P. RUSSELL

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CRASHWORTHINESS DEVELOPMENT PROGRAM
JULY 1968

TECHNICAL SUMMARY

AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC.
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AIA

This report has been prepared by participants in the Aerospace Industries Association of America, Inc., Crashworthiness Development Program.

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REPORT NUMBER AIA CDP-S

FOREWORD

This report is one of seven prepared by the Aerospace Industries Association of America, Inc. (AIA), to report the Association's Crashworthiness Development Program. These seven reports are as follows:

Technical Summary, Crashworthiness Development Program, Aerospace Industries of America, Inc.	AIA CDP-S
Materials Technical Group Report	AIA CDP-1
Fire Suppression and Smoke and Fume Protection Technical Group Report	AIA CDP-2
Lighting and Exit Awareness Technical Group Report	AIA CDP-3
Evacuation Technical Group Report	AIA CDP-4
Recommended Regulation Changes	AIA CDP-RC
Recommended Research and Development	AIA CDP-R&D

The Crashworthiness Development Program was formulated as part of the Aerospace Industries Association's response to the FAA Notice of Proposed Rule Making (NPRM) 66-26, "Crashworthiness and Passenger Evacuation," in mid-1966. The program began with a letter of encouragement from the FAA, dated February 7, 1967. Program progress has been presented periodically to assigned FAA liaison team members. Figure 1 shows the relationship of the AIA members in management of the program.

The objective of the program has been to find ways to increase passenger survivability following an aircraft accident involving a large air-carrier-type transport airplane through improvements in (1) interior materials, (2) fire suppression and smoke and fume protection systems, (3) emergency lighting and exit awareness, and (4) evacuation systems. Extensive studies and tests have been conducted in these four areas; however, the program did not include studies to develop methods of crash avoidance or to modify fuel to limit fuel spillage or flame propagation in the fuel following an accident. Duration of the program was approximately 1 year.

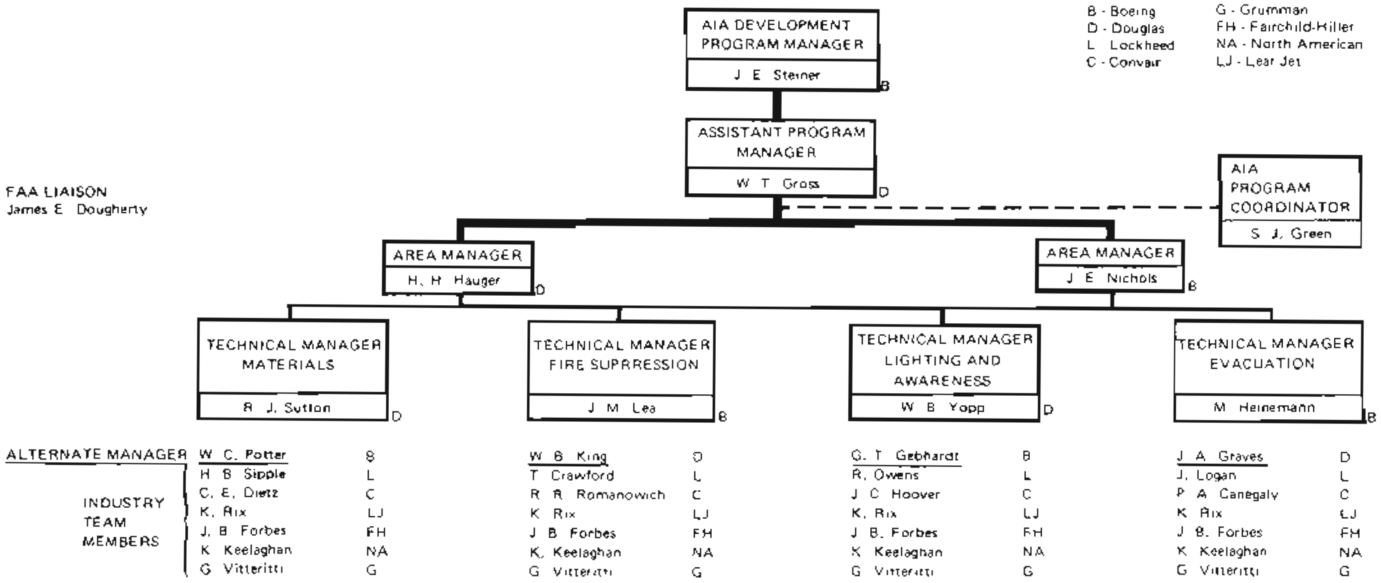

Figure 1. Program Management

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1.0 INTRODUCTION

This report summarizes over 1 year of technical work accomplished by participants in the AIA Crashworthiness Development Program. It provides the most significant results obtained and conclusions drawn from analysis and test work on interior materials, fire suppression and smoke and fume protection, emergency lighting and exit awareness, and evacuation systems. It also illustrates the scope of the program and identifies those technical studies and tests that resulted in the recommended changes to Federal Aviation Regulations described in report AIA CDP-RC.

The basic premise of the AIA Crashworthiness Development Program is that a crash has already occurred. Research areas not a part of the program are (1) crash avoidance through automatic landing and takeoff systems that might reduce human error and (2) ways to modify jet fuel to reduce the flammability hazard if fuel is accidentally spilled.

2.0 SUMMARY

Significant studies and tests accomplished in the AIA Crashworthiness Development Program and results and conclusions drawn from them are summarized in Table 1. The scope of technical and testing activities in the Materials Program and the Fire Suppression and Smoke and Fume Protection Programs is illustrated in Fig. 2. Similar information is shown in Figs. 3 and 4 for the Lighting and Exit Awareness Program and the Evacuation Program.

The studies and tests conducted in these AIA programs have confirmed many of the regulations enacted in FAR 25-15. The adequacy of certain FAR 25-15 lighting minimums has been established. The work of industry confirms the following significant evacuation improvements in FAR 25-15:

- Type A exits with double-lane slides
- Escape devices automatically deployed and erected in 10 sec
- Evacuation in 90 sec or less
- Manufacturer's evacuation demonstrations
- Overwing evacuation provisions including escape-route markings, slip-resistant evacuation path surfaces, and offwing escape devices

The work in the AIA program has also revealed that additional significant improvements to FAR 25-15 can be technically substantiated. These are:

- More severe interior-material burn tests applied selectively to locations in an airplane
- Automatic slide inflation at *all* floor-level exits (not limited to emergency exits as in FAR 25-15)
- Effectively brighter, more uniform emergency lighting
- More effective exit locators

These improvements are discussed in detail in report AIA CDP-RC. The technical reasons supporting them and the precise regulation language are given in report AIA CDP-RC. They are also discussed in the four technical reports of the AIA series of seven reports on the AIA Crashworthiness Development Program.

In certain technical areas, concepts that show promise were developed and tested, but not enough data were obtained to determine their feasibility for aircraft use or if they would be beneficial in increasing a passenger's chance of survival. Research on the following concepts would be required to supplement the AIA data so that a conclusion can be reached:

- Smoke and noxious-gas emission from materials
- Fire-resistant, low-smoke- and noxious-gas-producing thermoplastics and seat cushions
- Smoke hoods
- Fire curtains
- Reporting and postmortem criteria for accidents involving fire
- Auditory localization of emergency exits in an adverse visual environment
- Passenger warning and crew communication systems
- Mechanical escape devices
- Inflatable slide fabrication and materials

In addition to these items, the AIA recommends:

- Research on automatic takeoff and landing control systems that would reduce human error and, therefore, reduce the number of accidents
- Acceleration of studies of ways and means to eliminate or reduce hazards of burning fuel

Although the results of the AIA Crashworthiness Development Program are significant within the context of the program, they do not strike at fundamental problems–prevention of the crash and reduction of the hazard from the primary contributor to a fire, the jet fuel itself.

The AIA does not propose to continue its Crashworthiness Development Program to accomplish additional work in research and development. Such research and development should be coordinated and funded by a central Government agency. The result would be beneficial to much of the transportation industry as well as other industries and the military services.

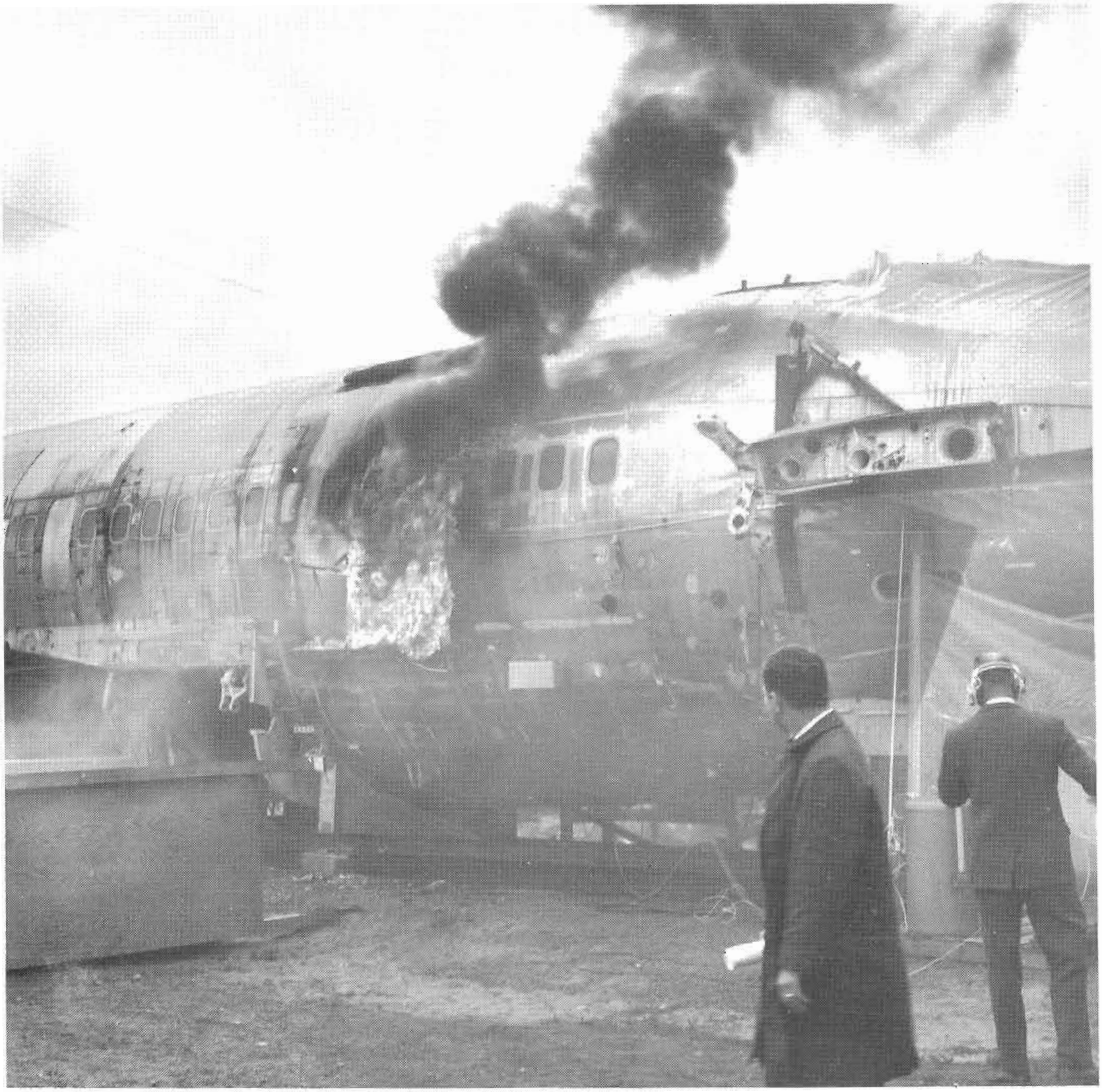
Table 1. Technical Summary–AIA Crashworthiness Development Program

AIA REPORT	TECHNICAL AREA	PROGRAM	SIGNIFICANT STUDIES AND TESTS
CDP 1	Materials	Material survey and short-term development	1,385 survey charts sent to 336 manufacturers
		Flammability testing	20,000 specimens burned in evaluating 12 test methods
		Smoke testing	Several hundred specimens tested in XP2 and NBS smoke chambers
		Noxious gases	Literature Survey Individual Material Tests Mockup Tests
CDP-2	Fire Suppression and Smoke and Fume Protection	Accident Evaluation	Reviewed industry, FAA, and CAB reports of 170 jet airplane accidents, 1958 through 1966
		Fire suppression concepts water fog and foam, freon, self-extinguishing interior materials	52 fire tests in airplane fuselage sections with and without furnished interiors
		Fire barrier and smoke and fume protection fire curtains, passenger smoke protection hoods	Transparent fire curtain tested in full scale furnished fuselage section with exterior fire adjacent to rupture causing severe interior fire **Prototype devices tested in theatrical smoke and in hot fuel fire environments**
CDP-3	Emergency Lighting and Exit Awareness	LIGHTING Interior, exterior, slide, and ground illumination intensity, uniformity, and concepts EXIT AWARENESS: Exit signs; Tactile, Audible, and Visual Exit Locator Aids, Passenger Briefings SMOKE HOODS: Communication, visibility, and evacuation use	Individual and group human factors tests involving over 200 test conditions and approximately 1,400 people Over 2,000 evacuations of people without previous test experience from airplane mockup, with simulated emergency and control light and exit awareness concepts and conditions including smoke Analyzed passenger warning concepts
CDP-4	Evacuation Systems	Analyze current jet evacuation systems	Analysis of 134 jet aircraft evacuation tests for FAA certification Analysis of 137 CAB jet aircraft accident reports
		Research and development.	Analysis of evacuation flow Evacuation restraints study Inflation device development External device development Offwing evacuation studies

RESULTS	CONCLUSIONS
Instigated material development and produced self-extinguishing soft goods	Soft goods can meet a vertical self extinguishing requirement instead of horizontal burn rate
Vertical Bunsen burner most effective method for screening materials	Practical considerations dictate that vertical Bunsen burner test be basis for flammability regulation
Increased flame resistance increases smoke generation	Research needed to establish methods for selecting materials to minimize smoke emmission
Gas composition from burning materials varies as test conditions vary	Lab tests do not duplicate conditions in or data from mockup tests Elimination of noxious gases may not improve survivability
Fatalities attributed to fire in 12 accidents all these had exterior fuel fires, 10 also had significant fuselage rupture, total fires reported were 74, only 6 interior	Exterior fuel fire with fuselage break can produce overwhelmingly hostile environment. Exterior fire adjacent to fuselage rupture was selected as test condition
Agents effective to a degree against small interior fire Self-extinguishing materials suppress maximum temperature and its rise rate in small (less than 0.05 gpm of fuel) interior fire, exterior fire (less than 1 gpm of fuel) at fuselage rupture overwhelms self-extinguishment except when fire enters interior intermittently	Feasibility or effectiveness of built-in suppression system not established, self extinguishing interior materials effective under limited fire conditions
Curtain excluded hot gases and fire from compartment adjacent to that involved in fire	**Research would be required:** To determine effect of curtains on evacuation and in certain fire conditions
Hood seals not satisfactory, leakage quickly reduced effectiveness	To verify smoke hood effectiveness and use in realistic and stringent smoke environment
Subject's preference and evacuation performance generally improved by Brighter, more uniform emergency lighting Brighter, larger, uniformly lighted exit signs Passenger preadaptation to potential emergency light conditions Passenger briefings Tactile exit locator aids seldom used, audible locator delays people at exits that do not open Smoke hoods slow evacuation 30%, only 1/3 of people use	Results confirm general adequacy of FAR 25 and following improvements At least 0.01-ft-c aisle illumination High-reflectance overwing path Brighter, larger, uniformly lighted exit signs Placards to show location of nearest exit Research would be required to determine smoke hood, audible exit locator, and passenger warning system feasibility
Qualitative and quantitative level of system performance established Flow rates established Slide and inflation device improvements established	Current systems perform well Desirability of FAR 25-15 rules confirmed Automatic deployment and erection at all floor-level exits in new certificated airplanes should be required Multiaisle interior improved flow rates

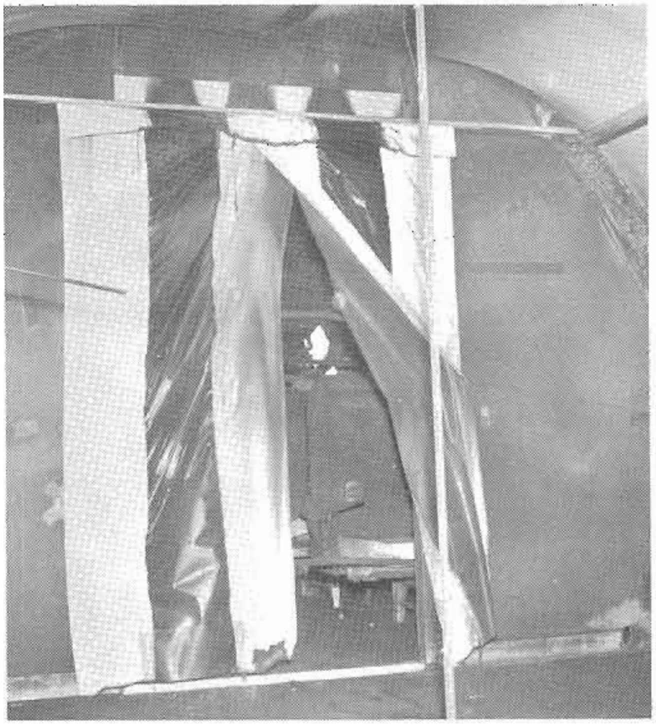
*(a) Full-Scale Fire Test Fuselage Section—***Windshield in Place** *Around Fuel Pan Next to Fuselage Rupture for Furnished Interior Materials Test*

Figure 2. Program Activity—Materials and Fire, and Smoke and Fume Protection



(b) External Fuel Fire– Less than 1 Gpm Burning in a 6.25-Sq-Ft Pan

Figure 2. (Continued)

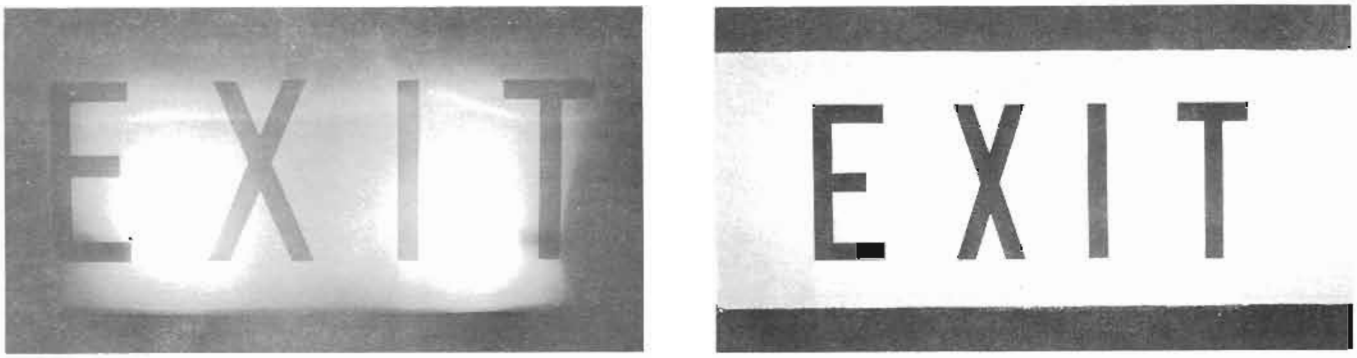


(f) Smoke Damage to Ceiling over Fire Curtain after Fire (Small extent of damage shows effectiveness of curtain in confining fire to involved compartment.)

(g) Smoke-Hood Test Subject in Position for Exposure to Jet-Fuel Fire

(h) Breath Sample Being Taken after Exposure of Smoke-Hood Test Subject to Jet-Fuel Fire

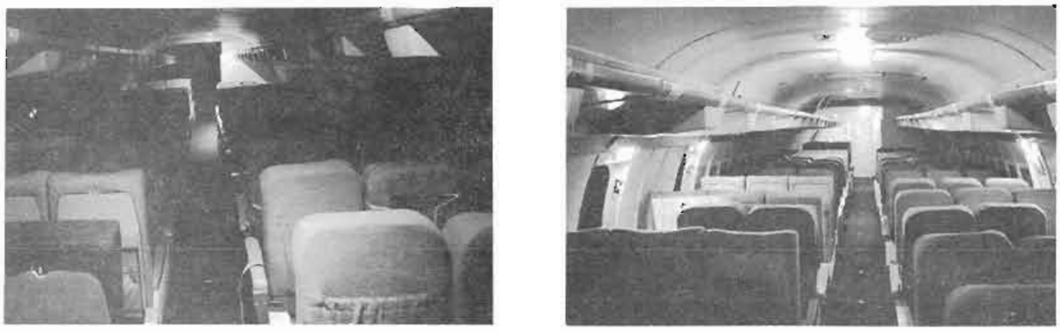
Figure 2. (Concluded)



CURRENTLY IN USE

EXPERIMENTAL

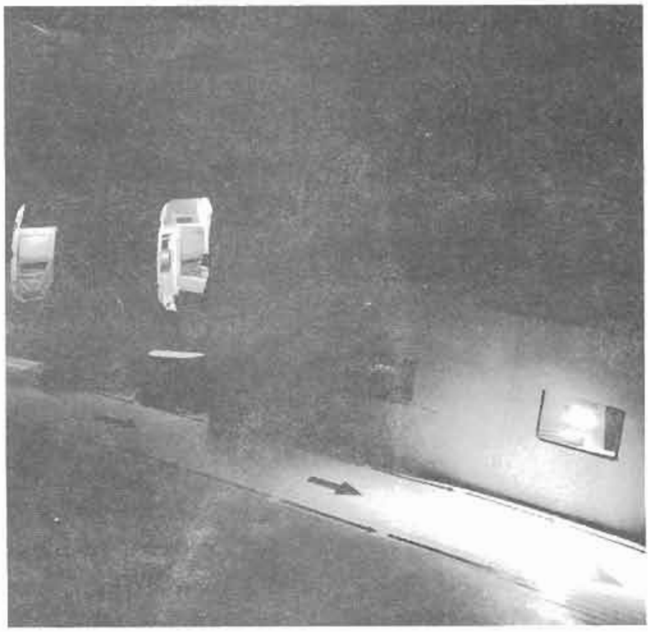
(a) Exit Signs That Were Tested, Shown in Simulated Partial Smoke



AVERAGE ILLUMINATION
CONTROLLED (0.05 ft-c AVERAGE)

UNIFORMITY OF ILLUMINATION
CONTROLLED (0.1 ft-c
AVERAGE, 0.01 ft-c MINIMUM)

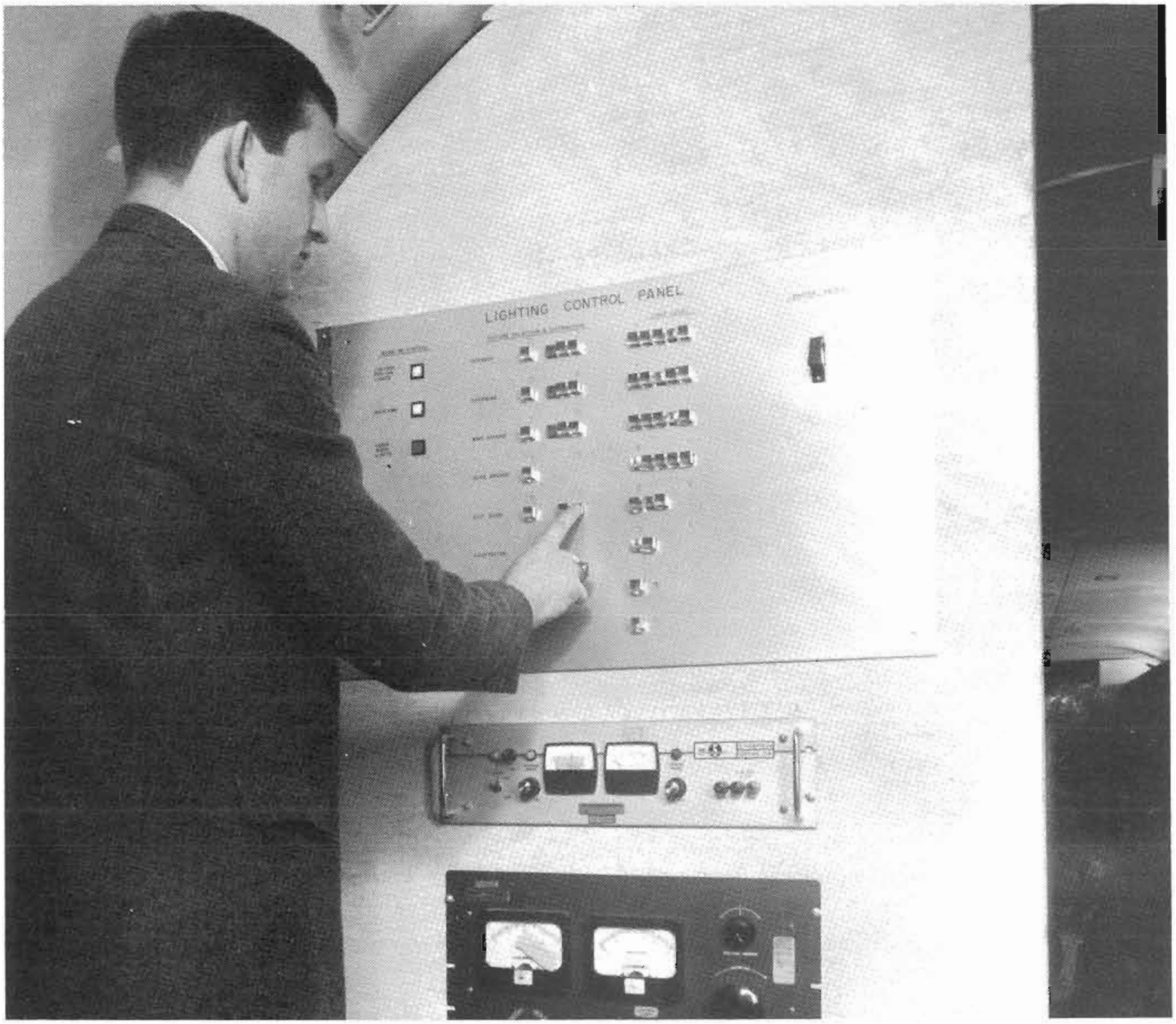
(b) Interior Lighting, Illustrating Two Lighting Conditions Tested



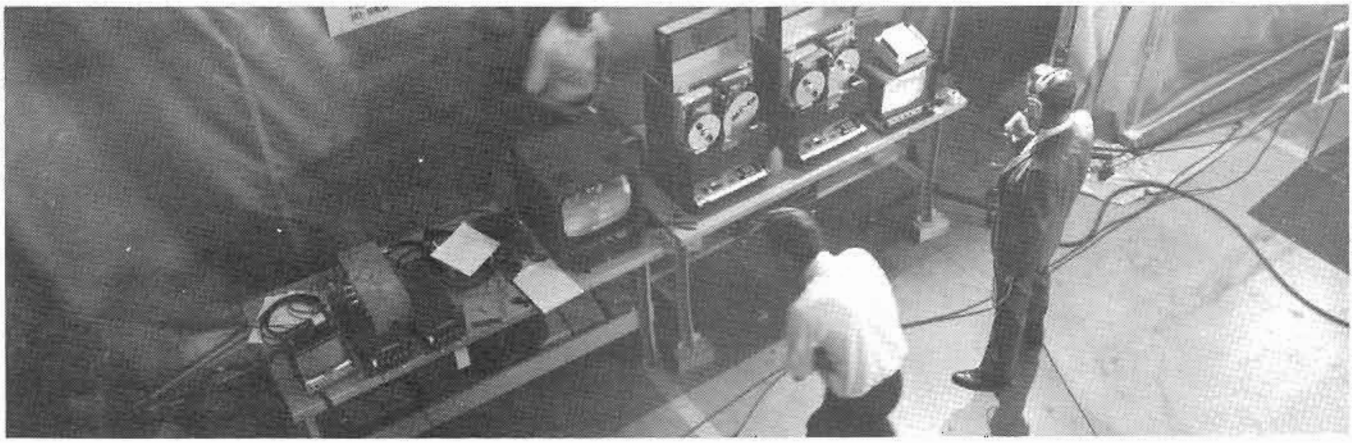
(c) High-Reflectance Overwing Path with FAA Minimum Illumination

(d) Test Subjects Entering Mockup

Figure 3. Program Activity – Lighting and Exit Awareness



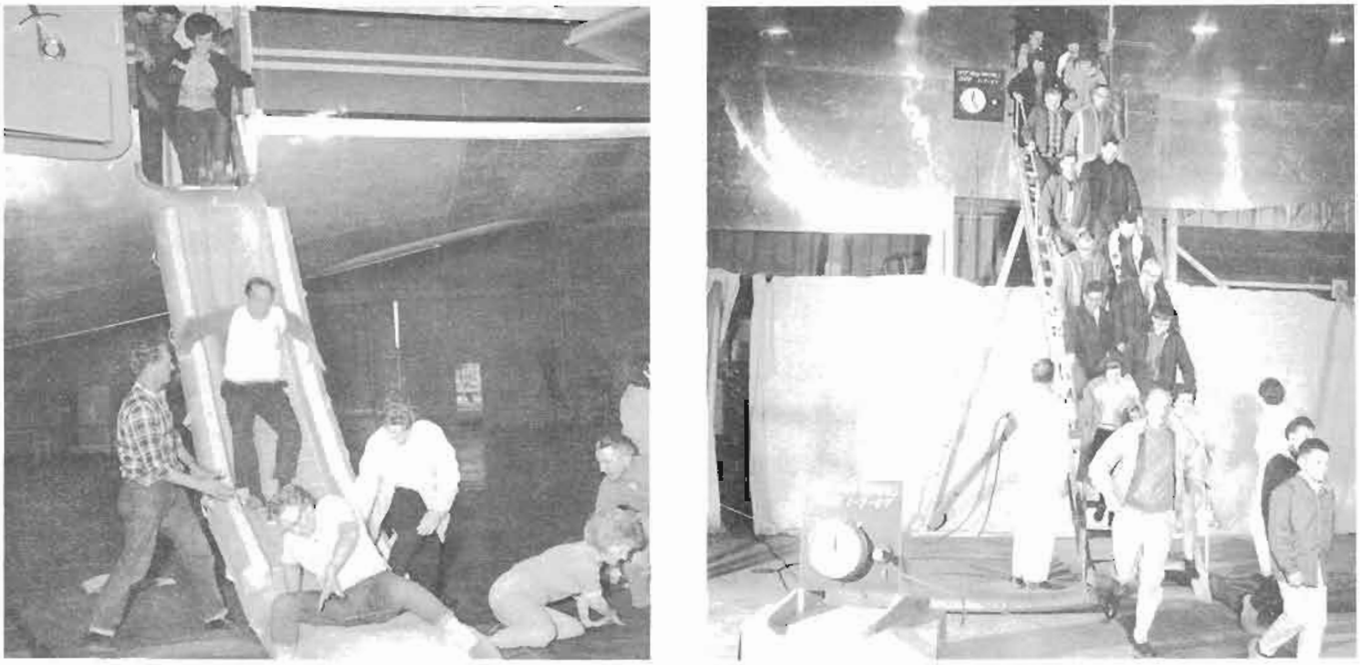
(e) Programmable Control Panel for Controlling Lighting Inside Passenger Mockup and Lightproof Tent



(f) Infrared Television Monitor and Tape Recorders Set Up Outside Lightproof Tent

Figure 3. (Concluded)

DOUBLE-LANE SLIDE

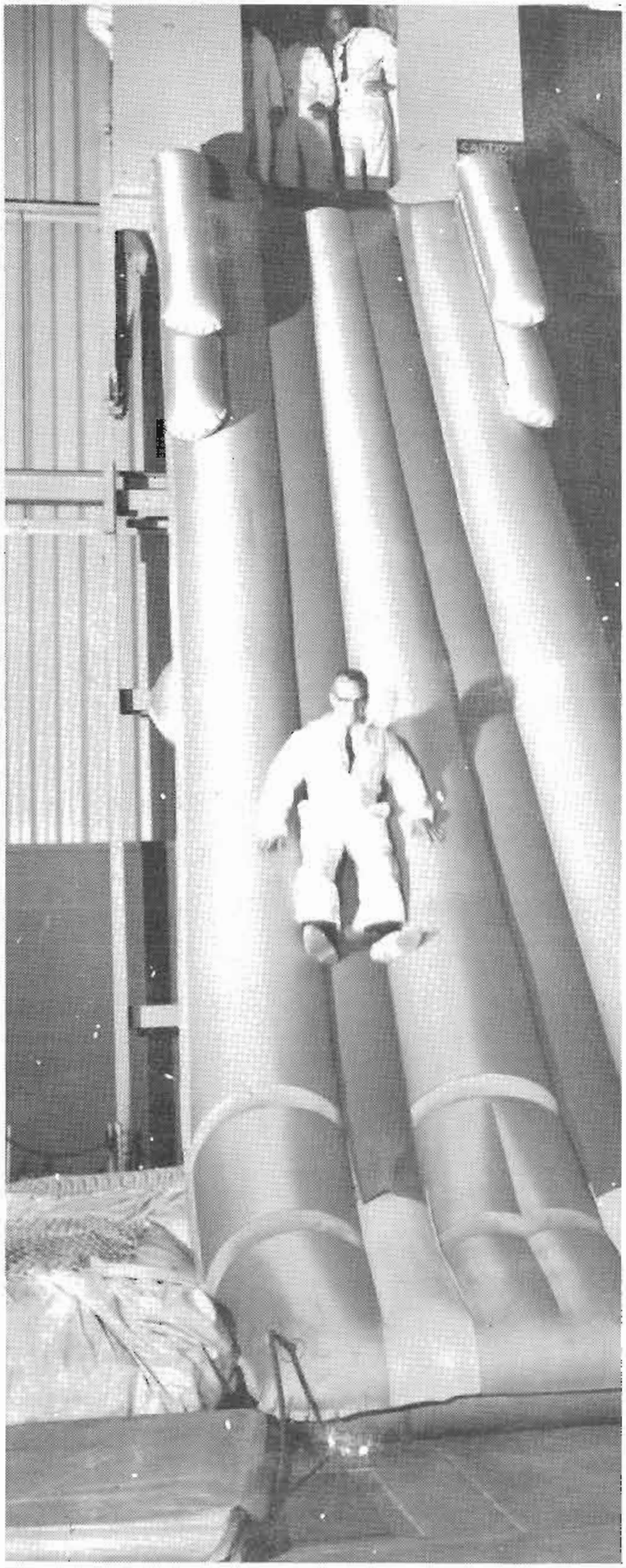


IN-SERVICE SLIDE

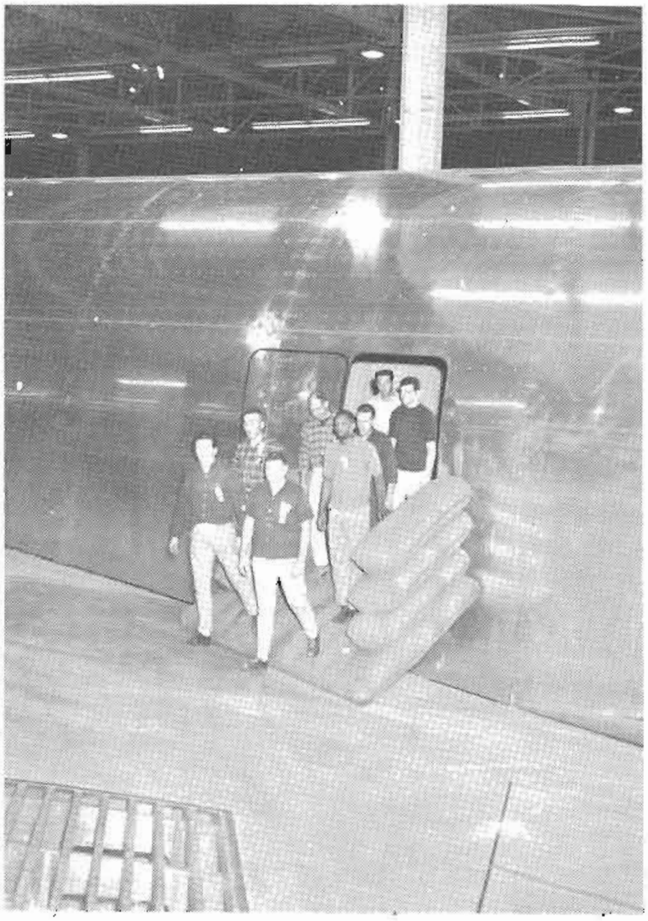
DOUBLE-LANE STAIR

(a) Evacuation Tests—Current and Advanced Equipment

Figure 4. Program Activity—Evacuation



IMPROVED DOUBLE-LANE SLIDE



OVERWING RAMP

FOLDING METAL STAIR

(b) Research and Development

Figure 4. (Concluded)

3.0 DISCUSSION

Summarized herein is the technical work accomplished in each technical area of the AIA Crashworthiness Development Program. This work is reported in detail in reports AIA CDP-1, -2, -3, and -4 which deal, respectively, with interior materials, fire suppression and smoke and fume protection, lighting and exit awareness, and evacuation systems studies and tests.

3.1 Materials

The materials study and test program consisted of: (1) a nationwide survey of material suppliers to verify the state of the art known to the aircraft industry, (2) extensive flammability testing, and (3) study and test of smoke and noxious-gas emission from materials subjected to high temperatures and flame. Significant program accomplishments are summarized in Table 2. Figure 5 illustrates the scope of this technical activity. Flammability testing in full-scale fuselage sections and mockup fire tests is discussed in Par. 3.2.

3.1.1 Material Survey

A nationwide survey of material suppliers was conducted to determine the state of the art of materials available for commercial aircraft in production quantities by June 15, 1968, and materials now under development, and available after that date.

The survey and material investigation showed that the aircraft industry knows the state-of-the-art materials suitable for use in airplanes and that materials are now available that exhibit a substantial increase in fire resistance. Results of the investigation have been that:

- The survey program made material suppliers aware of our needs. This instigated material development programs.
- New or improved self-extinguishing materials were found in the areas of soft goods (carpets and fabrics), structural panels, thermoplastics, and foams.
- Although progress has been made, further research is needed to develop materials that meet all functional requirements and are self-extinguishing, nonsmoking, and nontoxic. The greatest needs are in thermoplastics, seat cushions and padding, decorative and industrial coated fabrics, and seat belt webbing.

3.1.2 Flammability Testing

Both analytical and empirical test methods were examined as a part of the materials development program, and more than 20,000 separate test specimens were burned in studying 12 test methods. Additional methods were found in the literature. Test methods were found that were more meaningful than the horizontal Bunsen burner test. Some of these methods are suitable for basic research; others have characteristics that limit qualifying materials on a categorical basis. Other test methods are limited to material constructions or applications. A vertical Bunsen burner test with an ignition time longer than what is now required by regulation is recommended for critical flame propagation surfaces of an airplane. A more severe test is imposed by using a longer ignition time. Flame temperature, self-extinguishing time, and maximum burn length should be measured.

Large-scale flammability tests conducted in airplane mockups furnished with both present in-service and improved lower flammability materials are discussed in Par. 3.2.

3.1.3 Smoke Testing

Various methods of measuring smoke were evaluated. The XP2 and NBS smoke test chambers were used to obtain data. It is concluded that:

- A meaningful regulation on smoke emission cannot be proposed because of insufficient data.
- No correlation currently exists between the XP2 and NBS smoke test chambers.
- Flame-retardant additives generally increase smoke emission. Materials that are both nonsmoking and nonflammable are not generally available.
- Research should be conducted into the chemistry of materials to determine the mechanisms that cause materials to produce smoke.

Table 2. Technical Summary–Materials

PROGRAM ELEMENTS	SIGNIFICANT STUDIES AND TESTS
MATERIAL SURVEY AND DEVELOPMENT Determine best fire-resistant materials commercially available and initiate short-term development	22 categories of 106 materials 1,385 charts sent to 336 manufacturers
FLAMMABILITY TESTING	20,000 test specimens burned in evaluating 12 test methods; additional methods found in the literature
SMOKE TESTING	Several hundred specimens examined in both XP2 and NBS smoke test chambers Smoke data also obtained in ASTM E 84 tunnel and ASTM E 162 radiant-panel tests Visual observations of smoke made during Bunsen burner tests and during mockup fire tests
NOXIOUS GASES Develop methods for measuring noxious gases generated from burning materials and study physiology of noxious gases	Literature survey Methods for gas analysis Methods for gas generation from individual materials Gas sampling from individual materials tests Gas sampling from mockup tests

RESULTS	CONCLUSIONS
106 responses to survey Instigated material development programs by manufacturers Developed self-extinguishing carpets, upholstery, and seat foams	Aircraft industry is aware of materials developments Soft goods can meet a self-extinguishing regulation Development work remains to produce low-smoke-producing, low-noxious-gas-producing, fire-resistant materials
The vertical Bunsen burner test is a simple and practical method of screening materials The ASTM E 162 radiant-panel test is more discriminating than the Bunsen burner test Other test methods were more suited to basic research	Practical considerations dictate that the vertical Bunsen burner test be the basis of any new flammability regulation The ASTM E 162 apparatus is presently uncommon and expensive Further research is required in the basic combustion mechanisms of materials
Data from the XP2 and the NBS chambers do not correlate with each other at present. Further work is necessary to establish methods for selecting materials that minimize smoke and gas emission	Because of insufficient data, no meaningful smoke regulations can be proposed at this time. Almost without exception, increased flame resistance has been achieved at the expense of increasing smoke emission The ability to simultaneously reduce flammability and smoke emission requires further research and development
Data on effects of combined gases is nonexistent Gases from individual materials vary as test conditions vary Data on individual materials do not indicate the amount given off in mockup tests Improvement in fire-resistance decreases noxious-gas generation rate in small ignition fire tests Improved fire-resistant materials do not reduce noxious-gas buildup in large fire ignition tests	Laboratory tests do not reproduce conditions in airplane fires R & D is required to determine physiological effects of combinations of noxious gases Noxious gases travel in clouds and are not uniformly distributed Elimination of noxious gases may not improve survivability

3.1.4 Noxious Gases

The study of noxious gases is an extremely complex problem:

- Gaseous decomposition products of a fire vary from moment to moment, from fire to fire, and with temperature and atmosphere. The same material can give off different gases under different conditions in one fire.
- The literature generally agrees that in any fire situation, carbon monoxide production and oxygen depletion are important factors affecting human endurance. However, insufficient applicable knowledge as to the severity of their combined effect is available, especially in relationship to the short duration of exposure associated with airplane evacuation times.
- Noxious gases of one kind or another are emitted during the combustion of all organic materials and, regardless of improvements in materials, a fuel-fed fire will result in heat, oxygen depletion, and noxious gases.
- There is no single technique that is accurate for analyzing all of the likely candidate gases.

Mockup fire tests, using a small ignition source, comparing specific old versus new materials indicate that the available new materials used in a particular configuration reduced the rate of noxious-gas buildup. However, replacement of materials that could potentially produce HCl and HCN with other organic materials would probably result in higher carbon monoxide levels or higher temperatures and faster fire propagation and, therefore, provide no improvement in survivability. Self-extinguishing, fire-resistant properties are probably the most important material characteristics in terms of survivability.

3.2 Fire Suppression and Smoke and Fume Protection

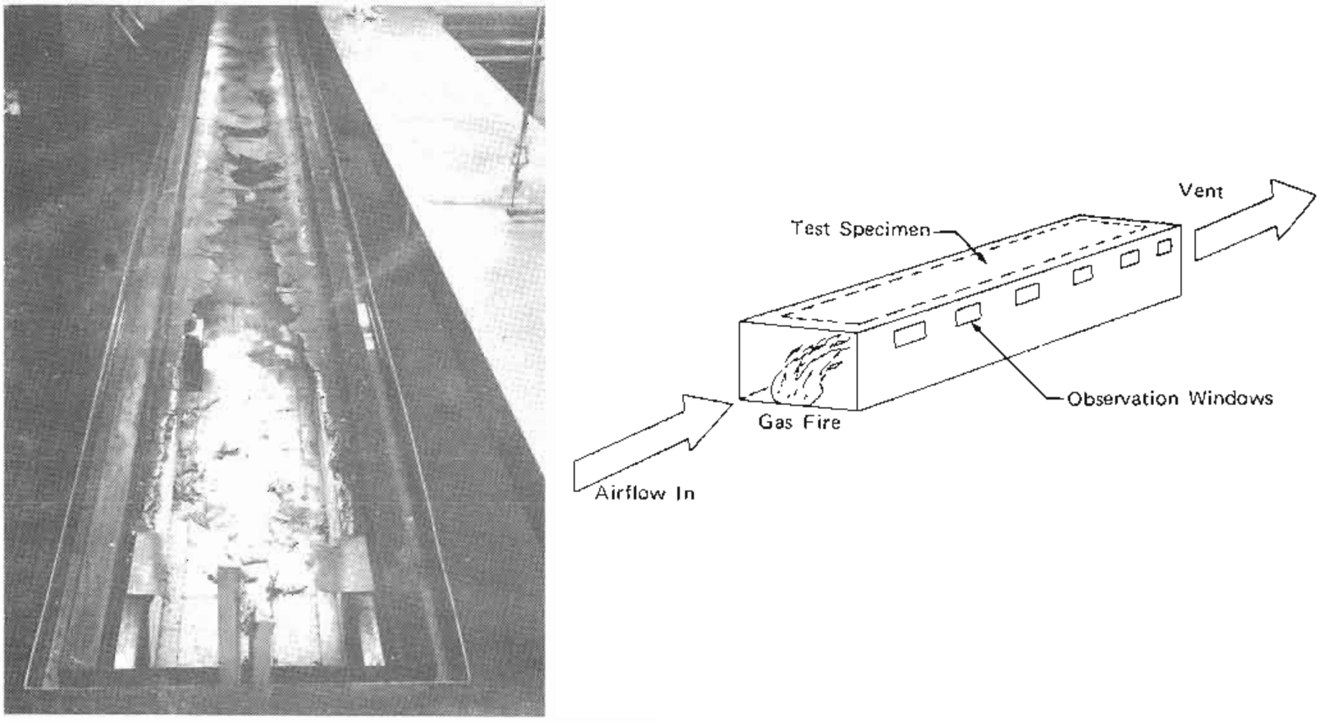
This program included an analysis of jet aircraft accidents for conditions involving fire; studies and tests of potential fire-suppression system agents and devices; and tests of fire stops, compartmentation concepts, and individual passenger smoke masks or hoods. The program also included large-scale material flammability testing in airplane fuselage sections furnished with various combinations of interior materials. Some significant aspects of the program are summarized in Table 3. The testing activity that led to the results and conclusions shown is illustrated in Fig. 6.

The most significant conclusion of the fire suppression program is a negative one. It is that a relatively modest size, jet fuel fire that involves as little as a gallon of fuel burning per minute under certain conditions presents an extremely hostile thermal environment against which to protect. No active fire suppression system using extinguishing agents was found to be effective enough to be suitable for aircraft use at this time. Flammability testing of interior materials in small and large airplane fuselage sections, exposed to interior and exterior fuel fires, indicated that improved self-extinguishing materials will suppress flame propagation under certain quite limited fire conditions. From experience gained in fire testing in this program, it has become easy to understand how actual crash fires can exhibit such marked differences in characteristics and resulting damage.

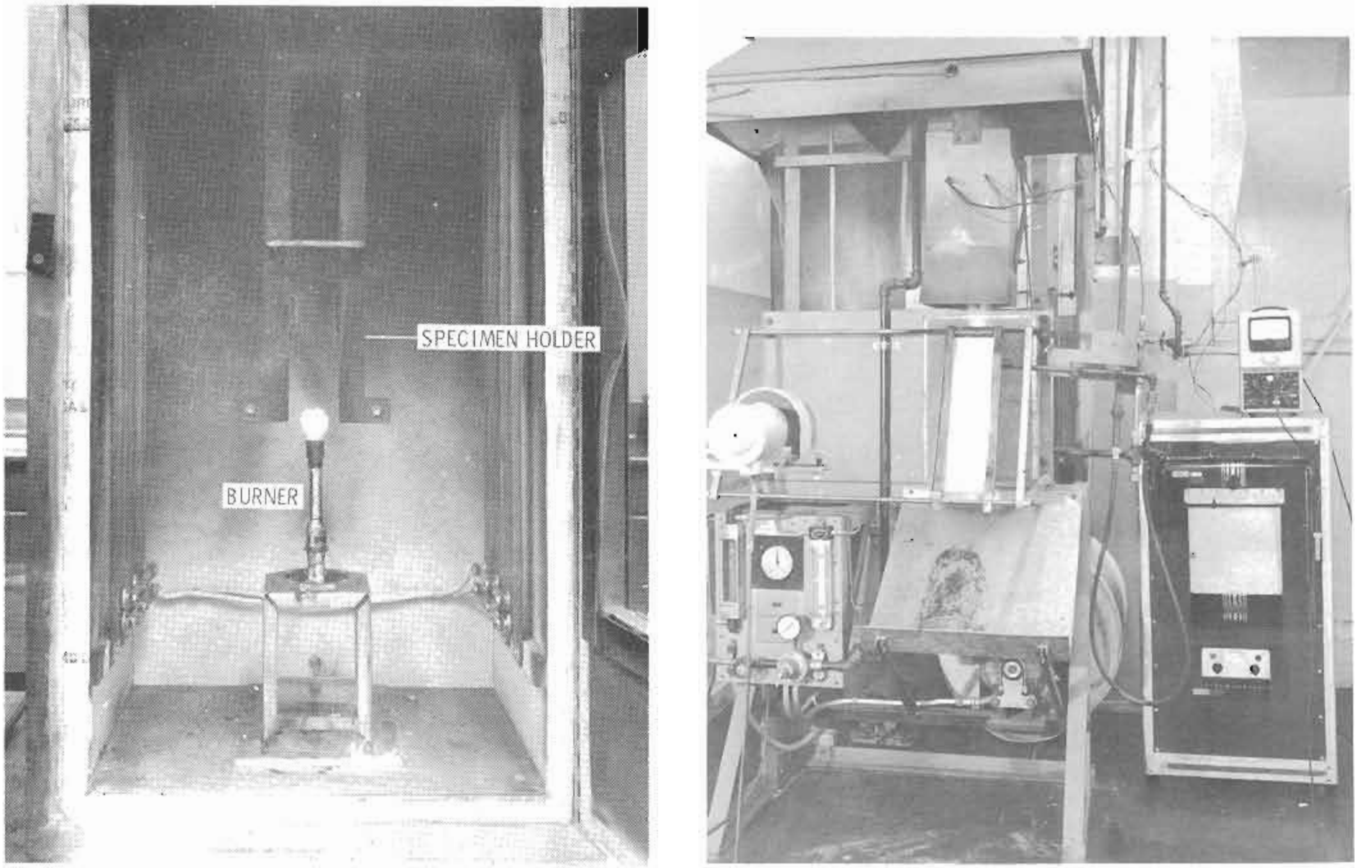
Investigations of fire compartmentation curtains and passenger smoke hoods were carried to the point that it was decided they showed promise. However, additional data are required before it can be concluded that they could be made feasible for aircraft incorporation. Work statements for the investigations that would be required to obtain the additional data needed to conclude their feasibility are in report AIA CDP-R&D.

3.2.1 Accident Evaluation

Reports of 170 jet aircraft accidents occurring from 1958 through 1966 indicated that all deaths attributed to fire occurred in 12 accidents with large fuel fires. In 10 of these 12 accidents, there were breaks in the fuselage through which the fire could enter. An exterior fuel fire adjacent to a simulated fuselage rupture was therefore selected as a realistic test condition.



25-FT FLAMMABILITY TEST TUNNEL

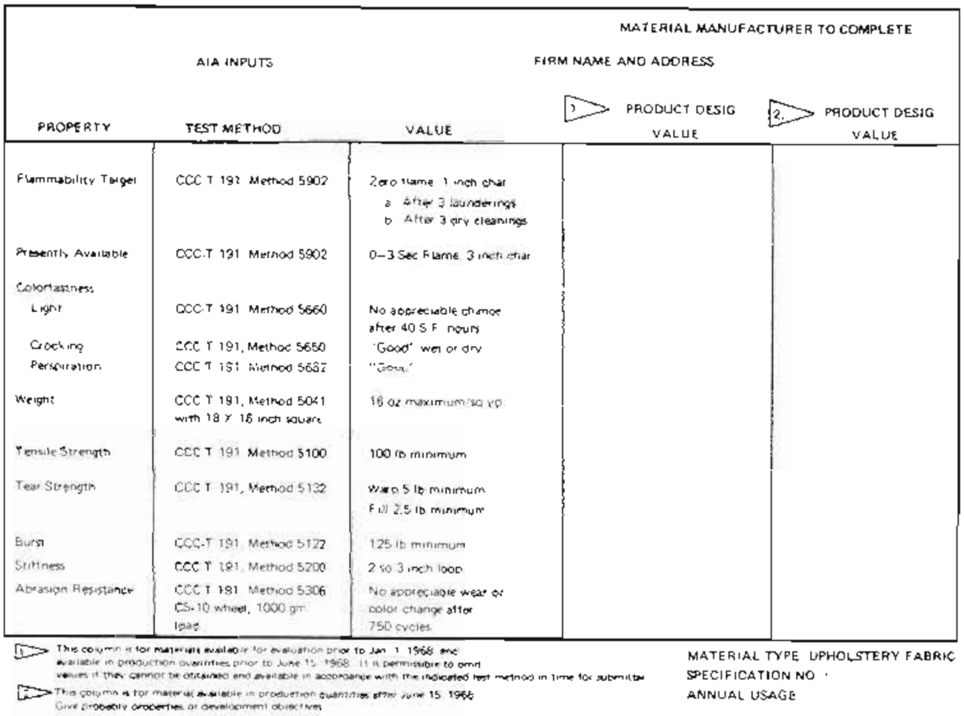


BUNSEN BURNER–VERTICAL TEST

RADIANT PANEL

(a) Flammability Testing

Figure 5. Program Activity–Materials



PROPERTY	TEST METHOD	VALUE	▷1 PRODUCT DESIG VALUE	▷2 PRODUCT DESIG VALUE
AIA INPUTS			MATERIAL MANUFACTURER TO COMPLETE FIRM NAME AND ADDRESS	
Flammability Target	CCC-T-191, Method 5902	Zero flame, 1 inch char a. After 3 launderings b. After 3 dry cleanings		
Presently Available	CCC-T-191, Method 5902	0–3 Sec Flame, 3 inch char		
Colorfastness				
Light	CCC-T-191, Method 5660	No appreciable change after 40 S.F. hours		
Crocking	CCC-T-191, Method 5650	"Good" wet or dry		
Perspiration	CCC-T-191, Method 5687	"Good"		
Weight	CCC-T-191, Method 5041 with 18 X 18 inch square	16 oz maximum/sq yd		
Tensile Strength	CCC-T-191, Method 5100	100 lb minimum		
Tear Strength	CCC-T-191, Method 5132	Warp 5 lb minimum Fill 2.5 lb minimum		
Burst	CCC-T-191, Method 5122	125 lb minimum		
Stiffness	CCC-T-191, Method 5200	2 to 3 inch loop		
Abrasion Resistance	CCC-T-191, Method 5306 CS-10 wheel, 1000 gm load	No appreciable wear or color change after 750 cycles		

▷1 This column is for materials available for evaluation prior to Jan. 1, 1968 and available in production quantities prior to June 15, 1968. It is permissible to omit values if they cannot be obtained and available in accordance with the indicated test method in time for submittal.

▷2 This column is for material available in production quantities after June 15, 1966. Give probably properties or development objectives.

MATERIAL TYPE UPHOLSTERY FABRIC
SPECIFICATION NO.
ANNUAL USAGE

REPRESENTATIVE MATERIAL SURVEY CHART

NBS CHAMBER

XP2 CHAMBER

(b) Smoke and Noxious-Gas Testing

Figure 5. (Concluded)

3.2.2 Fire Suppression Concepts

Fire suppression concepts selected for test included built-in concepts using water (as fog or foam) and Freon 1301 as extinguishing agents. These agents were effective to some degree under relatively limited fire conditions. None of the concepts studied have yet proved effective or suitable for aircraft use.

Improved self-extinguishing materials, indicated to be such by laboratory Bunsen burner flammability tests, and those presently in service were used to furnish the interiors of aircraft fuselage sections for comparative fire tests. Testing has shown that improved fire-resistant materials are effective in providing a reduced rate of temperature rise within an airplane interior subjected to a fuel-fed fire, *provided the fire is small* or is burning in such a way that flames are only intermittently entering the interior passenger compartment. This reduced rate of temperature rise somewhat extends the time available for escape from such a fire condition.

Figure 7 compares the results of two separate test fires, each of which used a fire burning in a 1-sq-ft fuel pan in a small mockup. In one fire test, the mockup contained certain materials presently used on in-service airplanes: in the other, it contained new, improved materials being used on the newest in-production airplanes like the Boeing 747. For these specific tests, the rate of temperature rise over a 3-min interval was reduced by about 50 percent through the use of new materials. The maximum temperature was reduced about 50 percent, and it occurred at a somewhat later time for the improved materials than for present materials. Fuel was consumed in these tests at a rate of less than 0.05 gpm.

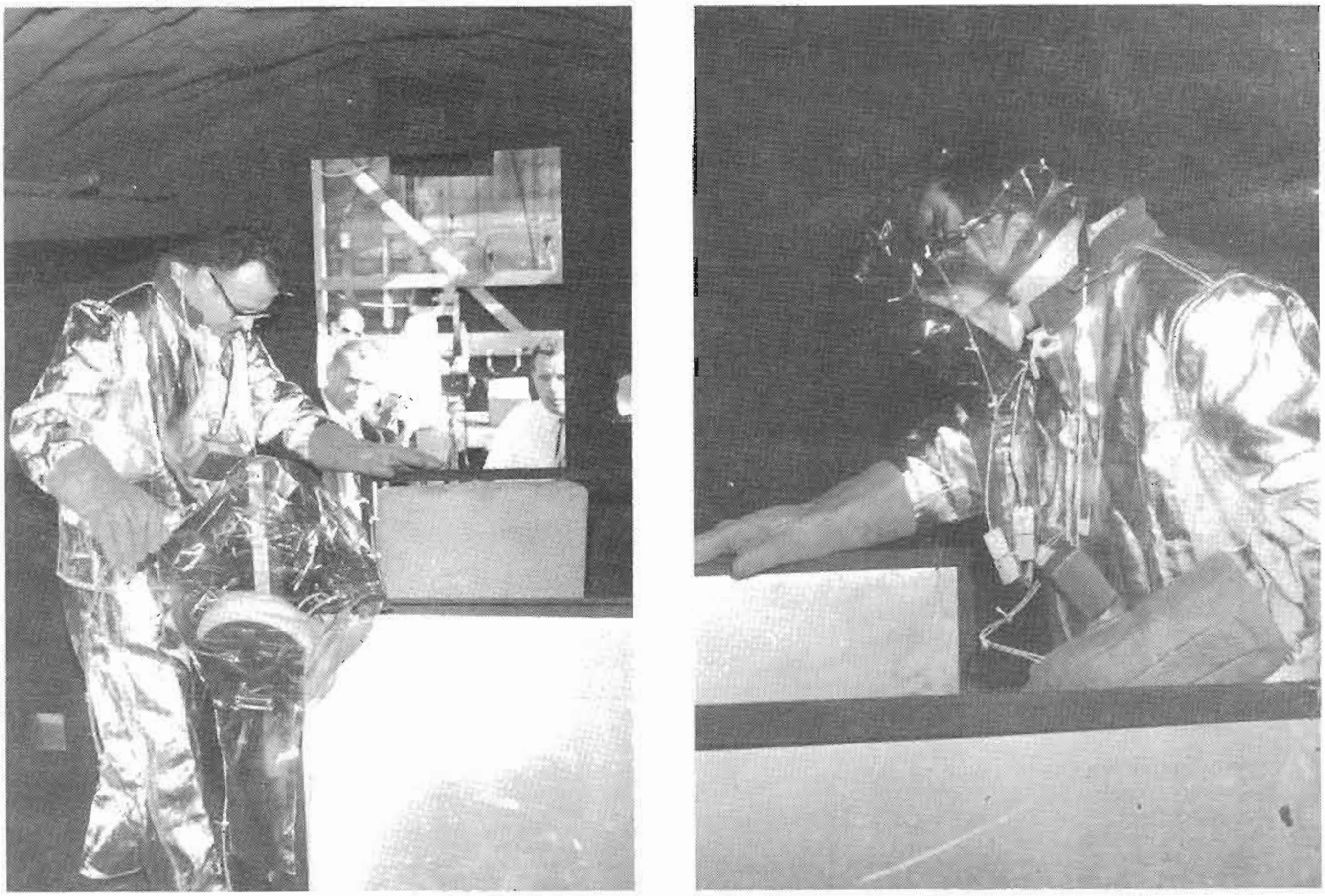
(a) External Fuel Fire -6.25-Sq-Ft Fuel Pan for Flammability Test of Interior Materials

Figure 6. Program Activity–Fire Suppression and Smoke and Fume Protection

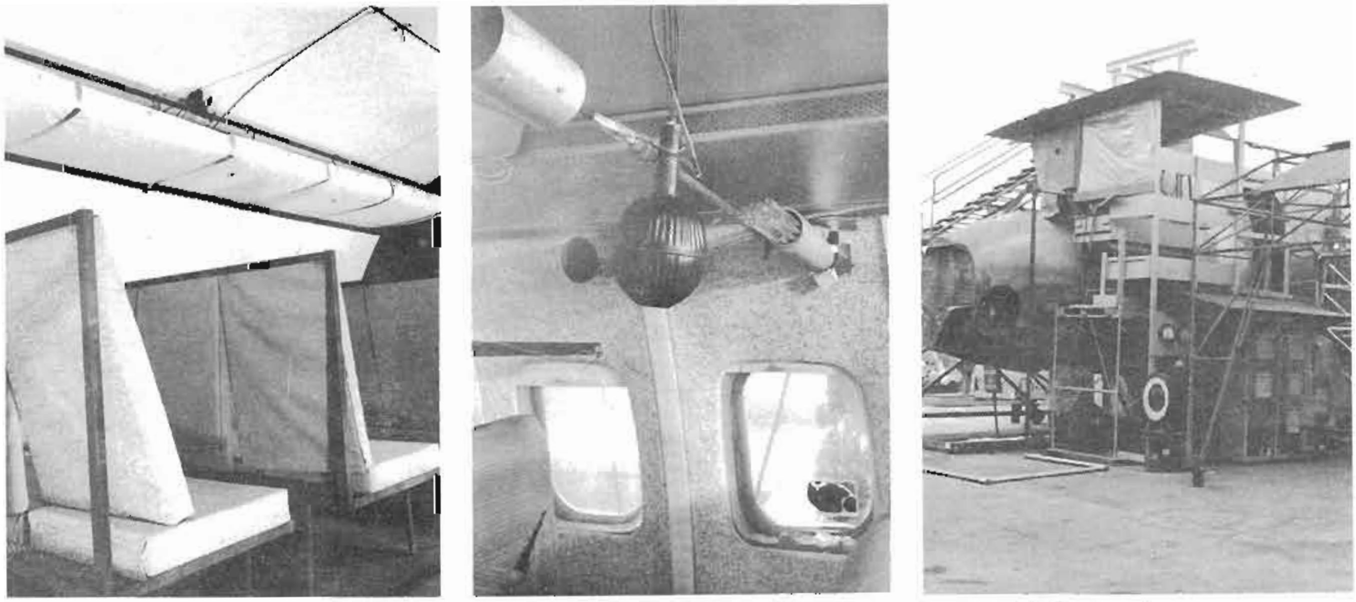
Table 3. Technical Summary—Fire Suppression and Smoke and Fume Protection

PROGRAM ELEMENTS	SIGNIFICANT STUDIES AND TESTS		
ACCIDENT EVALUATION	Reviewed industry, FAA, and CAB reports of 170 jet aircraft accidents, 1958 through 1966		
FIRE SUPPRESSION CONCEPTS	SUPPRESSION AGENT	NUMBER OF TESTS	TEST CONDITIONS
Built-in extinguisher concepts	Water fog—with and without additives	5	Interior fire in mockup or exterior fire adjacent to puncture in full-scale fuselage section, unfurnished and furnished interiors
	Freon 1301	7	
	High-expansion water foam (air entrapped in water with detergent)	12	
Fire-resistant interior materials	Some of above agents tested following determination of material characteristics	9	
	Baseline control fires (for comparison with materials and suppression tests)	19	
Hand-held hose extinguisher	Water fog and high-expansion foam	9	96 sq ft fuel pan fire
FIRE BARRIERS AND SMOKE AND FUME PROTECTION Fire curtains	Tested in full-scale furnished fuselage section with exterior fuel fire adjacent to fuselage rupture causing severe interior fire		
Passenger smoke protection hoods	Prototype hoods tested in theatrical smoke and one in hot fuel-fire environment Airplane evacuations conducted using 40 people each in 13 tests with 3 prototypes		
SUPPORTING STUDIES Human compatibility—Freon 1301	More than 51 animal exposures More than 20 human exposures		
Emergency Fire Procedure	Review of NFPA and airline emergency procedures and manufacturers operation and maintenance manuals		

RESULTS		CONCLUSIONS
CONDITIONS REPORTED	NUMBER OF ACCIDENTS	
Exterior fires	68	Large external fuel fire with extensive fuselage breakup produces overwhelmingly hostile environment Limited external fire adjacent to fuselage rupture may be a likely and tractable suppression design criterion, this criterion selected for follow-on tests Fire usually enters cabin through fuselage rupture; burn-through has not been a factor in accidents ? ?
Interior fires (not fuel)	6	
Fuel spillage	50	
Fuselage break or puncture	48	
Break or puncture plus fuel spill	34	
Fatalities attributed to fire (Fuel fire occurred in all of these)	12	
Large exterior fire plus fuselage break	10 (Of 12 above)	
Water Cooled hot interior gases Retarded interior fire growth Fog discharge mixed interior gases		Probably not effective against exterior fire at realistic fog flow rates achievable in airplane Fog discharge speeds spread of smoke and noxious fumes Cooling effect significant in small test fires
Freon Extinguished interior but not exterior fires Fires reignited as concentration went below 3% Freon discharge mixed interior gases		Could extinguish interior fire Little effect on small exterior fire Freon discharge speeds spread of smoke and noxious fumes
Exterior fire extinguished only after foam reached fuselage rupture Temperatures inside mockup reduced only after foam reached external fire		Foam flow rate with "airplane size" foam generator too slow to be effective Foam has little effect on conditions outside foam environment
Temperature rise rate and maximum temperature reduced 50% by use of low-flammability materials in small mockup with interior fire Ceiling fire propagation occurred at about 300°F higher temperature with low-flammability materials in large mockup with exterior fire		Self-extinguishing materials effective against propagation of small fire Relatively small fuel fire can overwhelm self-extinguishing materials under certain conditions
Fire fighter with sufficient room to maneuver and with protective clothing can extinguish fire with water fog. Partial extinguishment and reignition occurred with foam		Concept not practical with equipment tested
Curtain excluded fire and hot gases from compartment adjacent to that involved in fire		Curtains are effective against fire Research is required to determine curtain's effect on human survivability in compartment involved in fire and whether evacuation will be delayed
Hood seals unsatisfactory, leakage quickly reduced effectiveness. In hot fire test, subject lost consciousness after 130 to 140 sec apparently due to lack of oxygen Evacuation rates decreased about 30%. Only 1/3 of people used their hoods.		Prototypes tested are not recommended for use Research using realistic and stringent smoke test conditions with adequate safeguards is recommended
No body or tissue damage up to 2 hr at 20% volume concentration Inebriation starts at 10% (20 min) vol concentration		Further human tests could be conducted safely at up to 10% vol concentration, data not yet sufficient to establish exposure criteria
Procedures are generally satisfactory and consistent with experience gained in this program		Increased crew knowledge of crash fire characteristics should be emphasized



(b) Smoke-Hood Testing In Jet-Fuel Fire Environment



(c) Small Fire-Test Mockup with "Furnished" Interior Materials

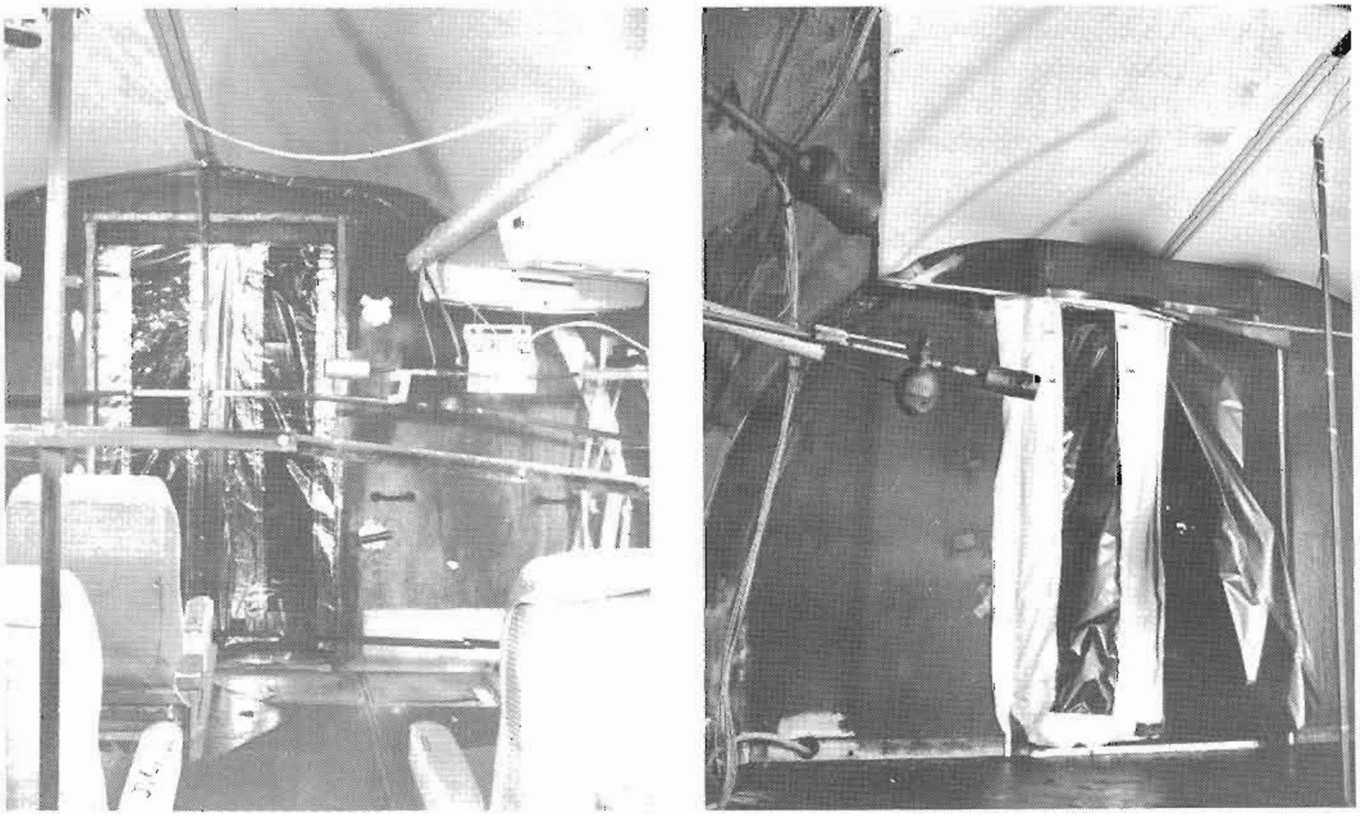
(d) Instrumentation for Full-Scale Flammability Tests—Shielded Thermocouples, Gas Sampling Tubes, Movie Camera Outside

(e) Facility for Water Fog and Foam Fire Suppression Tests

Figure 6. Program Acitivity—Fire Suppression and Smoke and Fume Protection (Continued)

(f) Short Fuselage Section for Materials, Suppression, and Smoke-Hood Tests

(g) Full-Scale Fuselage Section for Interior Materials Tests (Note gas-sampling apparatus)



(h) Transparent Compartmentation Curtains Before and After Fire

Figure 6. (Concluded)

Figure 8 illustrates test results from larger fires which, however, are still relatively much smaller than those that may occur in an airplane crash. In these tests, a 6.25-sq-ft fuel fire was burned adjacent to a 3-sq-ft hole simulating a crash puncture in the side of a large airplane fuselage section equipped with seats and interior furnishings. Fuel was consumed at less than 1 gpm. Here, improved materials did not reduce the measured rate of temperature rise. This rate was apparently determined by heat from the fuel fire entering the fuselage. A relatively small amount of burning fuel rapidly produces an extremely severe interior environment once hot gases from the fire enter the fuselage.

The only difference attributable to materials used in this test was that rapid flame propagation apparently occurred at about a 300°F higher temperature with the improved materials than with the present in-service type of materials. This is noted in Fig. 8. The difference in the recorded peak temperatures of the two curves illustrated in Fig. 8 is attributed to somewhat different fire conditions occurring in each test. In the test with improved materials, the fuel fire was observed to be larger and to have entered the fuselage at a higher rate of flow of hot gases from the fire. This fire is illustrated in Fig. 6. The higher sustained temperature following the peak temperature shown in Fig. 8 for new materials may also be attributable to the fire's being more hostile in this test.

Data obtained in the testing described above included bare and shielded thermocouple temperatures, motion pictures, and interior gas samples, which were later analyzed for gas constituents. Instrumentation for these data is illustrated in Fig. 6. In an attempt to evaluate comparative survivability, these gas and temperature data were utilized in an analytical model of human impairment that considers the combined effect of heat and noxious gases.

At this time, however, this analytical approach to physiological impairment is not yet sufficiently established to conclude with any certainty reliable specific trends or provide absolute measurements of human tolerance to such an environment. Results are inconclusive as to whether heat or noxious gases or fumes constitute the primary physiological impairment factor in an aircraft fire.

3.2.3 Fire Barrier and Smoke and Fume Protection

Testing accomplished indicates that two concepts show promise. These are transparent fire curtains to compartment a fire and individual passenger smoke hoods. Although they are promising concepts, data obtained in AIA-conducted testing are not yet sufficient to conclude their suitability or feasibility for aircraft use.

The fire curtain was effective in full-scale-mockup fires. These tests showed the ability of transparent, lightweight curtains to contain fire, heat, and noxious gases within the compartment involved. Curtains photographed before and after tests are illustrated in Fig. 6.

The possibility that appropriately located curtains would retard the flow of hot gases into the airplane by preventing continuous draft paths should also be assessed. Optimum locations relative to possible fire ingress points and evacuation routes remain to be determined. Configurations would need to be developed to be compatible with interior design and service requirements, and compartmentation devices would have to be tested under actual fire conditions with simulated wind and fire drafts.

None of the escape hoods or masks evaluated in this program were suitable as tested. Because of the adverse effects of high temperatures over the body, use of such a device must not increase evacuation time. These devices should be tested in actual fire conditions using instrumented dummies and while being worn by human subjects under conditions of high radiant and atmospheric temperatures in an irritating smoke environment.

Extreme caution and positive safety precautions are imperative in all realistic smoke hood effectiveness testing. In the hot jet-fuel fire environment tests illustrated in Fig. 6, the test subject lost

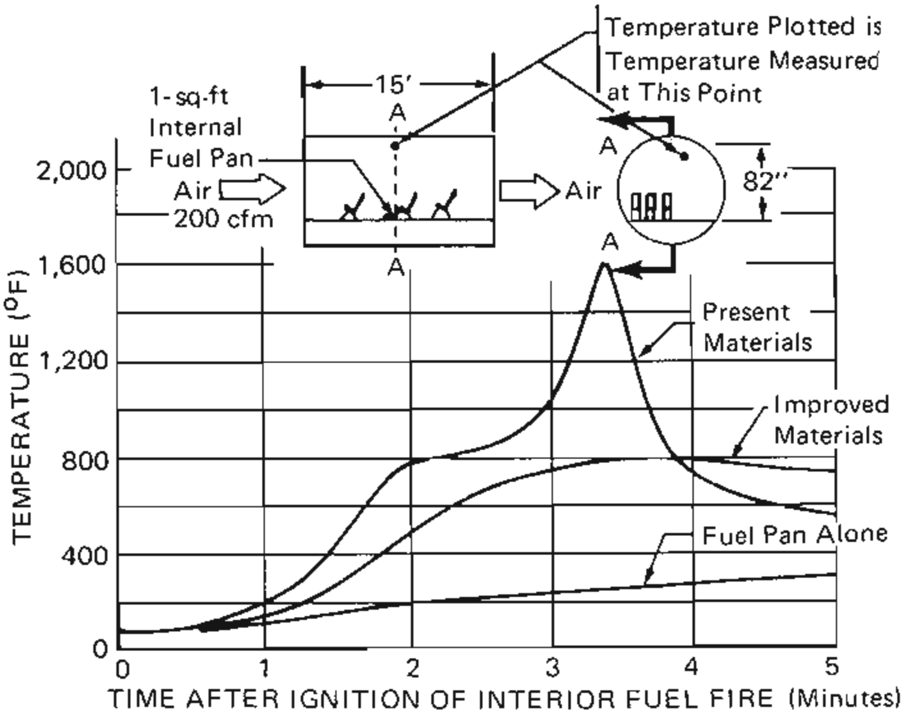


Figure 7. Effect of Improved Materials–Small-Mockup Fire Tests

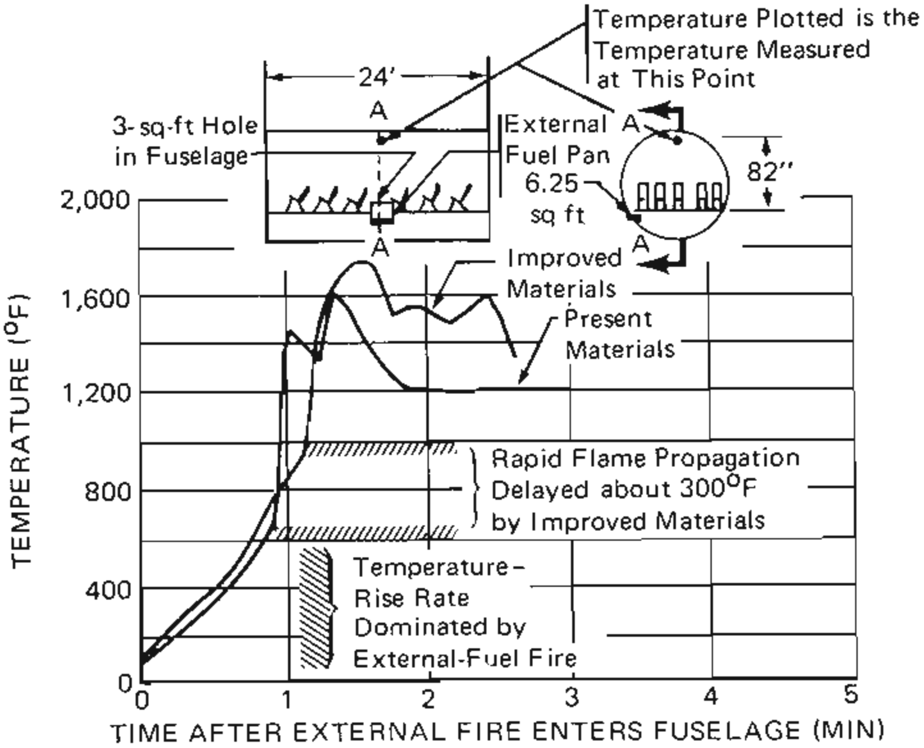


Figure 8. Effect of Improved Materials–Large-Mockup Fire Tests

consciousness during his fourth consecutive test exposure apparently from lack of oxygen after an exposure of 130 to 140 sec. The following precautions were in effect for these tests and are recommended if future similar tests are conducted:

- Manual and oral signal devices with a procedure requiring mandatory periodic response from subjects
- Medical and fire safety personnel standing by with self-contained breathing apparatus and resuscitator
- Provisions for quick access to subject so that he can be removed from fume environment

Any devices incorporated for fire protection should be developed for their minimum effect on evacuation time and thoroughly tested for this in mockups under realistic evacuation conditions. In evaluating the effectiveness of the devices, the time required to escape to a safe environment away from the fire, such as adjacent compartments, should be considered, as well as time required to escape overboard.

3.3 Lighting and Exit Awareness

Emergency lighting and exit-awareness concepts were investigated in two phases of human factors testing involving about 1,400 people. In the first phase, tests were designed to isolate certain variables related to emergency lighting and exit awareness to be later investigated in group evacuation tests. Lighting level and uniformity for the cabin aisle, exit areas, escape devices, and overwing and exit escape paths were evaluated to determine acceptable minimums. Exit awareness concepts tested included exit sign configurations and tactile and audible exit locator aids.

Concepts developed in the first phase were incorporated into the design of group evacuation experiments. These experiments were conducted in an airplane mockup with a furnished interior. Forty passengers per test condition were evacuated in simulated emergency environments. Over 750 people without previous test experience were used. Variables tested included cabin interior and exterior lighting levels and uniformity, exit sign configurations, audible and tactile evacuation aids, exit location placards, smoke hoods, and passenger briefing techniques. Table 4 summarizes certain results and conclusions of the two program phases. Figure 9 illustrates the scope of test activity in this program.

3.3.1 Emergency Lighting

Results of the first phase of the program generally confirmed the acceptability of FAA minimum interior and exterior lighting levels, with one exception—uniformity of interior aisle lighting. An average illumination of 0.05 ft-c is acceptable provided minimum aisle illumination is at least 0.01 ft-c.

In the group evacuation tests, an experimental lighting system, both interior and exterior, was compared to an interpretation of the FAA minimum system using the 0.05-ft-c average interior lighting with an uneven light distribution and with only incandescent exit marking and locator signs. Exterior lighting included a high-reflectance surface for the overwing path in addition to FAA minimum illumination. The experimental system provided 0.1 ft-c average illumination, with an 0.01-ft-c minimum distribution in the interior aisle and on the exterior wing path. Incandescent exit marking and locator signs were used in the aircraft interior.

The experimental system was found to be better than the tested FAA minimum lighting system. The tested FAA system is considered, however, to provide acceptable illumination. With the addition of experimental exit signs, substantial improvement in overall lighting and exit awareness is attained. Establishing a minimum of 0.01 ft-c for all aisles of the aircraft ensures a more uniform lighting in the interior. Standardization of ground lighting to the 0.03 ft-c already confirmed and required by the FAA for the ground end of slides or stairs and addition of a high-reflectance path extending over the entire overwing evacuation route are also recommended. Prominent markings showing the overwing evacuation route should be placed on this path.

Both individual and group studies showed beneficial effects from visual adaptation to low light levels prior to emergency evacuation. The effect was reported by test subjects to be more pronounced for the FAA minimum system tested. It was concluded that adaptation to a lower night lighting system prior to night takeoffs and landings could be potentially beneficial in the event of an accident requiring evacuation.

3.3.2 Cabin Flight Attendant Switch

A reliability analysis indicated that an auxiliary emergency lighting switch should not be placed in the flight attendant cabin area. It is recommended that a locking device, along with an annunciator light to indicate if the emergency system is not armed, be incorporated at the control presently required at a flightcrew station.

3.3.3 Exit Signs

Emergency exit and locator signs should have: a minimum of at least 25 ft-l in brightness, excluding the legend; a brightness high-to-low contrast ratio no greater than 3 to 1; a background-to-legend contrast ratio of at least 10 to 1; and a specific letter stroke width-to-height ratio. Background contrast ratio should be relatively even. Background-lighted signs are better seen in a dark environment than figure-lighted signs. Flashing of the exit sign does not increase its efficiency.

3.3.4 Tactile Evacuation Aids

Tactile cues were found feasible in tests of individual people. Group evacuation tests, however, showed such cues to be relatively ineffective. They were used infrequently, and additional time was needed to use them.

3.3.5 Audible Evacuation Aids

It was concluded from tests of individuals that audible aids were effective in locating exits in a dark smoke environment. These aids were effective also in group evacuations. A voice cue was better than a horn. However, although the audible aid concept has merit, further feasibility research and development would be required to find ways of mechanizing such a system to avoid the tendency to delay a passenger at an exit that will not open and to avoid stereophonic (poor localization) effects at doors that are close together or opposite each other.

3.3.6 Exit Location Placards

These aids were effective in getting people to an exit in a dark smoke environment. Placards were noted to draw attention to an exit, give direction and instructions in an emergency, and control exit distribution. Exit location placards were the most used of all evacuation aids tested for use in a dark smoke environment.

3.3.7 Smoke Hoods

Smoke hoods, as presently designed, lead to approximately 30-percent slower evacuation rates in group tests. This decrease in rate was obtained even with relatively infrequent (34 percent) usage. It was concluded that the present hood concepts tested could constitute a safety hazard if incorporated in commercial airplanes.

3.3.8 Passenger Briefings

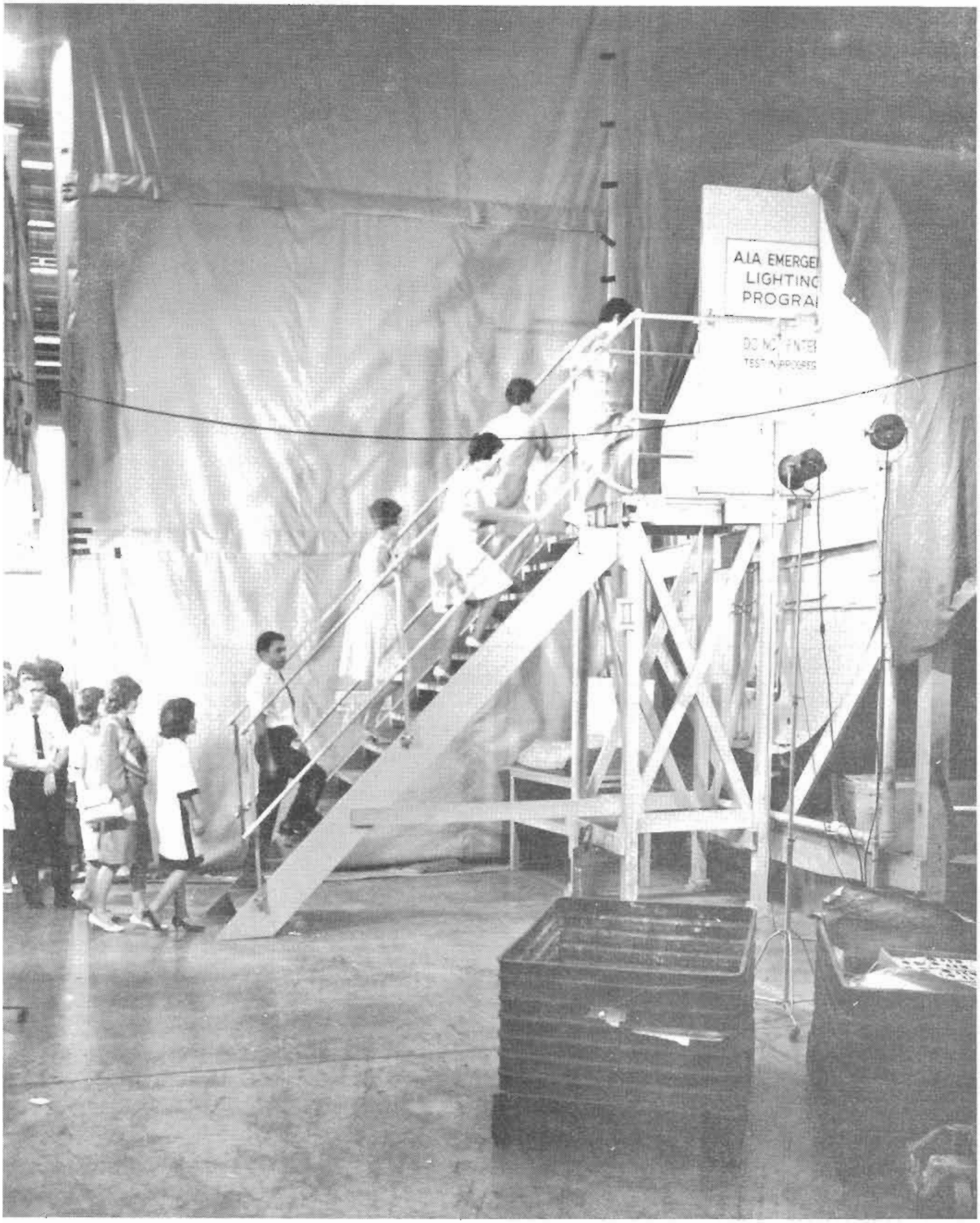
In group evacuation studies, it was found that information given in passenger briefings on the location and use of exits, flotation cushions, and smoke hoods could be retained after only one exposure to this information. People expressed interest in obtaining emergency procedure information throughout the group evacuation test program.

Table 4. Technical Summary–Lighting and Exit Awareness

PROGRAM ELEMENTS	SIGNIFICANT STUDIES AND TESTS		
		NUMBER OF	
TESTS OF PARTICULAR LIGHTING AND EXIT AWARENESS CONCEPTS EMPHASIZING INDIVIDUAL PERFORMANCE	TEST OBJECTIVE	* TEST CONDITIONS	PEOPLE PER CONDITION
Interior aisle lighting	Determine effect of light intensity and uniformity on evacuation	22	7
Exit area and escape slide lighting	establish light level for night evacuation	17	7
Overwing exit and exit path lighting	Evaluate overwing and ground light level and uniformity	17	8
Escape slide actuation handle illumination	Determine effect of lighting on operating time	6	4
Integral slide illumination	Determine effect of integral vs exterior light on evacuation	2	2 Groups of 29
Exit signs	Determine standards for exit sign brightness, color, and type of lighting	48	7 to 10
Audible and tactile exit locator evacuation aids	Determine best tactile form and audible cue type, intensity, and location	56	8 to 14
Passenger warning system analysis	Analyze accident reports and warning system studies	———	———
TESTS OF INTEGRATED LIGHTING AND AWARENESS CONCEPTS USING GROUPS OF PEOPLE IN SIMULATED AIRPLANE EVACUATIONS			TOTAL PEOPLE
Emergency lighting	Determine effect of passenger light adaptation and interior and exterior light intensity and uniformity on evacuation	8	320
Exit signs	Evaluate new experimental electrically illuminated exit sign vs older radioactive type		
Audible, tactile, and visual "nearest exit" evacuation aids	Determine if exits can be located in dark (simulating dense smoke) using exit locator aids	3	120
Smoke hoods	Determine effect of hood use on evacuation and passenger communication and visibility	10	276
Passenger briefings	Evaluate effectivenss of TV or color slide passenger briefings	5	457

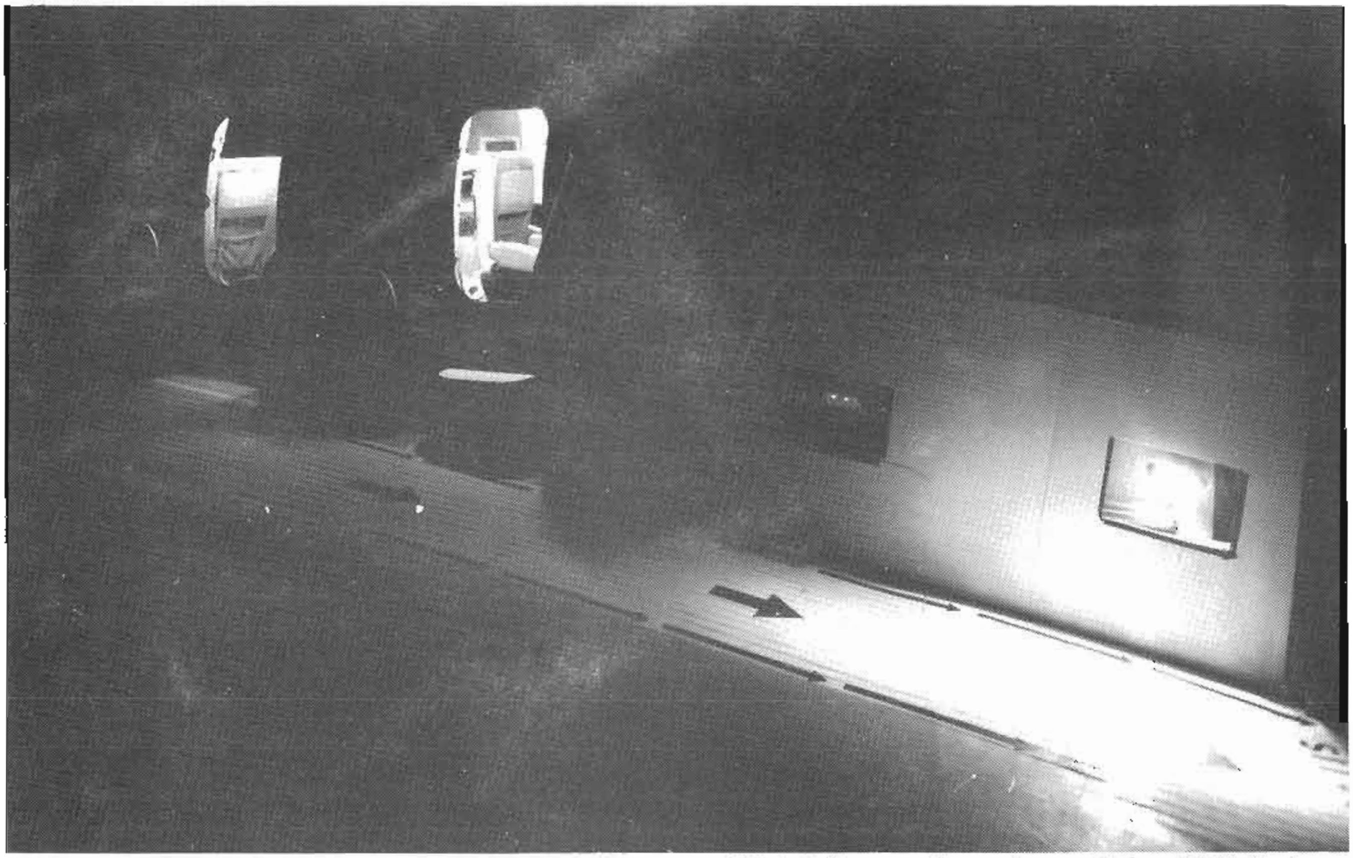
* Pretest and successive tests not included

RESULTS	CONCLUSIONS
Improved performance with uniform light and as average illumination increased from 0.02 to 0.05 ft-c	FAR 25 average of 0.05 ft-c adequate if combined with 0.01 ft-c (minimum)
No performance difference between 0.05 to 2.0 ft-c at interior exit floor, same evacuation performance for 0.1 ft-c and 0.03 ft-c exterior light	Exit floor light not important, 0.03 ft-c exterior light adequate
No trend evident in evacuation time data, questionnaires indicate better visibility with light level; acceptance ratings favored uniformity but were not conclusive	FAR 25 0.05 ft-c adequate if overwing path has high reflectance
Time to find handle is reduced with lighted handle	Handle should be illuminated
Slight trend favoring use of slide illuminated only by interior exit signs	Data not conclusive
Characteristics of signs detected quickest in smoke: bright, large, uniformly lighted background; on-off flashing no improvement	Improved experimental sign selected for group test verification.
Teardrop and triangle most quickly indicate direction. Source of sound can be located in dark airplane, horn and male voice favored	Select triangle, horn, and male voice for group tests
Some type of warning system considered beneficial	Recommended for research and development
Observation of group evacuation tests and analysis of questionnaires indicate improved performance and subject preferences for improved interior and exterior lighting and exit signs; passenger preadaptation to potential emergency light level favored	Adequate interior light requires specification of minimum illumination of 0.01 ft-c Brighter, larger, uniformly lighted exit signs needed; overwing high reflectance path needed Passenger preadaptation to emergency light desirable
Tactile aids seldom used Audible aids get people to exits, but delay them at exits that do not open People prefer "nearest-exit" placard most	Research and development recommended for audible aid feasibility Nearest-exit placards used enough to recommend
Prototypes tested slowed evacuation rates 30% Used by 1/3 of people in test group	Concepts tested would require further research to develop
Questionnaires indicate passengers prefer briefing and retain information after one exposure	Passengers desire more information



(a) Test Subjects Entering Passenger Mockup for Simulated Emergency Evacuation into Controlled Light Inside Lightproof Tent (Behind Stairway)

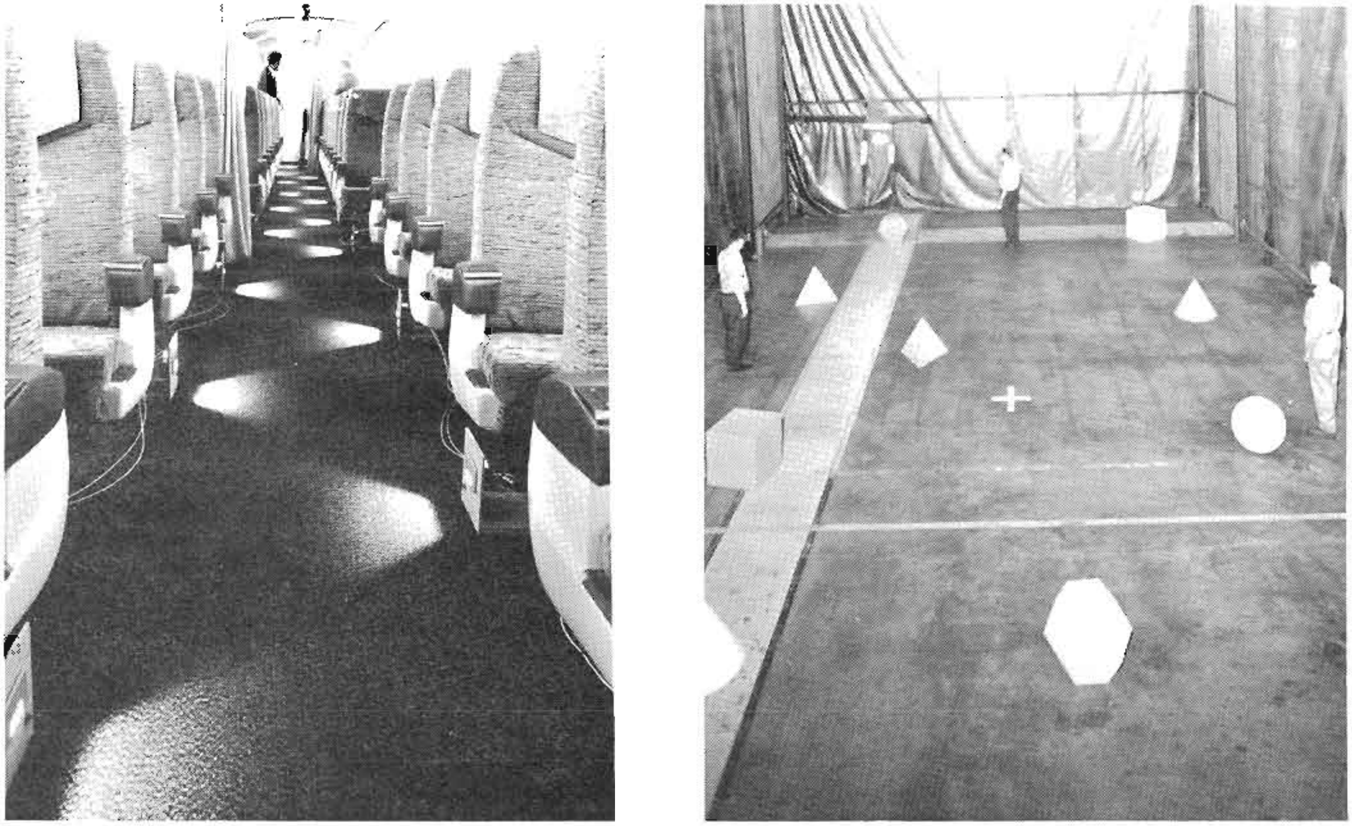
Figure 9. Program Acitivity–Lighting and Exit Awareness



(b) Overwing Lighting Required by FAR 25-15 plus Experimental High-Reflectance Escape Route—At Least 0.05 ft-c in 30 Percent Of Path Farthest from Exits

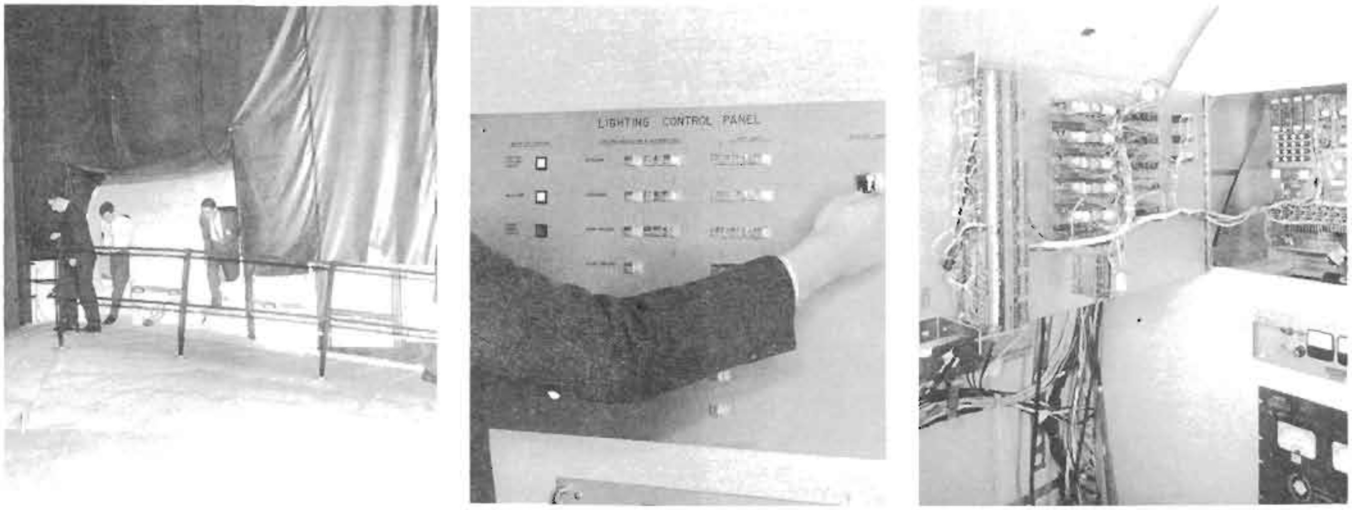
(c) Experimental Uniform Lighting—0.1 ft-c Average Illumination on Entire High-Reflectance Overwing Path

Figure 9. (Continued)



(d) Underseat Aisle Lighting Concept (One of three aisle lighting concepts tested, using individual test subjects in evaluating 11 test conditions of aisle light level and uniformity)

(e) Visibility Test Objects Used in Lightproof Tent for Individual Recognition Tests of Exterior Exit and Escape Slide Area



(f) Overwing Test Area for Individual Tests of Overwing Illumination Level and Uniformity

(g) Control Panel for Programming Lighting in Human Factor Tests of Lighting Level, Uniformity, and Concepts in the Airplane Mockup and the Lightproof Exit Tent

Figure 9 (Concluded)

3.4 Evacuation

The evacuation system program was organized into two major phases.

Phase I consisted of an evaluation of evacuation systems currently used on in-service airplanes, with attention to the following:

- FAA-witnessed evacuation tests
- CAB airline accident reports
- Interior escape provisions
- Inflatable escape slides

Phase II consisted of an evaluation of current research and development work, particularly in the following:

- Internal considerations
- Inflation devices
- External escape devices
- Offwing evacuation

A summary of the work is shown in Table 5.

3.4.1 Phase I—Evaluation of Current Evacuation Systems

Studies in this phase of the evacuation system program (Fig. 10) indicate:

- A good overall performance record, with many aircraft evacuated within 90 sec and evacuation systems performing well
- Commendable performance by airline crews in achieving evacuations within reasonable times and providing calm and effective leadership
- Time and malfunction reductions as a result of equipment improvements incorporated on later aircraft and by retrofit on earlier aircraft
- The extensive usage of Type I doors with inflatable escape slides for passenger evacuation (The Type III overwing exits, although less frequently used, have proved operationally reliable.)
- Approximately 79 percent of accidents associated with airplane landings (68 percent) or takeoffs (11 percent)

The following problems with evacuation system equipment were identified:

- Escape slides have been the principal source of malfunctions or delays because of deployment and inflation functional complexity.
- The attendant functions required to prepare the evacuation system are too complicated in some aircraft and must be reduced and simplified on new equipment.

Evacuation success is principally due to the rapid preparation of the escape device and the quick evacuation rate provided by the cabin attendant. The principal evacuation flow restraint was found to be that escape-slide usage was less than the flow capability of the cabin aisles.

Finally, the following human factors aspects were determined:

- The majority of accident evacuations were accomplished in a calm and orderly manner without evidence of panic.
- A well-trained crew is another principal factor in achieving rapid and safe evacuation of passengers.
- The briefing of passengers is a contributing factor toward achieving the maximum potential speed and safety in evacuation.

3.4.2 Phase II—Evaluation of Research and Development Effort

Studies in this phase of the evacuation system program indicated the following gains (Fig. 11):

- The evacuation flow restraint for large-capacity transports using twin aisles and Type A doors is the same as before – the escape device preparation time plus the evacuation usage rate of the external escape device.
- The integrated design of cabin doors and escape device systems will achieve minimum exit preparation times with simplified crew operation, as well as providing automatic deployment and automatic inflation of the escape device for emergency evacuation.
- The advent of double-lane escape devices having greater inflated volumes and requiring rapid inflation times has required industry development of new types of inflation devices

Table 5. Technical Summary–Evacuation

PROGRAM ELEMENTS	SIGNIFICANT STUDIES AND TEST
ANALYZE CURRENT JET EVACUATION SYSTEMS PERFORMANCE	
FAA-Witnessed evacuation tests	Analysis of 134 jet aircraft evacuation tests
CAB airline accident reports	Analysis of 87 jet aircraft accident reports
Interior escape provisions	Analysis of evacuation flow from passenger seat through aisles and exits, and via slides to ground
Current escape devices	
CONDUCT RESEARCH & DEVELOPMENT	
Internal considerations	Evacuation restraints associated with type A exits
Inflation devices	Inflation devices research; air reservoir cool-gas generator and high-pumping-ratio aspirators
Improved escape devices	External escape slides: Inflatable slides Inflatable ramps Inflatable stairs Mechanical stairs
Offwing evacuation	Offwing evacuation design concepts

RESULTS	CONCLUSIONS
Qualitative and quantitative level of current evacuation systems performance established 68% of accidents occur on landing; 11% on takeoff Many aircraft evacuate within 90 sec Principal source of malfunctions associated with slide deployment and inflation System components that control evacuation flow of people under emergency conditions were identified for both current and new large aircraft	Current systems perform well Equipment improvements have reduced malfunctions and reduced escape device readying time Escape slide evacuation usage rate is less than flow capability of cabin aisles Attendant's functions to prepare evacuation systems should be reduced and simplified on new equipment
Type A exit flow rate = 156 pass./min Twin-aisle flow rate = 144 pass./min Double-lane slide flow rate = 108 pass./min New devices developed to inflate large-volume, double-lane slides within 10 sec Drag-surfacing features incorporated on slide to slow passenger at ground end Stiffer inflatable slides and better surfacing developed to make slide walkable	Double-lane slide evacuation usage rate is less than twin aisle and Type A exit flow capability Drag-surfacing and increased stiffness will permit safe slide usage through a greater range of deployed angles New integrated design of cabin doors and escape device systems will achieve minimum exit preparation times, simplified crew operation, automatic deployment, and automatic inflation Inflatable escape slides are the safest, most reliable and rapidly operational escape devices for passenger safety
	Evacuation technical group studies confirm desirability of FAR 25-15 rules: Type A exits with double-lane slides Automatic escape-device deployment and erection at emergency exits 10-sec slide inflation Evacuation in 90-sec or less Manufacturer's evacuation demonstrations Offwing evacuation provisions including escape route markings, slip-resistant evacuation path surfaces, and offwing escape devices

such as cool-gas generators coupled with more efficient aspirators.

- An improved inflatable escape slide has been developed that provides a safer and more uniformly rapid egress capability regardless of evacuee weight or agility. The device is slideable from high door-sill heights because of the contouring and drag-surfacing features incorporated into the base of the slide. The slide is walkable from low door-sill heights because of the additional stiffness and inflated-sliding-surface features incorporated in the design.
- The large, new transports have initiated the first generation of offwing escape devices for passenger evacuation over the wing and thence to the ground.

In summary, a major effort has been accomplished with respect to evacuation safety on new aircraft. There are currently no new concepts that can effectively compete with or replace the newest inflatable escape slides. The system analysis approach leads to the conclusion that inflatable escape slides are the safest, most reliable and rapidly operational escape devices for passenger safety. The search for newer and better devices will not cease; however, better systems of this complexity do require time to develop and refine before they can be incorporated in new aircraft. The next series of advancements in escape devices will demonstrate their capability when tested on airplanes to be type-certificated within the next 2 to 3 years.

3.4.3 FAR 25-15 Rules

The AIA evacuation systems program results were obtained concurrently with the FAA Proposal of FAR 25-15 and confirmed the desirability of the rules as shown in Table 5. They provide:

- Faster and more simplified exit preparation, including escape-device deployment and means of inflation
- Improved evacuation-rate capability
- Better evacuation capability within less time from the start of the evacuation sequence

3.4.4 AIA-Recommended Rule Change

FAR 25-15 has required automatic deployment of escape devices concurrently with opening of the exits, plus automatic inflation within 10 sec, except that inflation at passenger and service doors may be achieved in a different manner.

A completely automated evacuation system integrated with the basic operation of major passenger and service doors is now feasible on doors for new uncertificated aircraft. Operation of the door via the external handle will disarm the escape system, prevent inadvertent slide deployment, and rearm the system when the door is closing. Door opening, using the interior handle with a manual arming lever engaged prior to takeoff, will result in automatic preparation of the escape device.

3.4.5 Proposals for FAA Study and Evaluation

The following subjects, which could significantly contribute to further evacuation safety, are proposed for FAA consideration:

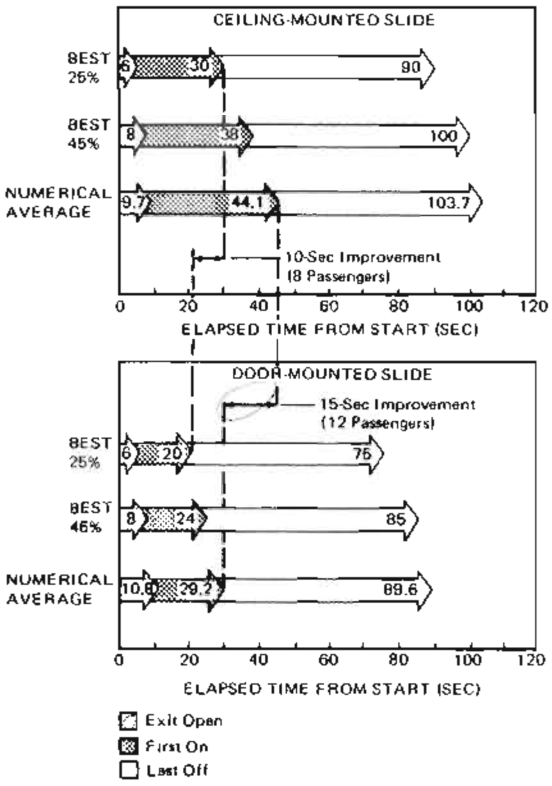
- Evacuation Demonstrations—Evaluate the feasibility of revising the current operational regulations for the purpose of not requiring airline evacuation demonstrations beyond the point of evacuation system preparation and escape-device deployment and erection.
- Passenger Briefings—Study the necessity and benefit gained from a requirement that passengers be rebriefed on the location of exits and evacuation procedures just prior to landing of the aircraft.
- Public Education on Aircraft Evacuation Safety—Consider the benefit or safety improvement gained from an educational television and movie program showing the public the rudiments of aircraft evacuation safety, such as exit operation, slide deployment, rapid and effective evacuation usage of escape slides, offwing evacuation techniques, and other evacuation safety factors.
- Emergency Exit Capacity Ratings—Consider the overall effect of such requirements as

90-sec evacuation, automatic slide deployment, 10-sec slide erection, and uniform exit distribution. The industry believes that the current exit ratings of 45 passengers per Type I door and 100 passengers per Type A door are unnecessarily conservative and should be revised upward.

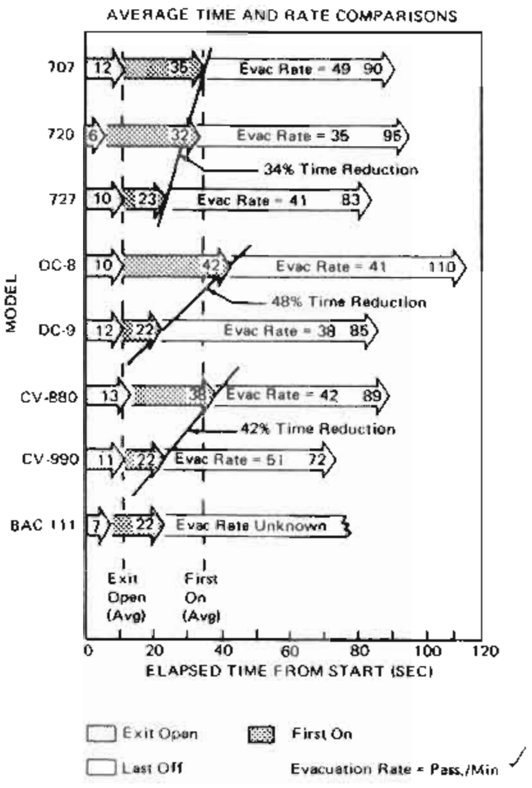
3.4.6 Future Research and Development

The future research and development necessary for improving evacuation systems and elemental components should continue on a gradual basis because of the increased complexity of the new concepts and time required to test, evaluate, and refine them. Some areas worthy of consideration are the following:

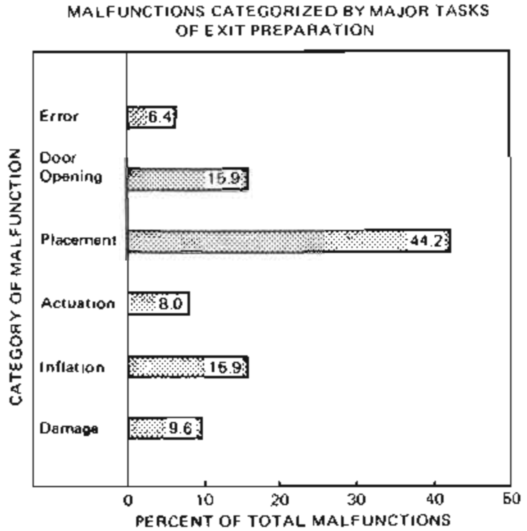
- Escape Devices–The feasibility of applying new construction technology to varying configurations of inflatable slides, and further development and evaluation of mechanical escape devices, should be accomplished.
- Evacuation Demonstrations–Elimination of the large number of people used in both manufacturer and airline evacuation demonstrations. Past experience has clearly shown mechanical failures and operational error to be the causes of evacuation system malfunctions. Therefore, the evacuation demonstration should be redefined to provide a complete proof test of the system components and escape devices, as well as a thorough check of crew proficiency in operation of the evacuation system. Highly reliable evacuation systems can be installed, maintained, and demonstrated to achieve a high level of confidence and safety without using planeloads of people in test demonstrations.
- Offwing Evacuation–Long-range research and development of escape devices and system components to achieve deployment from the cabin door, across the wing, and to the ground, with provisions for rapid and safe evacuation capability.



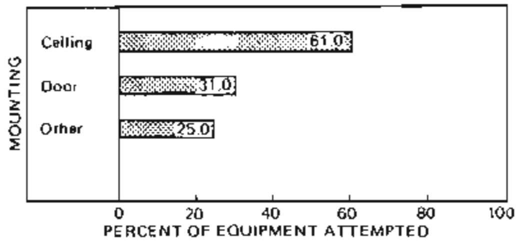
(a) Equipment Analysis–Type I Exit



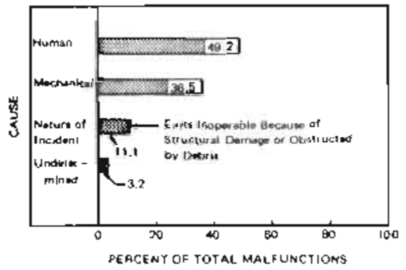
(b) Airplane Model Analysis–Type I Exit



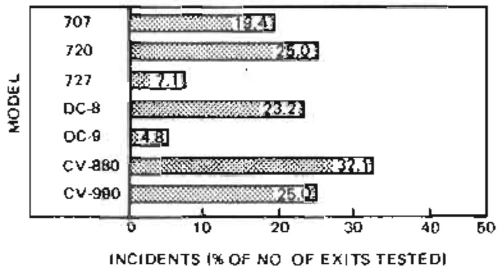
(c) Type I Malfunctions in 47 Emergency Accidents



(d) Malfunctions–Door- Versus Ceiling-Mounted Slides

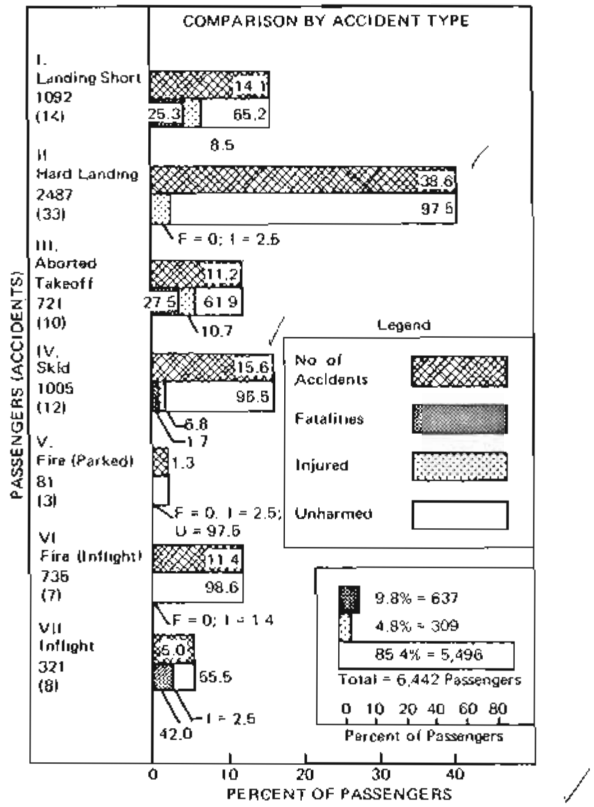


(e) Malfunctions–Human Error Versus Mechanical Failure

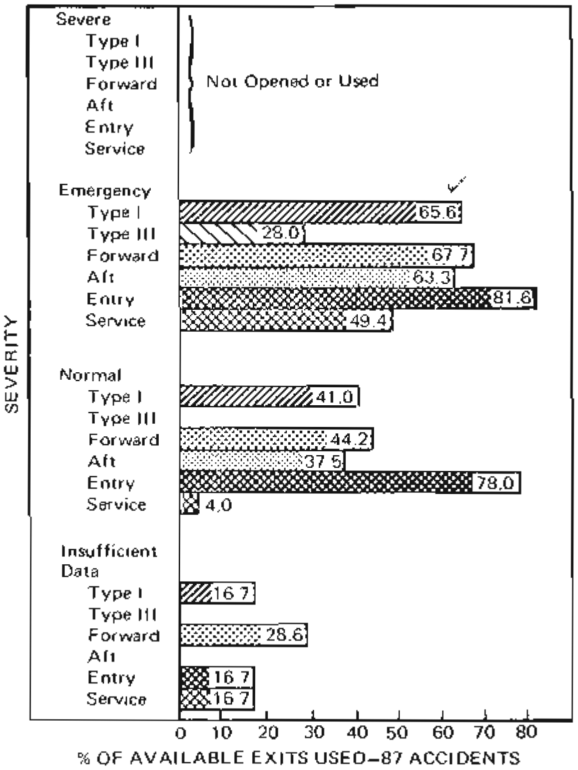


(f) Comparison of Malfunctions–Airplane Models

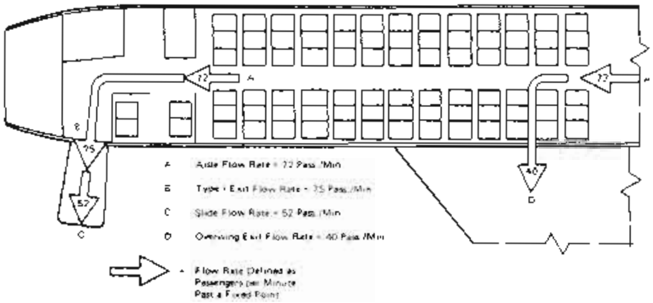
Figure 10. Program Activity–Evacuation, Current System Studies



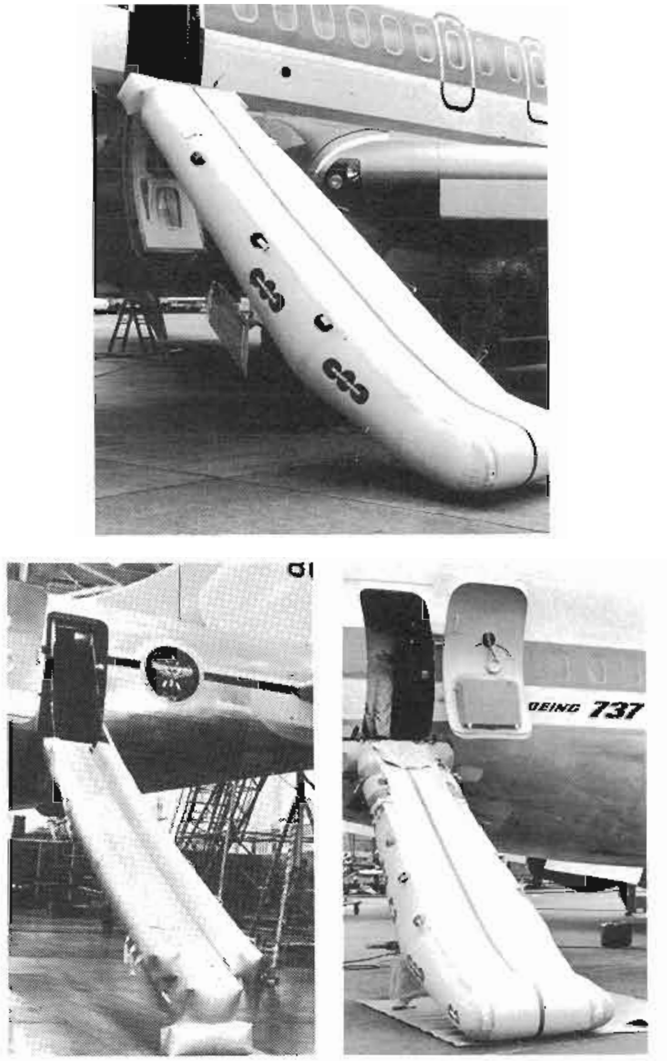
(g) Accident Frequency—Passenger Survivability



(h) Exit Usage Versus Accident Severity

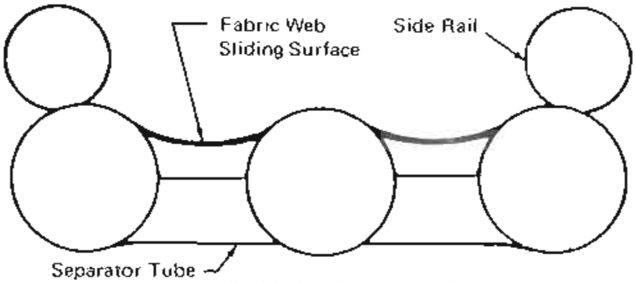


(i) Evacuation Flow—Current Jet Transports

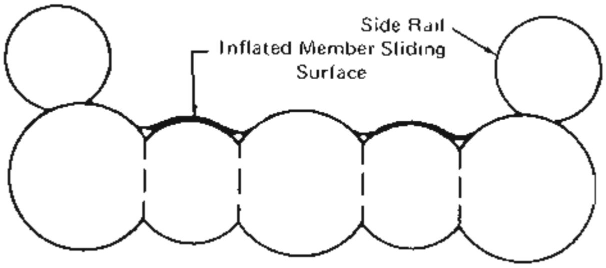


(j) Inflatable-Slide Evolution

Figure 10. (Concluded)



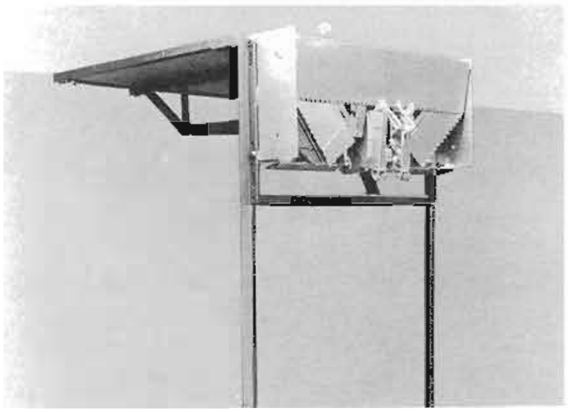
FABRIC WEB SLIDING PATH



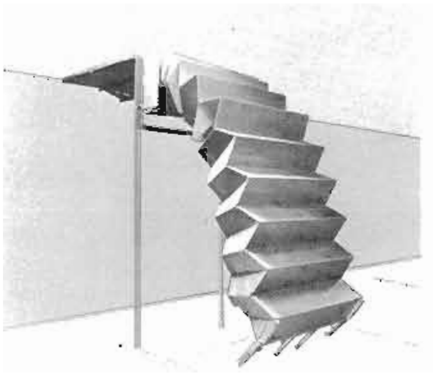
INFLATED MEMBER SLIDING PATH

(f) Dual-Slide Cross Section

(g) Inflatable Double-Lane Slide



FOLDED



PARTIALLY OPEN

DEPLOYED

(h) Folding Metal Stairs

Figure 11. (Concluded)