an "alarm" results and emergency procedures are warranted. Since the detectors are based on different principles, their response to spurious environment influences (altitude, humidity, etc.) is different, enhancing the overall reliability. The logic of the monitoring system which provides appropriate warning and alarm displays is discussed further in this section.

As indicated previously, reliability of an on-board detection system is a prime requisite. A detection system which fails to indicate an incipient fire condition would permit the situation to propagate unnoticed while an overly sensitive system, prone to nuisance alarms, would soon lose the confidence of the flight personnel leading to its deactivation. The dual system, properly designed and developed, has a good potential of achieving the objective of a dependable detection system.

It should be noted that the extensive development and testing of new detectors that is currently in progress may well reveal alternate equivalent detector systems superior to this study. As premised in Section 1, it was not the purpose of this study to endorse a specific system or a particular product.

5.2.3 DUAL DETECTION SYSTEM CONFIGURATION

To minimize installation and maintenance costs, it is recommended that the dual detector be a single assembly. A forced convection or flow-through detector, properly located, will be more responsive to an incipient fire condition than a detector relying on the natural convection of the same aerosol particles. The particle separator feature developed for NASA Space Shuttle Fire Detector System may be a desirable feature for best performance of an ionization detector. An integral fan is proposed to induce flow through both the ionization detector and the photoelectric detector. Since the airflow entrance and chamber design is of basic importance for the photoelectric type to reliably sense hazards by convection as shown by Heskestad (Ref. 11), it is conceivable that forced sampling of environmental air through the unit will improve its response. A schematic of a dual-element system is shown in Figure 5-1.



NOTES:

(1) NORMAL OPERATION, FORCED FLOW THROUGH Ⓐ AND EXHAUST AT Ⓑ

(2) IF BLOWER FAILS, PARTICLES ENTER THROUGH Ⓒ AND EXHAUST THROUGH Ⓓ UNDER NATURAL CONVECTION

(3) IN ZONES WITH NO VENTILATION, LOCATE ASSEMBLY IN PROXIMITY OF POTENTIAL IGNITION SOURCE

(4) IN ZONES WITH VENTILATION LOCATE ASSEMBLY IN PATH OF VENTILATION OUTFLOW

FIGURE 5-1 SCHEMATIC OF CONCEPTUAL DUAL-DETECTOR ASSEMBLY

5.2.3.1 Detector Power and Wiring Requirements

Assuming the dual purpose detectors are housed in a single assembly, as shown in Figure 5-1, the supply power and signal conditioning to the monotoring microprocessor will be less than 5 watts (28 vdc) and less than 1 watt (28 vdc), respectively. The fire detector system power can readily be supplied by the aircraft electrical system under normal operation and switched to ground cart or aircraft battery power in the RAMP condition; this switching being controlled from a panel in the flight station. During emergency conditions, the detection system will be designed to automatically switch to the aircraft battery power system. Based on the low power and signal conditioning demands, conventional 20-22 AWG size wiring could be used. A two-wire loop would provide power, from separate sources, to each detector of the dual assembly. A self-test/BITE loop serving both detectors and an alarm-reset loop could be provided for each detector, consisting of a minimum of four wires to the microprocessor for each detector. In total, a minimum of 10 wires to each detector assembly, consisting of 20-22 AWG would be adequate. Also, because of the low power requirements, each detector assembly could readily interface with other existing aircraft power supply systems.

5.2.4 FAIL-OPERATIONAL ANALYSIS

The operational reliability of an active system, such as the conceptual prototype Fire Detection System, (FDS), described herein, will be considered to be limited by the failure or the service lifetime, of any active non-redundant component of the system. Therefore, it will be necessary to anticipate the failure modes and lifetimes of all active components of the dual detector system in order to evaluate the fail-operational aspect of the total assembly.

5.2.4.1 Flow-Through Ionization Detector

This unit consists of four (4) active elements:

- o Separator
- o Sensor
- o Fan/Motor
- o Electronics

The separator is a fixed element of the system and functions to selectively direct only submicrometre particles , $< 0.7\mu$, to the sensor subassembly. The inlet housing of the entire unit has filtering capability to preclude clogging of the separator tube. Secondly, the sensor subassembly consists of the sampling and reference chambers. The ionizing element is a radioactive source, Americium 241, having a very long half-life, typical of radioactive sources. These low-level radioactive sources are not normally considered to constitute health hazards. The third subassembly, the fan and motor combination is the element governing lifetime expectations. However, the mean-time-between-failure (MTBF) of the motor, is in the order of 30,000 hours. This MTBF is equivalent to approximately 3.5 years of continuous operation. The electronics subassembly consists of microelectronic (semi-conductor) hybrid circuits for motor control and a source of voltage for the frequency converter functions. In addition, it also contains a Large Scale Integrated (LSI) chip consisting of many semiconductor components and is applied to signal conditioning, alarm, reset and self-test functions. Electrical connections between components is accomplished by "flex prints" and a printed circuit board. The components are designed to be easily removed, replaced and interchanged, precluding the need for calibration after repair. No specific information was available pertaining to the MTBF of these microelectronic components. However, theoretically LSI chips and other semi-conductor devices have a service life of 5-7 years with proper design incorporation and environmental control.

Counters employing these circuits and using LED displays reportedly provide approximately 100,000 hours or 11.5 years of service. Therefore, the MTBF of the flow-through ionization detector is limited by the fan/motor subassembly lifetime of 30,000 hours. However, in the event of motor failure, the conceptual Dual Detector Assembly (DDA) can still function by the natural convection of incipient particles, although probably at a reduced response time. At the time of this study, no information was available for consideration of other failure modes which may be applicable to the assembly. However, because of advanced solid state circuitry and absence of other mechanical working parts, additional failure modes are presumed minimal.

5.2.4.2 Light Emitting Diode (LED) Photoelectric Detector

The major components or subassemblies of the photoelectric LED units are:

- Light source
- Receiving photocell
- Power and signal conditioning circuitry

The light source is a light emitting semi-conductor or diode of the photo semi-conductor class. The diode produces light, the color of which depends on the semi-conductor material, when current passes through it. Historically, the limitations of photoelectric detectors has been the MTBF of incandescent light sources, especially under vibration or shock conditions. This situation has been greatly improved by the use of LEDs as light sources. As indicated previously, the lifetime of LEDs is on the order of 100,000 hours or longer, even to a theoretical 10^6 hours (Ref. 3). The receiving photocell of these sensitive photoelectrics may be either a photovoltaic, photocurrent or a photoresistive cell. The photovoltaic and photocurrent cells produce a voltage and current respectively when light is incident on the cells. The photoresistive type changes resistance when exposed to incident scattered light. The LED photoelectric unit proposed for the Dual Detector Assembly (DDA) utilizes the photoresistive type of photocell. However, other LED photoelectric detectors utilizing photoconductive or photovoltaic cells for receivers may also be applied. The MTBF of photoresistive semi-conductors is similar to that of light emitting diodes, i.e. the lifetime or endurance is dependent on the electrical current stress level. If proper design techniques are used and only half of the semi-conductor design stress level is assumed, the lifetime can be extremely long (10 to 30 years). Associated power and signal conditioning circuitry, properly designed, will not degrade the endurance lifetime or MTBF.

5.3 ZONAL DISTRIBUTION OF DETECTORS

The arrangement of Dual Detector Assemblies throughout the various cabin zones (see Figure 1-1) is described in this sub-section. A minimum of one DDA has been assigned to each zone, although some of the larger zones have as many as three. This approach may seem conservative, but elimination of some DDAs is a more appropriate consideration in the tradeoff studies. The zonal distribution of DDAs is:

- Flight Station (Zone 1)

  One DDA is required primarily for RAMP fire protection. (May be de-activated during the in-flight condition).

- Lavatories (Zones 2 and 6)

  Protection afforded for the in-flight and RAMP conditions with a DDA in each of seven lavatories, with a total of seven (7) assemblies. Of particular usefulness in the in-flight condition could be the detection of unauthorized smoking in these restricted areas.

- Cabin (Zones 3 and 4)

  To provide protection against a RAMP fire, two DDAs would probably be needed in each of these large zones.

The accident survey of Section 2 indicated little requirement for cabin fire detectors to supplement the alertness of the passengers and crew for in-flight fire situations. Further rationalization of these detection needs is discussed in the tradeoff analysis (Section 7).

- Attic (Zone 5)

  Protection can be provided against both in-flight and RAMP fire situations with three (3) DDAs equally distributed in this zone.

- Cargo (Zones 9 and 12)

  A DDA would be provided in each cargo zone (assumed to be Class D for this study). Even though an in-flight fire would be suppressed by lack of oxygen in these compartments, it might rekindle when the cargo doors were opened on the ground. Also, in the RAMP mode, the cargo doors are not always closed. If the compartments are Class C, current regulations require a detection and suppression system. Some wide-bodied aircraft have these systems.

- Lower Galley (Zone 11)

  The high service flame, smoke and overheat incident rate in galleys substantiates the need for a DDA to protect the in-flight and RAMP operational modes. Some current wide-bodied jets already have smoke detectors in this zone. Warning threshold levels should necessarily be set higher in this zone to avoid nuisance alarms from smoke and particulates associated with normal galley operations.

- Equipment Compartments

  - Zones 7 and 8 (Afterbody and APU): Active protection can be afforded for the in-flight, RAMP, and crash-fire conditions with one (1) DDA in each zone. These assemblies could be desensitized to accommodate normal operating levels of aerosols or mists. Performance of the early-warning detectors in extreme environments such as the APU compartment is uncertain. Therefore, conventional continuous element heat detectors, already installed on some aircraft, may prove to be a more appropriate selection for this type of compartment.

- Zones 10 and 13 (MLG, NLG, Hydraulic Service Center): Various aircraft possess diverse configurations of the compartments in these zones. Each wheel well compartment could be protected, which would require (1) DDA for the nose landing gear and (1) for each of the two main gear compartments. In some designs, the hydraulic service center is ventilated to the wheel wells and would be protected by the same DDAs. The environment of the gear well will differ in its exposure to one or more of the following: altitude, runway dirt and dust, grease, hydraulic oil, and temperatures resulting from hot brakes. As in Zones 7 and 8, a different type of detector assembly may be more appropriate for these zones. An additional demand on the detector is that it should function with the gear doors open. For purposes of this study, one (1) detector is provided for Zone 13 and two (2) for Zone 10 (right and left main gear wheel wells).
- Zones 14 and 15 (Avionic and Electrical Service Center): These zones contain a large number of electronic and electrical components in addition to the aircraft's battery. A potential hazard exists in these areas because of high power dissipation loads and possible component(s) overheat(s). An active DDA for each of these zones could provide maximum protection against in-flight and RAMP fires.

5.4 FIRE DETECTOR MONITORING AND DISPLAY SYSTEM CONCEPT

A conceptual aircraft fire detection microprocessor monitoring and display system (FDS) is described in this subsection. Utilizing metal oxide semiconductor (MOS) and integrated (LSI) electronics technology it should be possible to design a logic system having high performance which is reliable, economical and compact, for cyclic monitoring of the aircraft zone's Dual Detector Assemblies (DDAs). The outputs of the microprocessor system could be subsequently displayed on a LED Fire Management System (FMS) display panel of the flight engineer's console.

5.4.1 DUAL DETECTOR ASSEMBLIES THRESHOLD AND ALARM INPUTS

The microprocessor could be programmed to display an alarm on the FMS monitoring panel by two DDA input modes derived from:

- o A fixed minimum sensitivity or concentration level setting
- o Rate of concentration level rise of combustion particulates.

A minimum concentration level for the ionization detector of the DDA is in the range of 2500 micrograms (μgms) per cubic meter (Ref. 9). This level is fifty times the mean background level concentration of 50μgms per cubic meter which is present in a typical laboratory environment during the working day. However, in the typical air transport service environment, the background level may be significantly above the 50μgms per cubic meter. Similarly, the photoelectric detector of the DDA has a minimum sensitivity level of 1.5% light obscuration. These minimum sensitivity values are important for sensing slowly developing fires, similar to those resulting from electrical wire or equipment overloads. The rate-of-rise mode is important for sensing rapidly developing fires fueled, for example, by combustible fluids or waste paper. The microprocessor logic for both the rate and concentration modes is shown for one of the detector pairs in Figure 5-2. If the second detector, having the same logic, senses combustion products, then the warning is confirmed and a valid alarm condition is displayed. The rate and concentration settings for each zone are developed from test data and can easily be altered if service experience indicates the necessity. The LED photoelectric detector may be programmed to incorporate a special compensation feature which is responsive to a predetermined level of concentration and initiates an internal rate-compensation circuit which in turn increases the intensity of the LED light source. This particular feature reportedly elevates the detector sensitivity by a factor of 5 to 1.

5.4.2 IN-FLIGHT OPERATIONAL MODE

During an in-flight situation, the microprocessor could interrogate the continuous (analog) signals from each of a zone's DDA at least once each 0.01 second, taking approximately 0.48 second for a complete pass through the DDAs (48 detectors). The analog signals would be converted to digital output by a fast updating analog to digital converter and sent into the microprocessor. The microprocessor would, in turn, output status signals to update the FMS display panel. When either one of the detectors of the DDA identifies the presence of a hazardous, incipient fire condition in a zone, the output from the microprocessor would provide a continuous yellow light on the flight engineer's display panel. The microprocessor would continue to interrogate the remaining zones. If the other detector of the DDA in the same zone also trips, the yellow warning would change to red, indicating a valid alarm. The microprocessor logic could also possess the ability to shut off or reduce the ventilation flow and shutoff of non-critical equipment in the affected zone if incorporated into the system design. A reset button on the panel would enable the flight

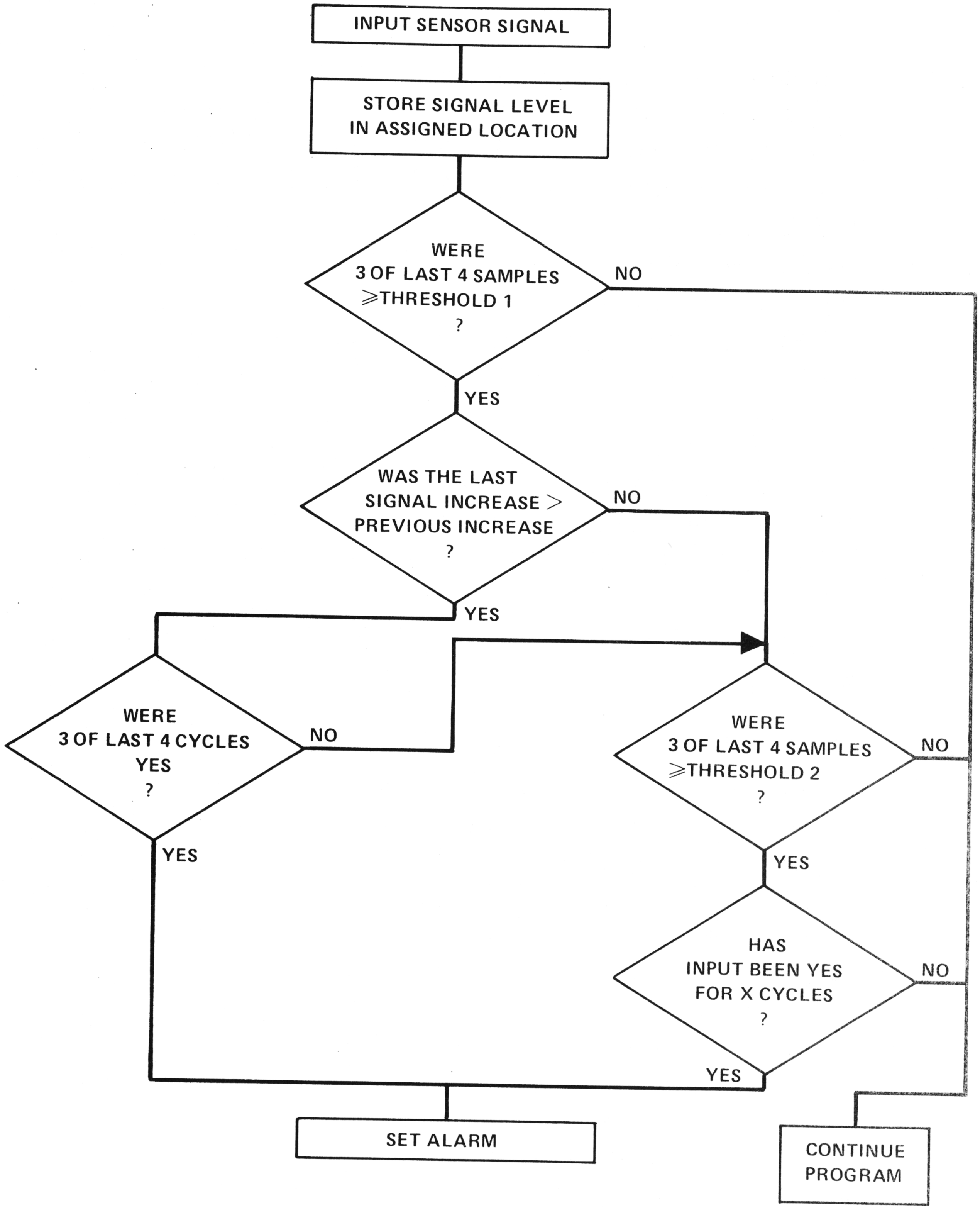


FIGURE 5-2 MICROPROCESSOR LOGIC FOR RATE AND CONCENTRATION MODES

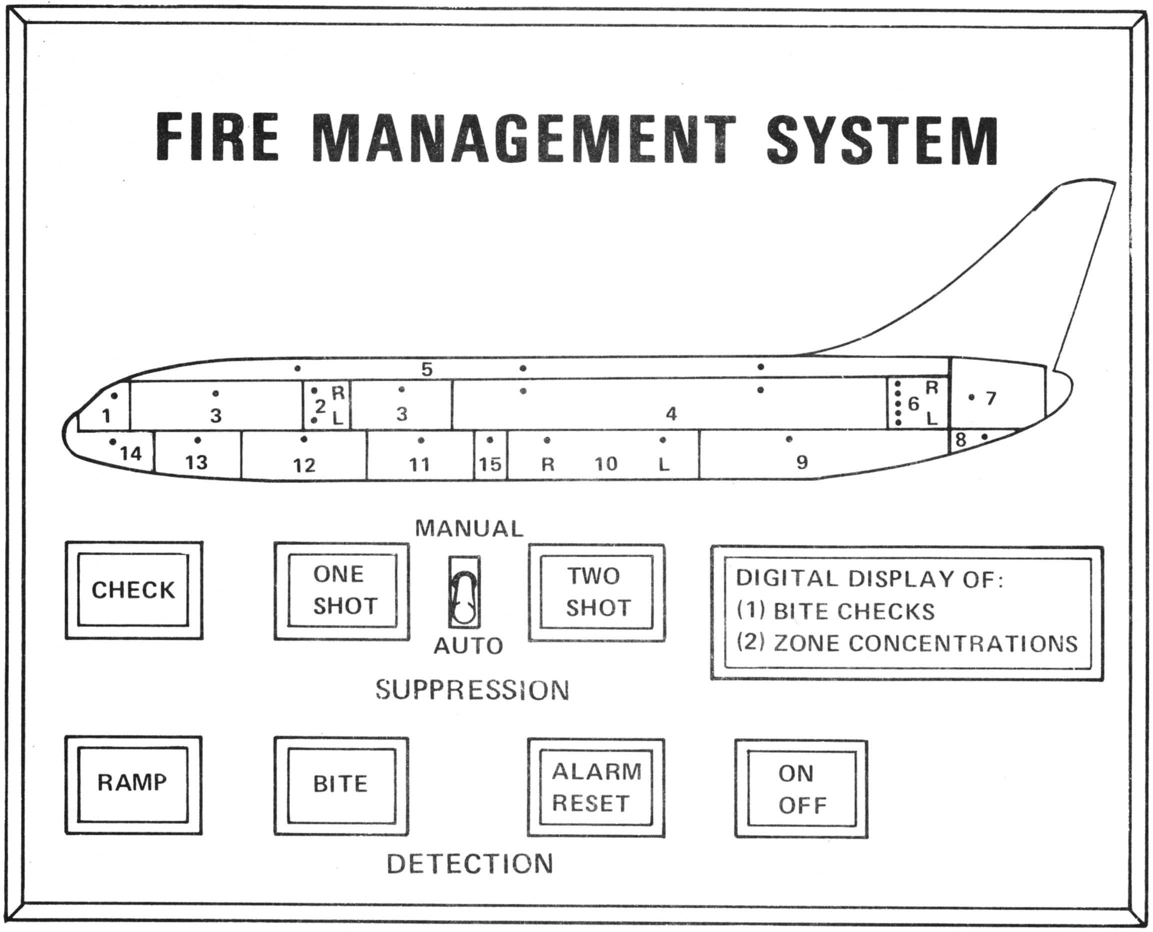
engineer to reset either the yellow or red light and recycle the logic search to confirm the hazard. In addition, a built-in-test (BITE) feature would be provided to enable the flight engineer to checkout the status of a selected zone DDA at any time to assure that the system is active. An important feature suggested for the FMS would be a lockout of the automatic dispersal capability of extinguishant while in the in-flight condition. The suppression system during in-flight would be manually operable only at the option of the flight engineer.

5.4.3 RAMP OPERATIONAL MODE

During the RAMP condition, the FMS could be switched to automatically monitor the zones, provide an external audible alarm, and also transmit a signal by radio-communication to local fire services. An additional capability could make it possible to automatically actuate either the onboard or ground suppression system.

5.4.4 FIRE MANAGEMENT SYSTEM DISPLAY

As the number and complexity of systems in modern aircraft have increased, the task of the crew in monitoring their status and providing rapid, logical decisions has become increasingly difficult. With the Fire Management System, as detailed above, it would be possible to simplify the monitoring and display system status to expedite logical decision-making in the event of an on-board incident. The FMS display system is envisioned as a small-scale cross-sectional presentation of the aircraft as shown in Figure 5-3. A combined yellow/red LED light would be located at each of the 25 DDA positions. Also, beneath the pictorial display would be on-off switches to control the FMS power provisions for alarm/reset, selection of extinguishant by one-shot or two-shot, ability to monitor extinguishant pressure, to set self-test or BITE and pre-set the ramp condition.



NOTES: (1) DOTS IN ZONES REPRESENT LED LIGHTS INDICATING DDA STATUS, WARNING: YELLOW, ALARM: RED
(2) R REPRESENTS RIGHT SIDE, L REPRESENTS LEFT SIDE, LOOKING FORWARD
(3) CABIN ZONES (3 AND 4) DDA'S OPERATIONAL IN RAMP CONDITION ONLY

SIMPLIFIED CONTROLS CONCEPT

SWITCH	FUNCTION
ON/OFF	FMS ACTIVE STATUS
ALARM/RESET	ALARM INDICATION AND RESET CYCLING FOR VERIFICATION
BITE	SEQUENTIAL SELF-TEST OF ALL DDA'S FOR ACTIVE, PROPER OPERATION
RAMP	ACTIVATE CIRCUITS FOR EXTERNAL LOCAL AND RADIO-COMMUNICATION ALARMS
CHECK	GREEN: EXTINGUISHANT PRESSURE NORMAL RED: EXTINGUISHANT PRESSURE FAULTY
ONE SHOT	ACTIVATE EXTINGUISHANT DISPERSAL INTO LOCKED-IN, FIRE ZONE WHEN IN MANUAL MODE
MANUAL AUTO	EXTINGUISHANT SYSTEM OPERATION SELECTION
TWO SHOT	DOUBLE EXTINGUISHANT DISPERSAL INTO LOCKED-IN, FIRE ZONE WHEN IN MANUAL MODE
ALPHA-NUMERIC WINDOW DISPLAY	INDICATES FAULTY DDA(S) IN BITE CHECK BY ZONE LOCATION. INDICATES EXTINGUISHANT CONCENTRATION IN FIRE ZONE. INDICATES NON-CRITICAL EQUIPMENT AUTOMATIC SHUTDOWN AS PRESELECTED IN FIRE ZONE

FIGURE 5-3 FMS PANEL DISPLAY

An alfa-numeric window display would be provided for malfunctioning detection identification and extinguishant concentration readout. By use of a two-position switch, the extinguishant could be automatically (except in the in-flight condition) or manually activated.

5.5 FIRE DETECTION SYSTEM WEIGHT AND COST ANALYSIS

An analysis was made of the conceptional Dual Detector Assembly requirements for each of the zones of a hypothetical aircraft indicated in Figure 1-1. By assuming 20 AWG fully qualified wiring at a unit weight of .00462 lbs/per ft. and locating the DDA in the center of a zone (or in the case of the attic or main cabin, evenly distributed) an analysis was made of the wiring lengths and weights. For the analysis, the power loop (2 wires) to each unit was assumed to be 14 feet and connected to separate 28 vdc power sources (for increased reliability). The signal conditioning wire loops (4) to each DDA leading to the flight station (Flight Engineer's Console) were also determined for each zone. For the analysis, production wiring costs, in 1975 dollars, including material, labor, installation, associated harnessing, and connectors, were estimated at $0.46 per foot. The DDA unit weight was assumed to be 4.0 lbs., including 1.5 lbs. for the ionization unit, 1.5 lbs. for the LED photoelectric unit and 1.0 lbs. for related enclosures and attachments. For analysis, the ionization detector cost was estimated to be $1000 per detector, with $250 for the LED photoelectric detector and $3000 for the flight station microprocessor and display panel which provides cyclic interrogation, signal conditioning, and displays. Table 5-1 summarizes the weight, cost, and power requirements of the individual zones. The total FDS required power was estimated as 156 watts with a weight of 180 lbs. and a cost of approximately $42,000. These are estimated recurring costs based on similar equipment and systems.

TABLE 5-1 FDS WEIGHT, COST, AND POWER REQUIREMENTS BY ZONE

ZONE	DDA REQ.	POWER (watts)	POWER WIRE LENGTH (ft)	SIGNAL COND. LENGTH (ft)	TOTAL WEIGHT (lbs)	TOTAL COST ($)
1	1	6	14	40	4.2	1280
2	2	12	28	550	10.7	2770
3	2 (a)	6	14	144	4.7	1320
	(b)	6	14	428	6.0	1450
4	2 (a)	6	14	616	6.9	1540
	(b)	6	14	882	8.1	1660
5	3 (a)	6	14	241	5.2	1370
	(b)	6	14	616	6.2	1540
	(c)	6	14	882	8.1	1660
6	5	30	70	5410	45.3	8770
7	1	6	14	1199	9.6	1800
8	1	6	14	1210	9.7	1810
9	1	6	14	941	8.5	1690
10	2 (a)	6	14	665	7.1	1560
	(b)	6	14	665	7.1	1560
11	1	6	14	423	6.0	1450
12	1	6	14	265	5.3	1380
13	1	6	14	134	4.7	1320
14	1	6	14	16	4.1	1260
15	1	6	14	529	6.5	1500
24		150			174.0	38,690

Total weight and cost including $3000 for a Microprocessor and Display Panel = 180 lbs. and 41,690.

NOTE: Power and Signal Wiring: 20 AWG.

5.6 FIRE SUPPRESSION SYSTEM (FSS) CONCEPT

5.6.1 REQUIREMENTS

For a fire extinguishing system which will protect against fire in individual fuselage compartments by selective flooding of the compartment, the agent should possess the following characteristics:

- o Physiologically compatible, both in the neat and pyrolyzed form, with passengers and crew.
- o Effective in a post-crash situation despite open doors and fuselage ruptures.
- o Effective against all classes of fire.
- o Produce no damage to cabin materials, equipment, and cargo, that it will come in contact with during dispersal.
- o Efficient such that a low concentration is effective for extinguishing all classes of fires.
- o Safe - requiring no unusual storage or handling provisions.

None of the gaseous agents that were investigated in Section 4 possess all of the desired characteristics. Agents which show promise as being the most physiologically inert are inefficient extinguishants; therefore, requiring high concentrations with associated high weight penalties. The more efficient extinguishing agents present problems relative to their toxicity in the neat and pyrolyzed forms. With the exception of toxicity considerations, the agent which approaches the desired characteristics identified above is Halon 1301 ($CBrF_3$). The toxicity and resulting physiological effects of Halon 1301 are undergoing further experimental research in various government-sponsored programs. However, since Halon 1301 was the only agent available during the study which had significant potential, a system design having the following criteria was considered:

- o 5% Halon 1301 concentration limit in occupied compartments.

- All numbered fuselage zones were considered for agent application.
- High agent discharge rate was presumed in occupied areas for adequate mixing and extinguishing and also to minimize pyrolysis products of the agent.
- Minimum weight system.
- Optimized agent discharge rate in unoccupied areas to take advantage of possible weight savings resulting from use of small diameter distribution tubing, without jeopardizing effectiveness.

5.6.2 GENERAL SYSTEM DESIGN CONSIDERATIONS

Since the agent and its storage container form a major portion of the weight on a suppressant system, an effort was made to optimize the design. A computer program was written to predict agent storage bottle weight as a function of discharge time, discharge orifice size, and other parameters. The results of the analysis are detailed in the Appendix. By selecting stainless steel storage bottles and a two-second discharge time, the weights shown in Figure 5-4 were obtained. The total system weight was influenced by assumptions regarding the discharge configuration and bottle support structure. These assumptions were extrapolated parametrically based on several detailed designs of similar systems. A minimum bottle and agent weight (per volume protected) occurs in the range of 3000 to 4000 cubic feet of volume. For example, to protect a 7000 cubic foot compartment, two bottles represent a lighter configuration than one bottle. As explained in the Appendix, the minimum weight occurs in a tradeoff between discharge plumbing per bottle and the higher nitrogen charging pressure (heavier bottle construction) required to discharge all the agent in the desired time from larger bottles. Using the assumptions of Figure 5-4, an estimate of weights and costs for one and two-shots systems

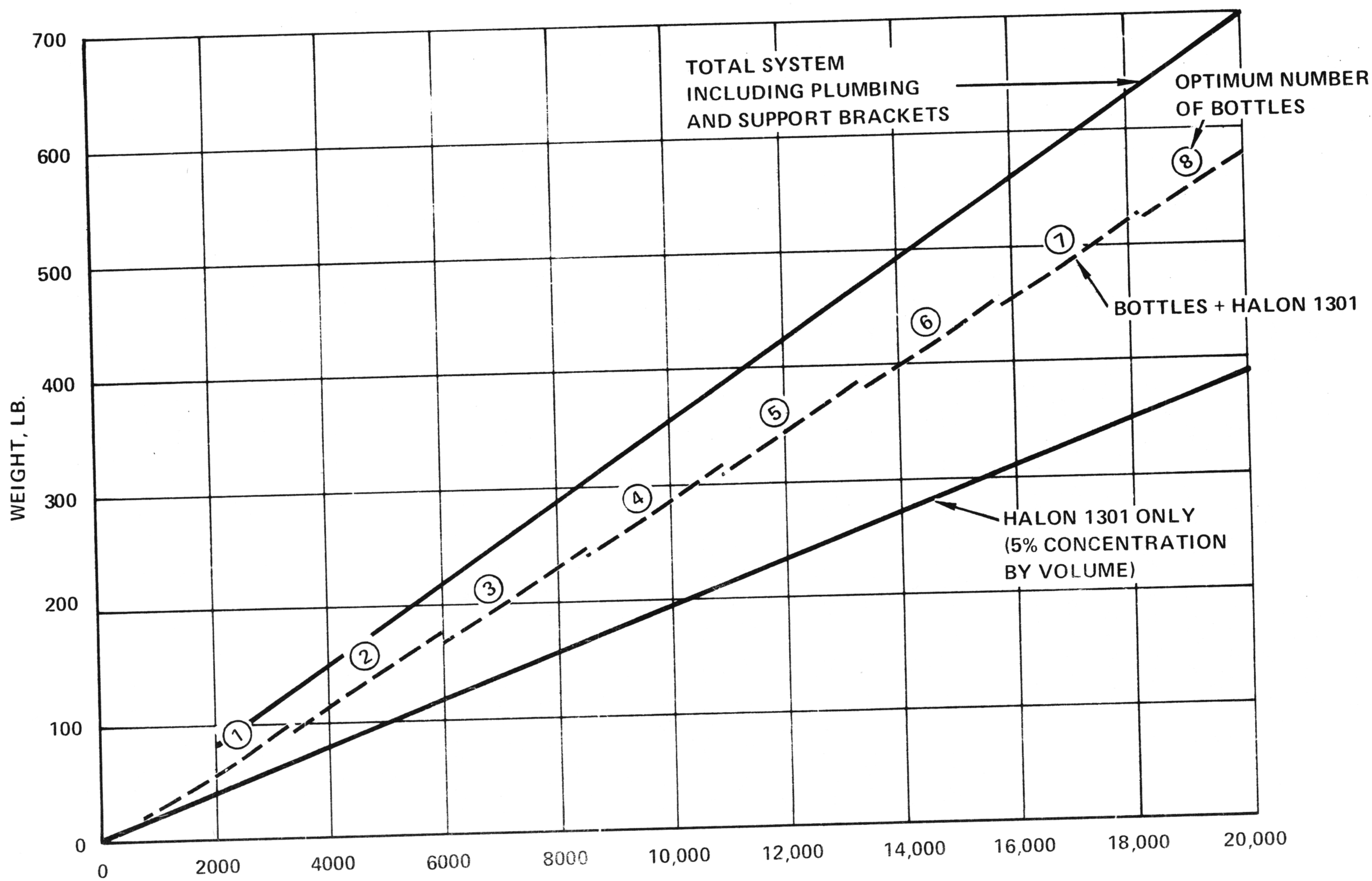


FIGURE 5-4 WEIGHT OF HALON 1301 FIRE EXTINGUISHING SYSTEM AS A FUNCTION OF VOLUME PROTECTED 2.0 SEC DISCHARGE TIME

is made considering individual bottles systems mounted in each zone. The data are presented in Table 5-2. This design obviously results in large total costs and weights, but is useful information for this study. The heaviest single element in a Halon 1301 extinguishing system is the charged agent container. Therefore, in order to achieve a minimum system weight, it becomes necessary to supply the minimum amount of agent that will provide adequate protection for each of the zones on a selective basis, but will not protect all zones simultaneously. A further extension of minimum weight design requires that container placement in the airplane be such as to minimize the length of the distribution tubing. This is particularly true where larger diameter tubing is required to achieve high discharge rates. Additionally, a minimum weight design suggests a deviation from the concept that agent supply must be adequate to provide for a two-shot system to any zone. A two-shot requirement would in effect double the amount of agent required. With the system concept described, two shots are possible in all unoccupied zones "Except Zone 5". In the main cabin zones, the one-shot system is justified on the following basis:

- o <u>In-Flight Fire</u> - It has been one of the assumptions of this study that the suppression system for the occupied areas would be used in-flight only in extreme emergencies.
- o <u>RAMP Fire</u> - Concentration would be maintained for a period long enough for the airport fire department to arrive.
- o <u>Post-Crash Fire</u> - Evacuation must take place before external fire consumes the fuselage structure - effective agent concentration could probably be maintained during this interval, until airport crash fire/rescue crews arrive.

An alternate concept is detailed later in this section of providing suppression for the RAMP fire case only by utilizing a

TABLE 5-2 APPROXIMATE COST AND WEIGHT FOR PROTECTING EACH ZONE INDIVIDUALLY

ZONE	DESCRIPTION	VOLUME (ft^3)	WEIGHT OF AGENT (lbs)	ONE SHOT SYSTEM		TWO SHOT SYSTEM	
				WT. (lbs) (1) TOTAL	COST ($)	WT. (lbs) (1) TOTAL	COST ($)
1	Flt. Station	400	8	21	1350	39	1950
2	Fwd. Lavatory(2)	70 ea	1.5	8	1000	14	1450
3	First Cabin	7000	140	240	8960	455	14620
4	Coach Cabin	10000	200	355	12100	681	19800
5	Attic	4000	80	140	6000	264	9900
6	Aft Lavatory (5)	70 ea	1.5	8	1000	14	1450
7	Equip.						
8	APU	--	18	54	3400	90	4250
9	Aft Cargo	2300	46	89	4750	161	6600
10	Hyd. Center	700	14	41	2360	71	3220
11	Galley	1400	28	63	3600	111	5100
12	Fwd. Cargo	1600	32	68	3950	119	5400
13	ECS	1000	20	40	2860	72	3820
14	Avionics	600	12	30	2350	51	2900
15	Electr. Serv. Cntr.	400	8	21	1560	39	2160
	TOTALS		609	1178	55240	2181	82620

(1) Includes weight of agent, bottles, distribution plumbing and support brackets.

ground cart. In this case, only the distribution tubing is carried on the aircraft.

5.6.3 DESCRIPTION OF AN ON-BOARD SUPPRESSION SYSTEM

Assuming that the protection of all fuselage compartments is on a selective basis, the minimum amount of agent required is determined by the largest single compartment volume to be protected. The largest compartment volume is represented by the main cabin area, Zones 3 and 4, for a total volume of 17,000 cu. ft. Based on the NFPA 12A Standard, approximately 20 pounds of Halon 1301 are required to protect a 1000 cu. ft. volume at a 5% agent concentration. A total of 340 pounds of agent is therefore required to inert this total cabin volume. The optimization study described in the Appendix revealed that as the agent requirements increased beyond 60 pounds, a substantial weight penalty would result, if only a single bottle was used. Based on these considerations, six containers with 60 pounds of agent each resulted in a minimum system weight and the greatest flexibility of arrangement.

Following the selection of the number and size of agent containers, consideration was given to their placement within the aircraft. For maintenance, the most desirable location for the containers is the underfloor area in various equipment bays. However, increased weight resulting from the tubing requirements to achieve a high rate discharge into the cabin, is the primary factor causing the six containers to be mounted in the attic area, spaced at approximately equal intervals along the length of the fuselage. As a result, advantage is taken of individual distribution tubes that are less than 10 feet long. The necessarily longer pipe lengths into the equipment and cargo compartments were accepted on the basis that these plumbing lines can be of significantly smaller diameter since the discharge rate into these compartments is not as critical. This is true for all underfloor areas except the lower galley zone where the ducting would be sized to assure a high discharge rate.

5.6.4 SYSTEM FUNCTIONAL CONCEPT

In the conceptual design, all bottles are identical, each with three individually fired (discharged) outlets. With the bottles numbered from one to six, fore to aft, their system function would be as follows: (See Fig. 5-5)

1. Bottle Number One

   a. Outlet number one supplies first shot agent to Zone 13 and Zone 14 simultaneously. Fire in either zone would result in agent dispersal into the adjacent zone as well.
   b. Outlet number two supplies first shot into Zone 12.
   c. Outlet number three supplies agent through two nozzles into forward end of first class cabin area, Zone 3.

2. Bottle Number Two

   a. Outlet number one supplies second shot into Zone 12.
   b. Outlet number two supplies agent through two fore and aft oriented nozzles into forward and mid-attic area Zone 5.
   c. Outlet number three, aft end of first class cabin, Zone 3.

3. Bottle Number Three

   a. Outlet number one supplies agent for the lower galley, Zone 11. To assure that agent concentration in the Galley does not exceed 6%, the excess agent is discharged into the adjacent Zone 12. This outlet will not discharge with fire in Zone 12.
   b. Outlet number two - supplies second shot to Zones 13 & 14 simultaneously
   c. Outlet number three - fwd end of coach cabin, Zone 4.

4. Bottle Number Four

   a. Outlet number one - supplies first shot agent for wheel well and hydraulic service center, Zone 10.
   b. Outlet number two supplies agent through two fore and aft oriented nozzles aft and mid-attic area, Zone 5.
   c. Outlet number three, middle of coach cabin, Zone 4.

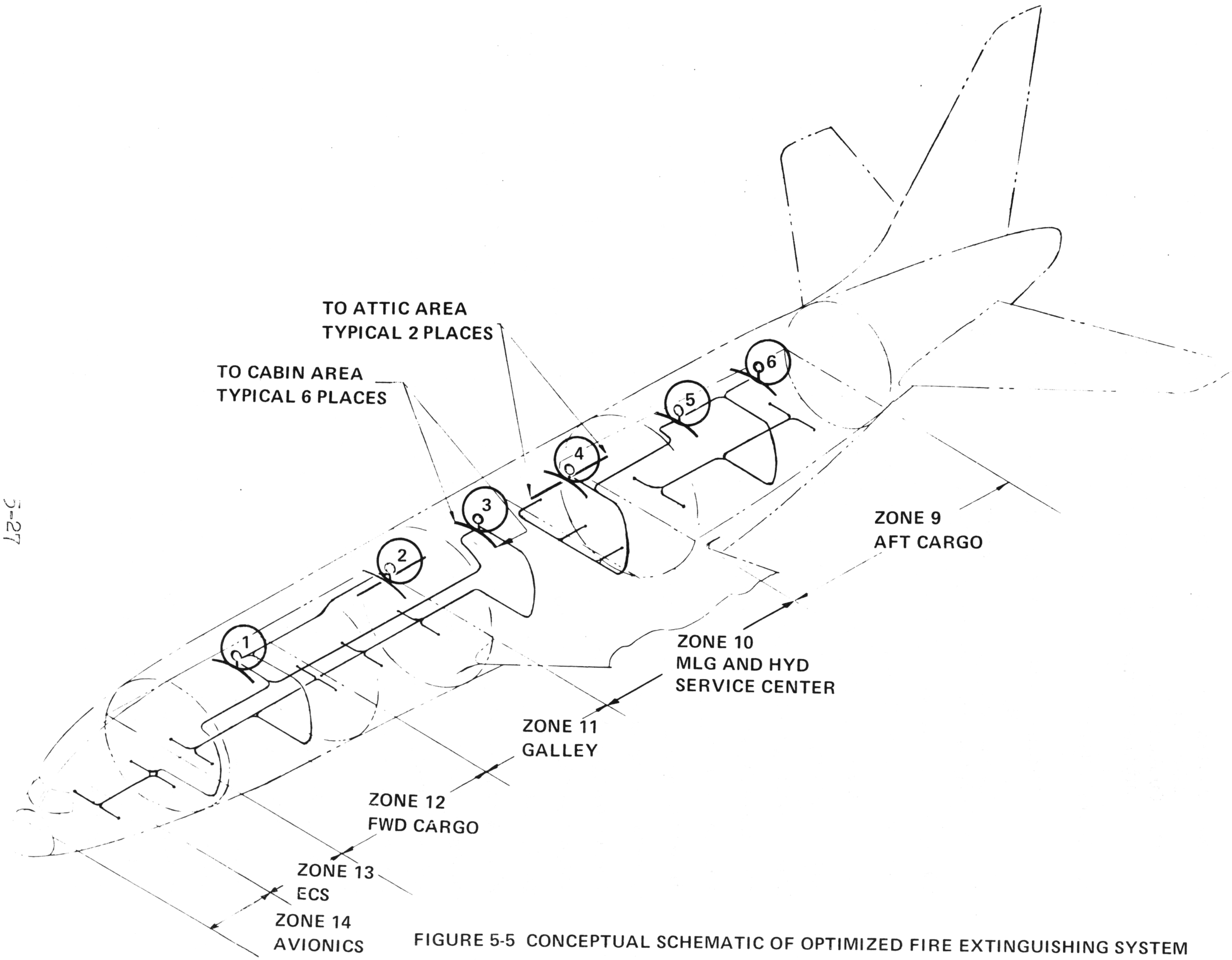


FIGURE 5-5 CONCEPTUAL SCHEMATIC OF OPTIMIZED FIRE EXTINGUISHING SYSTEM

5. Bottle Number Five

   a. Outlet number one supplies first shot into aft cargo hold, Zone 9.
   b. Outlet number two, second shot to Zone 10.
   c. Outlet number three, middle of coach cabin, Zone 4.

6. Bottle Number Six

   a. Outlet number one supplies second shot into aft cargo hold, Zone 9.
   b. Outlet number two - supplies second shot into Zone 7
   c. Outlet number three, aft end of coach cabin, Zone 4.

Based on the above system description, Table 5-3 summarizes the various zone volumes, the agent required for each zone and the actual quantity dispersed. The optimized fire suppression system functional aspects are presented in Table 5-4.

The flight station (Zone 1), the lavatories (Zones 2 and 6), and the electrical service center (Zone 15), are not protected by the basic integrated suppression system although equipped with fire detector assemblies. These zones are relatively small and large discharge of agent into these spaces might raise the agent concentration to unsafe levels in the area. Therefore, these compartments could be protected by self-contained systems (see Table 5-4). Also, the hazard survey of Section 2 indicates that with early warning detection, an in-flight fire incident in these zones could be adequately suppressed with portable hand-held extinguishers. In the hypothetical wide-bodied aircraft chosen for study, the electrical service center (Zone 15) is accessible through a door from the galley. In designs where this zone is less accessible, the zone could be added to those protected by the overall system.

Agent dispersal and effectiveness in the cabin for an in-flight emergency would be controlled by the flight engineer. Agent effectiveness would be affected by the normal cabin ventilating flow (0.3 air changes per minute). This ventilation flow would dilute the concentration of the dispersed agent too rapidly

TABLE 5-3 AGENT CONCENTRATIONS PROVIDED BY ON-BOARD SUPPRESSION SYSTEMS

ZONE	DESCRIPTION	VOLUME (ft^3)	AGENT REQUIRED (lbs) 5% CONCENTRATION	AGENT DISPERSED (lbs) 5% CONCENTRATION	AGENT CONCENTRATION ACHIEVED (%)
3	F/C Cabin	7000	140	146	5
4	Coach Cabin	10000	200	214	5
5	Attic	4000	80	120	7
7	Aft Body	2100	42	60	7
9	Aft Cargo	2300	46	60	6.5
10	MLG/Hyd.	700	14	60	21
11	Lwr. Galley	1400	28	28	5
12	Fwd Cargo	1600	32	60	9
13	NLG/ECS	1000	20	30	12
14	Avionics	600	12	30	12

TABLE 5-4 OPTIMIZED SYSTEM FUNCTION

ZONE		BOTTLE 1			BOTTLE 2			BOTTLE 3			BOTTLE 4			BOTTLE 5			BOTTLE 6		
		OUTLET			OUTLET			OUTLET			OUTLET			OUTLET			OUTLET		
NO.	DESCRIP.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	Flt Sta	Can be protected by self-contained zone system - See Table 5-2 for cost and weight data																	
2	Fwd Lav	Can be protected by self-contained zone system - See Table 5-2 for cost and weight data																	
3	Frst Cab.			△1			△1												
4	Coach Cab.									△1			△1			△1			△1
5	Attic					△2						△2							
6	Aft Lav	Can be protected by self-contained zone system - See Table 5-2 for cost and weight data																	
7	Equip.																	△13	
8	APU	Protected by self-contained zone system △3 See Table 5-2 for cost and weight data																	
9	Aft Cargo													△4			△5		
10	Hyd Ctr										△6				△7				
11	Galley							△8											
12	Fwd Cargo		△9		△10			△8											
13	NLG/ECS	△11							△12										
14	Avionics	△11							△12										
15	El. Ser.Cntr	Can be protected by self-contained zone system - See Table 5-2 for cost and weight data																	

△1 Bottles discharged simultaneously to protect Zones 3 & 4.

△2 Bottles discharged simultaneously to protect Zone 5 (conc.7%)

△3 Currently FAR requirement, & provides second shot to Zone 7.

△4 First shot Zone 9.

△5 Second shot Zone 9.

△6 First shot Zone 10 - achieves 21% agent concentration.

△7 Second shot Zone 10 - achieves 21% agent concentration.

△8 Discharge only with fire in galley - excess agent discharged into Zone 12 to assure agent concentration in galley does not exceed 6%.

△9 First shot into Zone 12.

△10 Second shot into Zone 12.

△11 First shot agent discharge into Zones 13 & 14 - fire in either zone results in agent dispersal to adjacent zone.

△12 Second shot Zones 13 & 14.

△13 First shot into Zone 7, second shot from APU system.

(e.g. Figure 3-1). Consequently, emergency procedures by the flight engineer would require manipulation of the ECS flow valves, reducing the ventilation flow to the minimum required to sustain pressurization. Typically, this reduction would be about one-third the normal flow (0.1 changes per minute), thus affording additional time for fully suppressing a fire. The microprocessor would provide the required logic to select which bottle valves are opened based on the alarm conditions. As mentioned earlier, the actual in-flight discharges would be at the discretion of the flight engineer, allowing time to assess the situation and alert passengers, as required.

With the on-board integrated system described, RAMP protection would be provided with the FMS activated for the RAMP mode. Operational procedures would be required to leave the flight station door (Zone 1) and doors to the lavatories (Zone 6) open for cabin suppressant protection.

5.6.5 WEIGHT AND COST ANALYSIS OF ON-BOARD FIRE SUPPRESSION SYSTEM

The weight and cost estimates are based on current design and fabrication of similar installations in cargo and APU compartments with appropriate modifications for compatibility with designated compartments.

For an integrated minimum weight design, based on the 17,000 cubic foot volume of the main cabin Zones 3 and 4, the weight and cost breakdown is shown in Table 5-5. The total suppression system, providing protection to all zones and shown in Table 5-6, is estimated to be $37,840 and the weight penalty would be 725 pounds.

5.6.6 MAINTAINABILITY AND RELIABILITY CONSIDERATIONS FOR THE FIRE MANAGEMENT SYSTEM

Considering the optimized system, maintenance and delay costs were estimated based on service experience with similar system components in APU and cargo compartments. It is suggested that

TABLE 5-5 WEIGHT AND COST FOR THE INTEGRATED FIRE SUPPRESSION SYSTEM

ITEM	TUBING LENGTH (ft)	WEIGHT (lbs)	COST (DOLLARS)
Zones 3 and 4 (Volume = 17,000 ft^3)			
Agent and Containers (6)*	--	500	$12,000
Plumbing	60	18	1,800
Supports	--	30	6,000
Wiring	2098	28	1,050
Miscellaneous		6	1,000
Total Zones 3 & 4		582 lbs.	$21,850
Plumbing (Zone 5)	20	4	600
Plumbing (Zone 7) **	5	2	200
Plumbing (Zone 9) **	90	18	2,700
Plumbing (Zone 10) **	54	16	1,670
Plumbing (Zone 11)	54	16	1,620
Plumbing (Zone 12) **	60	12	1,800
Plumbing (Zones 13 and 14) **	83	17	2,490
Total - Zones 3, 4, 5, 7, 9, 10, 11, 12, 13 & 14		667 lbs.	$32,930

* Total agent weight is 360 lbs. and the cost to recharge 6 bottles would be $2400.

** Two-shot capability.

TABLE 5-6 WEIGHT AND COST TOTALS OF COMPLETE ON-BOARD FIRE SUPPRESSION SYSTEM

	ZONE	WEIGHT (lbs)	COST (DOLLARS)
1	Flight Station (From Table 5-2)*	21	$ 1,350
2	Fwd. Lavatory (From Table 5-2)*	8	1,000
3, 4, 5, 7, 9, 10, 11, 12, 13 & 14	(From Table 5-5)**	667	32,930
6	Aft Lavatory (From Table 5-2)*	8	1,000
8	APU Compt. (Already Equipped)	-	-
15	Elec. Service Ctr. (From Table 5-2)*	21	1,560
	TOTALS	725	$37,840

* One-shot in occupied zones (self-contained system)

** Two-shot in unoccupied zones (Except zone 5 where 7% concentration is provided)

TABLE 5-7 FIRE DETECTION AND EXTINGUISHING SYSTEM - ESTIMATED MAINTENANCE COST (EXCLUDING CONSUMABLE EXTINGUISHING AGENT)

ITEM	LABOR MANHOURS PER FLIGHT HOUR		MATERIAL $ PER FLIGHT HOUR
AIRCRAFT FIRE DETECTION SYSTEM			
Dual Sensors	0.00722		0.02005
Analog to Digital Converter	0.00100		0.01200
Microprocessor	0.00375		0.02750
AFDS Display Panel	0.02150		0.10000
FIRE EXTINGUISHING SYSTEM			
Container, Extinguishing	0.00486		Insig.
Indicator, Discharge & Pressure ("A" Check)	0.00400		Insig.
Initiator	0.00466		0.23333
Panel, Control	0.00011		0.00122
Nozzle, Discharge	Insig.		Insig.
Plumbing	Insig.		Insig.
Wiring	0.00250		Insig.
TOTAL	0.04960		$0.39410
Labor at $8.00 per hour	$0.40		-
Burden (180% of labor)	$0.72		-
Material Warehousing (25%)	-		$0.10
TOTAL 1975 U.S. Dollars	$1.12		$0.49
GRAND TOTAL per Flight Hour		$1.61	

TABLE 5-8 FIRE DETECTION AND EXTINGUISHING SYSTEM - ESTIMATED DELAY COST

ITEM	1975 U. S. DOLLARS LENGTH OF DELAY (Minutes) 0 - 29	30 - 59	60 & Over
Net Revenue Loss	0	68	1,038
Goodwill Loss[1]	0	34	519
Passenger Handling Costs[1]			
Baggage Delivery	0	4	48
Meals	0	0	69
Other Transportation	0	0	63
Hotels	0	0	58
Taxicabs	0	1	15
Telephone & Telegraph	0	11	11
Other	0	7	7
Operating Costs (Crew Salaries)	161	479	1,224
Analysis Cost [1]	46	46	46
TOTAL	207	650	3,098

Typical airline -
System Delay Rate = 0.0007 delays per departure and
System Delay Time = 47 minutes
Therefore, Delay Cost = 0.0007 x \$650. = \$0.46 per Flight Cycle

(1) Data based upon a study conducted by a major U. S. Air Carrier - updated for wide-body aircraft - 1975 dollars.

operational checks, using the FMS Microprocessor in the BITE mode, provide low bottle pressure indication and a continuity check of all bottle squibbs. The maintenance cost summary shown in Table 5-7 assumes that the installation would provide adequate access for maintenance. The maintenance and material costs are projected at $1.61 per flight hour (Ref. Table 5-7). These costs would be additive to the total aircraft direct maintenance cost, which for wide-bodied aircraft of this size is currently in the range of $200 to $430 per block hour (Ref. 50). The costs due to delays attributable to the FMS are estimated in Table 5-8. The delay costs are projected as 46 cents per flight cycle.

5.7 GROUND SUPPLIED FIRE SUPPRESSANT SYSTEM FOR RAMP FIRE PROTECTION

An alternative to the self-contained cabin fire suppressant system is to provide a permanently installed agent distribution system with the agent supplied from a portable, external supply. This approach affords a substantial reduction in weight and cost over the self-contained system. However, cabin protection is limited to RAMP or unattended aircraft only. An evaluation of this concept was requested (Ref. 49) as part of the feasibility study. Since RAMP fires do not generally threaten human life, the hazard must be judged primarily on economic grounds. Other methods of providing RAMP protection are considered in the tradeoff analysis (Section 7). For the survivable post-crash case, the integrity of the cabin agent distribution system cannot be relied on. Therefore, plug-in for post-crash protection may not be usable at all times. However, some circumstances could make this system concept attractive for RAMP protection if it were economically feasible.

5.7.1 DESIGN CRITERIA

System design is based on the following criteria:

1. Agent distribution to Zones 3 and 4, main cabin area only.
2. Agent discharge rate 10 seconds.
3. 7% Halon 1301 maximum concentration.
4. Temperature range -40°F to +130°F.
5. Single point "plug-in" quick disconnect.
6. Wheeled ground cart for agent supply.
7. Automatic agent dispersal electrically triggered by aircraft fire detection system.

5.7.2 SYSTEM DESIGN

The quantity of agent required to protect the main cabin area of Zones 3 and 4 is established by the volume, the required agent concentration and the minimum anticipated ambient temperature. Based on the NFPA 12A Standard (Ref. 23) 400 pounds of Halon 1301 would protect the Zone 3 and 4 volume of 17,000 cu. ft. with approximately 4.5 to 6.5 percent agent concentration over the -40° to +130°F temperature range.

The aircraft distribution system would be supplied from a single point quick connect fitting near the bottom fuselage centerline at approximately the fuselage mid-point (Fig. 5-6). A vertical header duct from the quick connect fitting following the fuselage contour would "tee" into the fore and aft overhead distribution duct at approximately mid-point. The distribution plumbing would be sized to maintain the agent in the liquid state throughout the 10-second discharge time.

The ground cart would be a towable four-wheeled cart similar to current airline inventory Oxygen System service carts (Fig. 5-7). This cart design could be modified to provide support for two (2) 200 lb. Halon 1301 storage cylinders (15 dia. x 48 and the required manifold and pressure gauges. Additionally, stowage for approximately 20 ft. of 2-inch high pressure flexible hose would be incorporated into the cart.

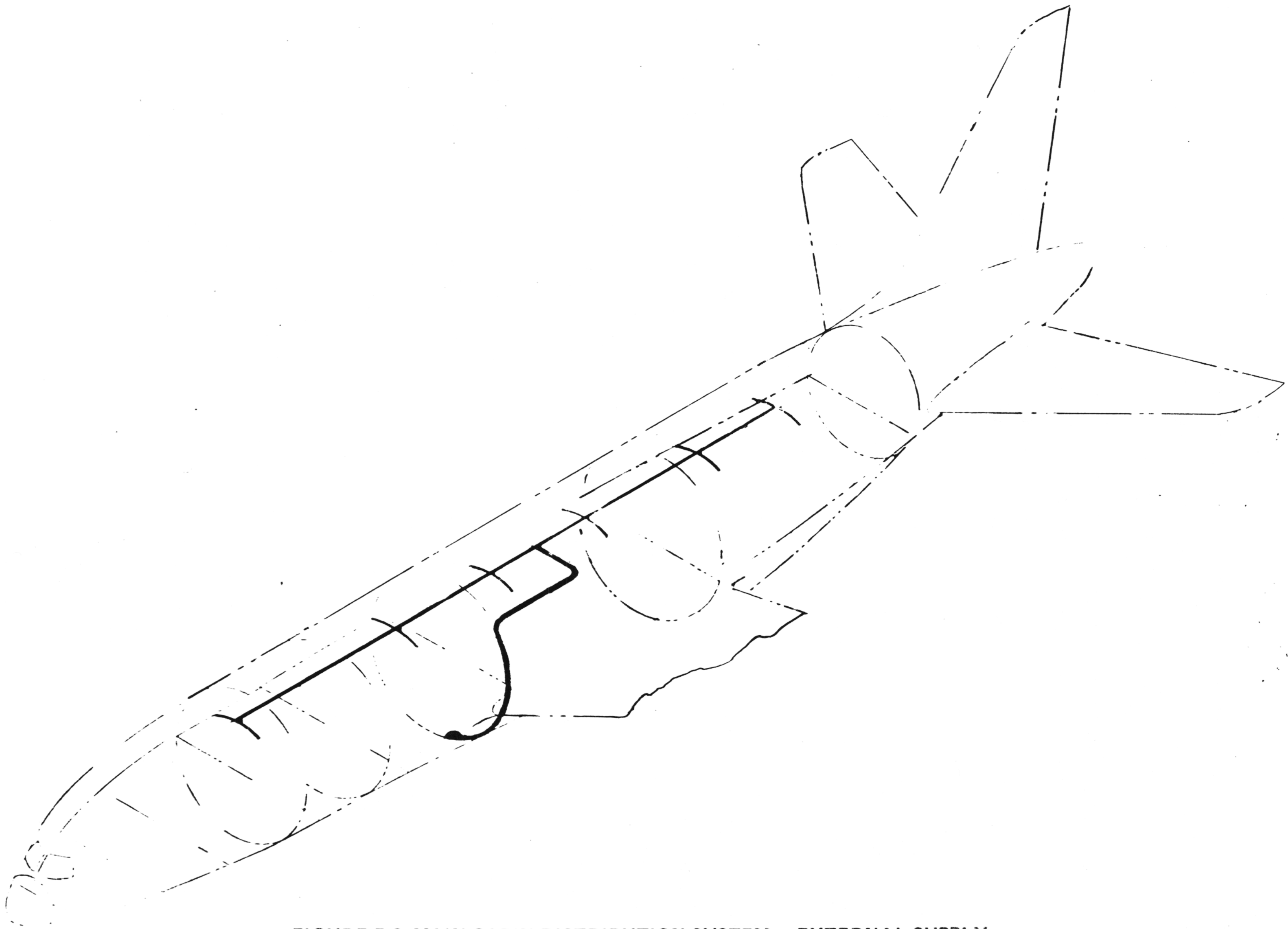


FIGURE 5-6 MAIN CABIN DISTRIBUTION SYSTEM – EXTERNAL SUPPLY

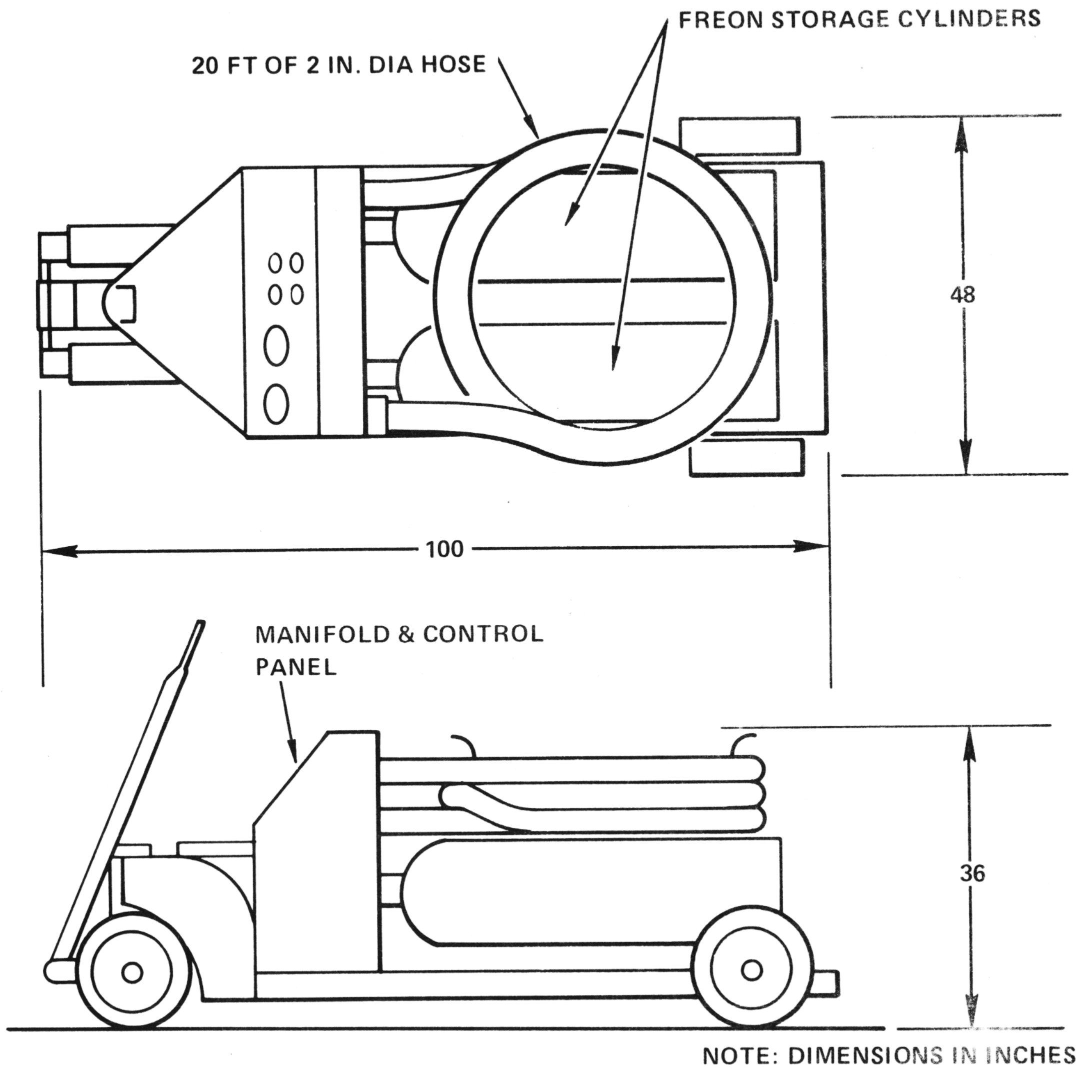


FIGURE 5-7 FIRE SUPPRESSION GROUND CART

5.7.3 WEIGHT AND COST OF GROUND CART

In Table 5-9, the weight penalty to the aircraft is shown to be approximately 86 pounds. The cart is estimated to cost $8400. With aircraft on-board detection and alarm, it is probably not necessary to provide a cart for every parked aircraft. Within a few minutes of an alarm, a nearby cart could be plugged into the aircraft quick disconnect fitting and accomplish the fire suppression until fire services arrive.

TABLE 5-9 WEIGHT AND COST ANALYSIS OF A GROUND SUPPLIED CABIN FIRE SUPPRESSION SYSTEM

AIRCRAFT INSTALLATION

ITEM	LENGTH (ft)	WEIGHT (lbs)	COST (Dollars)
Plumbing	175	77	5300
Supports		5	1200
Miscellaneous		4	1000
	TOTAL Aircraft	86	7500

GROUND CART

ITEM		WEIGHT (lbs)	COST (Dollars)
Agent & Container (2)		644	2500
Cart (incl. Manifold, Gauges, Elec. Controls & Flex Hose)		2000	5900
	TOTAL Cart	2644	8400

SECTION 6

IMPROVED FLAME RESISTANT AIRCRAFT INTERIOR MATERIALS

In this section, activity by governmental and industrial research organizations directed toward developing improved fire safe materials is reviewed. Promising materials developments are highlighted and conceptually incorporated in the hypothetical transport to compare these selected material improvements with the fire management system under study.

6.1 MATERIAL IMPROVEMENT OBJECTIVES

6.1.1 MATERIAL REQUIREMENTS

Improvement in the fire safety properties of a material must be accomplished without degrading other important material characteristics, such as:

- Serviceability, including endurance and tear resistance, etc.
- Resistance to cleaning solvents.
- Manufacturing properties, such as ease of forming, bonding, and fabricating without major re-tooling.
- Production and maintenance handling properties.
- Aesthetic appeal.

In addition, weight and cost must be consistent with economic realities. While holding the above characteristics on a par with existing materials, improvements are sought in:

- Greater resistance to ignition.
- Less smoke emission.
- Less toxic gas emission.

- o Less fuel contribution and lower flame spread in on-going fires.

It has been typical in the field of material development that improvements in one property, such as reduced flame spread, may be accomplished at the expense of other properties; for example, smoke emission or serviceability. Fire safety improvements, therefore, involve difficult balancing and tradeoffs between the important factors affecting the practical application of a material.

6.1.2 TEST METHODS

Because material fire safety improvements must be judged by some criteria, a variety of test methods are employed. The quality and reliability of these test methods are of primary concern since, if not valid, they may exclude good materials and pass poor ones. It is beyond the scope of this study to attempt a detailed assessment of available test methods; however, comments on the current state-of-fire safety testing will be briefly included.

The principal fire safety properties which the designer needs to know about a material are:

1. Ignitability - Resistance to ignition and flame propagation when exposed to small and large ignition sources.
2. Smoke Emission - Rate and magnitude of smoke emission when exposed to flame and radiant energy.
3. Irritating and Toxic Gas Emission - Rate of emission of all physiologically harmful gases.
4. Rate of Heat Release - A measure of the potential contribution of the material as a fuel to an already on-going fire.
5. Flame Spread Rate - The rate at which an on-going fire propagates through a material, including radiant

heat effects.

Other relevant properties which also are of concern are the ignition temperature and the propensity of the emitted combustible gases to produce a flash fires.

The Federal Aviation Administration has selected vertical and horizontal flammability tests for evaluation of ignitability and self-extinguishing characteristics of aircraft interior materials (Refs. 51, 52). For evaluating smoke emission of materials, the airframe industry and the FAA have selected a test using the NBS-developed smoke chamber (Ref. 53). Both the vertical and horizontal flammability test and the NBS smoke chamber test methods are in the process of being adopted by the ASTM-F7 Committee (Aerospace Industry Test Methods) as standard test methods. Measurement of toxic gas emission is much more difficult and although some advanced techniques (Ref. 54) are being evaluated, more research remains to be done before a widely accepted technique will be available.

6.2 PROGRESS IN MATERIALS

A broad national effort is underway to upgrade the fire safety properties of non-metallic materials used in aircraft and industrial applications. Some of this work is proceeding with governmental agency sponsorship and in many cases by the material suppliers. Basic improved material thermochemical studies are being conducted by NASA-Ames Research Center (ARC) and some full-scale burn tests using improved materials are being performed at NASA-Johnson Spacecraft Center (JSC). It should be recognized that a fairly long development cycle of 2 to 5 years is typical for most new materials. This includes not only the time required for material development, pre-production testing and evaluation, but also the time for the market to mature to the point where production quantities are available at reasonable prices.

6.2.1 THERMOFORMING AND INJECTION MOLDING COMPOUNDS

Chemical companies have been working on new low smoking polymers for replacing certain resins and fire retardant inhibitors used in the manufacture of thermoplastic materials which emit excessive smoke. In addition, development of new materials is being performed to replace those materials which emit suspected toxic gases during fire conditions. Certain resin systems for impregnating fiberglass fabric for laminates, sandwich skins or compression molded parts such as phenolic, Xylok, and polyimides, are already in production. However, low smoking adhesives used for bonding these reinforced parts to the core materials are not in production. Therefore, substitution is not easily made without further development and manufacturing investigations. In addition, various new thermoforming materials have been developed such as modified polycarbonate, modified polysulfone, polyphenylene sulfide and polyether sulfone. These materials appear to offer improvements for the over-all safety characteristics of thermoformed or injection molded parts if the materials can be made in various colors, are secondarily bondable and can withstand the service environment. Evaluation of these materials for replacement of presently used Acrylonitrile-Butadiene-Styrene co-polymer, modified polyphenylene oxide, and polycarbonate parts are now being pursued by several airframe companies, including the Lockheed-California Company under a NASA-ARC contract.

6.2.2 LAMINATES AND SANDWICH CONSTRUCTIONS

Sandwich constructions are being developed which have the potential to resist the penetration of a 2000°F. flame for 15 minutes and, therefore, could be appropriate as barrier panels in areas in which limited "hardening" would be considered for improved fire safety. Cargo liner materials are being developed which offer the potential of increased resistance to flame and lower emission of combustion by-products. There are many new polymers and resin systems such as the addition-type polyimide, Kerimid 601, and the aromatic polyimides (PBI) which appear promising. These resins may possibly be combined with fiberglass or Kevlar fibers to produce a fairly light-weight sandwich structure, which resists flame and produces a low emission of smoke and toxic fumes. This type of structure could be considered for many of the ceiling, partition and sidewall assemblies. However, there is much development work still required to produce usable interior assemblies, including the volume of production material which would be required to achieve reasonable costs.

6.2.3 SEATS AND UPHOLSTERY

Current aircraft seat cushions, which are also used for emergency flotation, are usually made of fire retardant urethane foam covered with a variety of upholstery materials. The problems of urethane include high smoke and gas emission and a tendency to drip and flow under fire conditions. Some interesting tests on nine theatre seats were performed by E. I. Dupont, Elastomeric Division. A 3/16" layer of fire retardant (FR) neoprene foam was applied to the back of a fabric and used to cover the FR urethane foam cushions. In comparative tests with FR urethane cushions, the FR neoprene-fabric covered seats showed great improvement, primarily by limiting drippage and material flow, such that damage was confined to one seat instead of nine seats. This is an example of a tradeoff between smoke emission and flame spread. Even though the neoprene has a smoke emission D_s value of 400 in 4 minutes as determined by the NBS smoke test procedure, it prohibited flame spread, such that evacuation in a real fire situation would probably have been safer.

Another promising material for seat ticking is Kynol yarn, a phenolic fiber derivative, which has low smoke and toxic gas emission. Tests are being performed to confirm the benefits of this application. These two methods of approach, for reducing the overall fire hazard by controlling the spread rate of small seat fires, could be employed to improve the fire safety of seat cushioning until better foam materials are developed. Among new cushion foams being considered for replacing older latex and polyurethanes are the polyphosphazenes and polyimide type foams. Also under development are new upholstery fabrics having greater fire safety properties (e.g., Kynol, FR improved Nylon, PBI and advanced Nomex).

6.2.4 DECORATIVE FILMS FOR INTERIOR PANELING

Research is proceeding on the development of new decorative films. These new films include phenolphthalein polycarbonate, polyethersulfone, Kynar, and combinations of these may be made which should give promising results. Additional work is needed for determining serviceability and cleanability.

6.2.5 FLOOR COVERINGS

Current materials in aircraft interior usage include FR wool, FR modacrylics and some Nomex carpetings with urethane or latex backings. New material development programs in this area include work on Kel-F 2401 coated asbestos (the Kel-F seals the fibers; preventing dispersion in the atmosphere), improved Nomex carpeting with FR neoprene backing, Kynol and relatively new fiberglass carpeting with improved polymeric backings. In these categories of interior furnishings, there is a time span between qualification of new materials for replacement of existing materials and their actual implementation into service aircraft. This delay is caused by (1) lack of an adequate supply of the material in production quantities and (2) the time required for evaluation of other necessary design properties.

6.3 POTENTIAL MATERIAL IMPROVEMENTS FOR EACH ZONE

The non-metallic materials improvements which appear promising at present and in the near future are conceptually applied to the hypothetical aircraft in this subsection. Tables 6-1 through 6-7 depict the parts and assemblies in the various zones which could be replaced. The tables show the effect of the change in materials, with respect to presently used materials on potential weight increase, a rough estimate of the possible cost impact, and a best estimate of the initial availability of production material to make the substitution. The availability dates shown in the tables assume that the design requirement for the material is firmly established one year prior to the dates indicated. Another 1-1/2 years after the dates shown would be required for tooling, manufacturing, etc., before a material would appear on a production aircraft.

In several instances it is impossible, at this time, to forecast the approximate cost impact or the availability of production quantities of material and the tables indicate this problem. Rough cost estimates are based on finished parts and assemblies at 1975 prices, and include the cost of processing within the state-of-the-art.

As mentioned earlier, not all the test methods to evaluate improved materials have been resolved, and thus assessment of material for their fire safety improvement features often rest primarily on knowledge about ignitability and smoke emission. Consideration given to the area of toxicity is limited by available knowledge. In order to proceed with tradeoff studies between improved materials and fire safety management, it was necessary to estimate the cost and weight impacts, by zone, of the materials changes. These estimates are shown in Table 6-8.

TABLE 6-1. MATERIALS ANALYSIS BY ZONES

Zone 1 - Flight Station

ASSEMBLY OR PART	PRESENT MATERIAL AND CONSTR.	MATERIALS FOR IMPROVED FIRE SAFETY	INCREASED WEIGHT (1)	INCREASED COST (1)	MATERIAL AVAILABILITY DATE
Ceiling Panels (Sandwich Const.)	Epoxy or Polyester/ Fiberglass Laminate Nomex Core	Phenolic or Polyimide Fiberglass Laminate Nomex Core	Same	Phenolic + 10% Polyimide + 200%	1/78 1/78
Walls and Partitions (Sandwich Const.)	Epoxy or Phenolic/ Fiberglass Skins Nomex Core	Phenolic/Fiberglass Skins	+ 15%	25% Higher	1/77
		Nomex Core	+ 15%	Same	Available
	Decorative Tedlar Laminate Film	New Decorative Film	+ 15%	50% Higher	7/78
		New Lower Smoking Adhesive Film	None	25% Higher	7/78
		Panel with Resistance to Burn-Through (NASA Panel)	+ 30%	100% Higher	1/79
Cockpit Trim (Thermoformed)	Mod-Polyphenylene Oxide	Modified-Polysulfone	+ 12%	25% Higher	7/78
	Polycarbonate	Chlorinated Polyvinyl Chloride	+ 15%	25% Higher	7/78
	Acrylonitrile Butadiene-Styrene (ABS) Copolymer	Other Low Smoking Thermoplastic-Mod-Polycarbonate	+ 15%	10% Higher	1/78
ECS Conditioned Air Ducting	Epoxy or Polyester/ Fiberglass Laminate	Phenolic/Fiberglass Laminate	+ 10%	25% Higher (Processing)	1/78
		New Resin/Fiberglass Laminate	+ 15%	50% Higher	1/79
Overhead Insulation Covering	PVF-Polyamide Scrim	PVF_2/Polyamide Scrim Polyimide Film	+ 30% + 70%	200% Higher 1000% Higher	1/78 1/78

(1) Production Parts

TABLE 6-2. MATERIALS ANALYSIS BY ZONES

Zones 2 and 6 - Lavatories

ASSEMBLY OR PART	PRESENT MATERIAL AND CONSTR.	MATERIALS FOR IMPROVED FIRE SAFETY	INCREASED WEIGHT (1)	INCREASED COST (1)	MATERIAL AVAILABILITY DATE
Ceiling Panels (Sandwich Const.)	Epoxy or Phenolic Resin/Fiberglass Skins, Nomex Core	Phenolic or Polyimide Resin/ Fiberglass Skins	+ 25%	Phenolic 10% Higher, Polyimide 60% Higher	1/79
	Nomex Core	Nomex Core Coated With Intumescent Film	+ 15%	Higher (2)	1/79
		Fiberglass Core	+ 15%	Same	7/78
	Decorative Tedlar Film Covering	New Decorative Film Covering	+ 15%	50% Higher	7/78
		NASA Panel (Resists 2000°F Flame Penetration for 15 Minutes)	+ 30%	100% Higher NASA Development	1/79
Walls & Back (Sandwich Const.)	Epoxy/Fiberglass Nomex Core	NASA Panel, 2000°F Flame Resistant	+ 30%	100% Higher	1/79
Doors & Under Sink Cabinet Doors (Sandwich Const.)	Epoxy/Fiberglass Nomex Core	Phenolic/glass	+ 15%	25% Higher	1/78

(1) Production Parts

(2) Cost unknown at this time

TABLE 6-2. MATERIALS ANALYSIS BY ZONES (Continued)

Zones 2 and 6 - Lavatories

ASSEMBLY OR PART	PRESENT MATERIAL AND CONSTR.	MATERIALS FOR IMPROVED FIRE SAFETY	INCREASED WEIGHT (1)	INCREASED COST (1)	MATERIAL AVAILABILITY DATE
Floor Pans (Thermoformed)	Vinyl-Laminated/ Hardboard With Non-Skid Grit	No Change	None	None	Presently Available
Bins & Accessory Service Holders (Thermoformed or Injection Molded)	Modified Polyphenylene Oxide Polycarbonate	Mod-Polysulfone	+ 13%	+ 25% Higher	7/78
		Polyether Sulfone	+ 10%	+ 50% Higher	1/79
		Chlorinated Polyvinyl Chloride	+ 30%	+ 25% Higher	7/78
		Modified Polycarbonate	+ 10%	+ 10% Higher	7/77

TABLE 6-3 MATERIALS ANALYSIS BY ZONES

Zones 3 and 4 - Main Passenger Cabins

ASSEMBLY OR PART	PRESENT MATERIAL AND CONSTRUCTION	MATERIALS FOR IMPROVED FIRE SAFETY	INCREASED WEIGHT(1)	INCREASED COST (1)	MAT'L AVAIL. DATE
Ceiling Panels: (Sandwich Constr.)					
a-Regular Type	a-Epoxy or Phenolic Fiberglass	a-Phenolic/Fiberglass, & Nomex	a- +25%	a-+10%	7/78
b-Light Weight	b-Kevlar Fabric Skins-Nomex Core-PVF/PVF (Film)	b-Core, PVF_2/PVF_2(Film)	b- +50%	b-None	7/78
c-Acoustical Type	c-Epoxy Scrim/Fiberglass Skins-Nomex Core-PVF/PVC/PVF (Film)	c-Phenolic Scrim/Fiberglass Skins-Nomex Core, New Adhesive (low smoke) New Decorative Film	c- +20%	c- +20%	7/79
		d-Flame Resistant Panel to meet 2000°F, 15-Min. (NASA Panel)	d- +30%	d- +100%	1/79
Partitions, Sidewalls, Cabinets, Service Center, Clothes Closet, etc. (Sandwich Constr.)	Epoxy/Fiberglass Skins	Phenolic/Fiberglass-Nomex Core	+15%	+ 10%	7/78
	Nomex Core	New Low-smoke Adhesive System	None	+25%	7/78
	PVF/PVC/PVF (Film)	New Decorative Film	+10%	+25%	7/78
Class Dividers (Sandwich Constr.)	Aluminum Skins Nomex Core	No change	None	None	-
	PVF/PVC/PVF (Film)	PVF_2/PVF_2 (Film)	+10%	+25%	7/78
Light Deflectors (Thermoformed)	Polycarbonate	Mod-Polysulfone	None	+25%	7/78
		Mod-Polycarbonate	None	+10%	7/77
Psngr Serv Assys (Injection Molded)	Polycarbonate	Polyether Sulfone	None	+25%	7/78
		Polyphenylene Sulfide	None	+15%	7/78
		Modified Polycarbonate & Sulfone	None	+10%	7/77

(1) Production Parts

TABLE 6-3 MATERIALS ANALYSIS BY ZONES - continued

Zones 3 and 4 - Main Passenger Cabins

ASSEMBLY OR PART	PRESENT MATERIAL AND CONSTRUCTION	MATERIALS FOR IMPROVED FIRE SAFETY	INCREASED WEIGHT(1)	INCREASED COST (1)	MAT'L AVAIL. DATE
Complex Door Surround Parts (Thermoformed)	PVC/ABS (Abskyn)	Chlorinated Polyvinyl Chloride (CPVC)	+30%	+25%	7/78
		PVF_2/Mod-Polycarbonate	+10%	+25%	7/78
Seat Trays & Seat Surround Panels (Thermoformed)	ABS	PVF_2/Polyether-sulfone, PVF_2/Mod-Polysulfone	+10% +10%	+50% +25%	7/78
Fabrics	FR Wool, FR Rayon, Nomex	FR Nylon - Nomex	None	+200%	1/78
		PBI, Kynol	None	+300%	1/79
Seat Cushions	Polyurethane (FR)	Neoprene (FR)/Kynol Covers (Ref. 6.2.3)	+10%	+25%	7/78
Float Cushions	Polyurethane (FR)		+10%	+25%	7/78
Floor Coverings	Wool and Nomex Rugs	Nomex, Kynol, Nomex/ Kynol	None	+50%	1/78
Hard Floor Coverings	PVC/Glass Laminate	No change	None	None	Available
Seat Soft Trim	FR Vinyl/Fabric	Kel F Coated Fabric	+35%	+300%	1/78

(1) Production Parts

TABLE 6-4. MATERIALS ANALYSIS BY ZONES

Zone 5 - Attic Area

ASSEMBLY OR PART	PRESENT MATERIAL AND CONSTR.	MATERIALS FOR IMPROVED FIRE SAFETY	INCREASED WEIGHT (1)	INCREASED COST (1)	MATERIAL AVAILABILITY DATE
Electrical Wire	Kapton, Poly-X or Poly-Y Insulated Conductor	Kapton, TFE FEP or Polyarylene	None	None	Available
Convoluted Electrical Conduit	Teflon or Tefzel Convoluted Tubing	No change	None	None	Available
ECS Rigid Ducts	Epoxy or Polyester/Fiberglass Laminate	Phenolic/Fiberglass Laminate	+10%	+25% (Processing)	7/77
	Epoxy/Glass Skins, Foam Core	or New Resin/Fiberglass Laminate	+15%	+50%	7/78
Rubber/Fabric Duct Connectors	Silicone/Nylon	Silicone/Nomex	None	+100%	1/77
	Silicone/Fiberglass	No change	None	None	Available
Insulation	Glass Fibers, Phenolic Impregnated	No change	None	None	Available
Insulation Covering	Tedlar/Nylon Scrim and Heat Sealer	Kynar or Kapton Film and Heat Sealer	+35% +100%	+200% +1000%	1/78 1/78

(1) Production Parts

TABLE 6-5. MATERIALS ANALYSIS BY ZONES

Zone 11 - Food Service Lower Galley

ASSEMBLY OR PART	PRESENT MATERIAL AND CONSTR.	MATERIALS FOR IMPROVED FIRE SAFETY	INCREASED WEIGHT (1)	INCREASED COST (1)	MATERIAL AVAILIBILITY DATE
Ceiling Panels	Epoxy/Glass Laminate	Phenolic/Glass Laminate	None	+10%	1/77
Sidewalls-Cabinets (Sandwich Constr.)	Epoxy/Glass Skins	Phenolic/Glass Skins	+15%	+25%	1/78
	Nomex Core	No change	None	None	Available
	PVF/PVC/PVF Decorative Film	New Decorative Film	+15%	+50%	1/78
		New Low Smoke Adhesive	None	+25%	1/78
Thermoformed Parts and Pans Underfloor	Polycarbonate	Mod-Polycarbonate	+10%	+10%	7/77
	Mod - PPO	Mod-Polycarbonate (Kynar Surface)	+15%	+15%	1/78
Flooring (Sandwich Constr.)	Epoxy/Fiberglass Skins	Phenolic/Fiberglass Skins	+10%	+10%	1/78
	Nomex Core	No change	None	None	Available
Wall Rug Coverings	Wool Rugs - Meeting 60 Sec. Vertical Flame Test	Nomex, Kynol, Nomex/Kynol	None	+50%	1/78
	If used for acoustical value	Heavier Wall Panels and Floor Construction	+50%	+50%	1/78

(1) Production Parts

TABLE 6-6. MATERIALS ANALYSIS BY ZONES

Zones 9 and 12 - Cargo Compartments

ASSEMBLY OR PART	PRESENT MATERIAL AND CONSTR.	MATERIALS FOR IMPROVED FIRE SAFETY	INCREASED WEIGHT (1)	INCREASED COST (1)	MATERIAL AVAILABILITY DATE
Ceilings	Polyester/Glass Fabric Laminate Epoxy/Nomex Laminate Phenolic/Glass Laminate	Phenolic/Glass Laminate	None	+20%	1/78
Side Walls	Same as Ceiling	Same as Ceiling	None	+20%	1/78
Floors (Sandwich Constr.)	Aluminum or Titanium Skins Crushed Aluminum Core	No Change	None	None	Available
Ceiling Light Frame Parts (Injection Molded)	Polycarbonate	Polyether Sulfone Mod-Polycarbonate	None None	+50% +10%	7/78 7/77
Aft Cargo Tie-	Polyamide (Nylon)	No change	None	None	Available

(1) Production Parts

TABLE 6-7 MATERIALS ANALYSIS BY ZONES

Zones 14 and 15 - Avionics & Electrical Load Center

ASSEMBLY OR PART	PRESENT MATERIAL AND CONSTRUCTION	MATERIALS FOR IMPROVED FIRE SAFETY	INCREASED WEIGHT(1)	INCREASED COST (1)	MAT'L AVAIL. DATE
Rigid Cooling Ducts	Polyester or Epoxy/ Fiberglass Laminate	Phenolic/Fiberglass Laminate	+10%	+25% (Processing)	1/78
Insulation Covering	Tedlar/Nylon Scrim with Heat Sealer	Kynar or Kapton Film with Heat Sealer	+30%	Kynar +200% Kapton- +1000%	1/78 1/78
Insulated Wire	Kapton, Teflon or Polyarylene	No change	None	None	Available

Zones 7, 8, 10 and 13 - Unpressurized Areas

Insulation Covering	Tedlar/Nylon Scrim with Heat Sealer	Kynar or Kapton Film with Heat Sealer	+30%	Kynar +200% Kapton- +1000%	1/78 1/78
Insulated Wire	Kapton, Teflon or Polyarylene	No change	None	None	Available

(1) Production Parts.

TABLE 6-8 SUMMARY OF ESTIMATED COST AND WEIGHT INCREASES PER HYPOTHETICAL AIRCRAFT WITH ADVANCED MATERIALS FOR IMPROVED FIRE SAFETY

ZONE	ASSEMBLIES OR PARTS REPLACED	COST INCREASE ($)	WEIGHT INCREASE (lbs.)
Flight Station (1)	o Ceilings. o Barrier Material Installation. o Thermoformed Parts.	2,200	25
Lavatories (2 & 6)	o Ceiling & Backs Next to the Pressure Shell (2000°F. Resistant Panels) o Sides & Door Sandwich Constructions. o Thermoplastic Parts.	20,000	70
Main Cabin (3 & 4)	o Upper Surfaces Over Cabinets & Service Centers. o Injection Molded Passenger Service Assemblies. o Light Deflectors o Complex Door Surround Thermoformed Parts o Rigid Seat Trays and Side Panels o Service Centers and Closets Wall Structure. o Soft Trim (Seats)	260,000	470
Attic Area (5)	o Barrier Material and Installation, 5 places. o Insulation Batt Covering. o Wire Insulation. o ECS Ducts	10,000	120
Food Service Lower Galley (11)	o Sidewall & Cabinet Sandwich Panels o Thermoformed Parts	1,400	40
Cargo (9 & 10)	o Cargo Liners. o Injection Molded Parts	1,400	40
Avionics Electrical Load Centers (14& 15)	o Insulation Batt Covering o Air Cooling Ducts	500	10
Zones 7,8,10,&13	o Insulation Batt Covering	350	6
TOTALS		$295,850	781 lbs.

SECTION 7

TRADEOFF ANALYSIS

A tradeoff comparison has been made between the two approaches which have been examined in this study. Applying the approximate weight and cost data from Sections 5 and 6, the two approaches may be summarized as:

- <u>A Fire Management System</u> consisting of detection, monitoring and suppression subsystems. The weight of this system was estimated to be 905 pounds and the recurring cost (not including design, development and qualification testing costs) was projected to be approximately $80,000.
- <u>Improved Materials</u> throughout most zones. This approach involved an estimated weight increase of 781 pounds and a recurring cost increase to the aircraft of $296,000.

It is appropriate in this section to compare, as directly as possible, the advantages in performance, cost, and timely availability which one approach has relative to the other. Table 7-1 summarizes these factors which are discussed in more detail in the following sub-sections.

7.1 FIRE PROTECTION PERFORMANCE COMPARISON

Since the safety contribution of each of the systems under review is heavily influenced by the fire situation, all three fire scenarios are discussed below:

7.1.1 POST-CRASH-FIRE

It has yet to be substantiated that an on-board cabin fire suppression system using Halon 1301 can be effective in improving the probability of successful evacuation under post-crash fire conditions. If it is shown to be, then the Fire Management System would probably make a substantial contribution to cabin fire safety in the 50 to 60% of the survivable crashes where the fuselage is largely intact. Because of the large amount of uncontrolled combustibles brought aboard by the passengers, the increase in cabin fire safety which can be achieved using new improved cabin interior materials is limited. Also, the severity of potential ignition sources under post-crash fire conditions may cause even the best new materials to burn. In direct performance comparison, the development of a safe, effective on-board fire suppression system appears to offer greater fire protection potential than improved materials. If such a system cannot be developed, the incorporation of advanced fire retardant materials, which prolong the safe evacuation time, becomes the most promising approach to post-crash safety.

Because of the rapidity of the crash events, the detection portion of the Fire Management System probably would not play an important role in the post-crash fire. Its contribution to improved fire protection would be largely for the in-flight and RAMP cases.

7.1.2 IN-FLIGHT FIRE

The primary threat in this case is the undetected fire in unoccupied zones. The early warning fire detection system offers an excellent response to this problem. For inaccessible areas, on-board fire suppression capability would be a benefit. In occupied zones, hand-held portable extinguishers appear to be adequate. Fire retardant materials throughout the cabin currently provide in-flight protection against small ignition sources. Cabin fires have been shown to be quickly detected and extinguished by the crew and passengers. Improved materials and barriers in areas such as the attic, the lavatory, and certain equipment bays could provide additional protection. Material changes which confine and contain the fire and combustible gases within the zone would allow more time for successful extinguishment. While improved materials would not provide protection against flammable fluid leakage in the equipment bays, the Fire Management System should be effective in such cases. In summary, in overall performance, the Fire Management System appears to offer greater protection against the in-flight fire than improved materials.

7.1.3 RAMP FIRE

The Fire Management System would offer good protection for this case. Whether or not it is the most economical way to deal with RAMP fires is considered later. Improved materials, while offering some additional protection, could not be depended on to provide complete protection. The resistance of these new materials to large ignition sources, such as a large bundle of trash, has yet to be confirmed in full-scale tests.

7.2 ECONOMIC COMPARISON

As mentioned previously, the costs developed in this report are recurring costs in 1975 dollars. Non-recurring costs depend upon many indeterminate factors, such as the production tooling, degree of development of the component or materials at the time of go-ahead, etc. These non-recurring costs would include design, development, and qualification testing. For the improved materials this would include not only testing for fire-related properties but also production methods, development tests, and serviceability evaluations. New bonding, forming, and fabrication techniques would undoubtedly have to be developed. Depending upon the specific circumstances, the non-recurring costs for either improved materials or a Fire Management System could range from a small fraction to several times the recurring costs. Therefore, for the comparison purposes, the non-recurring costs for the two approaches will be assumed to be equivalent. Thus, on the basis of the estimated recurring costs, the Fire Management System at approximately $80,000 per aircraft has a lower cost than the improved materials at $296,000 per aircraft. The imbalance in recurring costs could be modified by variations in maintenance costs for the two approaches. Maintenance and delay costs for the Fire Management System are projected to be about $110,000 over an assumed aircraft life of 20 years with a utilization rate of 3000 hours per year and 2.5 hours per flight. Presumably, maintenance costs on improved materials would be less than on the Fire Management System, but more than current materials because replacement and/or repair materials would be more expensive. As a rough estimate, maintenance of improved materials might be about 50% of the Fire Management System (approximately $50,000 over the aircraft life). Increased aircraft weight is also an economic consideration. Both approaches have weight penalties, (905 pounds for the Fire Management System and 781 pounds for the improved materials). The aircraft fuel consumption cost-equivalent of this weight is estimated as follows: Using the value of $\frac{.094 \text{ lbs fuel}}{\text{lbs. equipment}}$ (Reference 50) for an aircraft of this size and assuming fuel costs of 36 cents per gallon, the 781 pounds carried over the 60,000 hour life of the aircraft would incur additional fuel costs of $237,000 for the improved materials. For the FMS, the additional fuel cost would be $274,000. The on-board Fire Management System provides RAMP protection also. However, the value of this protection should be assessed on the

SECTION 8

CONCLUSIONS

Based on the reported survey of aircraft accidents and incidents from 1963 and continuing into 1974, the following conclusions were derived:

- o The passengers and crew have generally functioned effectively to detect and extinguish in-flight fires in the occupied zones. The one exception has been the lavatories, which because of infrequent use, should be considered unoccupied.
- o Zones having a high incidence of fire and overheat problems were the galley, main and nose wheel wells, and the flight station. Zones having an unusually low incidence were the attic and the cargo compartments.

The tradeoff study compared two approaches to increased fire safety for a hypothetical wide-bodied transport aircraft: (1) an integrated Fire Management System, incorporating fire detection, monitoring, and suppression, and (2) improved nonmetallic materials having greater fire retardancy and lower emission of hazardous pyrolysis products. Both approaches were conceived to provide fire protection for all three fire modes; post-crash, in-flight, and RAMP. The study revealed:

- o Performance and cost factors favor a Fire Management System over improved materials. Some unresolved technical problems exist with both approaches.

- Both approaches involve weight increases, with the Fire Management System being about 16% higher than improved materials.
- The Fire Management System appears to offer an advantage over the materials approach in terms of timely availability, considering the time required for standardizing tests (particularly for toxicity) needed to evaluate a material for total hazard.
- The technology currently exists to provide an effective early warning fire detection and monitoring system.
- An on-board fire suppression system is technically feasible if the potential toxicity hazards associated with decomposition of the extinguishing agent by pyrolysis can be demonstrated to be minimal. No agent was found having a performance superior to Halon 1301, but its suitability for use in post-crash fires should be demonstrated.
- Numerous non-metallic materials with improved fire protection properties are becoming available. Current cost and weight forecasts indicate a sizable cost and weight increase over presently used materials.
- All the test techniques and qualifying standards needed to judge material improvements are not yet available.
- A combined approach involving a Fire Management System in conjunction with selective material improvements may offer the most potential for providing timely fire protection.

SECTION 9

REFERENCES

1. Lucha, G. V., et al, An Analysis of Aircraft Accidents Involving Fires, NASA CR 137690, May 1975

2. Airworthiness Standards: Transport Category Airplanes, Federal Air Regulations, Part 25.

3. Custer, R. L. P., Bright, R. G., Fire Detection: The State-Of-The-Art, NASA CR-134642, NBS TN-839, June 1974

4. Roeser, W. F. and Camy, C. S., Principles of Fire Detection in Aircraft Fire Spaces, WADC-TR-54-307, June 1954

5. Leen, A., An Ultraviolet Sensing Flame Detector For Use on High Performance Military Aircraft, AFAPL-TW-69-107, February 1970.

6. Fox, D. C., Development of Feasibility Demonstration Hardware For An Integrated Fire and Overheat Detection System, AFAPL-TR-72-105, May 1973.

7. VanLuik, F. W., Jr., Characteristics of Invisible Particles Generated by Precombustion and Combustion, 77th Annual Meeting of the National Fire Protection Association, St. Louis, Mo., May 17, 1973.

8. Bankston, C. P., Casanova, R. A., Powell, E. A., Zinn, B. T., Properties of Smoke Produced by Burning Wood, Urethane and PVC Samples Under Different Conditions, Georgia Institute of Technology, Paper presented at the Combustion Institute Meeting, SWRI, April 22 and 23, 1975.

9. NASA's Space Shuttle Orbiter-Incipient Fire Detector - A New Concept. Celesco Industries, Inc., Bulletin 01-378, October 1974.

10. Chuan, R. L., An Instrument For the Direct Measurement of Particulate Mass, Atlantic Research Corporation, Published in Volume 1, No. 2, Journal of Aerosol Science, May 1970.

11. Heskestad, G., Escape Potentials from Apartments Protected By Fire Detectors In High-Rise Buildings, Factory Mutual Research Corporation, Prepared for Department of Housing and Urban Development, Report No. PB-234014, June 1974.

12. Alvares, N. J. and McKee, R. J., The Response of Smoke Detectors to Pyrolysis and Combustion Products from Aircraft Interior Materials, Paper presented at the Symposium on Fire Detection for Life Safety, April 1975.

13. Custer, R. L. P., Detector Actuated Automatic Sprinkler Systems - A Preliminary Evaluation, NBS Technical Note 836, July 1974.

14. Bright, R. G., Recent Advances in Residential Smoke Detection, NBS, Fire Journal, Vol. 68, No. 6, 69-77, November 1974.

15. Bukowski, R. W., Bright, R. G., Some Problems Noted in the Use of Taguchi Semiconductor Gas Sensors as Residential Fire/Smoke Detectors, NBSIR 74-591, December 1974.

16. Figaro Engineering Inc., Newly Developed Figaro Gas Sensor #711 and #811, Figaro Report, April 1975

17. Byrd, N. R., Space Cabin Atmosphere Contamination Detection Techniques, Douglas Report SM-48446-F, Contract NAS 21-15, July 1968.

18. Senturia, S. D., Fabrication and Evaluation of Polymeric Early-Warning Fire Alarm Devices, Massachusetts Institute of Technology, NASA CR-134764, NASA-Lewis Research Center, 1973-1975.

19. Linford, R. M. F., Integration of a Fire Detector into a Spacecraft, Journal of Spacecraft, Vol. 9, No. 9, September 1972.

20. Technical Manual, Fire Detection and Extinguishing System, Publication No. 74-3, Pyrotector Inc., February 1975.

21. Scott, D., NOW - A "Dancing" Laser Beam to Detect Fire and Smoke, Popular Science, December 1972.

22. Friedman, R. and Levy, J. B., Survey of Fundamental Knowledge of Mechanisms of Action of Flame Extinguishing Agents, NADC-TR-56-568, AD 110685, January 1957.

23. Fire Protection Handbook, 13th Edition, 1969 - National Fire Protection Association.

24. Fawcett, H. H. and Wood, W. S., Chapter 28 - Fire Extinguishing Agents and Their Applications from Safety and Accident Prevention in Chemical Operations, 1965.

25. The Mechanisms of Halogenated Fire Suppressants, Symposium on, SWRI, San Antonio, Texas, April 1975.

26. Huggett, C., Combustion Processes in the Aerospace Environment, Aerospace Medicine, November 1969.

27. Cato, R., et al, Ignition and Suppression in Aerospace Vehicles, AFAPL-TR-72-96, 1972.

28. Attallah, S., et al, Development of Halogenated Hydrocarbon Foam (Halofoam), AFAPL-TR-71-21, April 1971.

29. Attallah, S., et al, Advanced Fire Extinguishers for Aircraft Habitable Compartments, AFAPL-TR-72-62, August 1972

30. Ford, C. L., An Overview of Halon 1301 Fire Protection Systems - Paper presented at the Symposium on the Mechanisms of Halogenated Fire Suppressants, April 23-24, 1975.

31. Gaume, J. G. and Barter, Paul, Theoretical Determination of the Time of Useful Function (TUF) on Exposure to Combinations of Toxic Gases, Aerospace Medicine, Dec. 1969.

32. Barter, P., Gaume, J. G., and Rostami, H. J., Dynamics Analysis for Time of Useful Function (TUF) Predictions in Toxic Combustive Environments, Aerospace Medicine, December 1970.

33. Gaume, J. G. Barter, P., and Rostami, H. J., Experimental Results on Time of Useful Function (TUF) After Exposure to Mixtures of Serious Contaminants, Aerospace Medicine, September 1971.

34. Huggett, C., Habitable Atmospheres Which Do Not Support Combustion, Combustion and Flame 20, 140-142, Atlantic Research Corp., 1973.

35. McHale, E. T., Life Support Without Combustion Hazards, Fire Technology, February 1974.

36. National Fire Protection Association, Standard on Halogenated Fire Extinguishing Agent Systems, Halon 1301, NFPA No. 12A, 1973.

37. Tatem, P., et al, Pressurization with Nitrogen As an Extinguishant For Fires in Confined Spaces, Combustion Sciences and Technology, Vol. 7, 1973.

38. Carhart, H. W. and Fielding, G. H., Application of Gaseous Fire Extinguishants in Submarines, National Academy of Sciences, Proceeding of a Symposium on An Appraisal of Halogenated Fire Extinguishing Agents, April 11-12, 1972.

39. Gassmann, J. J. and Hill, R. G., Fire Extinguishing Methods for Passenger/Cargo Aircraft, FAA-RD-71-68, November 1971.

40. Snow, C. C., Carroll, J. J. and Allgood, M. A., Survival in Emergency Escape From Passenger Aircraft, FAA AM 70-16, October 1970.

41. McFarland, R. A., Human Factors in Relation to the Development of Pressurized Cabins, Aerospace Medicine, December 1971.

42. AIA Crashworthiness Program - Fire Suppressant Section - Fire Suppression and Smoke and Fume Protection, AIA CDP-2, July 1968.

43. Smith, D. C. and Harris, D., Human Exposure to Halon 1301 ($CBrF_3$) During Simulated Aircraft Cabin Fires, Aerospace Medicine, February 1973.

44. Call, D. W., A Study of Halon 1301 ($CBrF_3$) Toxicity Under Simulated Flight Conditions, Aerospace Medicine, Feb. 1973.

45. Jensen, R., Summary, Proceedings of A Symposium on An Appraisal of Halogenated Fire Extinguishing Agents, April 11-12, 1972.

46. National Academy of Sciences, Proceedings of A Symposium on An Appraisal of Halogenated Fire Extinguishing Agents, April 11-12, 1972.

47. Lopez, E. L., Fire Test Technology, Lockheed Report 26835, January 1975.

48. Haun, C. C., et al. Inhalation Toxicity of Pyrolysis Products of Bromo Chloro Methane and Bramo Trichloro Methane, American Industrial Hygene Association Journal, Vol. 30, November 1969.

49. Contract DOT-FA75-WA-3657, Investigation of Feasibility and Tradeoffs of a Transport Fuselage Fire Management System, 6-5-75.

50. Aviation Week, "Operating and Cost Data", P. 44, February 9, 1976.

51. Federal Specification CCC-T-191b Method 5903T (revised Method 5902). Available from General Services Administration.

52. Federal Aviation Regulations, FAR 25. 853, Notice 69-33, Federal Register 34 F.R. 13036, August 1969.

53. Lee, T. G., Interlaboratory Evaluation of Smoke Density Chamber, NBS Technical Note 708, National Bureau of Standards, U. S. Dept. of Commerce, December 1971.

54. Spurgeon, J. C., A Preliminary Comparison of Laboratory Methods For Assigning A Relative Toxicity Ranking to Aircraft Interior Materials, FAA-RD-75-37, October 1975.

55. "Applied Fluid Mechanics," M. P. O'Brien and G. H. Hickox, McGraw-Hill Book Company, Inc., 1937.

APPENDIX

OPTIMIZATION OF SUPPRESSANT STORAGE CONFIGURATION

INTRODUCTION

The initial aim of this investigation was to compare the stored weights of a variety of extinguishing agents, such as Halon 1301, CF_4, C_2F_6, etc. A computer program was developed which will handle any of these agents when stored as a liquid. However, for reasons explained in Section 4, none of the agents except Halon 1301 appeared to warrant an optimization analysis of bottle configuration. Also, for most of the perfluroalkanes, insufficient thermophysical properties data were available to perform the analysis. Therefore, the optimization studies that follow were confined to Halon 1301.

A method was devised for determining the initial pressure and volume of the bottle storing the fire extinguishing agent at the minimum weight condition for a given agent, discharge system configuration, discharge time, and cabin volume. The method has been programmed for the CPS (Conversational Programming System) terminal and involves an iteration of various initial bottle pressure and volume combinations until the minimum weight is achieved. Each iteration involves the calculation of the complete discharge of the agent in order to insure that the specified discharge time is maintained and that the pressure in the discharge system remains sufficiently high to keep the agent as a liquid. Maintaining the agent as a liquid until it is discharged into the cabin atmosphere permits a more rapid and uniform distribution of the agent than if discharged as a gas.

The discharge configuration was assumed to consist of a tube 10 feet in length having a 1.0-inch diameter. Although the configuration of the actual discharge system has a strong influence on the analytical results, comparisons and effects of variables other than the discharge system for a preliminary design design study were believed to be most clearly understood by maintaining a fixed discharge system. An orifice was assumed at the tube exit plane in the analytic model in order to provide a means for maintaining a sufficiently high pressure in the tube to keep the agent in a liquid form throughout the discharge. Weight optimizations of orifice size for various discharge times (constant cabin volume) and of orifice size for various cabin volumes (constant discharge time) are presented.

CALCULATION METHOD

The various phases of the calculation procedure are shown in Figure A-1. The length and diameter of the discharge tube and the orifice diameter must be specified along with some physical properties of the agent (quantity, density, vapor pressure, viscosity, specific heat, molecular weight, and nitrogen solubility). The surrounding atmosphere was considered to be at sea level static pressure and 70°F for all studies presented in this appendix, although these are inputs to the computer program and could have been varied. The bottle is assumed to be spherical and made of steel. Nitrogen is assumed to be the pressurizing gas. The program has a built-in technique for initializing the pressure and volume prior to each iteration step.

The first phase of the calculation (tube fill-up) involves the numerical integration of the general differential equation describing a nonsteady, viscid flow of an incompressible fluid, (Ref. 55).

$$\frac{1}{\rho}\left(\frac{\partial p}{\partial s}\right) ds + \left(\frac{\partial v}{\partial t}\right) ds + \frac{\partial}{\partial s}\left(\frac{v^2}{2}\right) ds + \frac{4f}{D}\frac{v^2}{2}\, ds = 0$$

where ρ = density

p = pressure

s = axial distance

t = time

v = velocity

f = friction factor

D = diameter.

Since the fluid is assumed to be incompressible, the acceleration term, $\partial v/\partial t$, and the density, ρ, are independent of the distance s. Integrating the equation between limits of s = 0 and s = X_L, the equation becomes:

$$\frac{P_o - P_N}{\rho} + \frac{dv}{dt} X_L + \frac{v^2}{2} + \left(\frac{4f X_L}{D} + K_{ENT} \frac{v^2}{2} \right) = 0$$

where P_o = atmospheric pressure, i.e., the pressure at s = X_L

P_N = pressure of Nitrogen, i.e., the pressure at s = 0

X_L = distance that the liquid has travelled down the tube

K_{ENT} = entry loss factor between bottle and tube.

Initially, X_L and v are zero.

The pressure of the nitrogen is calculated in steps, using small time intervals, assuming an isentropic expansion from initial conditions. The friction factor is calculated as a function of Reynolds number for a smooth pipe. This method is used until the tube is full of liquid agent. The time increments used during the numerical integration are summed to give the time necessary for filling the tube.

The second phase of the discharge (bottle emptying, tube full) involves a balancing between the bottle driving pressure and the pressure losses associated with flow through the discharge duct. These losses include bottle discharge loss, friction loss, and orifice loss. The driving pressure varies as the nitrogen expands isentropically within the bottle. The flow rate is considered constant for very small time increments. Hence, the quantity of liquid being discharged is calculated assuming steady state conditions during these increments until the bottle is empty.

The third phase of the discharge (tube emptying) is done exactly as the second phase except that the friction effects are only considered for the length of the tube filled with liquid agent. The calculation ends as the last elemental volume of liquid agent passes through the orifice. The total time for the complete discharge is found by summing the incremental times involved in

Phases I through III. The pressure ahead of the orifice is monitored throughout the discharge in order to determine the minimum value at any time.

Calculations of this type are repeated using various combinations of initial bottle pressure and volume until 1) the required discharge time is attained, and 2) the minimum pressure just ahead of the orifice during the discharge is equal to the vapor pressure of the liquid agent. This pressure-volume combination represents the minimum bottle volume for which the agent can be maintained as a liquid throughout the discharge. The bottle is assumed to be a spherical steel container and its weight is calculated as a function of the volume and initial pressure assuming a stress safety factor of 4.

The minimum volume bottle may not, however, be the minimum weight bottle. Larger volumes, which increase bottle weight, offer the advantage of lower initial pressures, which decrease the weight. Initial bottle pressure-volume combinations for larger volumes, maintaining the same discharge time, are therefore determined until the minimum weight combination of agent, gas and bottle is eventually found. An out-of-scale sketch showing the general results of the pressure-volume relationship and the influence of discharge time is shown in Figure A-2.

RESULTS

The use of the calculation procedure described requires that the orifice diameter be specified. The program then calculates the optimum weight bottle for the particular orifice size. By repeating the calculation for various orifice diameters, the optimum size orifice can be determined. Figure A-3 shows the strong effect of orifice size on the bottle weight, bottle volume, and initial bottle pressure for a 1.0 second discharge into a cabin volume of 1000 cubic feet. For the conditions shown, the optimum orifice size is approximately 0.625 inches. The slope discontinuity in the initial bottle pressure line can be explained by referring to Figure A-2. If bottle discharge time is fixed, each orifice diameter will have a unique set of curves resembling Figure A-2. For small diameter orifices, the lightest bottle weight is at a pressure and volume where the Minimum Weight Bottle line intersects the specified Discharge Time line. As the orifice diameter increases, new sets of curves are developed with the intersections of these two lines eventually reaching the limiting line, above which the pressure must remain to keep the agent liquid in transit. This is the point of discontinuity in Figure A-3. For larger orifices, the specified time line intersects the limiting liquid agent line before it reaches the Minimum Bottle Weight line of Figure A-2. It is apparent that the initial bottle pressure for this condition is lower than would be experienced if the Minimum Bottle Weight line were extended to meet the specified time line.

The sudden change in slope of the Initial Bottle Pressure line in Figure A-3 has an attendant increase in bottle volume creating a barely discernable discontinuity in the Bottle Volume line. However, the effect of reduced pressure on bottle strength requirements is greater than the effect of increased bottle volume for slight increases in bottle volume. This causes the minimum initial bottle weight to occur at a slightly larger orifice diameter than exists at the point of pressure discontinuity.

To determine the effect of discharge time on bottle weight, orifice sizes have been optimized for several discharge times. The results are shown in Figure A-4. Bottle weight does not change substantially for discharge times greater than about 2 seconds. For shorter required discharge times, the bottle weight increases due to the higher storage pressures required for the small discharge times.

In application, the design of a fire-extinguishing system for various cabin volumes involves the determination of the number of bottles, e.g., whether one bottle containing all of the required agent or several bottles (and therefore several discharge systems) each containing a portion of the required agent results in the lowest weight. For this purpose, orifice sizes were optimized for appropriate amounts of Halon 1301 in a bottle for a 2-second discharge into cabin volumes between 300 and 5000 cubic feet. The results are shown in Figure A-5. It should be noted that the total system weight is the sum of the discharge system weight, the Halon weight, the bottle weight, and the weight of brackets to support the bottle. As the volume to be protected by a single bottle increases, the fixed discharge system weight represents a smaller fraction of the total weight. However, the bottle weight increases more than linearly because of the high pressures required to force all the Halon out in the specified time. Thus, there is an optimum volume to be protected, as indicated in Figure A-6.

The minimum weight system appears (for the assumptions made) to result if a separate bottle is chosen to protect every 3000 cubic feet of volume. In general, a few large bottles produce a lower weight than many small bottles, although the determination of the optimum number depends strongly on the weight of the discharge systems. In a real application it may not be possible to distribute uniformly a large amount of agent from a single bottle through the discharge system assumed in the calculation. In this case, either a different discharge system must be used or else a greater number of bottles must be used and a weight penalty accepted. A curve of total system weights as a function of cabin volume is presented in body of the report (Section 5, Figure 5-10).

<u>SUMMARY</u>

Many of the variables involved in a fire extinguishing system can be optimized in terms of weight by the method described in this report. For a real system, the discharge system has a strong effect on the results and must be defined prior to the bottle optimization. For preliminary design analysis, an approximate configuration for the discharge system enables the effects of other system variables to be quantitatively determined. The computer programmed method is general enough to handle any liquid fire extinguishing agent that is pressurized by nitrogen. Through the use of the method, weight optimizations of the number of bottles, orifice size, bottle pressure, and bottle volume are easily determined. A listing of this computer program is on file with the author of this report and/or the Federal Aviation Administration.

VARIOUS PHASES OF DISCHARGE CALCULATIONS

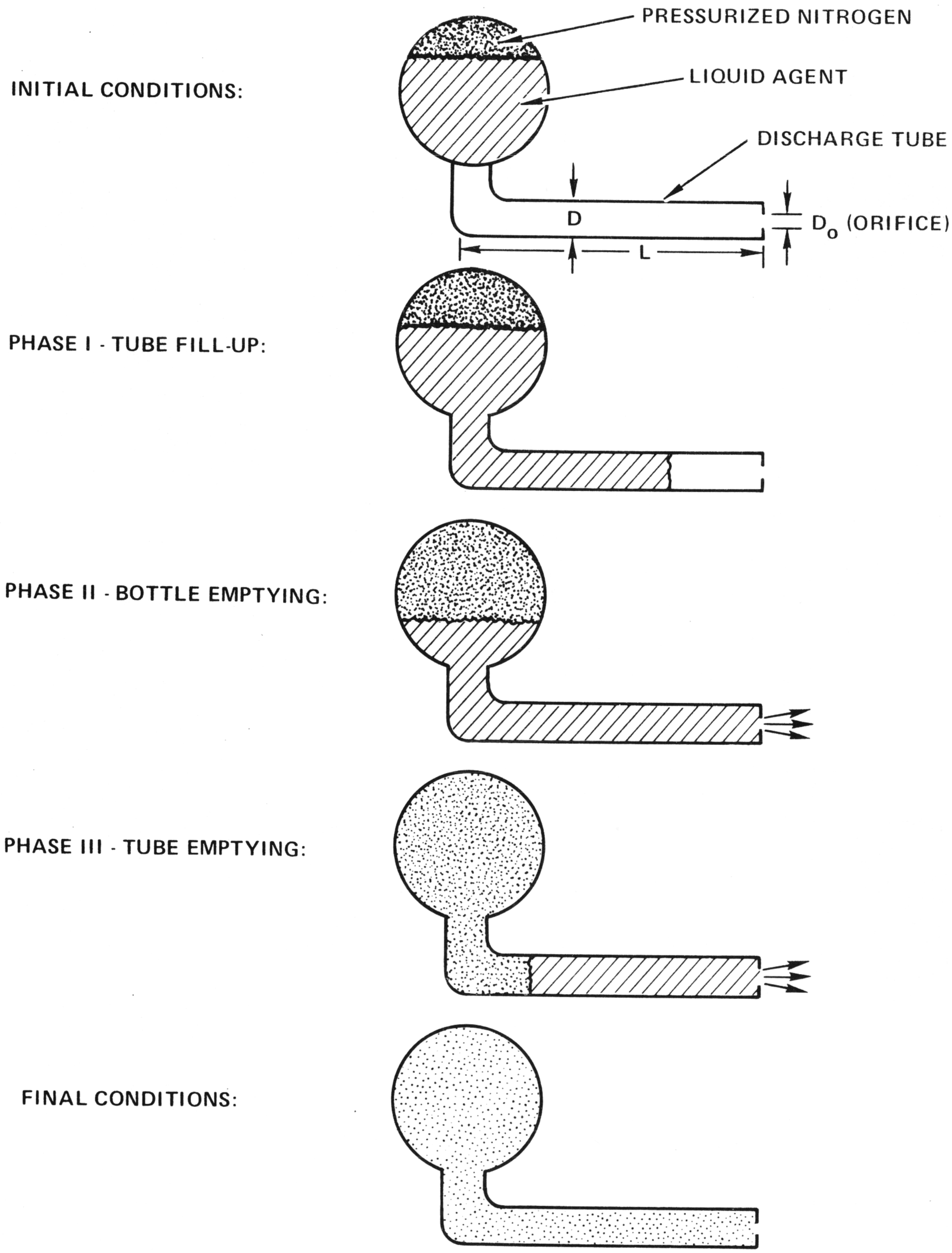


FIGURE A-1.

EXTINGUISHANT BOTTLE WEIGHT OPTIMIZATION STUDY

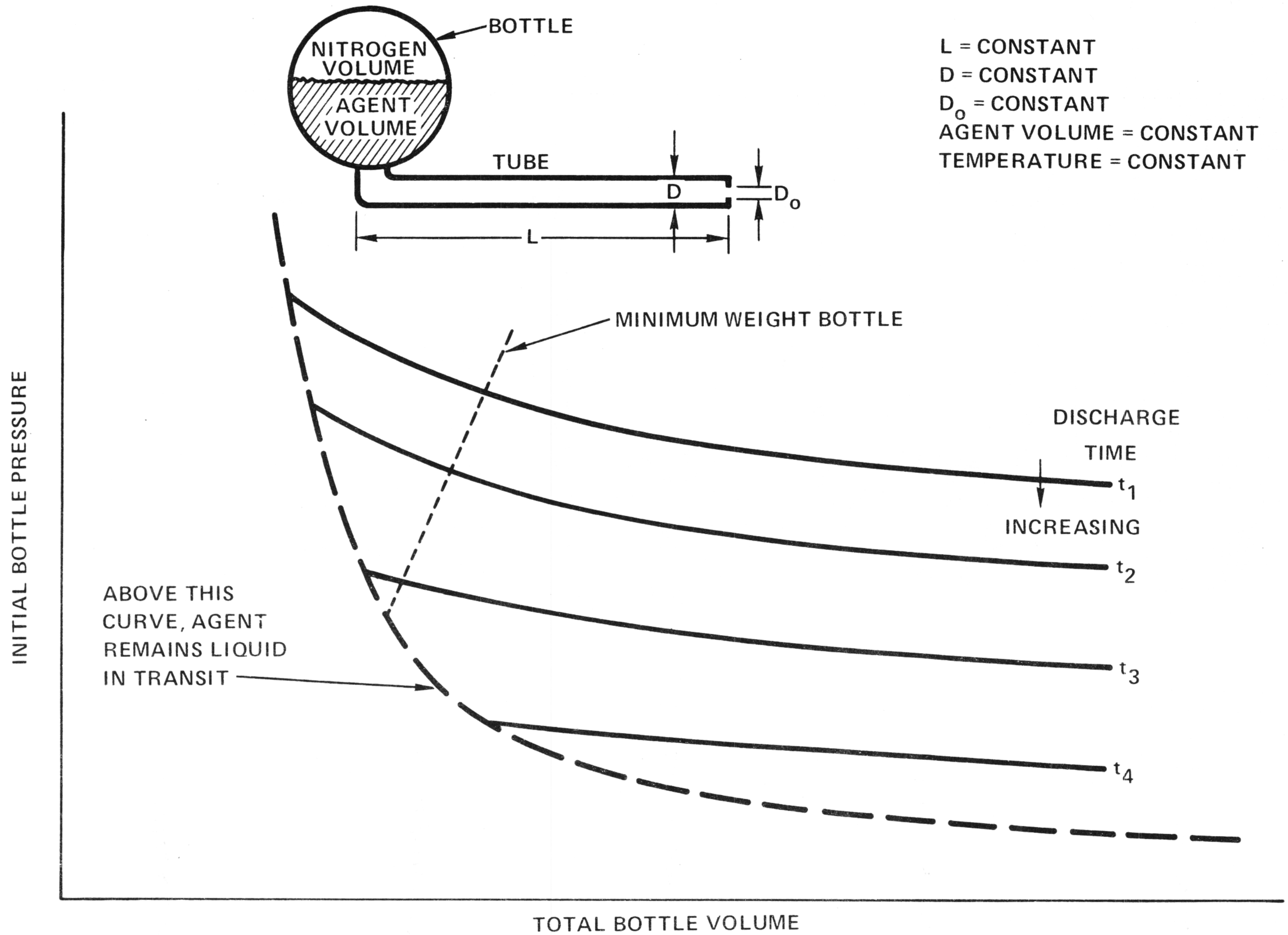


FIGURE A-2

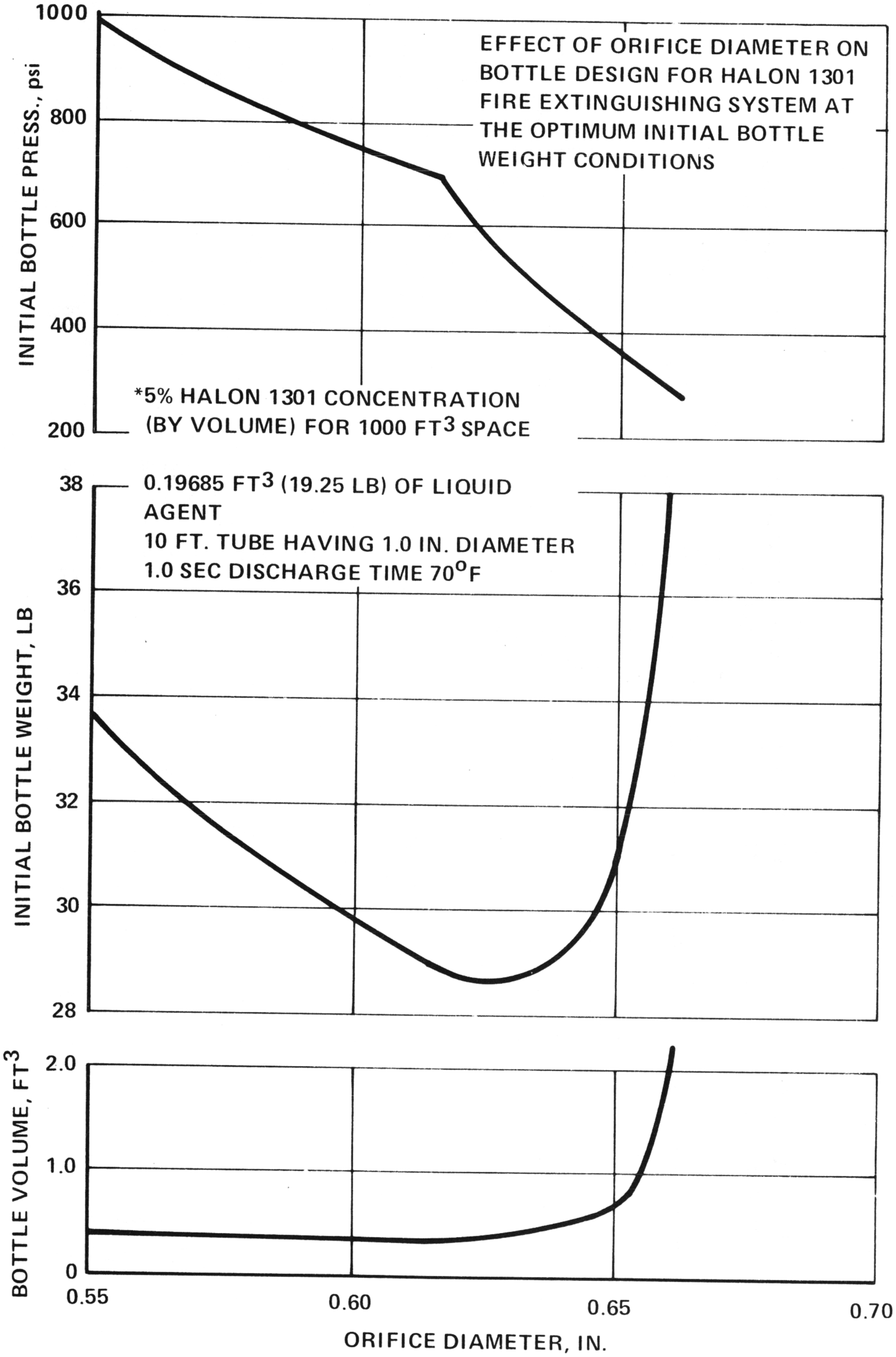
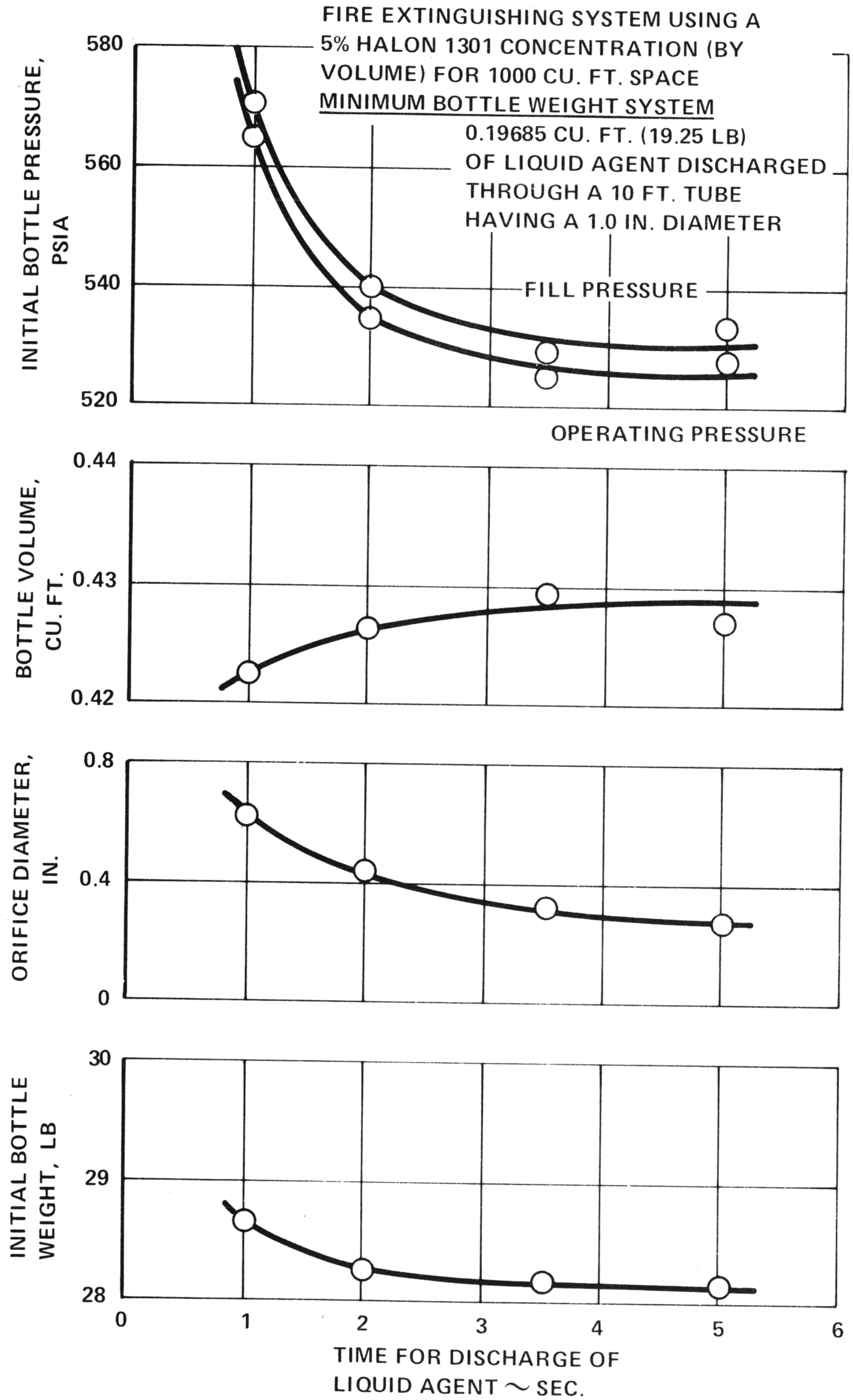

EFFECT OF ORIFICE DIAMETER ON BOTTLE DESIGN FOR HALON 1301 FIRE EXTINGUISHING SYSTEM AT THE OPTIMUM INITIAL BOTTLE WEIGHT CONDITIONS
*5% HALON 1301 CONCENTRATION (BY VOLUME) FOR 1000 FT3 SPACE
0.19685 FT3 (19.25 LB) OF LIQUID AGENT
10 FT. TUBE HAVING 1.0 IN. DIAMETER
1.0 SEC DISCHARGE TIME 70°F
INITIAL BOTTLE PRESS., psi
1000
800
600
400
200
INITIAL BOTTLE WEIGHT, LB
38
36
34
32
30
28
BOTTLE VOLUME, FT3
2.0
1.0
0
0.55
0.60
0.65
0.70
ORIFICE DIAMETER, IN.

FIGURE A-3



FIRE EXTINGUISHING SYSTEM USING A 5% HALON 1301 CONCENTRATION (BY VOLUME) FOR 1000 CU. FT. SPACE
MINIMUM BOTTLE WEIGHT SYSTEM
0.19685 CU. FT. (19.25 LB) OF LIQUID AGENT DISCHARGED THROUGH A 10 FT. TUBE HAVING A 1.0 IN. DIAMETER
FILL PRESSURE
OPERATING PRESSURE
INITIAL BOTTLE PRESSURE, PSIA
580
560
540
520
BOTTLE VOLUME, CU. FT.
0.44
0.43
0.42
ORIFICE DIAMETER, IN.
0.8
0.4
0
INITIAL BOTTLE WEIGHT, LB
30
29
28
0
1
2
3
4
5
6
TIME FOR DISCHARGE OF LIQUID AGENT ~ SEC.

FIGURE A-4

WEIGHT FOR A SINGLE
FIRE EXTINGUISHANT BOTTLE
CONTAINING HALON 1301 FOR
A 5% CABIN CONCENTRATION

2.0 SEC. DISCHARGE TIME
10 FT. TUBE, 1.0 IN. DIAMETER

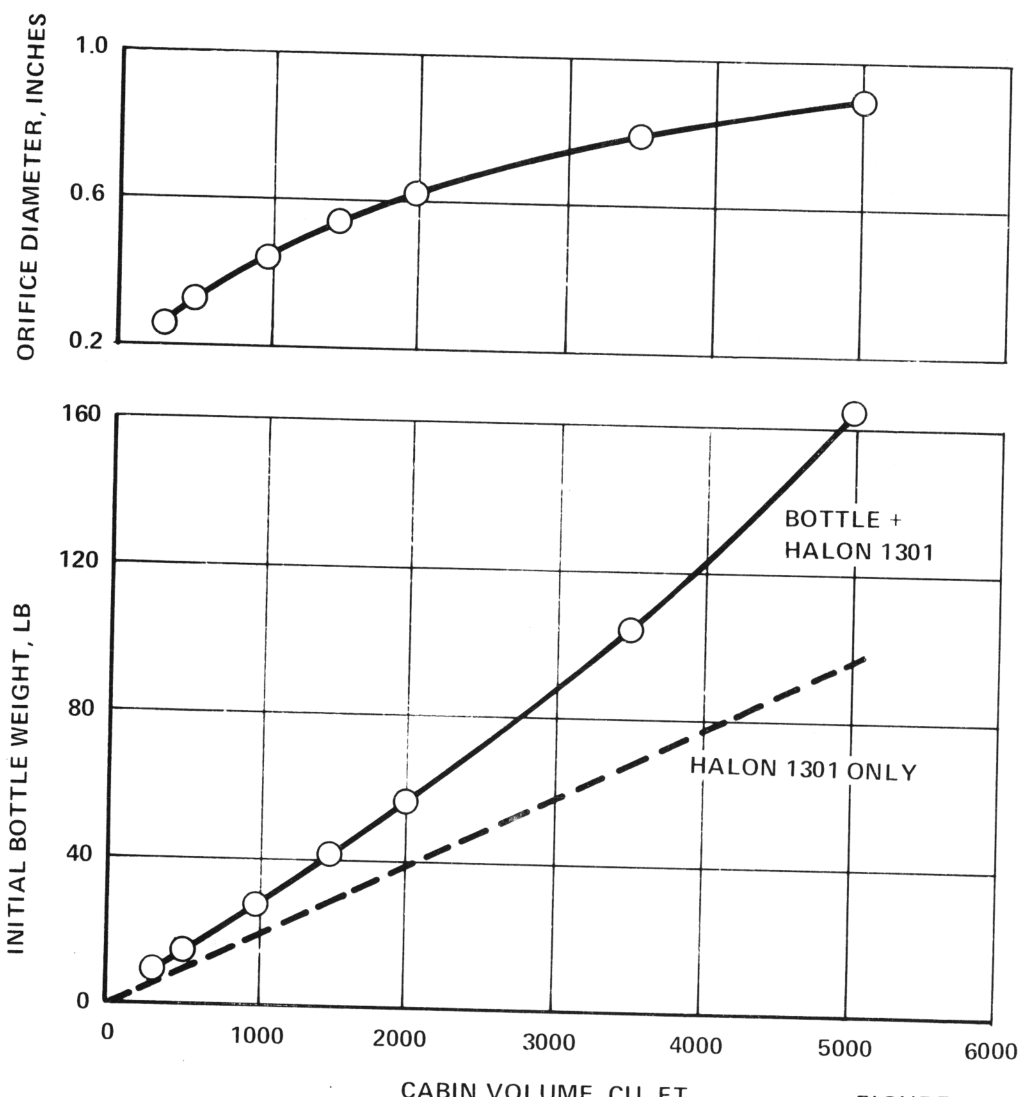


FIGURE A-5

WEIGHT OF A SINGLE BOTTLE
HALON 1301 STORAGE AND
DISTRIBUTION SYSTEM

2.0 SEC DISCHARGE TIME
FIXED DISCHARGE SYSTEM WEIGHT 8 LBS
STRUCTURAL SUPPORT BRACKETS 15% OF BOTTLE + HALON WEIGHT

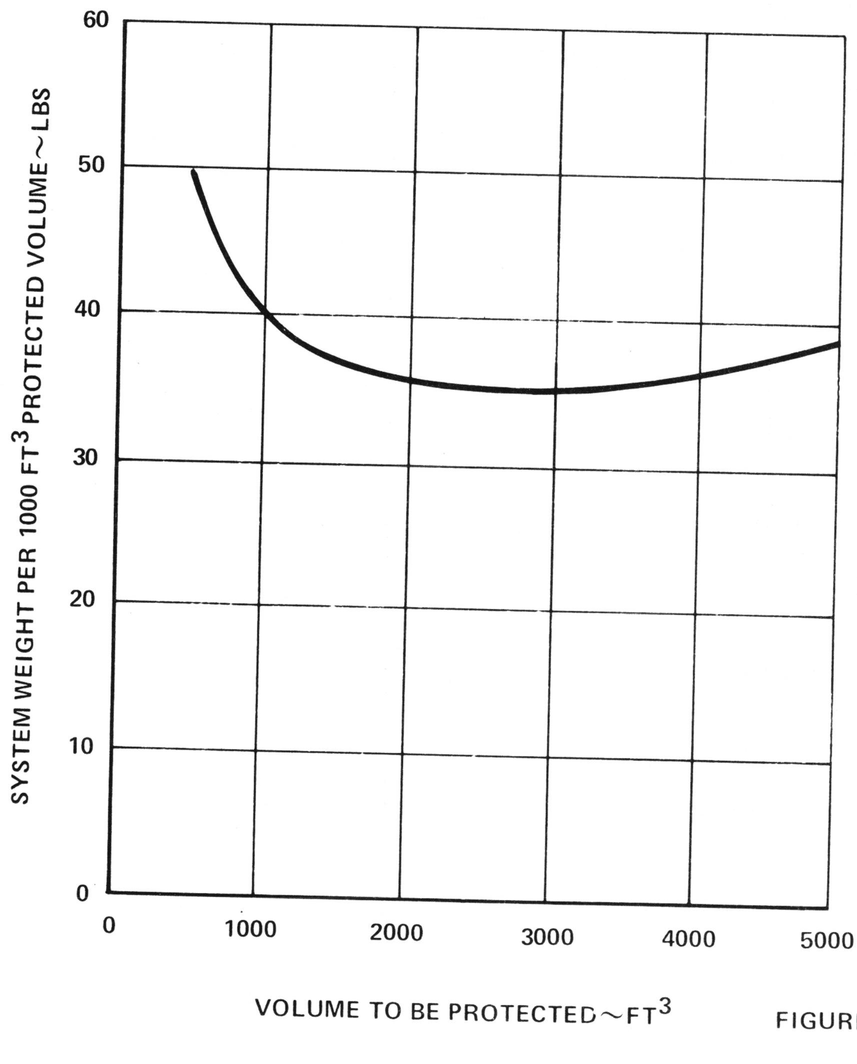


FIGURE A-6