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CONFERENCE ON THE DEVELOPMENT OF FIRE-RESISTANT AIRCRAFT PASSENGER SEATS

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16. Abstract

This report is a compilation of papers presented at the proceedings of the conference on the "Development of Fire-Resistant Aircraft Passenger Seats," held at NASA-Ames Research Center, Moffett Field, California, on 19 March 1976.

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INTRODUCTION

Dr. John A. Parker

Ames Research Center

There are two distinct civilian programs besides a substantial military program. They are (1) the FIREMEN Program and (2) the Research and Technology Data Base Program. The FIREMEN Program, a short range program funded at \$800,000-\$900,000 per year for 5 years, addresses itself to on-board interior aircraft fires. The Research and Technology Base Program addresses itself to material development.

The FIREMEN Program has three parts: (1) panels, conducted by the Boeing Aircraft Company; (2) seat development, conducted at McDonnell-Douglas Aircraft Company, and (3) thermoplastic materials and process development, conducted at Lockheed Aircraft Company.

It is expected that the advances achieved as a result of the FIREMEN Program will be used in all modes of transportation. It should be noted that the FIREMEN Program neither controls nor affects FAA; neither does it aim at developing commercial products or processes.

The Research and Technology data base program provides a technical base and key opportunities for inputs from industry. Material development work will be directed at Ames Research Center, NASA, by the Chemical Research Projects Office, which is under my direction.

Testing activities will be directed by the L. B. Johnson Space Center, NASA; Mr. Richard Bricker will be the principal investigator. In addition, toxicological studies will be principally directed by the L. B. Johnson Space Center. The materials program has the following additional information:

(1) D. Kourtides, Ames Research Center, will coordinate with the Boeing Company and keep them abreast of materials development at the Ames Research Center
(2) Eli Pearce of Brooklyn Polytechnical Institute will examine new materials
(3) The Lockheed Company program will examine new polymers of all kinds to assess their design capabilities and develop acceptance criteria for polymers. Examples of candidate polymers are ICI-U.S. polyether sulfone, G. E. advanced polycarbonates, E. I. duPont loaded polyethylene. Included in the Lockheed program is responsibility for improvements in thermoplastic polymer processing, for example, injection molding, etc.
(4) Dr. G. Tesoro has been asked to coordinate the materials developmental aspects of the program.

PROGRAM OVERVIEW

Larry L. Fewell

Ames Research Center

The objective of this program is to provide materials specifications of all seat material options and performance specifications of seat materials.

Figure 1 is an outline of the scope of the Fire-Safe Aircraft Passenger Seat Program. Materials must not only meet fire-resistivity criteria but must also meet such requirements as asthetics, minimum maintenance, light weight, and long service life. The aircraft passenger seat must not only be compact and suitable for close pitch, high density operation, but must have suitable fire-resistivity characteristics, such as minimum ignitibility, flame spread, heat release, and minimum production of smoke and toxic fumes. Materials to be procured and tested will consist of the following: (1) flexible foams for the seat cushion, such as polyurethane, neoprene, polyimide, and polyphosphazene foams; (2) thermoplastics, such as polycarbonate, ABS, and PVF, etc.; (3) textiles, such as wool, polyamide, and PBI; (4) leather, natural and synthetic; and (5) resin and fiberglass laminates. Because aircraft passenger seats consist of fabric, foam, and thermoplastic components, it is necessary to conduct full-scale testing of complete seats. Full-scale testing of seats will be used to generate a series or family of aircraft seats which are essentially seat material options with their corresponding fire resistivity characteristics. The need for such a program becomes quite clear when one considers figure 2 which is a typical seating arrangement on a wide-body jet. This figure depicts a wide-body jet with a passenger seating capacity of 270. At 13 lb of nonmetallic material per seat, this gives a total of about 3500 lb of nonmetallic material. The film which you are about to see is titled "Unknown Risks." Please note the degree and mechanism of the propagation of the fire from the initial burning seat.

The film, "Unknown Risks," showed a fire started under a theater-type seat in a room with eight seats. Polyurethane, a fire-retardant-treated polyurethane, and neoprene seat cushions were tested. Smoke obscuration and the temperature profile in the room were measured. The polyurethane seat cushion burned quite vigorously and gave off a great deal of smoke; the burning and flowing melted material soon had all the seats in the room involved in the fire. The fire at Kennedy Airport was described. The film makes the need for a program to develop fire-resistant seats quite obvious.

FIRE-SAFE AIRCRAFT PASSENGER SEAT PROGRAM

PROGRAM OBJECTIVES:

(1) Provide seat materials options for wide body aircraft.
  (a) Material evaluation and selection
  (b) Full - scale tests of aircraft seats

(2) Develop aircraft seats with the minimum fire risk.
  (a) Exhibit the minimum in ignitibility
  (b) Minimum flame spread
  (c) Maximum fire containment
  (d) Minimum heat release
  (e) Minimum of smoke and / or toxic fumes

(3) To provide:
  (a) Materials specifications of all seat material options.
  (b) Performance specifications of seat materials.

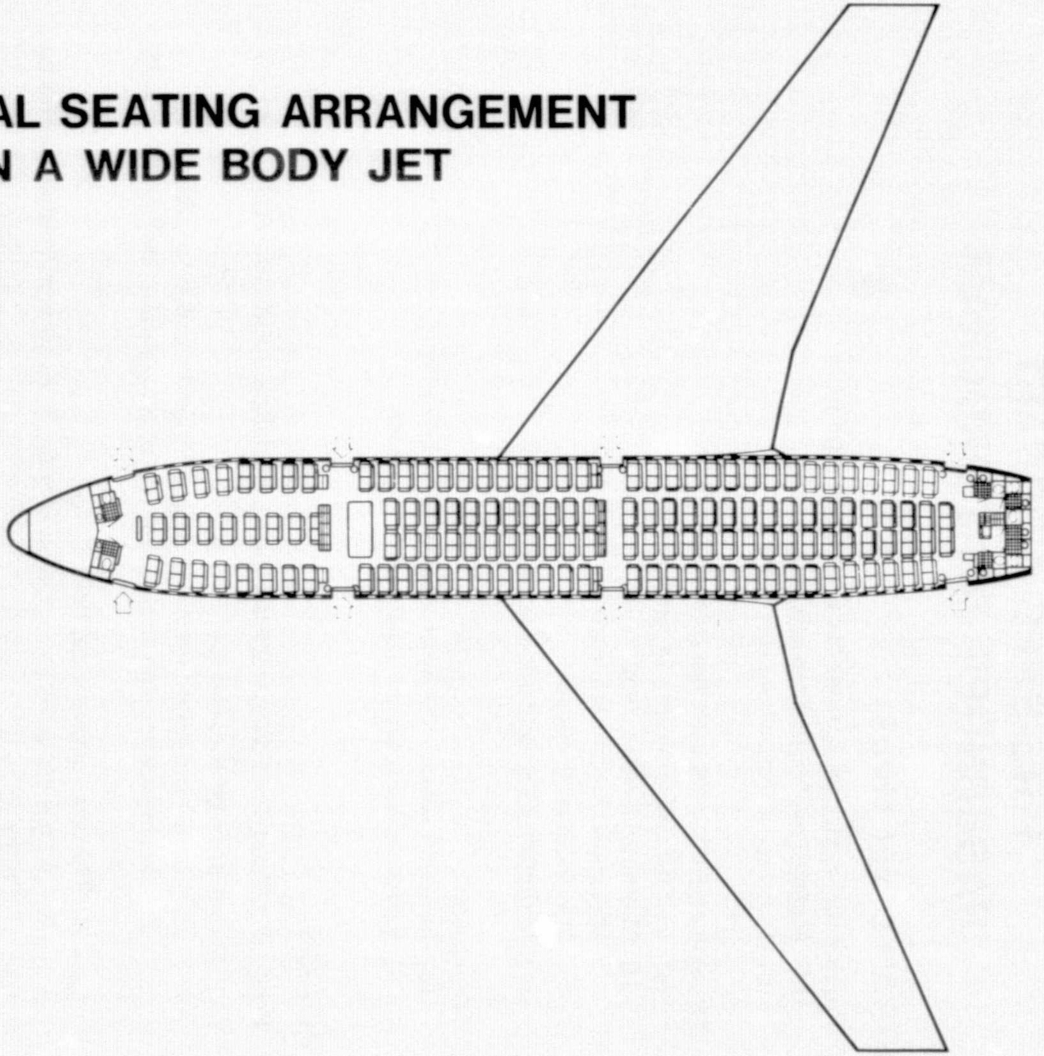
APPROACH:

(1) Procure and test candidate materials based on standardized laboratory tests.
  (A) Materials to be considered:
    1. Foam - polyurethane, neoprene, polyimide, polyphosphazene
    2. Thermoformed and molded parts - polycarbonate, polyarylene, ABS, PVF
    3. Textiles - polyamide, PBI
    4. Leather replacement - coated fabrics, F. R. treated leather, synthetic leather
    5. Resin/fiberglass laminate - silicone resin, phenolic resin, polyimide resin

(2) Full - scale testing of aircraft seats in Cabin Fire Simulator.

(3) Standardized test procedure for controlled burn testing of completed seats.

Figure 1.



TYPICAL SEATING ARRANGEMENT
ON A WIDE BODY JET

Figure 2.

STATE-OF-THE-ART MATERIALS USED IN AIRCRAFT PASSENGER SEATS

Dr. Giuliana C. Tesoro

MIT Dept. of Engineering

The state of the art of materials used in aircraft passenger seats was described. It was noted that the statements would be qualitative and exemplary, not definitive judgments. The objective would be to develop an approach to rapidly screen materials. After a preliminary look at cushioning foams. more attention will be devoted to fabrics.

The following figures and explanations will seek to define state of the art of materials and advanced candidate materials.

Figure 1.- Ten essential criteria for evaluating materials selection are described. The criteria should be weighed against each other in a specific situation to arrive at a judgment.

Figure 2.- Fire retardant treated materials in a real fire situation lead to toxic gaseous products and smoke.

Thermally stable materials produce less toxic products and smoke. In considering a scenario related to the fire hazard of seats, at least three situations must be considered: (1) catastropic — choice of materials is not important; (2) low heat flux fire — for example, a cigarette is dropped on a cushion (the present standards may be adequate); and (3) intermediate heat flux fire — for example, a trash fire (a major hazard). Critical elements to consider are the level of replacement allowed such as material performance, cost and availability. A major problem is the testing of materials. System testing is rarely done but the possibility of interactions and design of assemblies must be considered. In this program there are constraints due to time tables calling for quick answers. Therefore, fundamental research to provide answers is not possible.

Figure 3.- State-of-the-art foams commonly used are polyurethane, and fire retardant treated polyurethane. Advanced foams are based on polyphosphazene, modified neoprene, polyimides, etc.

Figure 4.- Performance requirements are described.

Figure 5.- Flexible foams — data from the literature.

Figure 6.- Relevant mechanical properties of textile materials are described.

Figure 7.- Performance requirements of seat upholstery fabrics are listed.

Figure 8.- Current fabrics in use and advanced state-of-the-art fabrics. The two classes will be compared; however, note that it is necessary to distinguish between fiber and fabric properties.

Figure 9.- Fibers from thermally stable polymers.

Figure 10.- Mechanical properties of fiber staple are listed, note that the cited costs are only ratios not actual prices.

Figure 11.- Fiber properties.

Figure 12.- Fabric properties related to fire hazards.

Figure 13.- Graph of critical oxygen index for materials. It is concluded that there is no one candidate fiber or fabric that is adequate as is. The best balance for design use will require modification of properties, or manipulation of construction, or an imaginative combination of materials, or all of these.

Figure 14.- This figure illustrates the complexity of the behavior of a fabric foam assembly under a thermal load.

Figure 15.- Modifications listed for the improvement of assembly performance.

Figure 16.- Design of an optimal assembly is shown. This will permit a minimizing of testing required to optimize results.

Figure 17.- The analysis of clothing material selection procedure as a guide for seat materials selection is shown.

Figure 18.- The flame barrier action of weight-percent of kynol on a jute carpet backing. This illustrates how to lower costs for a given behavior by taking advantage of kynol's superior properties.

Figure 19.- Coordination of industrial groups. It is noted that smoke production as a function of time is a critical property of a material. Perhaps 90 sec may be maximum allowable time in an aircraft interior where the low ceiling will soon involve the ceiling panel.

In testing, one must specify ventilation parameters, the height of the flame, etc. It was noted that if one could protect neoprene foam from involvement in the fire by a suitable fabric, it might be acceptable.

BASIC PROPERTIES FOR SELECTION OF AIRCRAFT POLYMERIC MATERIALS

STRUCTURAL REQUIREMENTS

COMMERCIAL AVAILABILITY

WEIGHT

PROCESSABILITY

MAINTAINABILITY

DURABILITY

AESTHETICS

ECONOMICS

FIRE SAFETY (FAA)

SMOKE AND TOXICITY

Figure 1

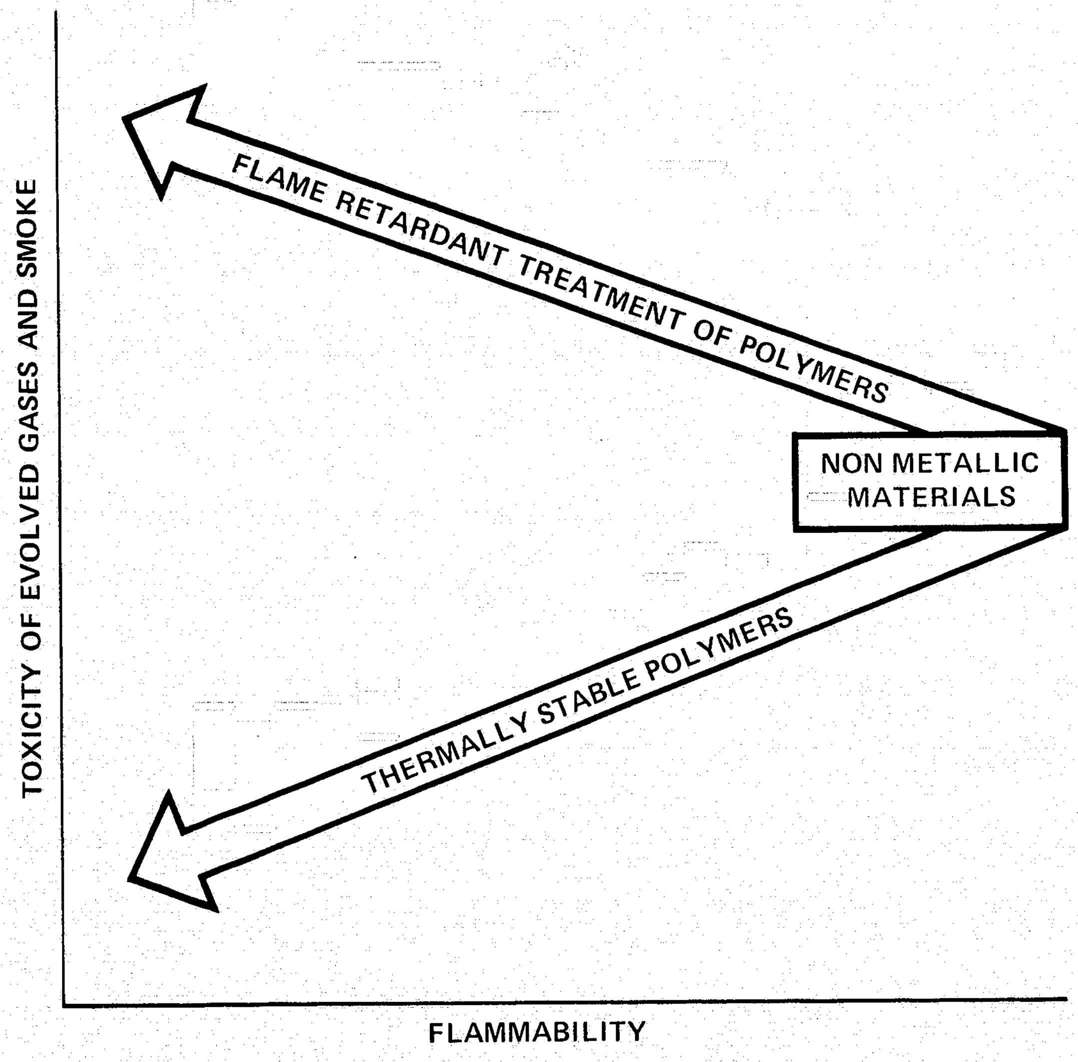

TOXICITY OF EVOLVED GASES AND SMOKE
FLAME RETARDANT TREATMENT OF POLYMERS
NON METALLIC MATERIALS
THERMALLY STABLE POLYMERS
FLAMMABILITY

Figure 2.

FOAM CUSHIONING

STATE OF THE ART	ADVANCED STATE OF THE ART
POLYURETHANE	POLYPHOSPHAZENE
FR POLYURETHANE	MODIFIED NEOPRENE
	POLYIMIDE

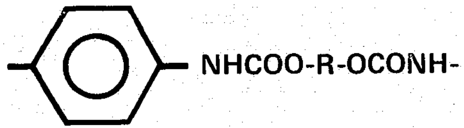
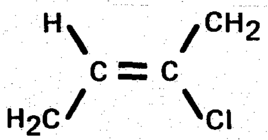
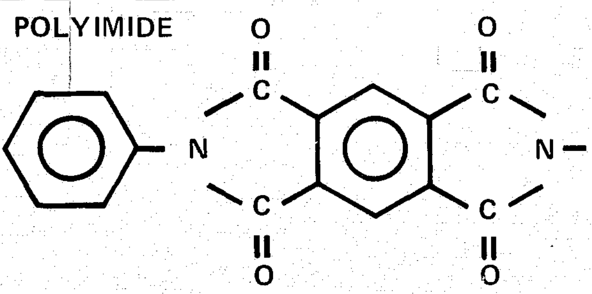
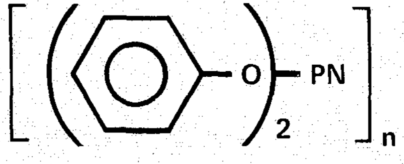
Figure 3.

PERFORMANCE REQUIREMENTS OF FOAM CUSHIONING

PROPERTY	ESTIMATED ACCEPTABLE
25% ILD (IDENTATION LOAD DEFLECTION)	9-44 LB/50 IN^2
65% ILD (INDENTATION LOAD DEFLECTION)	17-85 LB/50 IN^2
FLEX FATIGUE (E.G. 25 MONTHS SERVICE)	
(A) IRGL (35 LB)	2/3 UNCOMPRESSED HEIGHT
(B) COMPRESSION LOSS	33%
(C) HEIGHT LOSS	5%
FLAME RESISTANCE |FAR 25.853 (B)|	

Figure 4.

FLEXIBLE FOAMS

TYPE - POLYMER STRUCTURE	01 [% O_2]	SMOKE	OFF-GASES	REF.
POLYURETHANE 	20-28	MOD.	TOXIC	(1).(2)
POLYCHLOROPRENE (NEOPRENE) 	26-40	HIGH	TOXIC	(2).(3)
POLYIMIDE 	35-40	LOW	N.A.	–
POLYPHOSPHAZENE 	27-65	LOW	N.A.	(4)

(1) NASA - HOUSTON - JSC 09929 - OCTOBER 1975
(2) LEWIN ETAL. IN FR POLYMERIC MATERIAL - PLENUM PRESS - 1975
(3) P.R. JOHNSON - JAPS 18, 491 (1974)
(4) R. SINGLER ETAL. - POL. ENG. SCI. 15, 321 (1975)

Figure 5.

RELEVANT MECHANICAL PROPERTIES OF TEXTILE MATERIALS

- UNIAXIAL TENSILE BEHAVIOR
  - BREAKING STRENGTH
  - ELONGATION
  - MODULUS OF ELASTICITY
  - RECOVERY BEHAVIOR

- ABRASION RESISTANCE

- FLEXIBILITY AND BENDING
  - SIMPLE BENDING
  - DRAPE (MULTIDIRECTIONAL)
  - CREASE ACCEPTANCE AND RETENTION
  - FLEX FATIGUE RESISTANCE

- RESISTANCE TO STRESS CONCENTRATIONS
  - TEAR RESISTANCE
  - SNAG RESISTANCE
  - PUNCTURE RESISTANCE
  - CUTTING RESISTANCE
  - KNOT AND LOOP EFFICIENCY

- DIMENSIONAL STABILITY

- AESTHETIC OR SUBJECTIVE MECHANICAL PROPERTIES
  - "HAND"
  - SOFTNESS
  - RESISTANCE

Figure 6.

PERFORMANCE REQUIREMENTS OF SEAT UPHOLSTERY FABRICS

PROPERTY	ESTIMATED ACCEPTABLE MINIMUM
TENSILE STRENGTH	70 lb.
TEAR STRENGTH	2 lb.
ABRASION RESISTANCE (STOLL FLEX)	1000 CYCLES
DIMENSIONAL STABILITY (TO DRY CLEANING)	2% SHRINKAGE
COLORFASTNESS (LIGHT, CROCKING, PERSPIRATION)	
SEWABILITY AND SEAM STRENGTH	
CLEANABILITY (DRY CLEANING)	
FLAME RESISTANCE [FAR 25.853 (B)]	

Figure 7.

SEAT UPHOLSTERY FABRICS

STATE OF THE ART

- WOOL
- FR WOOL
- NYLON
- NYLON/NEOPRENE
- NYLON COATED WITH PVC OR CHLOROPRENE
- RAYON/NYLON
- FR RAYON/NOVOLOID
- FR COTTON/RAYON
- POLYESTER
- POLYESTER OR MODACRYLIC COATED WITH PVC
- MODACRYLIC/ARAMID

ADVANCED STATE OF THE ART

- ARAMID (NOMEX)
- NOVOLOID (KYNOL)
- ARAMID/NOVOLOID (NOMEX/KYNOL)
- PBI
- POLYIMIDE

Figure 8.

FIBERS FROM THERMALLY STABLE POLYMERS

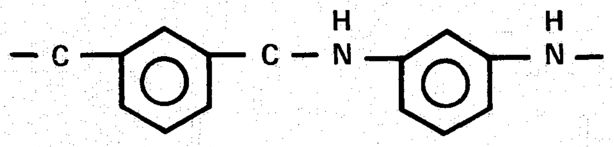
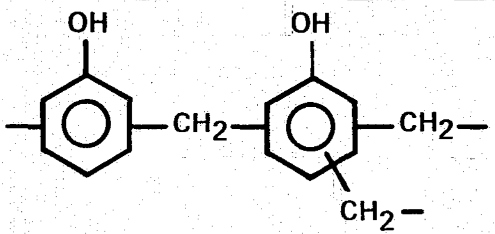
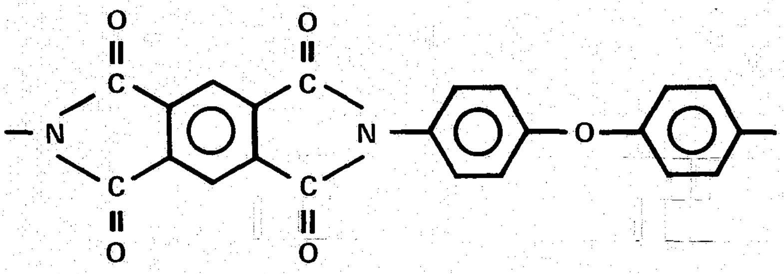
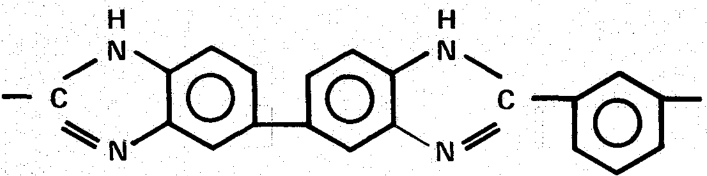
CLASS	EXAMPLE	STRUCTURE
AROMATIC POLYAMIDE	NOMEX	
PHENOLIC	KYNOL	
POLYIMIDE	KAPTON	
POLYBENZIMIDAZILE	PBI	

Figure 9.

FIBER PROPERTIES (STAPLE)

	COTTON	POLYESTER	NOMEX	KYNOL	PBI
TENACITY (gpd)	2-6	4-6	4.0-5.3	1.5-2.0	4-7
BREAKING ELONGATION (%)	7-12	40-55	22-32	25-35	22
MODULUS (gpd)	—	25-30	110-140	40-45	90-100
MOISTURE REGAIN (%)	7-8	0.4	6.5	6.0	13-14
PROCESSABILITY	EXC.	EXC.	GOOD	FAIR	GOOD
AVAILABILITY	EXC.	EXC.	GOOD	LIMITED	UNCERTAIN
COST (ORDER OF MAGNITUDE)	0.5	0.5	5	5	>25

Figure 10.

FABRIC PROPERTIES (5-7 oz/yd^2)

	COTTON	POLYESTER	NOMEX	KYNOL	PBI
TENSILE STRENGTH* lbs (W x F)	–	–	168 x 155	34 x 25	78 x 90
TEAR STRENGTH* lbs (W x F)	–	–	15 x 13	–	4.7 x 5.0
FLEX ABRASION RES.* CYCLES (W)	–	–	1100	124	693
LIGHT STABILITY (STRENGTH RET.)	GOOD	GOOD	FAIR	N.A.	FAIR
THERMAL SHRINKAGE (425°C)	–	[MELTS]	MODERATE	LOW	LOW
DYEABILITY	EXC.	EXC.	DIFFICULT	DIFFICULT	DIFFICULT
STATIC ELECTRICITY	LOW	HIGH	HIGH	HIGH	LOW

*R.J. COSKREN – SAMPE QUARTERLY 4 (4) 1973

Figure 11.

PROPERTIES RELATED TO FIRE HAZARD-QUALITATIVE ASSESSMENT

	COTTON	POLYESTER	NOMEX	KYNOL	PBI
IGNITION IN AIR-* CALROD TEMP °C TIME (SEC)	<550 INST.	–	871 1	788 –	927 6
FLAME IMPINGEMENT HEAT FLUX-PROTECTION	NIL	[MELT]	GOOD	GOOD	GOOD
CHAR YIELD CHARACTERISTICS	LOW –	[MELT] –	HIGH FRIABLE	HIGH STRONG	HIGH STRONG
SMOKE	MODERATE	LOW	MODERATE	LOW	LOW
OFF GASES (TOXICITY)	–	–	TOXIC	CO_2/H_2O PREDOM.	CO_2/H_2O PREDOM.
THERMAL STABILITY TEMP. DEGRADATION °C % APPROX. WT LOSS 900°C	– –	– –	437 60	– 40	590-680 30
OXYGEN INDEX (% O_2)	16-18	20-21	27-29	29-30	38-43

*R.J. COSKREN - SAMPE QUARTERLY 4(4) 1973

Figure 12.

DATA FROM STUETZ (1975)

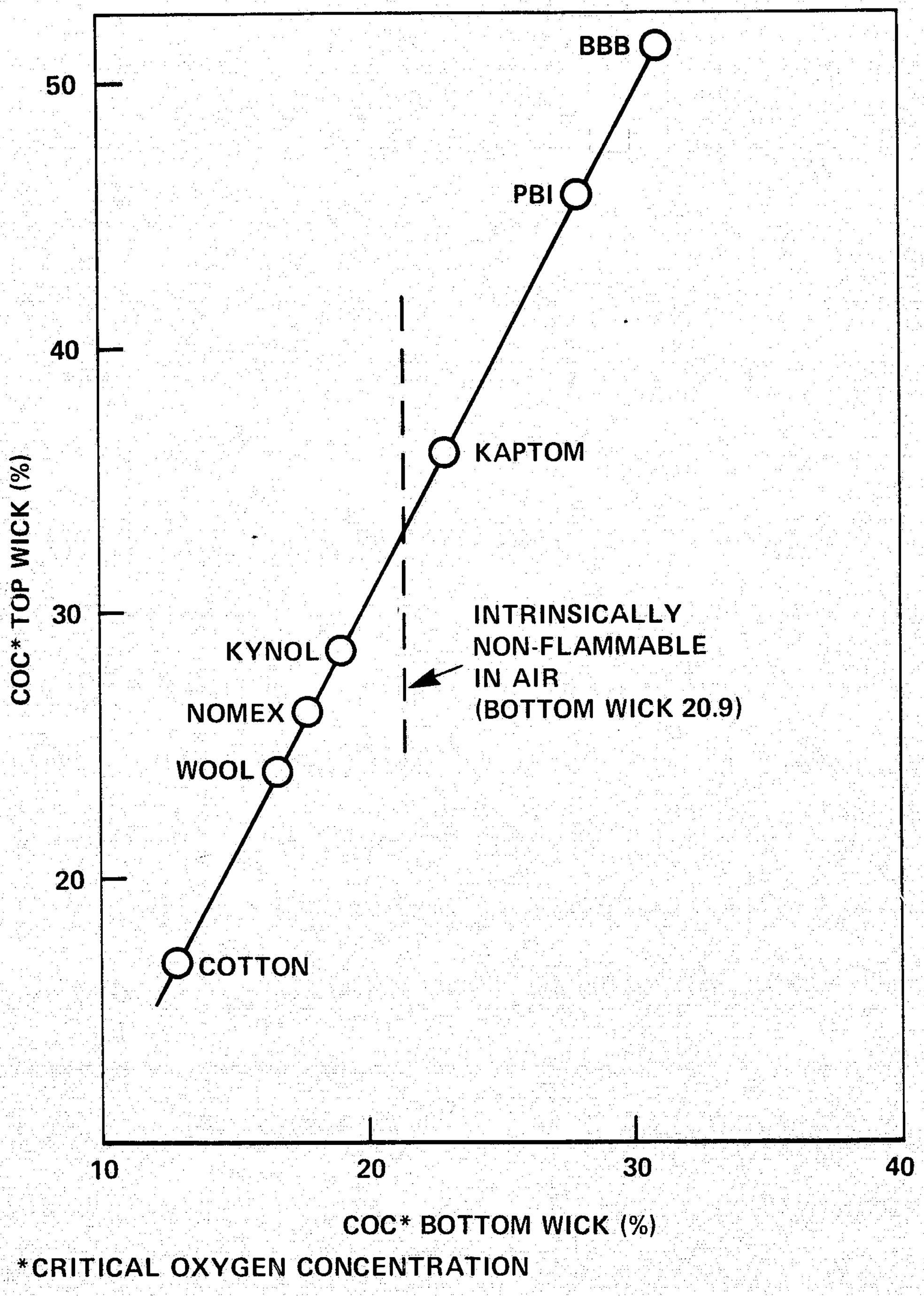


Figure 13.

BEHAVIOR OF A FABRIC/FOAM ASSEMBLY UNDER THERMAL LOADS

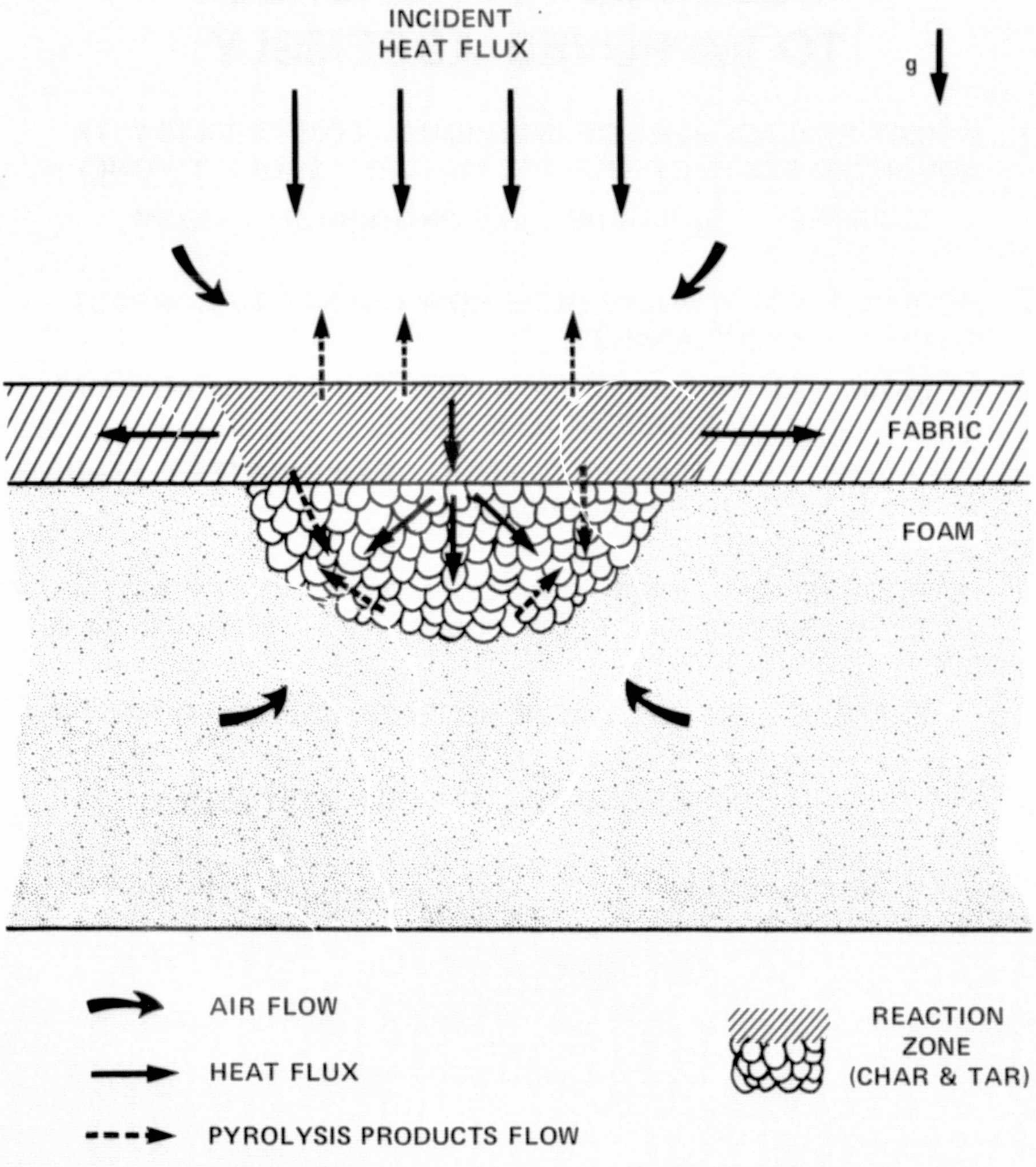


Figure 14.

POSSIBLE APPROACHES TO IMPROVED ASSEMBLY

1. DIRECT REPLACEMENT OF INDIVIDUAL COMPONENTS WITH ADVANCED STATE OF THE ART MATERIALS (ONE TO ONE)

   EXAMPLE: PBI FABRIC OVER PHOSPHAZENE FOAM

2. MODIFICATION OF INDIVIDUAL COMPONENTS TO CORRECT SPECIFIC SHORTCOMINGS

   EXAMPLES: FINISHING OF KYNOL FABRICS TO IMPROVE ABRASION RESISTANCE

   METALLIC COATING OF UPHOLSTERY FABRICS TO SHIELD FOAM

3. INTRODUCE ADDITIONAL COMPONENTS TO MODIFY ASSEMBLY AS TO HEAT FLUX, GAS FLOW, COMBUSTION PRODUCTS AND COST

   EXAMPLES: KYNOL LAYER BENEATH FABRIC TO PROTECT FOAM

   MULTICOMPONENT FOAM ASSEMBLY

Figure 15.

DESIGN OF OPTIMAL ASSEMBLY

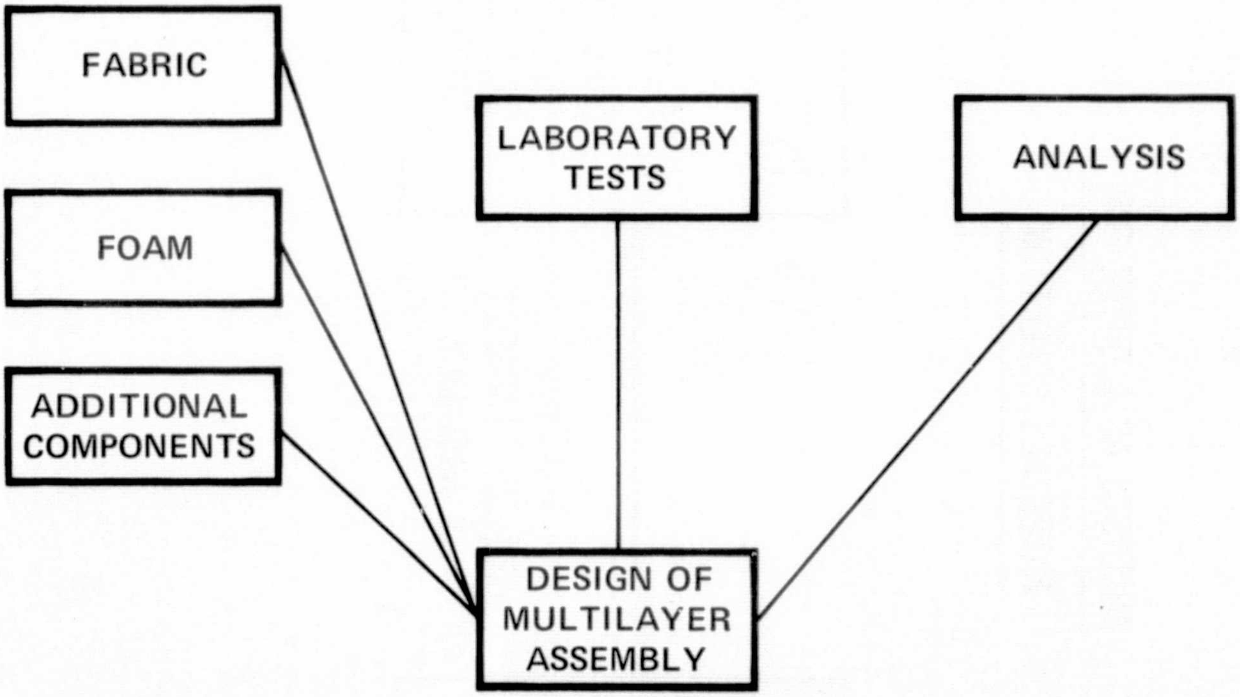
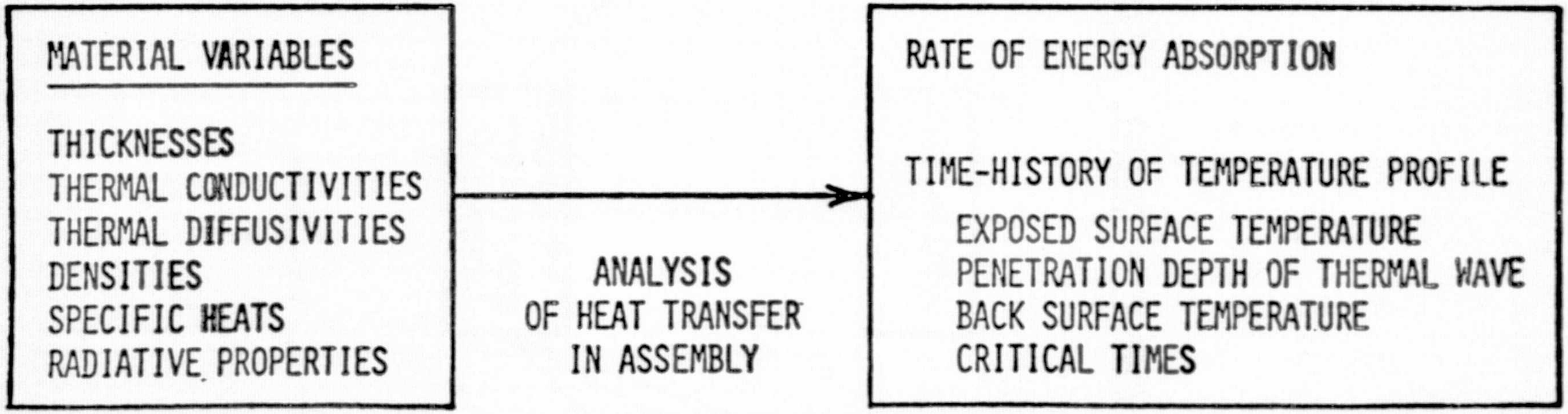


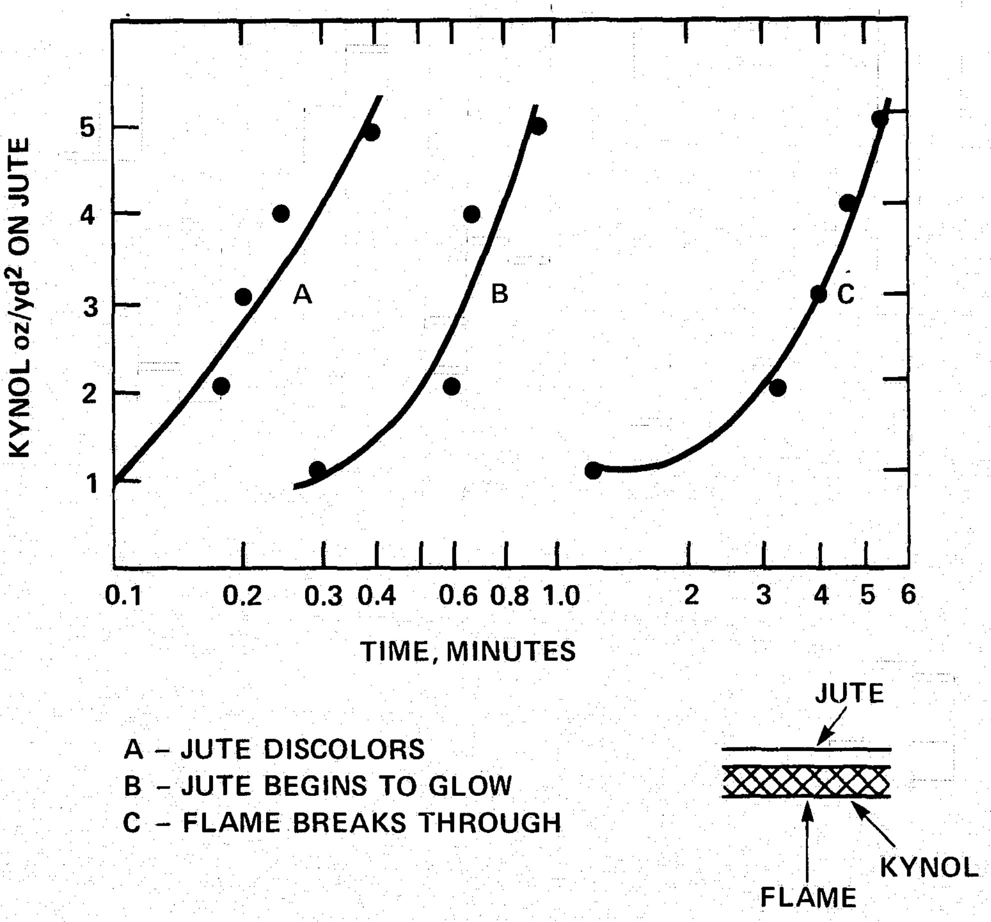
Figure 16.



ANALYSIS AS A GUIDE FOR MATERIALS SELECTION

Figure 17

FLAME BARRIER ACTION OF A KYNOL LAYER ON A JUTE CARPET BACKING



A – JUTE DISCOLORS
B – JUTE BEGINS TO GLOW
C – FLAME BREAKS THROUGH

TEXTILE INDUSTRIES - AUGUST 1974

Figure 18.

NEEDS

COORDINATION OF INDUSTRIAL GROUPS

- FOAM MANUFACTURERS
- FIBER MANUFACTURERS
- TEXTILE MILLS & FINISHERS
- SEAT MANUFACTURERS
- AIRLINES

TO DESIGN FIRE-SAFE AIRCRAFT SEATS IN 1977

Figure 19.

AIRCRAFT PASSENGER SEAT CONSTRUCTION

M. J. Dodd

Aerospace Division, UOP

If experience in aircraft passenger seats is a factor in our being selected to speak to this conference, then our origins back in the mid-thirties must put us in the vanguard of manufacturers of this equipment. At that time, Warren McArthur Corporation was making light metal furniture in Los Angeles. When Lockheed asked for a reclining chair for the Vega airplane, McArthur developed one. By 1939, the company had relocated to Bantam, Connecticut, where greatly expanded operations continue to this date.

Staying with the historical aspect for a new minutes, these first figures will show briefly how our passenger seats evolved from the first postwar models to our current production designs for both narrow- and wide-body jets.

Figures 1 and 2 were early passenger seats that were tubular in construction, had very little styling (few efforts were made to improve their appearance), and were designed to meet design load requirements of approximately 4.5 G. The DC-3 had seats such as this and development began more in earnest with the advent of the four engine DC-4.

The recline action was a simple one with positive stops at perhaps five different positions. The back pivoted at this point and the bottom frame was attached at the lower end of the back and articulated fore and after as the back reclined.

A refinement was made later which introduced a cable and drum type of locking mechanism which permitted an infinite number of positions from upright to full recline.

In figure 3, the earlier exposed tube became trimmed out with basic side panels as designs progressed and later the round tubing was changed to square tubing. The square tubing offered some advantages in appearance and made design of the interface between contoured and straight parts easier. The recline adjustment moved from a position down next to the lock (which made it somewhat hard to find), up to the front of the armrest where it has continued to be located to this day.

As the next round of aircraft developments came (fig. 4), the wider fuselage made it possible to put five seats across; this was the first triple seat built for such a configuration. Cruising altitudes were still low enough that air travel was occasionally rough, as evidenced by the air-sickness-container holder seen below the bottom cushion; it was standard equipment on all seats.

The articulated back and bottom recline action was considerably refined with this design (fig. 5) which was first used on the Martin 202 airplane. The back and bottom frames continued to be hinged together but the back pivot point, instead of being fixed, was now confined to a track, as was the hinge point between back and bottom; the "J" shape of the track resulted in a very comfortable recline action from upright to 65°.

However, as comfortable as this recline configuration (fig. 6) may have been, it did require more space in which to operate. The forward travel as it reclined was a penalizing factor, and the reduction in space beneath the seat was also inefficient. This version was used on the Canadair "North Star" airlines which were in service for several years with both Canadair and British Airways.

A later version also saw service with the Air Force in a deluxe version of the DC-4 (fig. 7).

At that time also, certain longer range airplanes made available sleeperette service which combined this full recline with a foldout leg rest for sleeping accommodations nearly as comfortable as a bed, but not occupying as much space fore and aft (fig. 8).

A trend now began among the nation's airlines to reduce fares and thus attract many more travelers. In order to do this, it was necessary to put more people in a smaller space. A series of seats was designed, starting with the one illustrated in figure 9, which spaced seats on 86 cm pitch fore and aft. In order to accomplish this, the recline action was limited to the angular adjustment of the back only; the cable and drum device was modified to a strap and drum device in order to achieve more braking capability, and was relocated on the rear lateral stretcher.

The trend continued with more aircraft and more seats per aircraft and the sleeperette concept disappeared entirely as travel time was reduced.

Weight had always been an important factor, but with the so-called high density seating, emphasis on weight reduction was increased and this series of seats, which we developed (fig. 10), was produced for the next 5 years in all types of configurations for the many types of aircraft flying the world's airlines.

One unique feature of the Zephyr seat was the location of the lock within the side arm, as this closeup shows (fig. 11). The cable and drum has on its shaft a pinion engaging a rack on the telescoping portion which attaches to the back. In operation, a spring maintains tension on the cable such that the back cannot be tilted aft. However, when the passenger depressed the recline button, tension was released allowing the drum and its pinion to rotate; this permitted the rack to telescope aft, and the back reclined until the button was released.

In this period of increasing air transport activity, it was advantageous to vary the mixture of first class and tourist seats from time to time, or even remove some seats and carry cargo in their place. Thus, a requirement developed for folding seats into a compact package for handling and stowing (fig. 12). For many years most Aerospace Division, UOP seats were designed with this capability. The advent of all-cargo airplanes, containerized freight, and finally the lower deck freight capacity of the wide body jets marked the end of this seat fold-up requirement.

Food and beverage service was placed on trays that either sat on a pillow on the lap of the passenger or had to be plugged in to the front of the arms on the seat. The plug-in type tables usually required a cabin attendant to install them, which was time consuming. In 1954 the first of the integral tray tables was built (fig. 13) on seats that were used in Vickers Viscount aircraft. The pivot point of the table legs had to coincide with the pivot point of the back in order that the seat back could be reclined independently of the table when in use. This basic design has undergone considerable development since that period of time and is now standard on substantially all types of airline seats.

One of the recurring problems on these integral tables was the design of a suitable latching arrangement. The earliest device was simply a leather tab with a snap fastener. We next progressed through pushbutton latches, a pull-type latch located in the table itself, and various other devices until the very simple pivoting type was settled upon (fig. 14); it too, is a worldwide standard today. The design objective was to have a reliable arrangement which would permit one-hand operation and, at the same time, not permit the table to fall free.

The 4.5 G strength factor remained the standard through the era of the DC-4 airplane until 1952. At this time added emphasis on strength and safety increased the standard to 6 G where it continued until the advent of the first passenger-carrying jet aircraft. Thus, the new standard (fig. 15) was 9 G in 1957, which is still the state requirement. However, in order to take advantage of the improved strength capabilities of jet aircraft floor structure, many seats have been designed and built to voluntary 12 G standards.

The first jet seats for the Boeing 707 were built to these new strength requirements and also included the incorporation of an energy absorption feature (fig. 16).

The improved strength together with the greater lifting capability of the jet aircraft resulted in a weight increase which reversed the trend of the 1950's. In order to incorporate the energy absorbing feature in the rear legs of these seats, it was necessary that the horizontal structure be made relatively rigid so that the tension load going into each member in emergency conditions would be more nearly equal (fig. 17). It was also necessary to have a rigid structure in the event the seat was partially occupied and the loading therefore unbalanced.

The companion seat on the original Pan American airlines was the double first class model shown here (fig. 17). Its structure and profile were similar to the tourist seat. Essentially, the difference was in the lateral configuration which offered substantially the same amount of space for two persons as the tourist seat did for three.

Figure 18 was a first class seat that evolved from the earlier tourist model; it is still being manufactured for United States carriers.

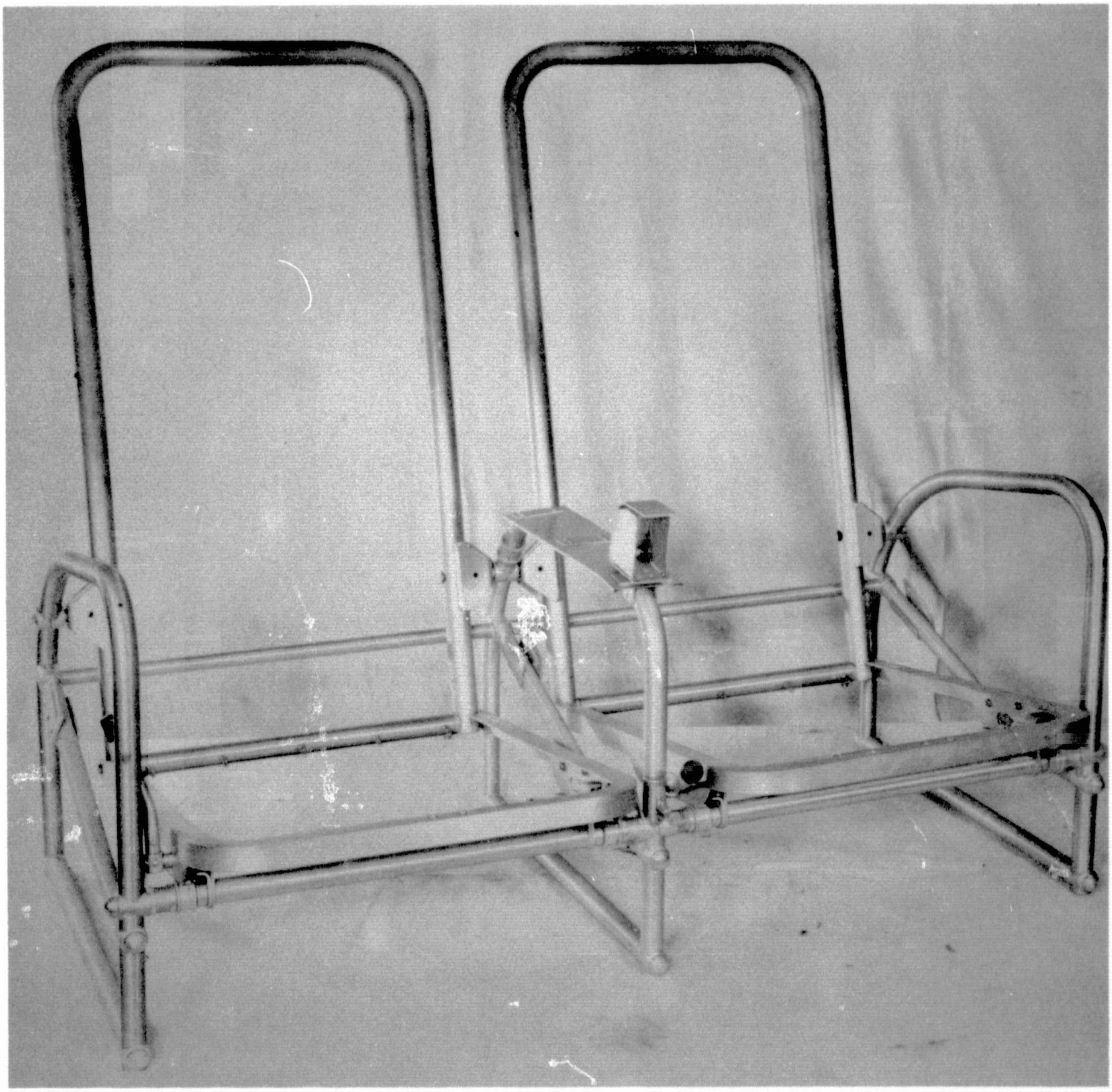
Figure 19 is a rear view of the same seat showing the large tray tables which are adjustable fore and aft. Also, this seat included two-position footrests of a simple tubular design.

The Northwest 747 tourist section uses these seats built by UOP. They also use the articulating recline with structural members at floor level. Overall styling and trim is completely different from the Pan American types. This same type of seat is used in 8-across configuration in the Northwest DC-10 aircraft. The design is such that the seats can be used in either aircraft by repositioning attach fittings. (See fig. 20.)

For 10-across configuration in the 747, some of the Pan American aircraft are converted to use this seat (fig. 21). The recline action consists only of the back pivoting with the bottom cushion remaining fixed.

The rear of this seat (fig. 22) indicates that the table design was the widest ever made because it fits on the outside of the back rather than between the vertical members.

Figure 23 is the side view of the same seat which shows the styling trim of the large thermoplastic panel on top of which is the self-skinned foam armcap. In the forward end is the stainless steel escutcheon.



ORIGINAL PAGE IS
OF POOR QUALITY

Figure 1.

Figure 2.

Figure 3.

Figure 4

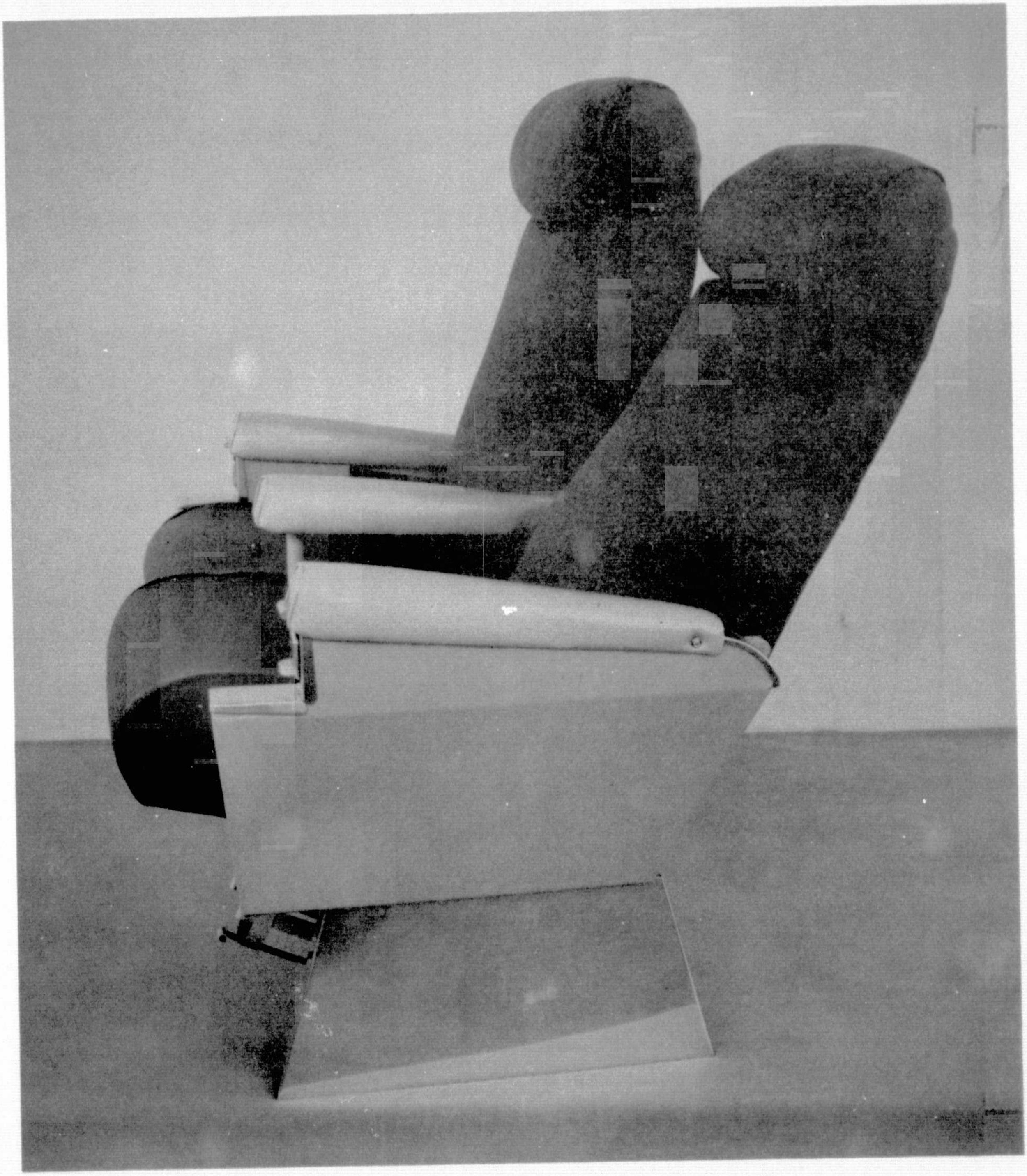


Figure 5.

Figure 6.

Figure 7.

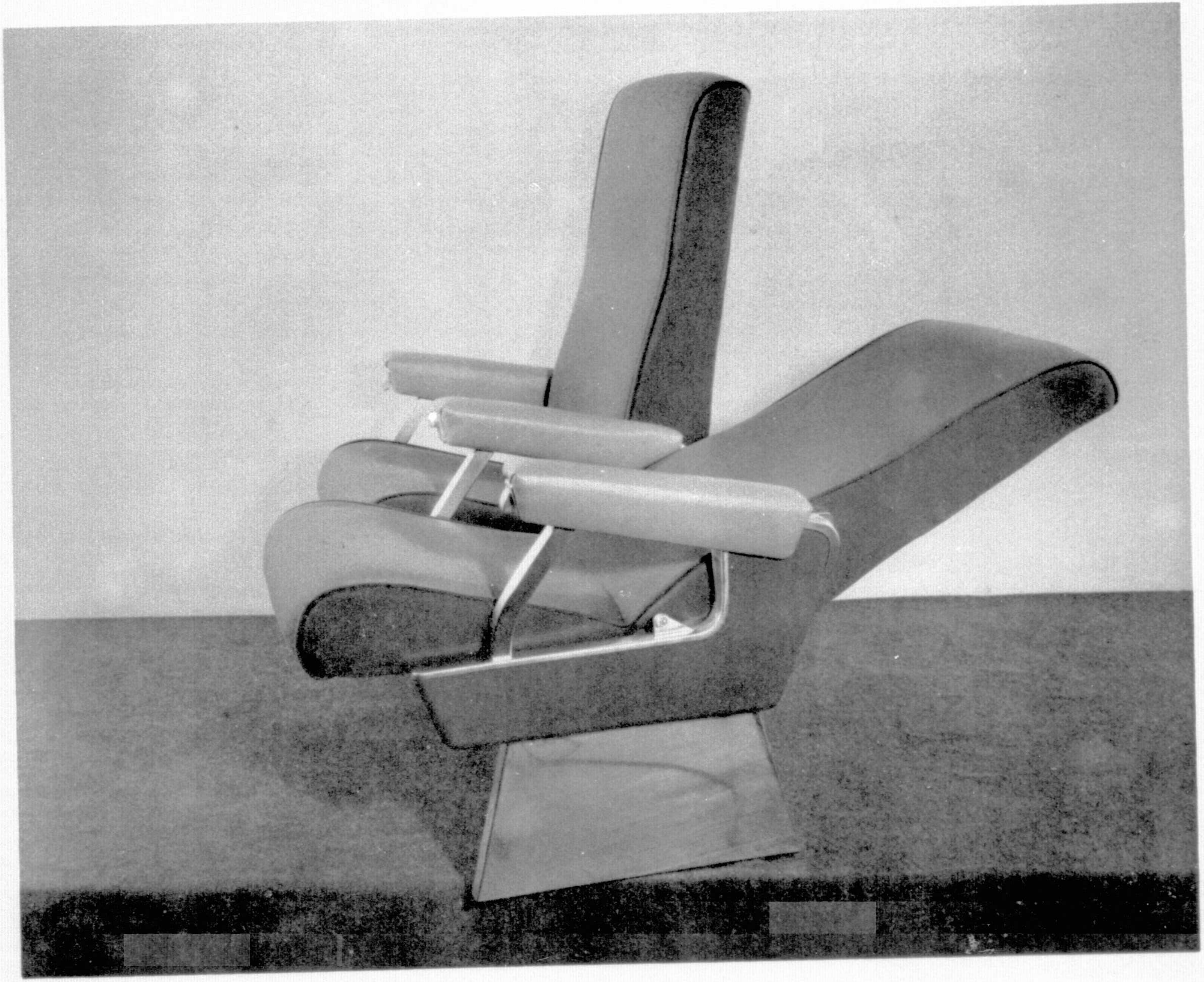


Figure 8.

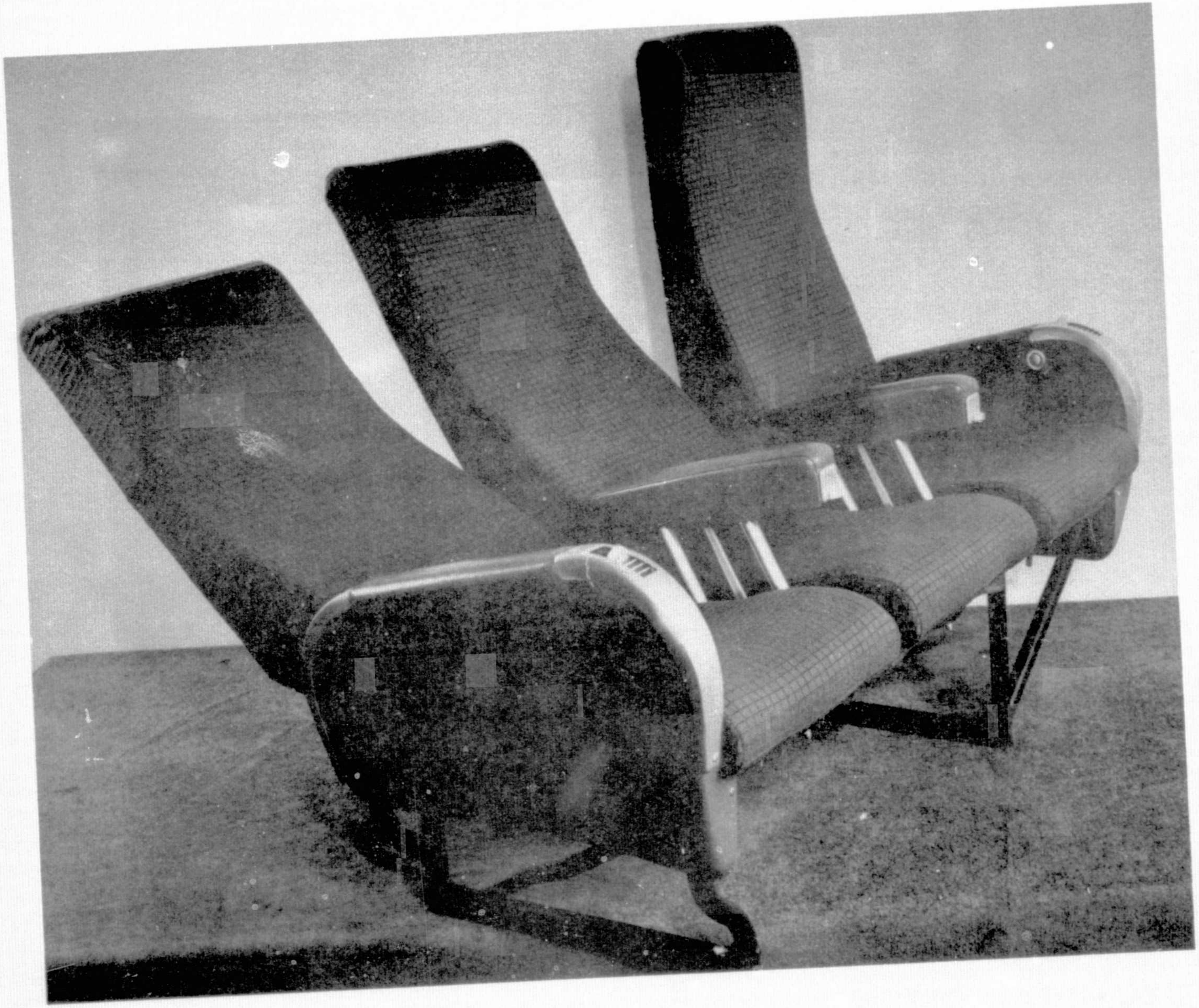


Figure 9.

Figure 10.

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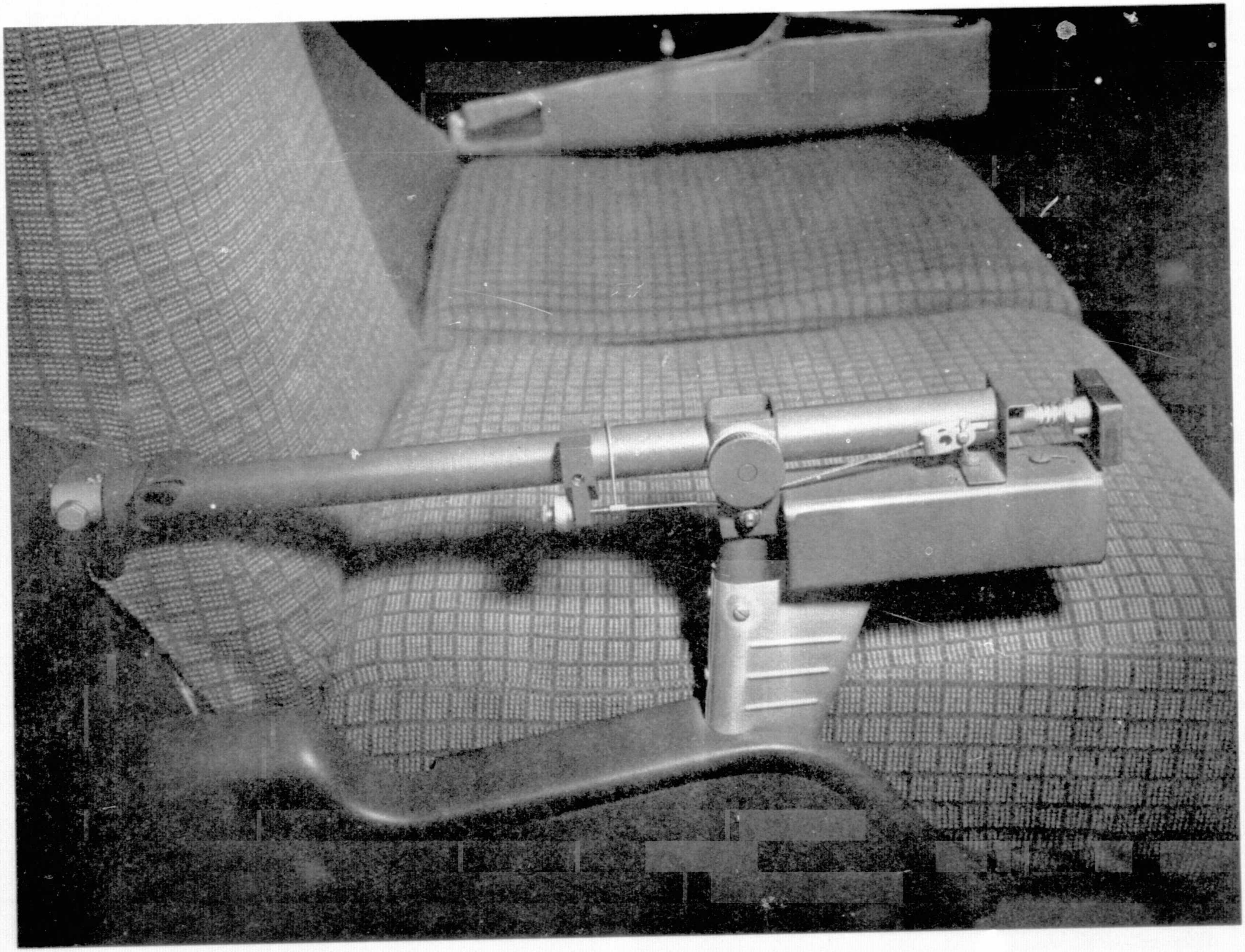


Figure 11.

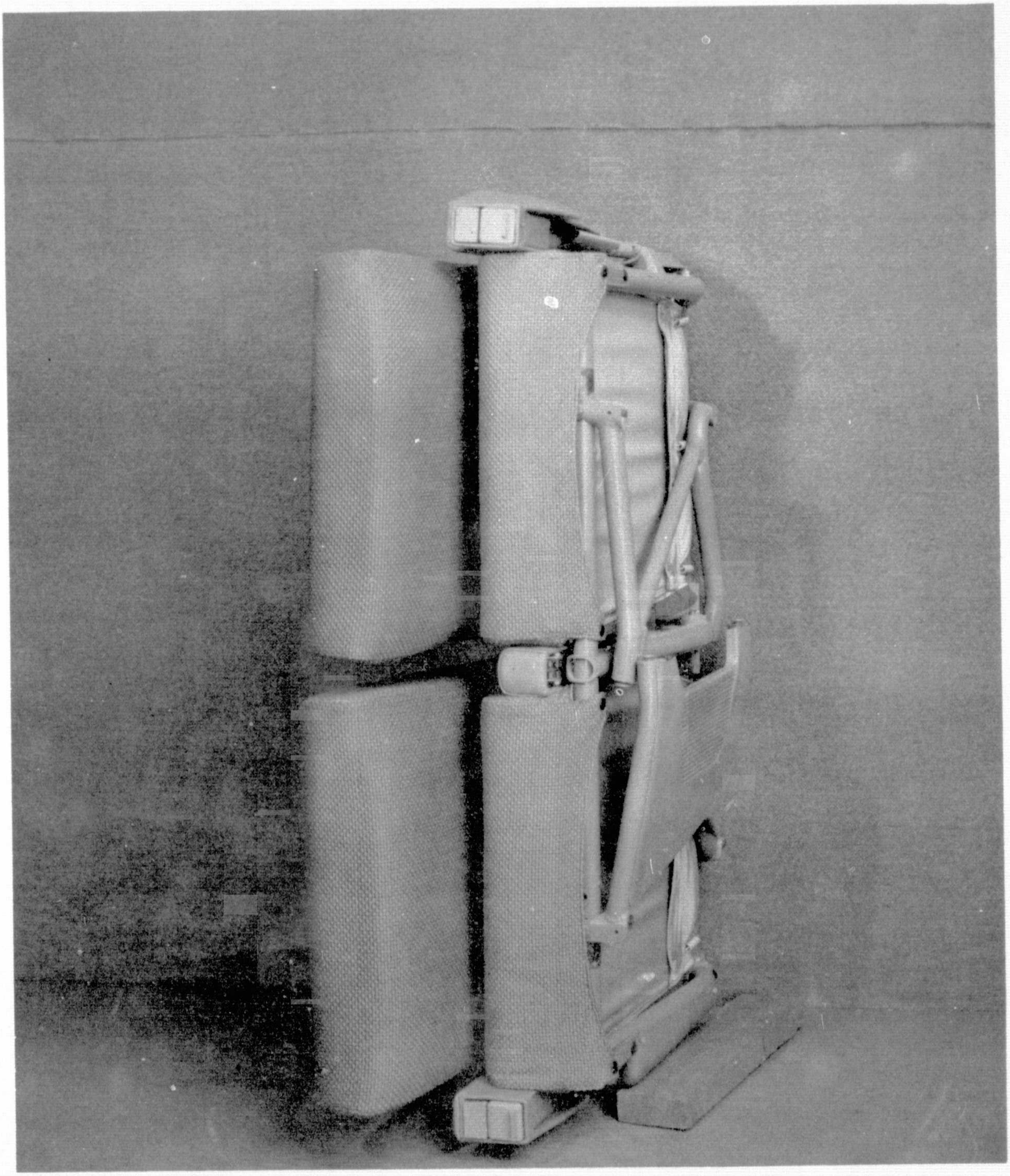


Figure 12.

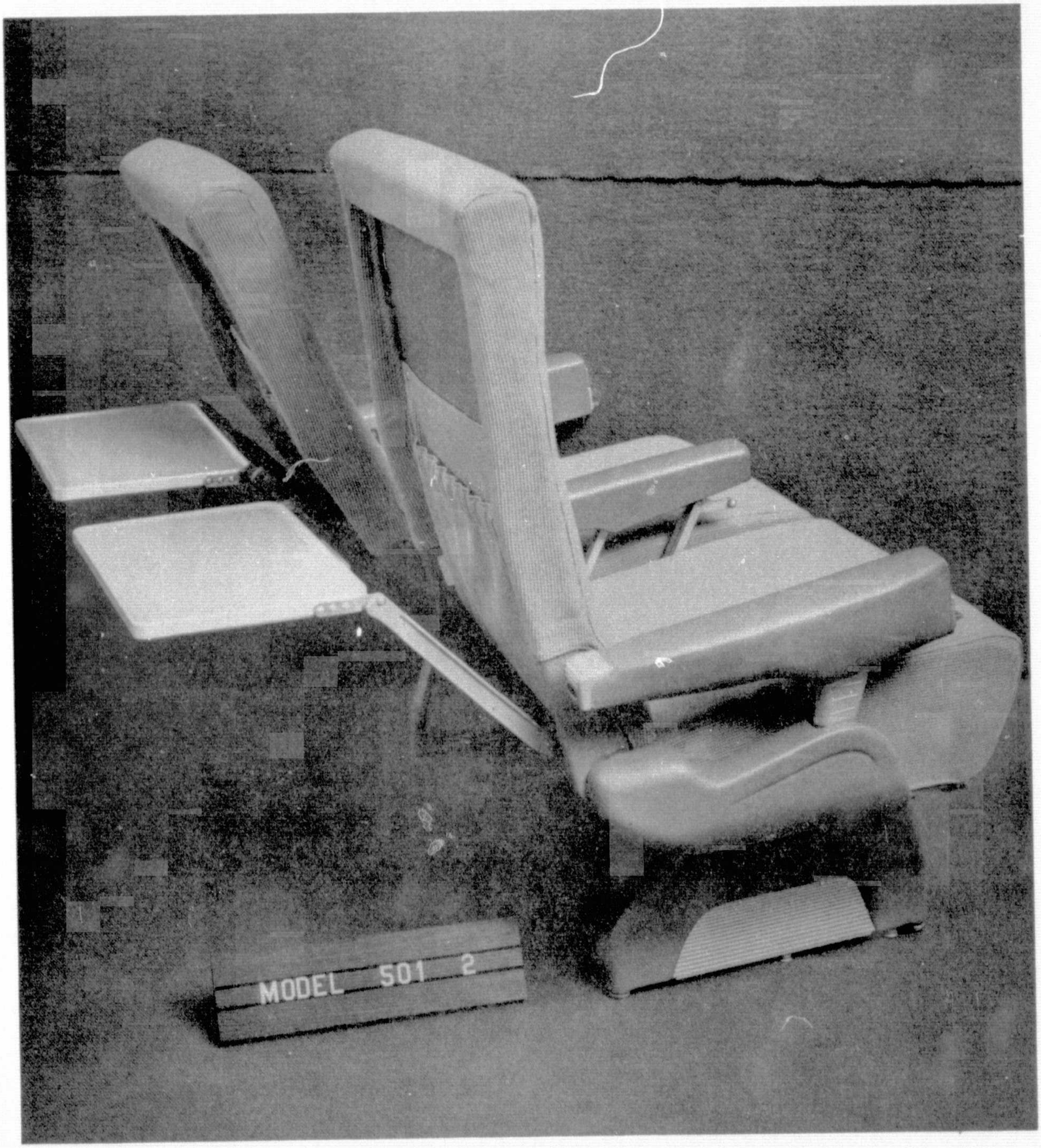


Figure 13.

Figure 14.

Figure 15.

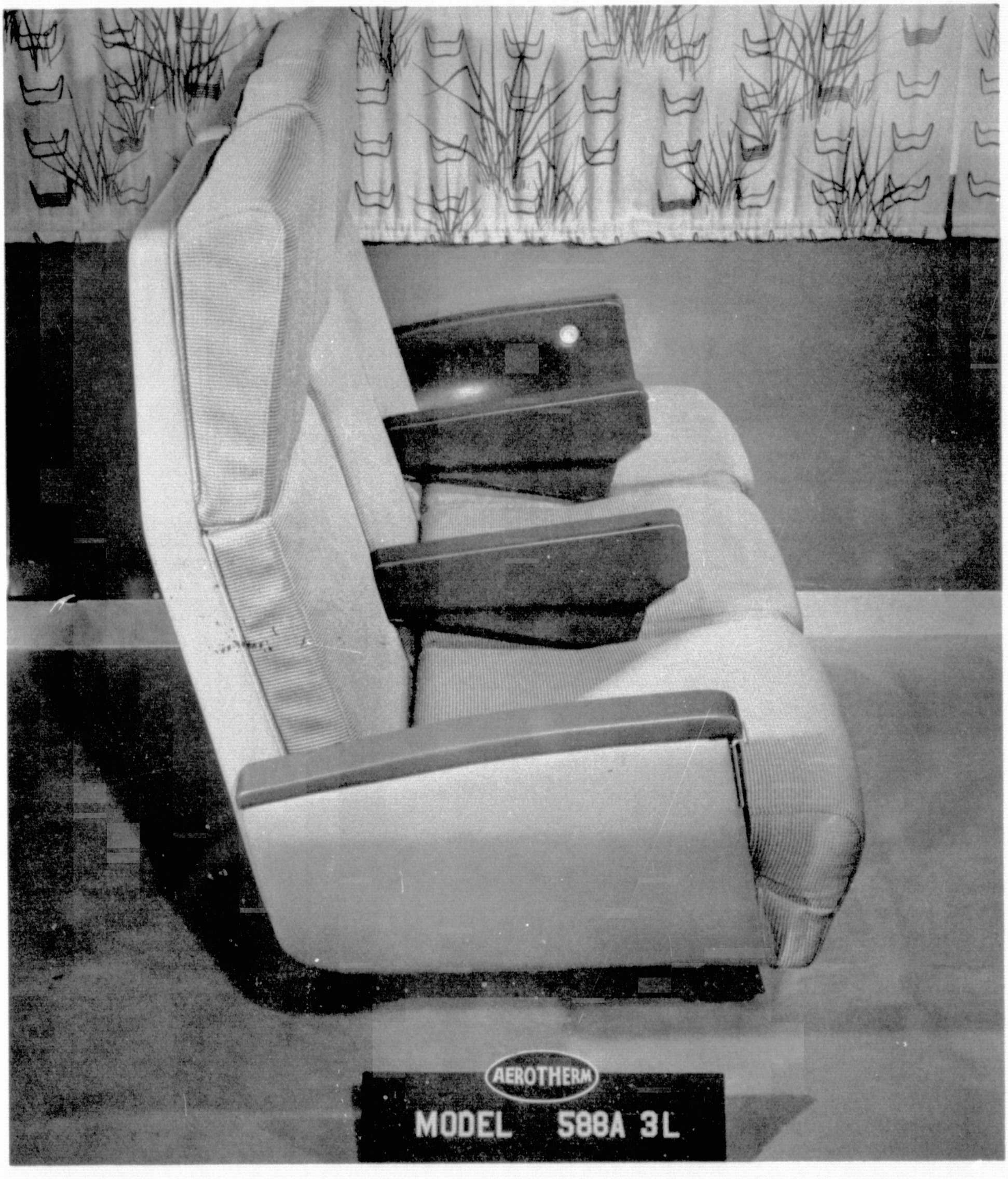


Figure 16.

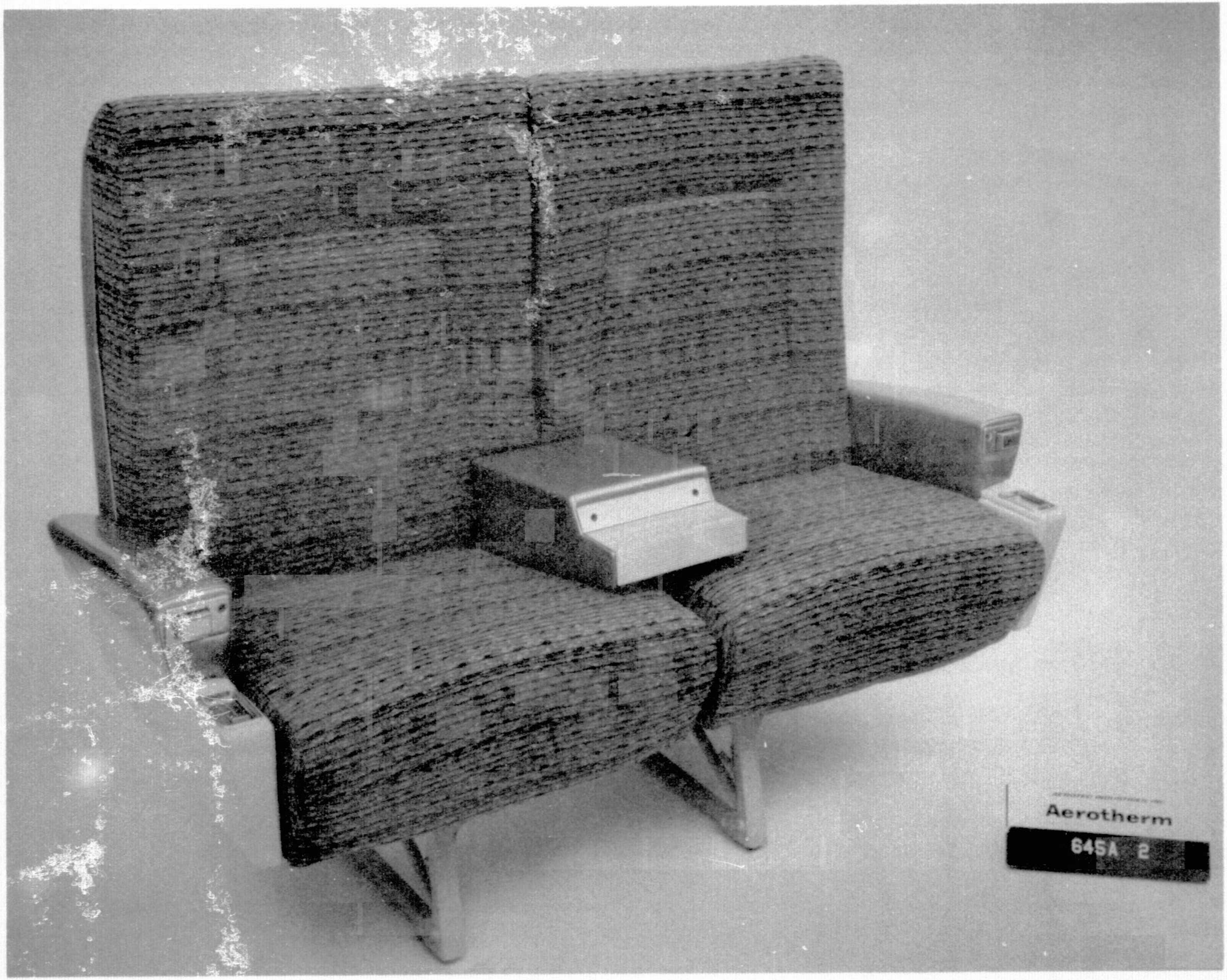


Figure 17.

Figure 18.

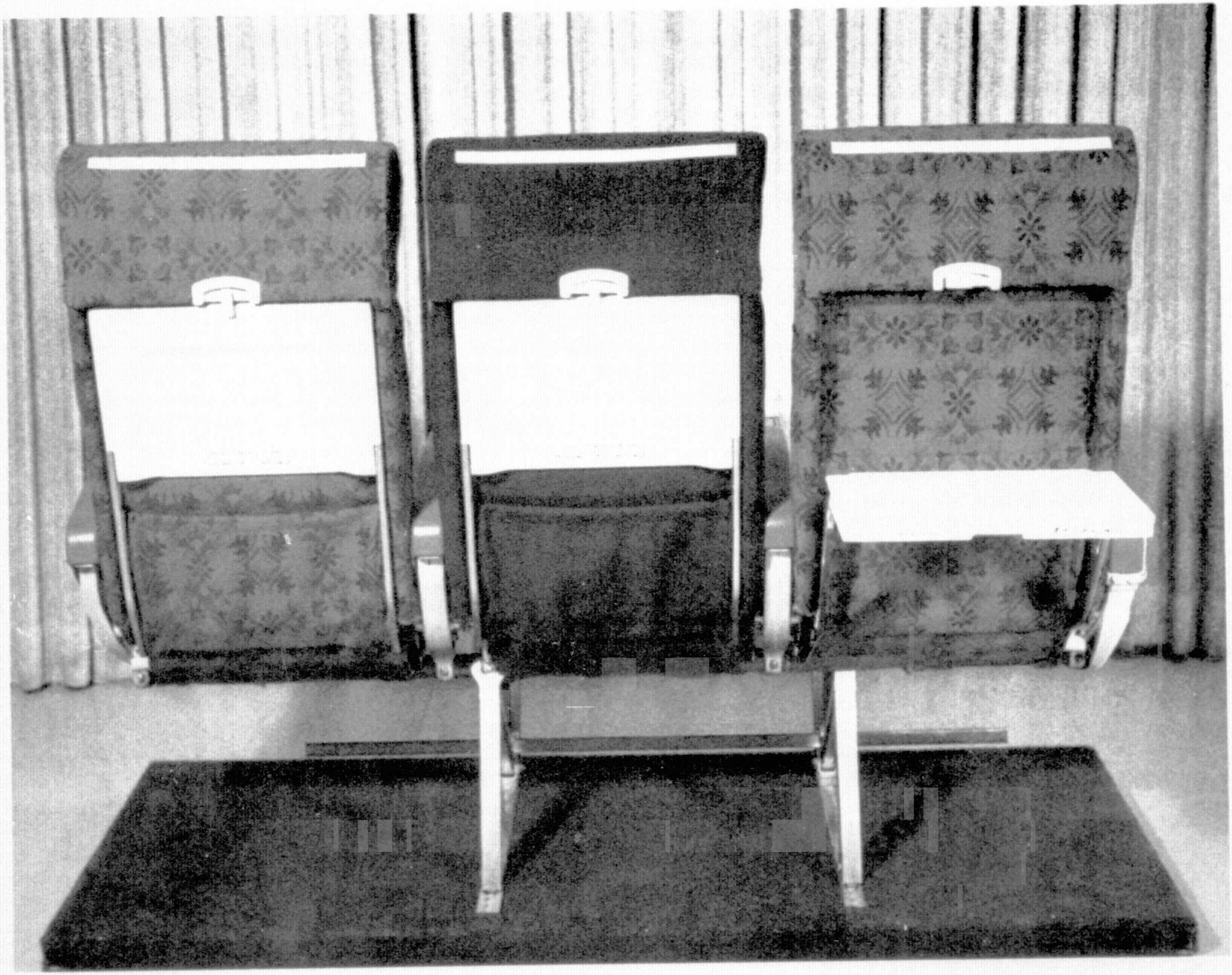


Figure 19.

Figure 20.

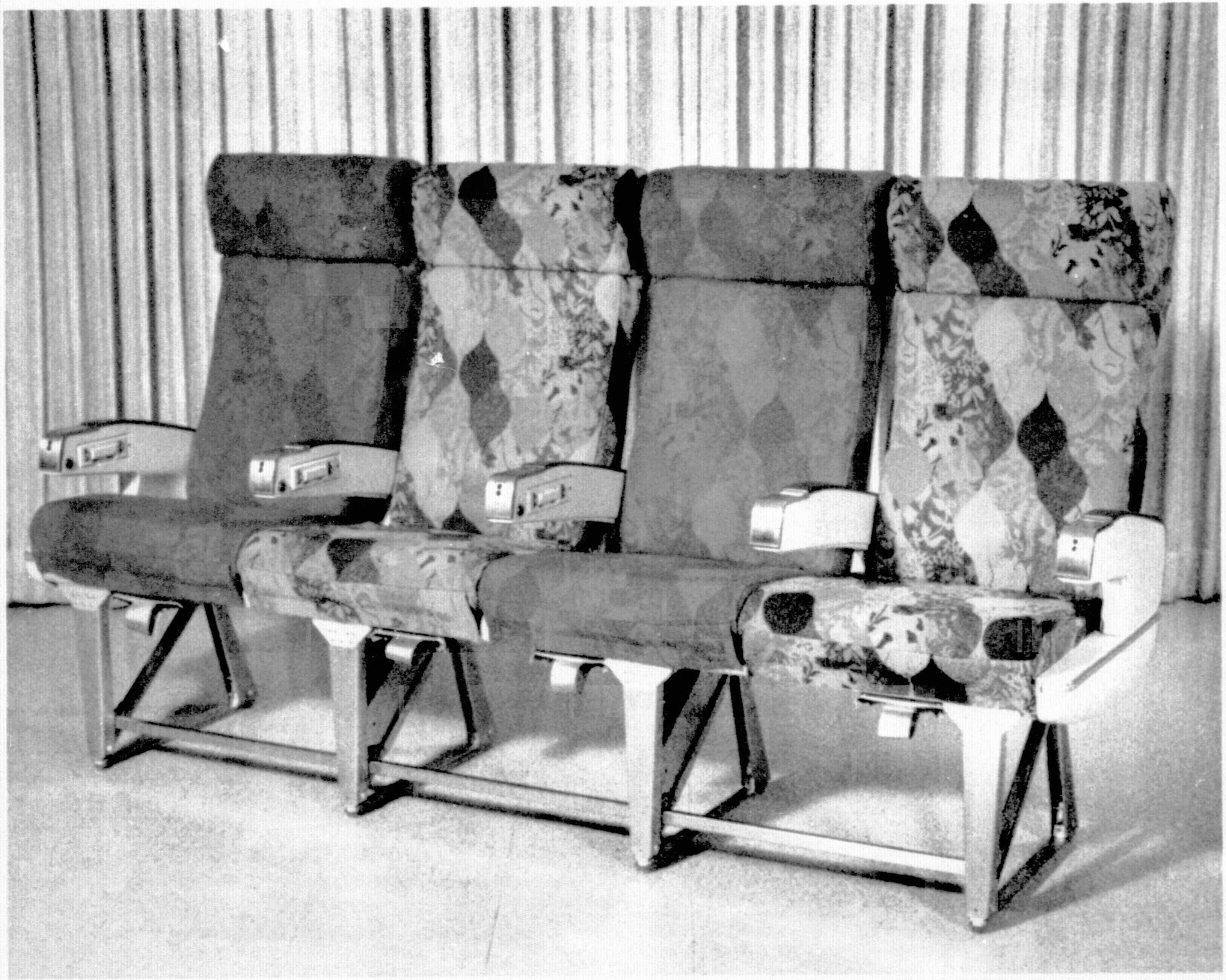


Figure 21.

Figure 22.

Figure 23.

AIRCRAFT INTERIOR THERMOPLASTIC MATERIALS

Bernard Silverman

Lockheed Missiles and Space Company

Thermoplastic materials for use in aircraft interiors are described. These thermoplastic materials are lightweight and better than present materials in respect to fire resistivity, maintenance and service life.

Figures 1 and 2 are outlines of the problem areas and their classifications.

Figure 3 depicts the purpose and long-range goals of the program.

Figure 4 is a statement of design criteria and philosophy.

Figures 5 through 8 describe the distribution of six thermoplastic materials in the lavatory, galley, passenger section, and the flight station of a wide-body jet aircraft.

Figure 9 describes the necessary steps for material selection.

Figure 10 describes controlling factor and composite technique for thermoplastic material development.

Figures 11(a) and 11(b) show the chemical and physical properties of compression molding material candidates. Polyether sulfone is quite promising; polyarylsulfone is rather costly; polysulfone is now being marketed; however, polysulfone has the undesirable feature of solvent cracking.

Modified polycarbonate for injection molding looks especially good for ceiling panels; it does not melt or drip when exposed to a fire environment. Polyether sulfone chars and doesn't drip when tested as a panel; however, bondability and cleaning problems need to be overcome.

PROBLEM HAS SEVERAL FACETS

TECHNICAL

MANY COMMONLY USED PLASTICS OBJECTIONABLE (FIRE, SMOKE, TOXICITY)

- NEW DEVELOPMENTS NEEDED

ECONOMIC

AIRCRAFT PROVIDE ONLY LIMITED MATERIAL MARKET

- COMMONALITY IN REQUIREMENTS, AIR AND GROUND TRANSPORT, PUBLIC HOUSING ETC., NEEDS DEFINITION

SOCIAL

HIGHER STANDARD OF SAFETY MEANS HIGHER COST

- HOW MUCH IS A FREE SOCIETY WILLING TO PAY?

POLITICAL

SOCIALLY, ECONOMICALLY AND TECHNICALLY ACCEPTABLE TARGETS NEED DEFINITION

- GOVERNMENT PROGRAMS SEEKING TO ESTABLISH TARGETS (E. G. NASA FIREMEN)
- AIRCRAFT RELATED PROBLEM CATALYZING ACTION

Figure 1.

PHASE III: TECHNICAL PROBLEMS

MAJORITY OF COMMERCIAL PLASTICS OBJECTIONABLE

- FLAMMABILITY
- LOW MELTING
- HIGH SMOKE
- TOXICITY

MAJORITY OF FIRE RETARDANTS OBJECTIONABLE

- IRRITATING GASES
- NERVE GASES

Figure 2.

PHASE III: PURPOSE

LONG TERM

- REPLACE OBJECTIONABLE MATERIALS WITH NEW LIGHT WEIGHT MATERIALS
    - HIGH FIRE RESISTANCE
    - LOW SMOKE
    - LOW TOXICITY
    - ACCEPTABLE COST

1975

- BRING PROBLEM TO THE ATTENTION OF MATERIALS PRODUCERS
- IDENTIFY NEW DEVELOPMENTS (WHAT, WHEN, PROJECTED COSTS)
- PARTICIPATE IN DEVELOPMENT

Figure 3.

DESIGN PHILOSOPHY

- MATERIALS WITHIN PRESSURIZED SHELL
- BETTER THAN PRESENT REQUIREMENTS
- CHOICE OF MATERIALS
    - Non-Burning
    - Self Extinguishing
    - Highest Decomposition Temperature
    - Least Smoke
    - Least Toxic Byproducts
- SERVICE LIFE
- MAINTENANCE

Figure 4.

LAVATORY

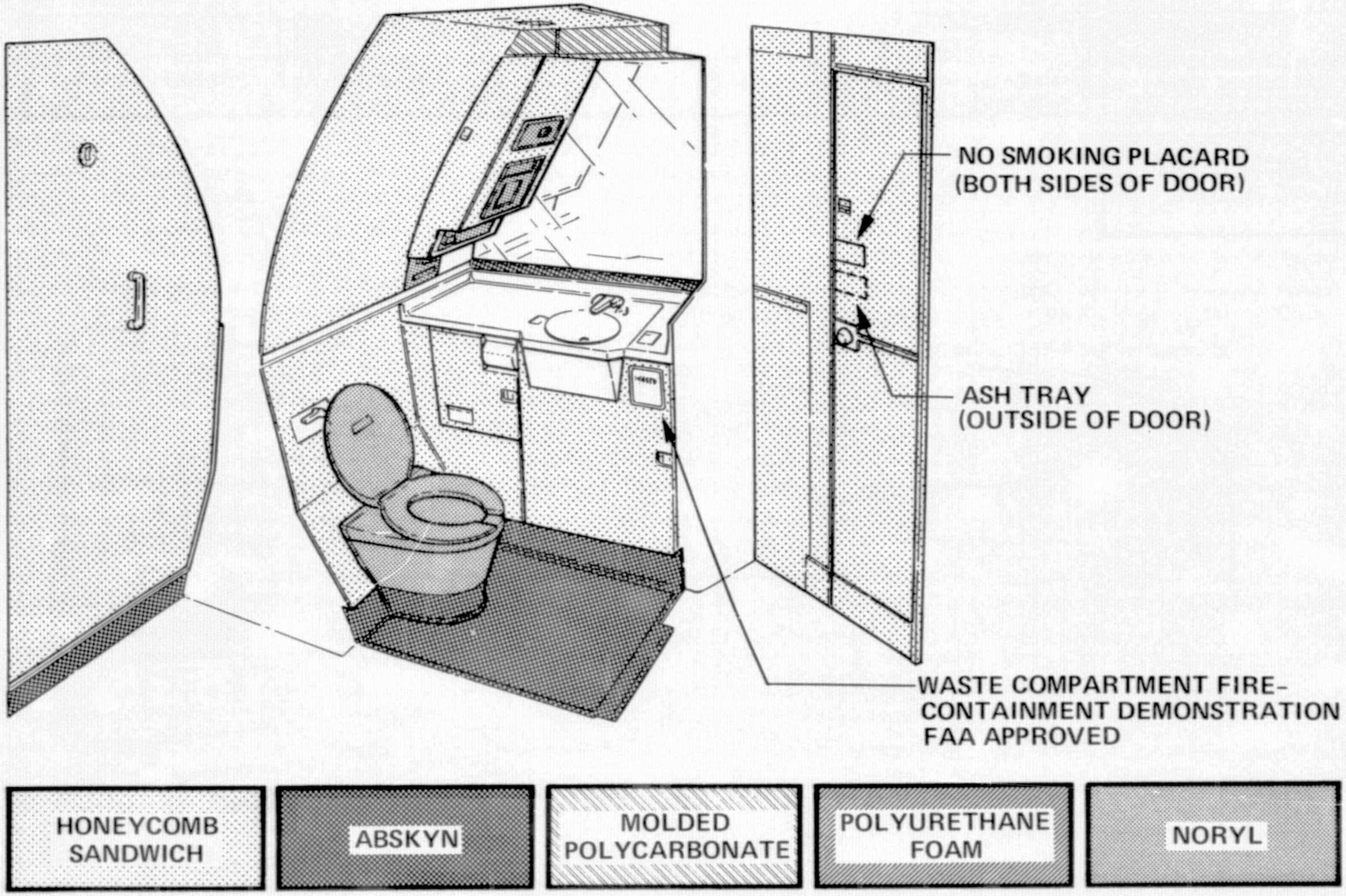


Figure 5.

GALLEY - L.H. SIDE

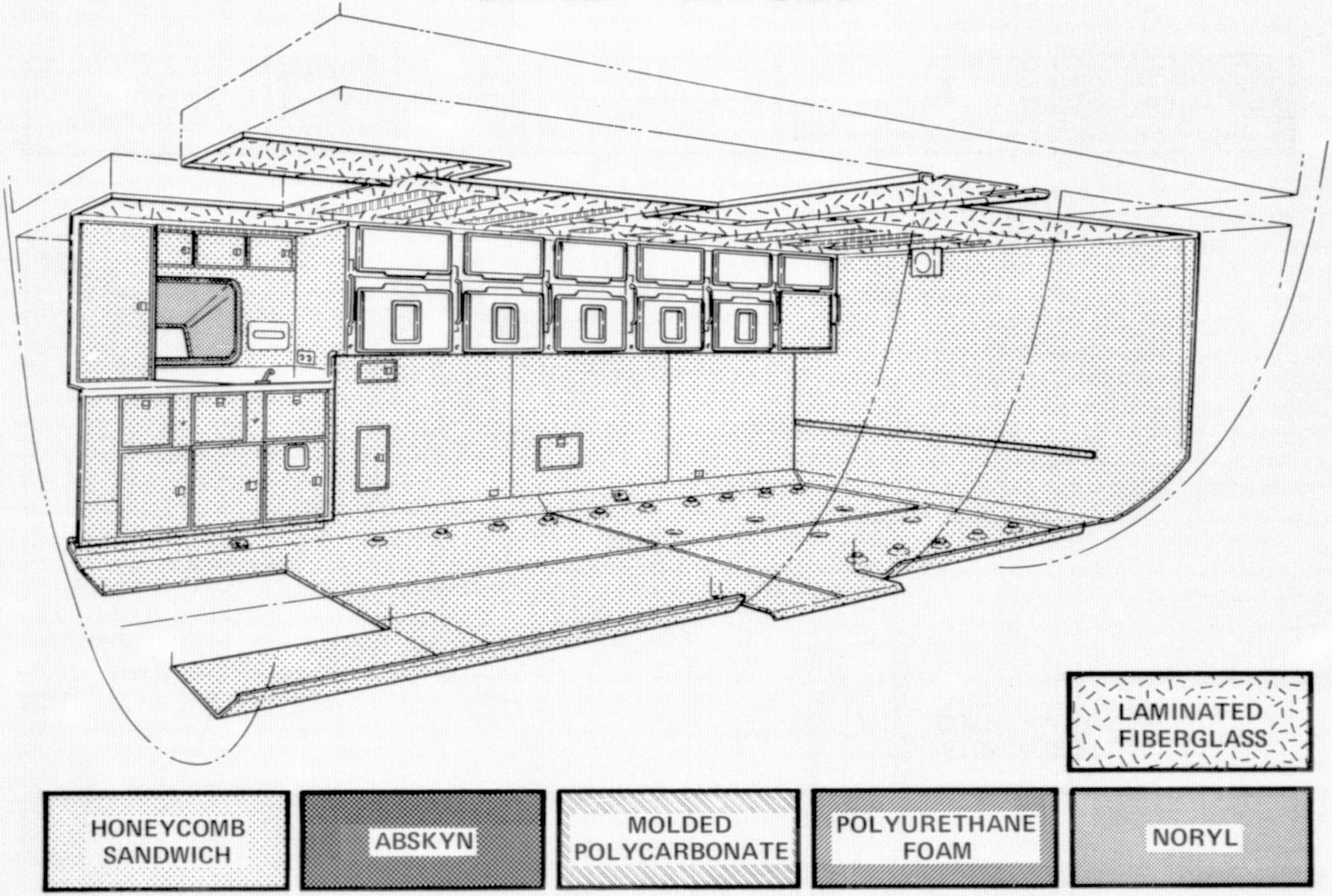


Figure 6.

PASSENGER CABIN

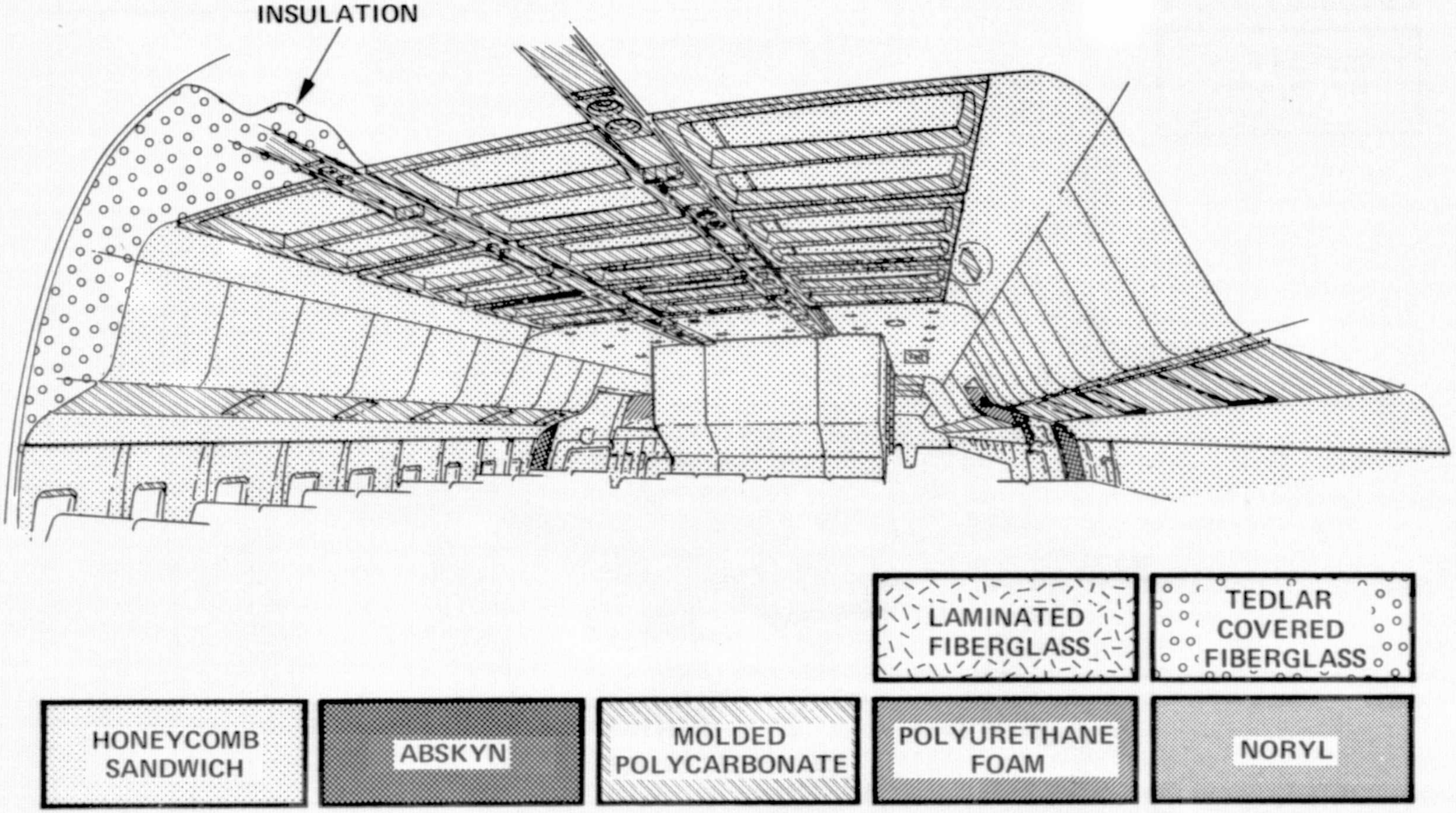


Figure 7.

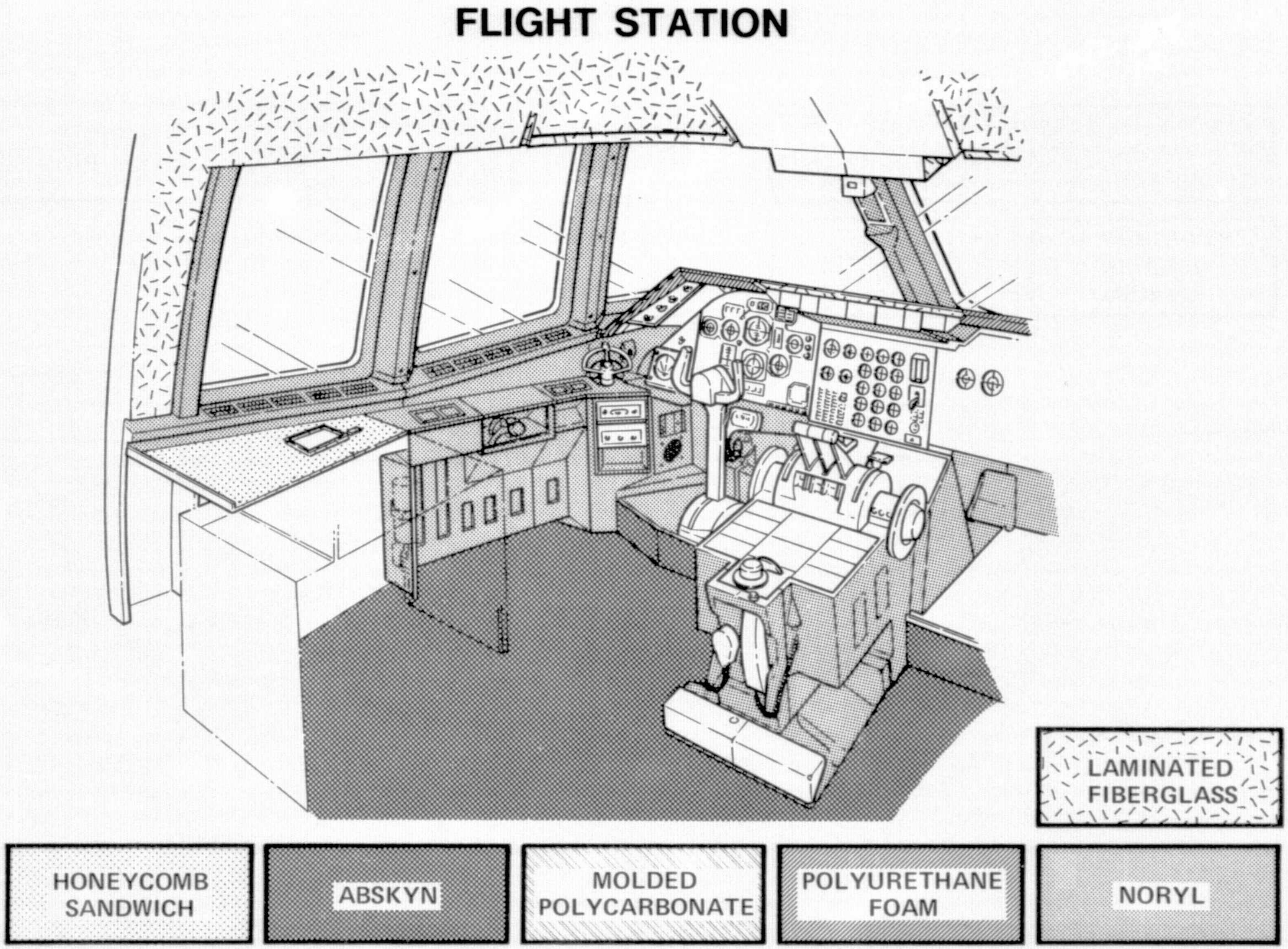
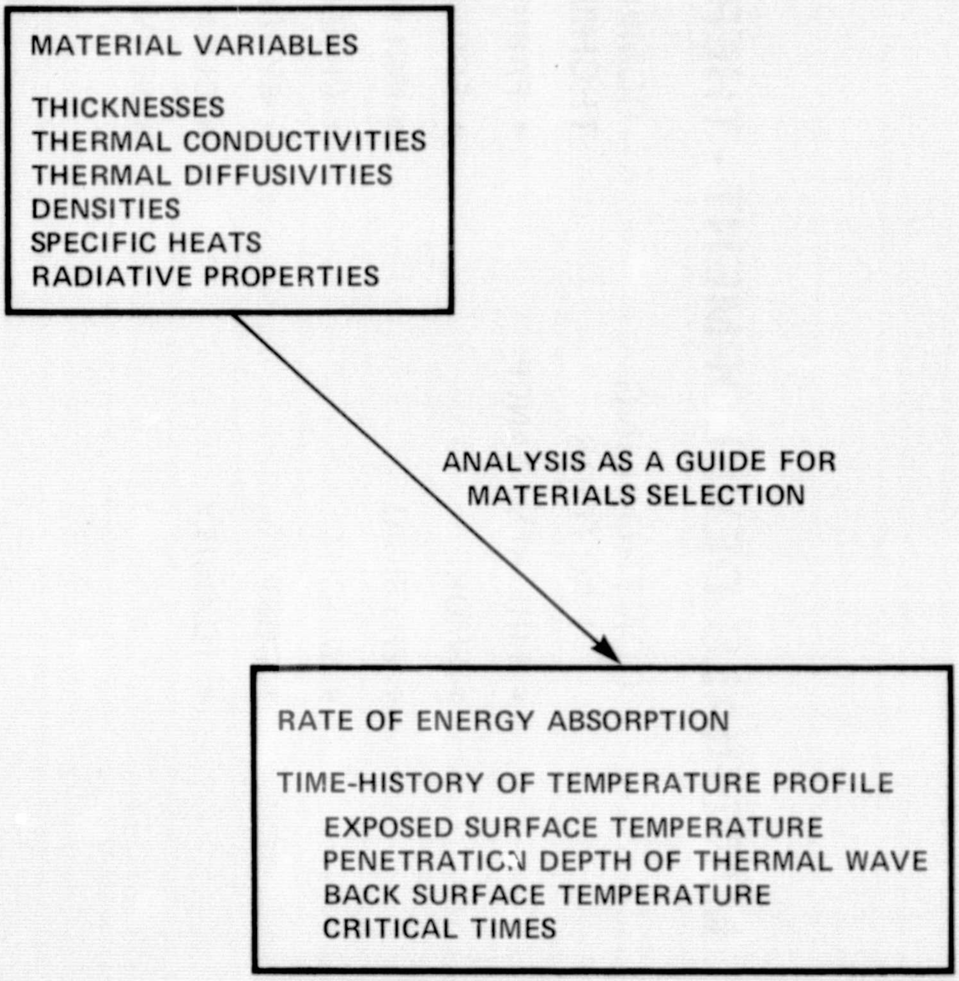

FLIGHT STATION
LAMINATED FIBERGLASS
HONEYCOMB SANDWICH
ABSKYN
MOLDED POLYCARBONATE
POLYURETHANE FOAM
NORYL

Figure 8.

ANALYSIS AS A GUIDE FOR MATERIALS SELECTION



MATERIAL VARIABLES

- THICKNESSES
- THERMAL CONDUCTIVITIES
- THERMAL DIFFUSIVITIES
- DENSITIES
- SPECIFIC HEATS
- RADIATIVE PROPERTIES

ANALYSIS AS A GUIDE FOR MATERIALS SELECTION

RATE OF ENERGY ABSORPTION

TIME-HISTORY OF TEMPERATURE PROFILE

- EXPOSED SURFACE TEMPERATURE
- PENETRATION DEPTH OF THERMAL WAVE
- BACK SURFACE TEMPERATURE
- CRITICAL TIMES

Figure 9.

MATERIALS DEVELOPMENT - THERMOPLASTICS

CONTROLLING FACTORS

- FIRE RESISTANCE
- SMOKE
- PHYSICAL
- WEIGHT
- COST
- TOXICITY

COMPOSITE TECHNIQUES

- FABRICATION
- FORMING
- MOLDING
- CEMENTING
- SYNERGISM
- CLEANING
- SERVICE LIFE

Figure 10.

PROPERTIES OF CANDIDATE COMPRESSION MOLDING MATERIALS-(PRELIMINARY)

PROPERTY	POLYETHER SULFONE	POLYPHENYLENE SULFIDE	POLYARYL SULFONE	POLYARYLENE	POLYSULFONE	MOD-POLYCARBONATE
Tensile Strength PSI	11,000	9,500			10,000	8,500
Elongation % R.T.		1.5			40%	50%
Flexural Strength PSI	16,000	13,000			15,000	12,000
Heat Deflection Temp. of @ 264 PSI	390	275			330°F	270°F
Specific Gravity	1.37	1.3		1.45	1.25	1.20 to 1.26
Impact Strength (Notched Izod) Ft-lb/in of Notch	1.6	1.5			1.3	9.0
Mod of Elasticity PSI	350,000	500,000			340,000	300,000
Compressive Strength PSI	12,000	15,000			13,500	12,000
Smoke Density Flaming D_s (6 min.) .060	20 (.060)	100 (.070)			80 (.060)	130 (.060)
TGA °C	440°C	430°C	490°C			
Ultra-Violet Fade-o-Meter	50 hrs	50 hrs				60 hrs
Liming Oxygen Index (LOI)	37	44			30	23
Surface Bonding Acceptance 180° Peel					8#/in	10#/in
Soil & Cleaner Resistance	Fair	Excellent		Fair	Fair	Fair
LC$_{50}$ 1 mg/700°C in air/liter	55					65

Figure 11(a).

PRELIMINARY PROPERTIES OF CANDIDATE THERMOFORMED MATERIALS

PROPERTY	MOD-POLYCARBONATE	MOD-POLYSULFONE	CHLORINATED - PVC	MINERAL FILLED POLYETHYLENE	BIS-PHENOL "A" POLYCARBONATE
Tensile Strength PSI	8,500	8,000	5,400	2,300	
Elongation %	70		40	200 Takes Permanent Set	
Flexural Strength PSI	12,000	12,500	10,000	3,800	
Heat Dflection Temp of @ 264 Psi	220°F		200°F	160°F	
Specific Gravity	1.26	1.26	1.57	1.7	
Impact Strength (Notched Izod) Ft-lb/in of Notch	10.0	9.0	6.6	12	
Mod of Elasticity PSI	300,000	320,000	300,000	450,000	
Smoke Density Flaming D_s (6 min)	130(.060)	105(.050)	140(.060)	20	
TGA °C		400°C			
Ultra-Violet Fade-o-Meter	60 hrs	60 hrs	60 hrs		
Limiting Oxygen Index (LOI)	23	30	42	35	
Soil & Cleaner Resistance	Fair	Fair	Good		
Surface Bonding Acceptance 180° Peel #/in	10#/in			Poor No Adhesive Sticks	
LC_{50} Img/700°C					

Figure 11(b).

FLAME RESISTANCE OF PHOSPHAZENES

K. L. Paciorek and R. H. Kratzer

Ultrasystems, Inc.

Nitrogen and phosphorus are two of the elements known to impart flame resistance to polymeric compositions, especially when present in combination and in form of the phosphazene unit. Aside from lowering burn rates and making the substrate self-extinguishing, the presence of phosphazene groups drastically increases char yields and autoignition temperatures. The major advantages offered by phosphazene groups, as compared to the behavior of other flame retardants during oxidative thermal decomposition, are due to the fact that the flame retarding elements remain in the char, that the formation of toxic decomposition products is strongly inhibited, and that smoke formation apparently is also reduced.

Phosphazene units have been found to be equally effective both as components of a polymer backbone or in pending side chains. All compositions tested self-extinguished immediately after removal of the flame and did not glow. A material containing phosphazene units, aliphatic segments, and s-triazine groups in the backbone did not autoignite in air at 500°C; this compares favorably with an autoignition temperature of 570°C for Teflon under identical conditions. Char yields in air at 600°C of phosphazenes containing the PN unit in the backbone with aliphatic segments were ~ 20% and with aromatic moieties ~ 60%; those of modified polystyrenes, which have pending PN units, were as high as 41%. The char yield of polydimethoxyphosphazene under the same conditions is a surprising 62.5%.

The only toxic products found to be formed upon oxidative thermal decomposition, aside from carbon monoxide, were benzene and toluene and traces of hydrogen cyanide in the case of those materials that contain the s-triazine nucleus in the backbone. Toxicity studies on animals using three different formulations containing phosphazene units in pending side chains revealed that no mortalities were recorded in six individual experiments.

Figure 1 depicts elements ranked according to their flame retardant capabilities.

Figures 2, 3, and 4 show the variety of ways to incorporate P=N units into a polymers structure.

Figures 5 and 6 show TGA, DTA curves of the polymer in air.

Figure 7 shows the use of the P=N unit as a pendant group.

Figure 8 shows monomers of polystyrenes and their various P=N modifications.

Figure 9 shows the method for preparing P=N modified polystyrenes.

Figure 10 shows the method of crosslinking reactions of modified polystyrene.

Figure 11 indicates the structure of materials for toxicological testing.

Figures 12 and 13 are TGA, DTA curves of the polymer TDA-DPPS in air and a TGA of Dow Styron 475B in air.

Figure 14 depicts modification schemes for polyphosphazenes.

Figure 15 shows some polyphosphazene model compounds.

Figure 16 shows TGA, DTA analysis in air of polydimethoxyphosphazene.

Figure 17 indicates the various methods by which P=N units are incorporated into the polymer structure.

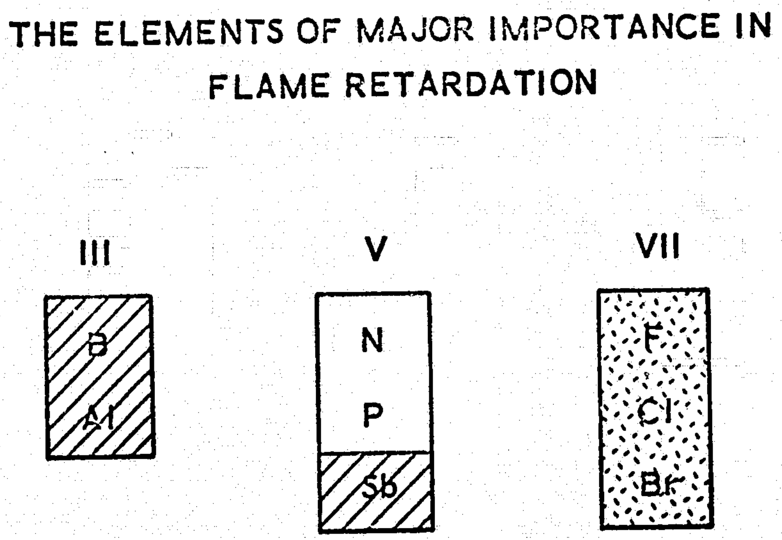

THE ELEMENTS OF MAJOR IMPORTANCE IN FLAME RETARDATION
III
B
Al
V
N
P
Sb
VII
F
Cl
Br

Figure 1.

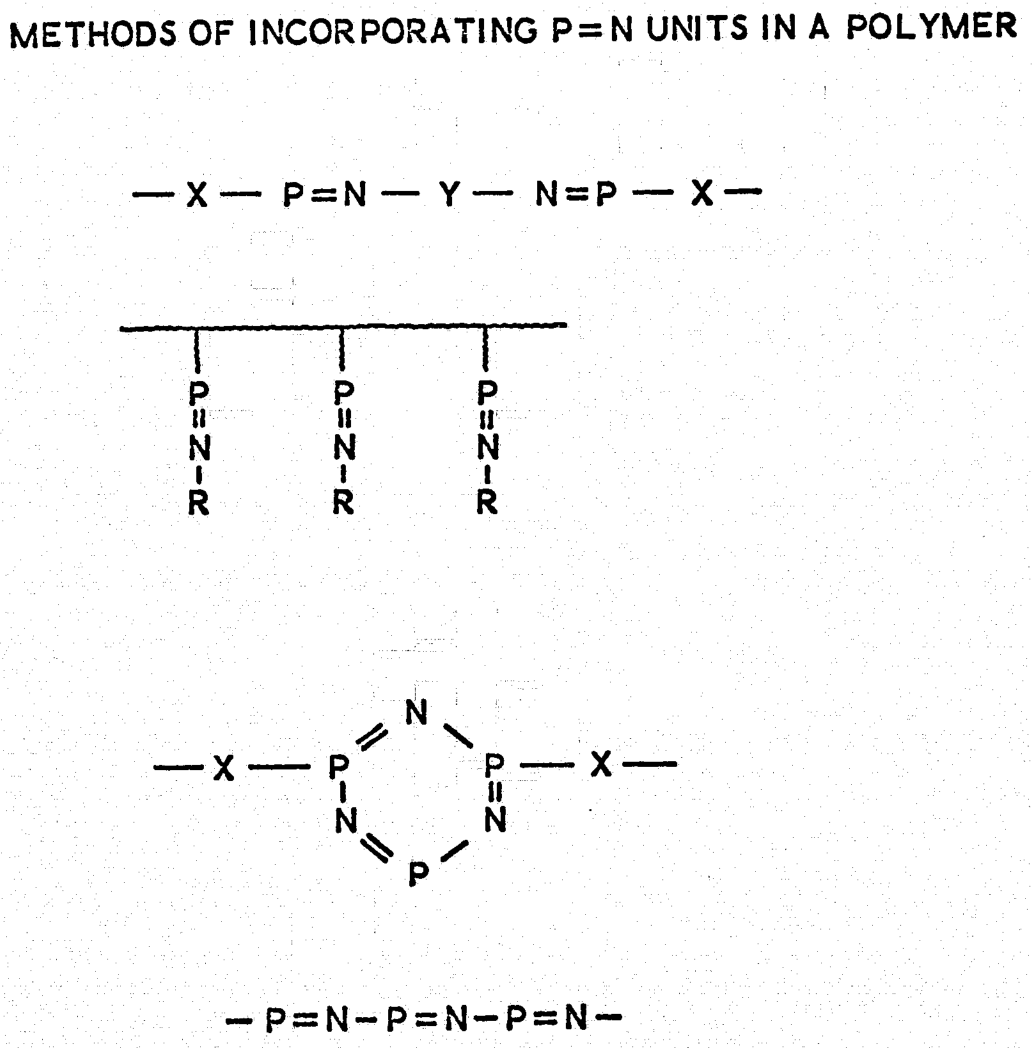
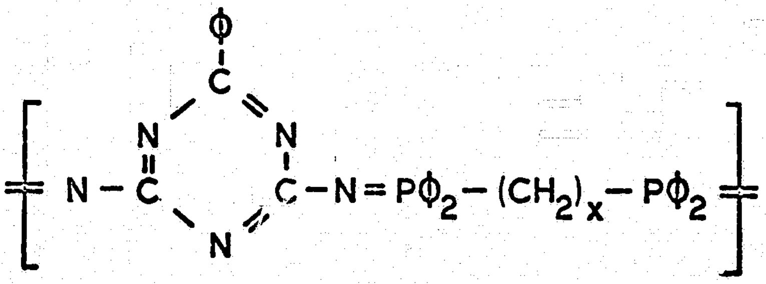

METHODS OF INCORPORATING P=N UNITS IN A POLYMER
— X — P=N — Y — N=P — X —
P=N—R
— X — P — P — X —
N
P
— P=N—P=N—P=N —

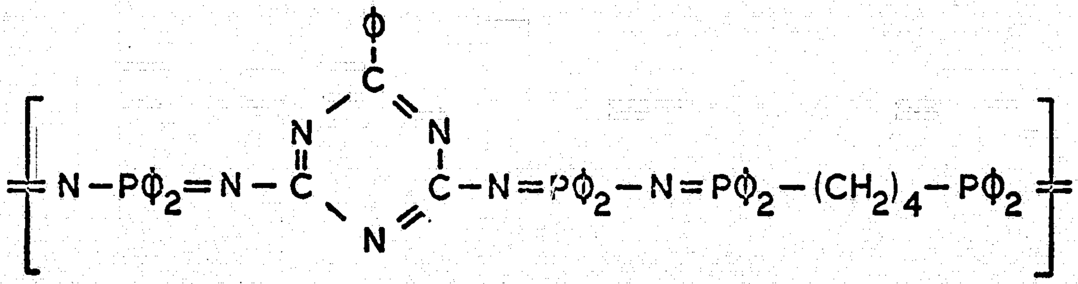
Figure 2.

POLYMERS WITH P=N UNIT IN BACKBONE



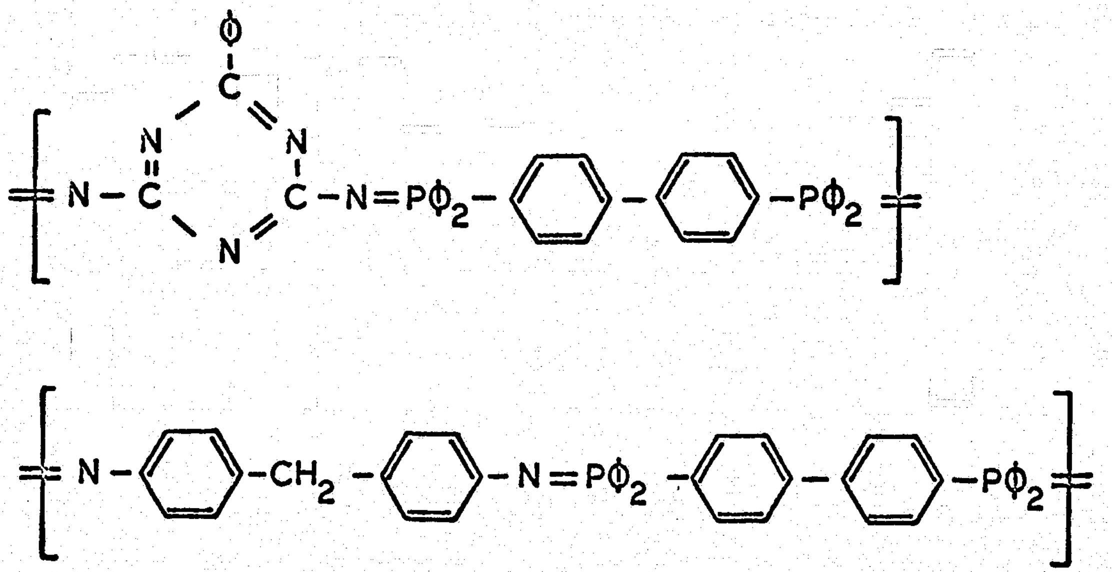
XXI $x = 2$

XX $x = 4$



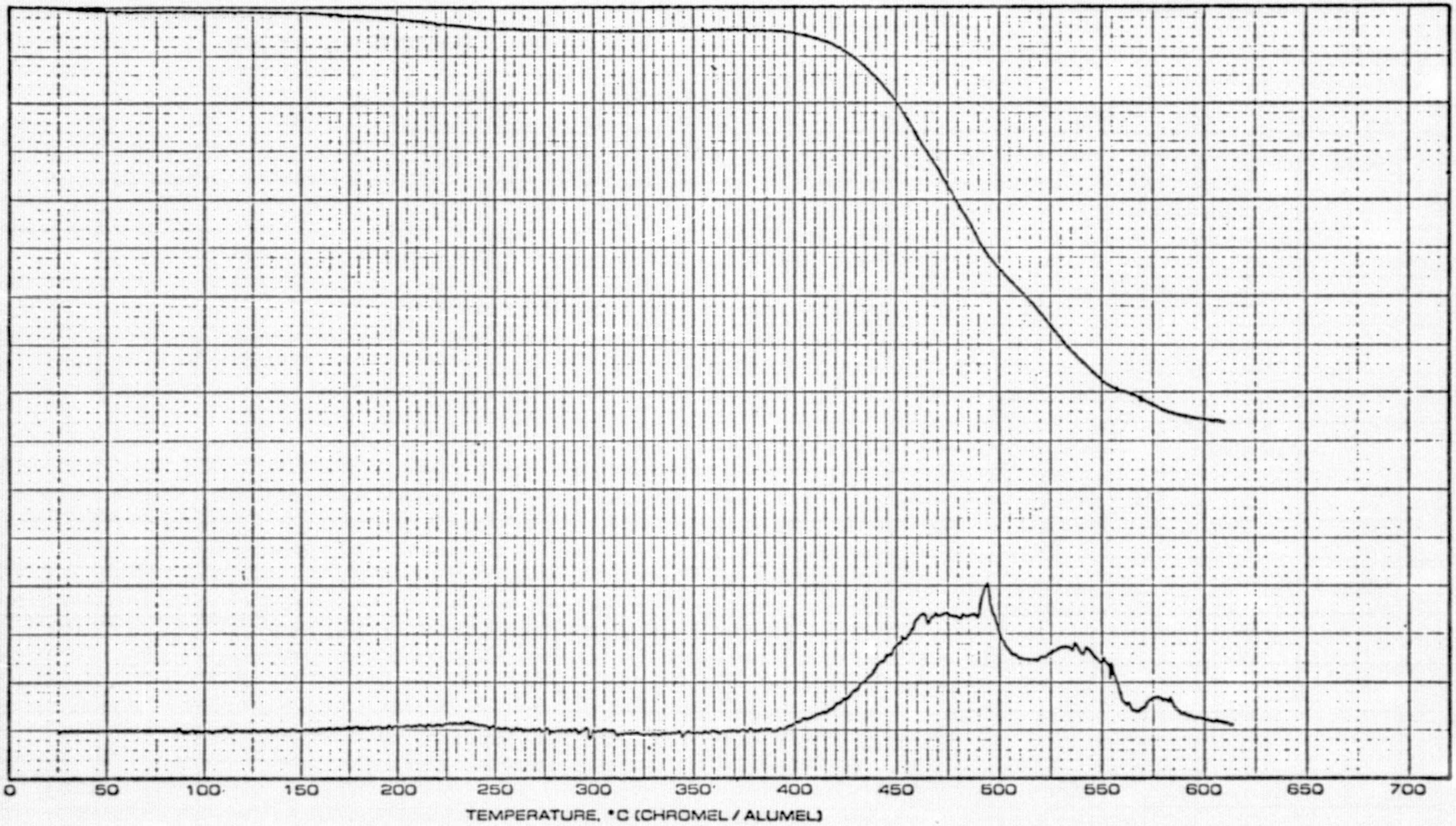
XXIII

Figure 3.



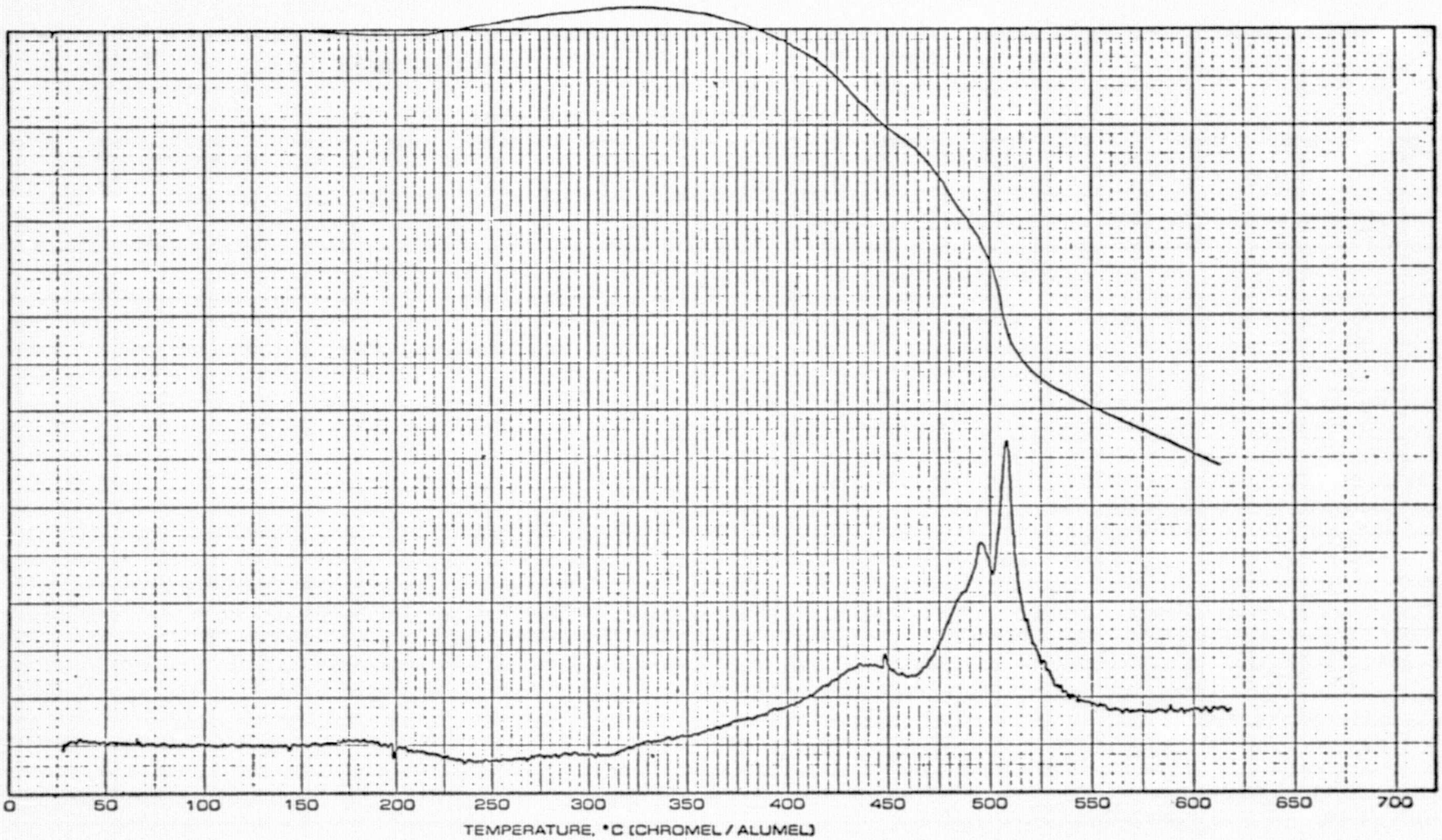
POLYMERS WITH P=N UNITS IN BACKBONE

Figure 4.



TDA — BDBI in Air

Figure 5.



MDA — BDBI in Air

Figure 6.

POLYMERS WITH PENDING P=N UNITS

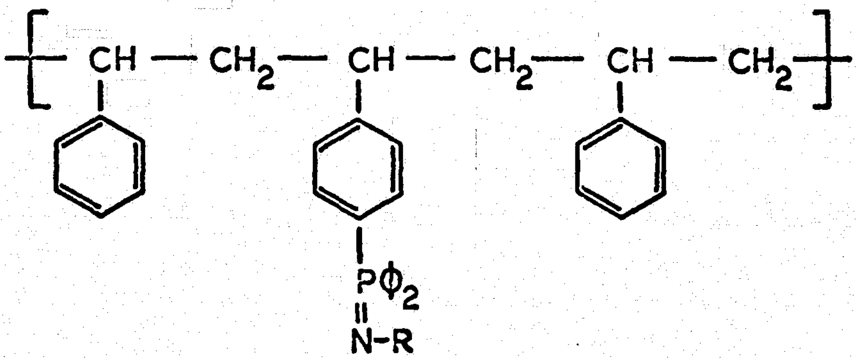


Figure 7.

MONOMERS FOR MODIFIED POLYSTYRENES

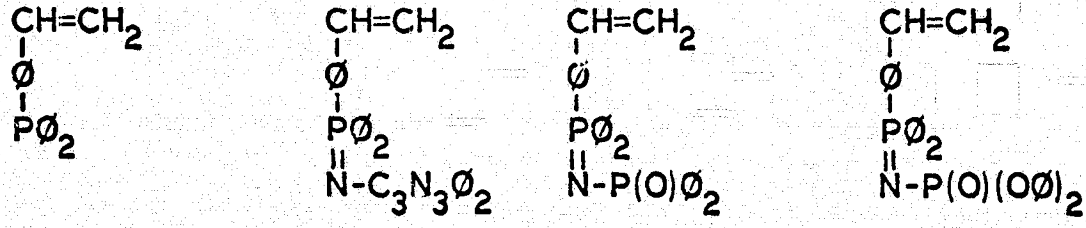


Figure 8.

PREPARATION OF MODIFIED POLYSTYRENES

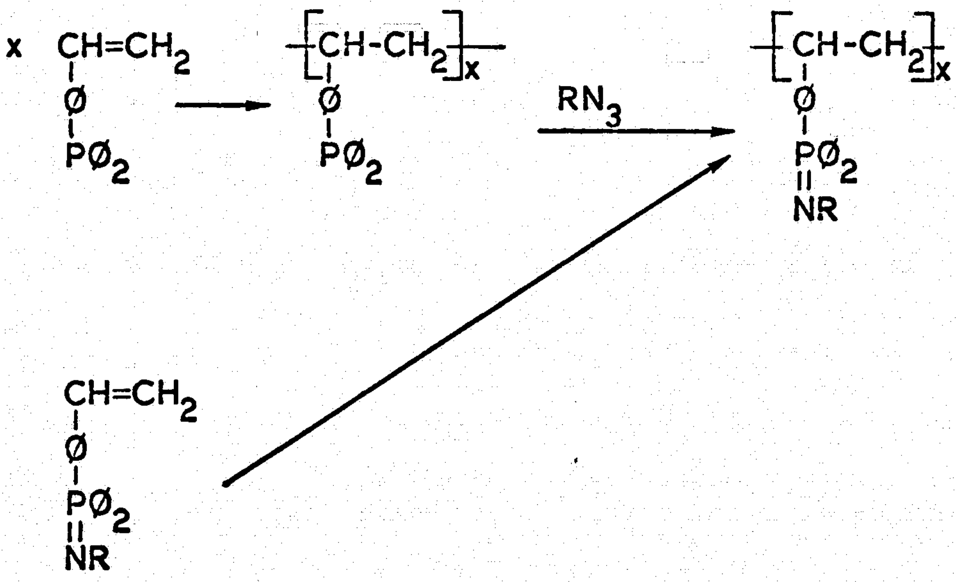


Figure 9.

CROSSLINKING OF MODIFIED POLYSTYRENES

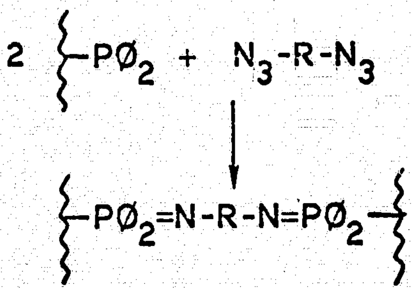
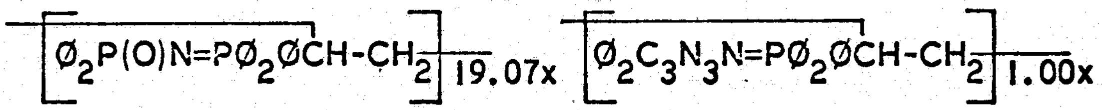
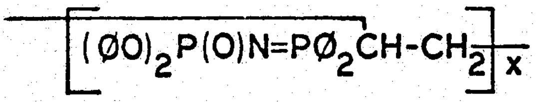


Figure 10.

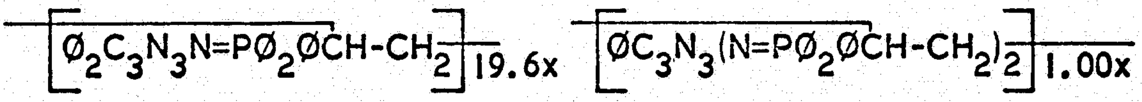
SPECIFIC MATERIALS SUBMITTED FOR TOXICOLOGY TESTING



$$\left[\emptyset_2P(O)N{=}P\emptyset_2\emptyset CH{-}CH_2\right]_{19.07x}\left[\emptyset_2C_3N_3N{=}P\emptyset_2\emptyset CH{-}CH_2\right]_{1.00x}$$

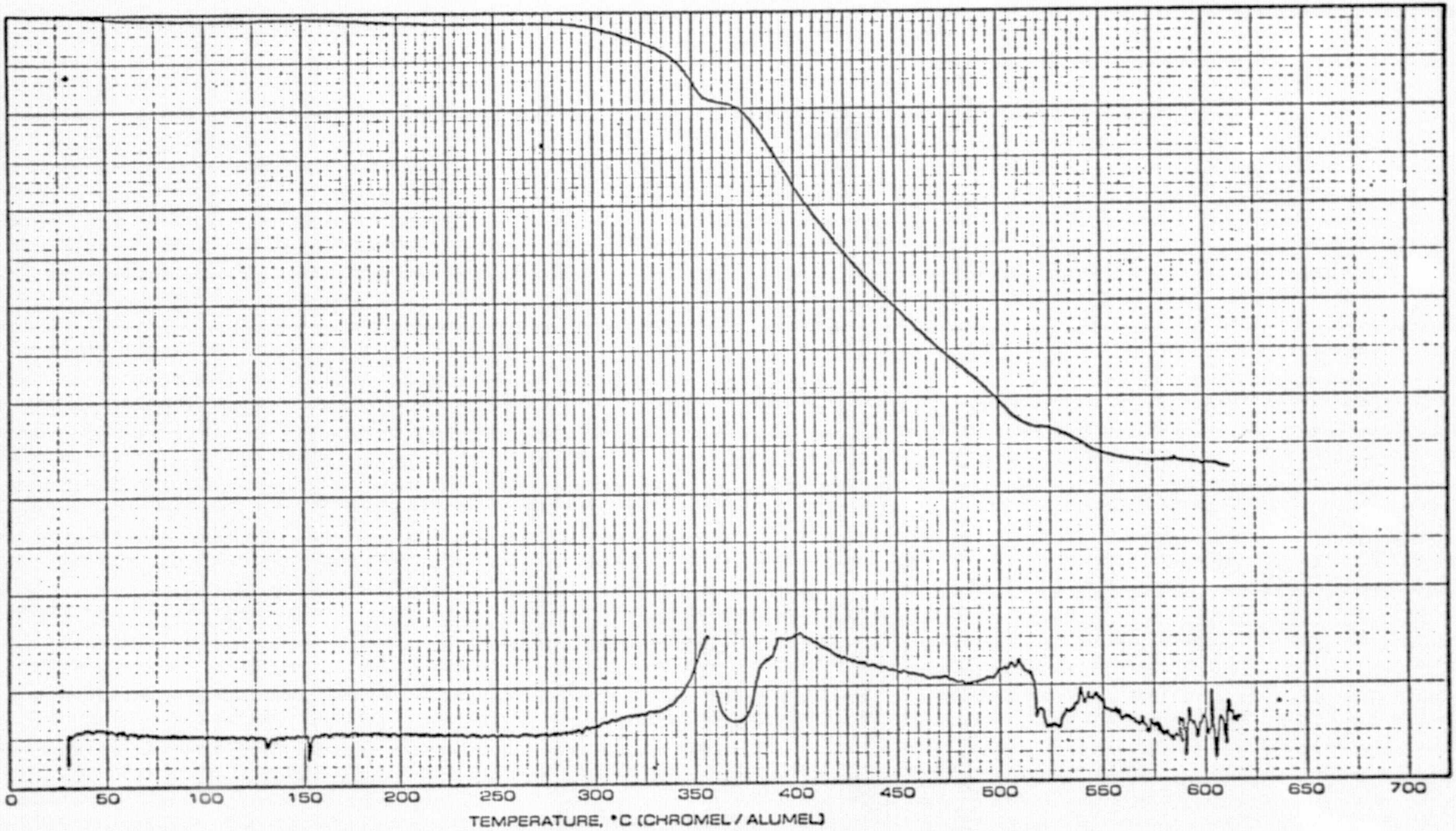


$$\left[(\emptyset O)_2P(O)N{=}P\emptyset_2CH{-}CH_2\right]_{x}$$



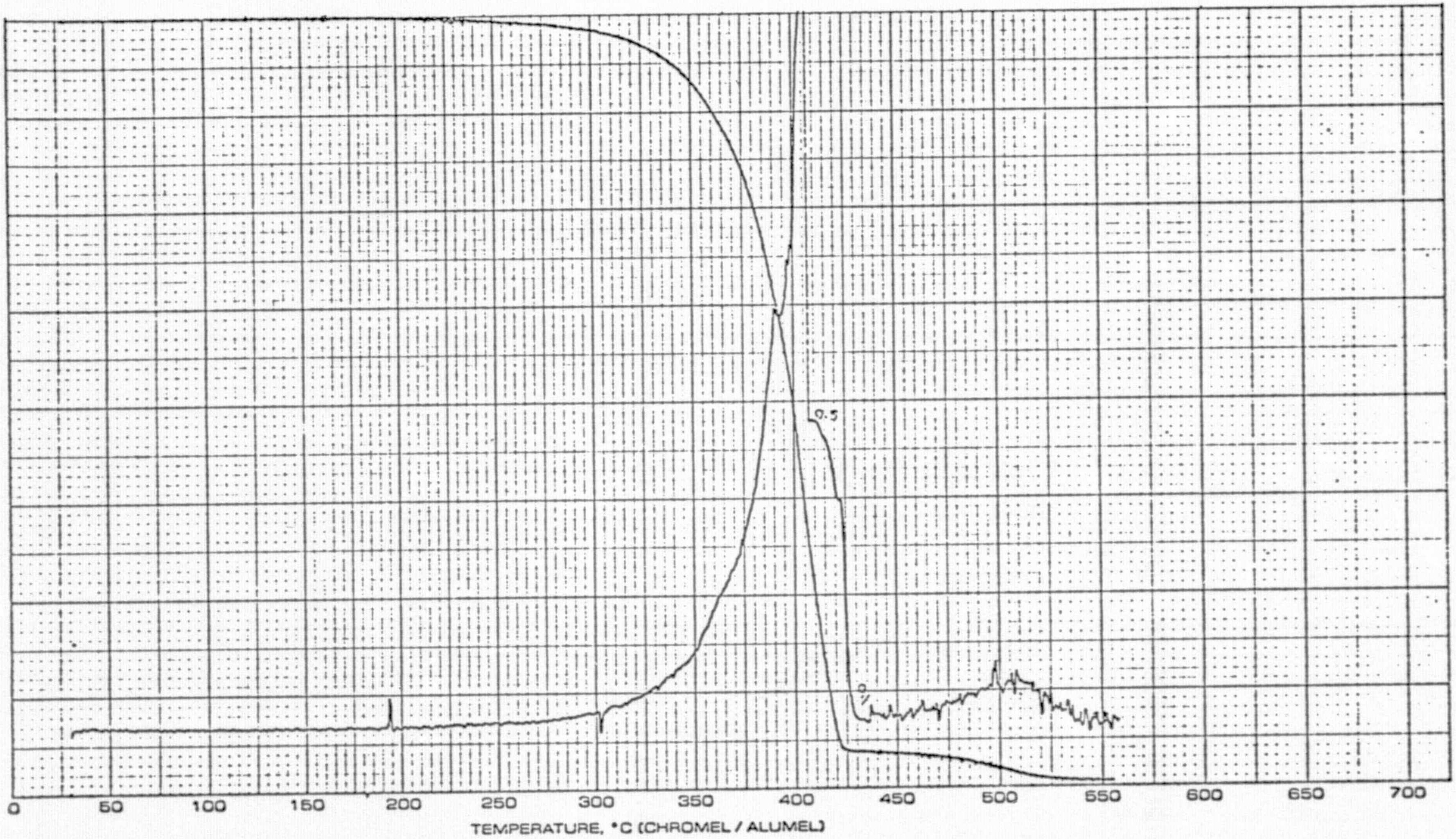
$$\left[\emptyset_2C_3N_3N{=}P\emptyset_2\emptyset CH{-}CH_2\right]_{19.6x}\left[\emptyset C_3N_3(N{=}P\emptyset_2\emptyset CH{-}CH_2)_2\right]_{1.00x}$$

Figure 11.



TDA – DPPS in Air

Figure 12.



TGA of Dow Styron 475B in Air

Figure 13.

MODIFICATION OF POLYPHOSPHAZENES

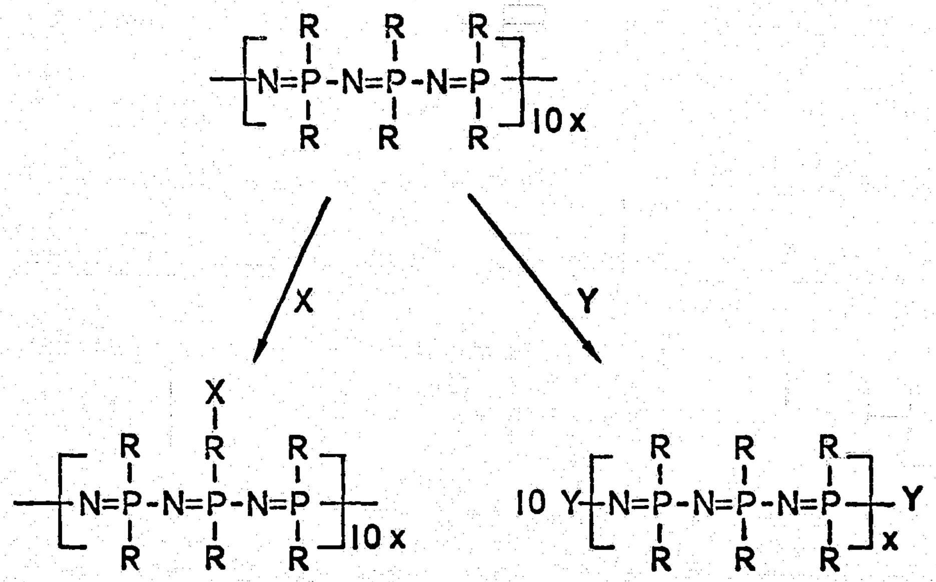
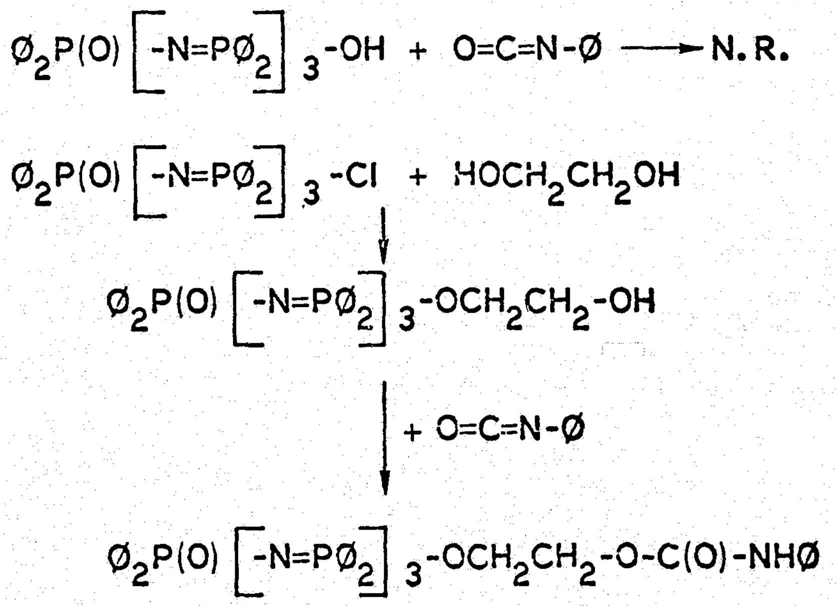


Figure 14.

POLYPHOSPHAZENE MODEL



$$\phi_2P(O)\left[-N{=}P\phi_2\right]_3\text{-}OH + O{=}C{=}N\text{-}\phi \longrightarrow \text{N.R.}$$

$$\phi_2P(O)\left[-N{=}P\phi_2\right]_3\text{-}Cl + HOCH_2CH_2OH$$

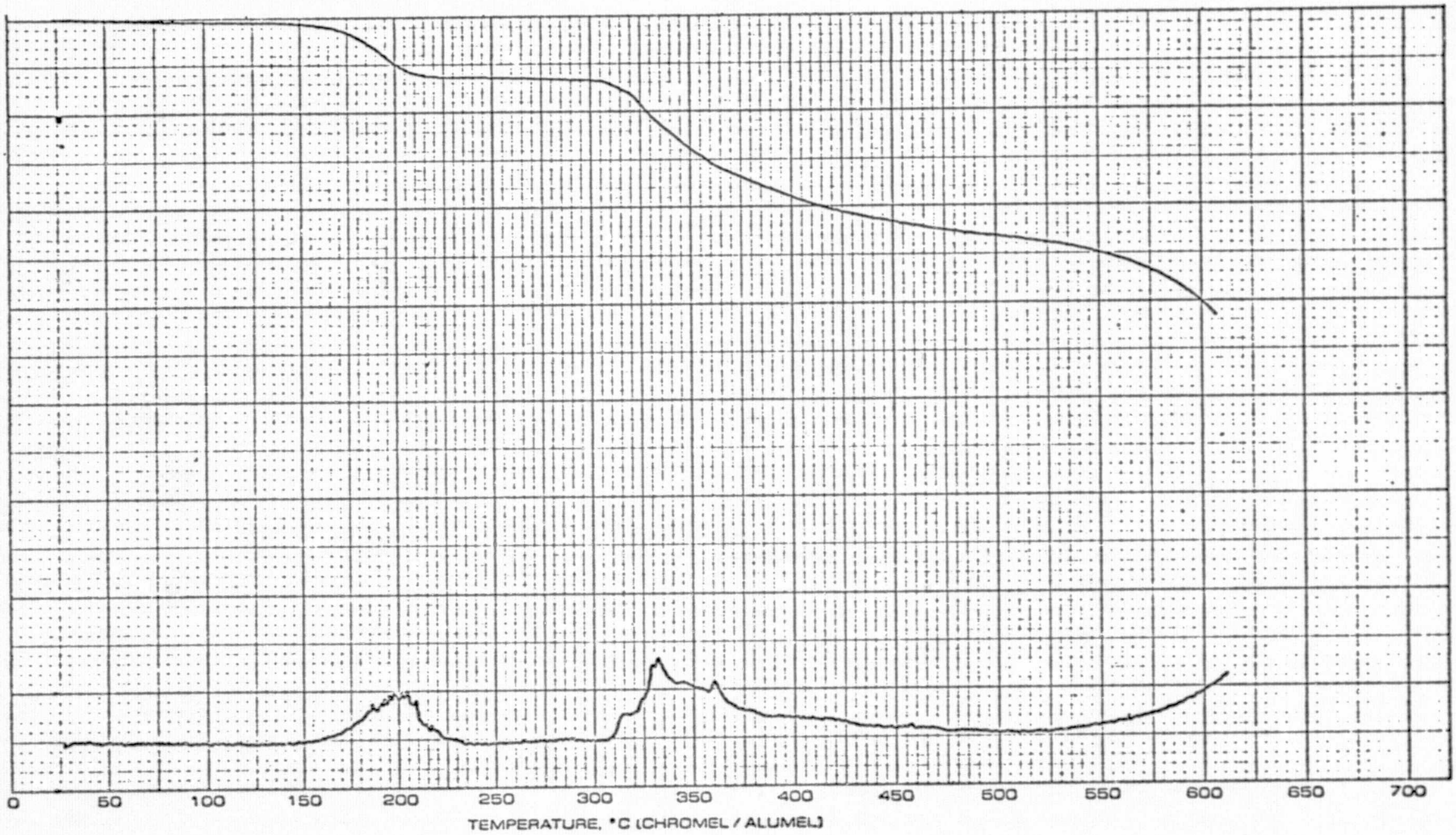
$$\downarrow$$

$$\phi_2P(O)\left[-N{=}P\phi_2\right]_3\text{-}OCH_2CH_2\text{-}OH$$

$$\Big\downarrow + O{=}C{=}N\text{-}\phi$$

$$\phi_2P(O)\left[-N{=}P\phi_2\right]_3\text{-}OCH_2CH_2\text{-}O\text{-}C(O)\text{-}NH\phi$$

Figure 15.

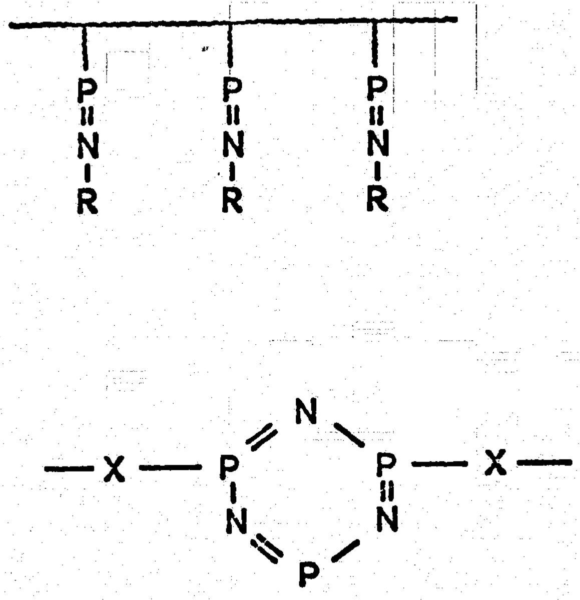


TGA of Polydimethoxyphosphazene in Air

Figure 16.

METHODS OF INCORPORATING P=N UNITS IN A POLYMER

$—X— P{=}N — Y — N{=}P — X—$



$— P{=}N—P{=}N—P{=}N—$

Figure 17.

CABIN FIRE SIMULATOR

Pete DuBovy

McDonnell-Douglas Aircraft Company

Small-scale tests were run mainly on lavatories and extinguishing systems plus one full-scale test. The test setup was discussed in detail (size, design, instrumentation, data readout via computer, cameras, closed circuit TV, and testing capability). Dr. Parker suggested an analysis on potential for quenching during flashover. Seat testing for NASA-Houston will start in about 9-12 months with contemporary seats being tested first. Later, subscale seats made by seat manufacturers will be tested. The equipment can be contracted for by other companies but only for complete test rig use.

Figure 1 is a representation of the Cabin Fire Simulator.

AIRCRAFT SAFETY PROGRAM
CABIN FIRE SIMULATOR (CFS)

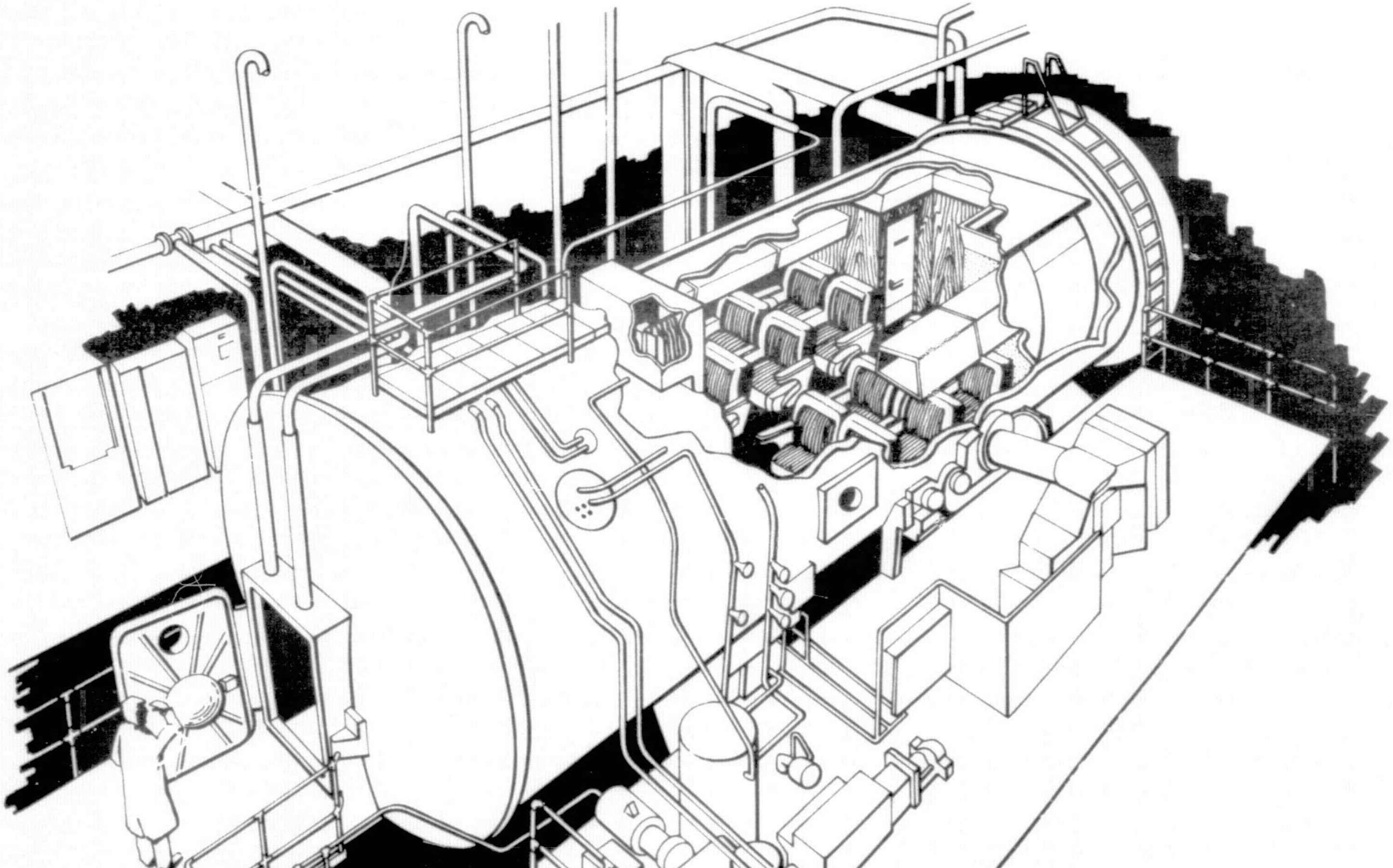


Figure 1.

FLEXIBLE POLYIMIDE FOAM FOR AIRCRAFT MATERIAL

Dr. John Gagliani

Solar Div., International Harvester

New approaches to the flammability problem of plastic materials have been devised at Solar Research Laboratories. This consisted in synthesizing a whole new polymer system rather than modifying existing polymers. This new polymer is based on polyimide technology.

Foams produced from polyimide resins are thermally stable, fire resistant, and produce virtually no smoke or toxic by-products when exposed to open fires. These are open-cell foams that can be produced in density range of from 16 to 640 kg/m^3 (1 to 40 lb/ft^3) and can be modified for specific applications.

The work was conducted under a program funded by L. B. Johnson Center, NASA; Mr. D. E. Supkis was technical monitor. The program was organized to include the synthesis of 33 copolyimide and terpolyimide foam precursors followed by evaluation, screening, optimization and characterization of the flexible, resilient open-cell foams for use as seat cushions in commercial aircraft. The characterization of the final two polyimide foam candidates was conducted in accordance with standard methods for testing physical and mechanical properties of flexible urethane foams and the flammability characteristics by oxygen index, thermogravimetric analysis, and smoke density tests. The two candidates met most technical development goals for physical and mechanical properties and exceeded all requirements for flammability characteristics. The most significant deviations in foam properties were fatigue and steam autoclave testing. New foaming methods, which afford a more homogeneous heat transfer through the foam, were recommended for improving the cellular structure and the fatigue life of the foams. A re-evaluation of the most promising resins developed during the program and new polyimide compositions with improved hydrolytic stability were also recommended to overcome the degradation of the foam under the conditions of the steam autoclave test.

EXPLANATION OF FIGURES AND TABLES

Figure 1 describes the objectives of the polyimide foam program.

Figure 2 is a description of the polyimide foam production.

Figure 3 describes the various experimental polyimide foam formulations.

Figure 4 shows the effect of ester on the tension and elongation on polyimide foams.

Figure 5 is a graphical representation of the effect of the amount of silicone surfactant on the mechanical properties of polyimide foam.

Figure 6 is a graph of the effect of the mole-mole ratios of monomers (diamineopyridine/Benzophenone-3-3,4,4 tetracarboxylic acid dianhydride) on the density and mechanical properties of polyimide foams.

Figure 7 illustrates the effect of foaming temperature on the density and mechanical properties of the polyimide foam.

Figure 8 is a table which summarizes the physical and chemical properties of polyimide foam and resin type.

Figure 9 and Tables II and III are a letter conveying the results of toxicological tests and the analysis of the degradation products of polyimide foam.

OBJECTIVE

DEVELOP A FIRE-RESISTANT, LOW-SMOKE-GENERATING, THERMALLY-STABLE, FLEXIBLE, OPEN-CELL, HIGH-RESILIENT FOAM FOR SEAT CUSHIONS APPLICATIONS

PLAN

- FORMULATE AND DEVELOP AT LEAST 25 OPEN-CELL, FLEXIBLE, RESILIENT POLYIMIDE FOAM COMPOSITIONS.
- SCREEN 2 TO 4 CANDIDATES ON THE BASIS OF TENSILE, ELONGATION, AND TEAR CHARACTERISTICS.
- SELECT ONE OR TWO BEST CANDIDATES.
- PERFORM FINAL TESTING IN ACCORDANCE WITH STANDARD METHODS OF TESTING FLEXIBLE URETHANE FOAMS (ASTM DESIGNATION D-1564).
- SUBMIT 3-4 SQUARE YARDS OF THE CANDIDATE OPEN-CELL POLYIMIDE FOAM TO NASA.
- PROVIDE RECOMMENDATION FOR ADDITIONAL AREAS OF INVESTIGATION.

Figure 1.

POLYMIDE FOAM PROCESS DESCRIPTION

BTDA $\xrightarrow{\text{ESTERIFICATION}}$ BTA HALF ESTER $\xrightarrow[\text{ADDITIVES}]{\text{DIAMINES}}$

MONOMERIC LIQUID PRECURSOR $\xrightarrow[\text{(150-220° F)}]{\text{HEAT}}$ MONOMERIC POWDER PRECURSOR

$\xrightarrow[\text{377-411°K (220-280° F)}]{\text{B-STAGE}}$ POLYIMIDE FOAM RESIN $\xrightarrow[\text{(500-600° F)}]{\text{HEAT}}$ FLEXIBLE, RESILIENT POLYIMIDE FOAM

FOAM RESIN PROPERTIES

- MP (248-293° F)
- % VOLATILE 17-20
- SOLUBILITY - INSOLUBLE ALCOHOLS, KETONES, HYDROCRABONS, SOLUBLE POLAR SOLVENTS, ALKALINE SOLUTIONS

Figure 2.

POLYMIDE FOAM FORMULATIONS AND PHYSICAL TEST

Polyimide Foam Precursors							Polyimide Foams			
Foam Resin No.	Composition	Molecular Ratio	BTDA Half Ester	L5420 (%)	MP (K)	Volatile (%)	Density (Kg/m^3)	Tension (N/m^2)	Elongation (%)	Tear (N/m)
1	BTDA:2,6DAP:4,4'DADPS	1:0.5:0.5	Ethyl	0	402-411	17.7	29.52	86.17 x 10^3	36.62	108.5 (1)
2	BTDA:2,6DAP:4,4'DADPS	1:0.5:0.5	Ethyl	2.3	413-417	17.2	35.5	55.6 x 10^3	27.6	56.0 (2)
3	BTDA:2,6DAP:4,4'DADPS	1:0.5:0.5	Ethyl	5.0	407-415	17.7	32.0	24.8 x 10^3	15.0	105.0 (3)
4	BTDA:2,6DAP:4,4'DADPS	1:0.5:0.5	Ethyl	7.5	423-428	18.0	21.0	20.33 x 10^3	2.5	45.5 (4)
5	BTDA:2,6DAP:4,4'DADPS	1:0.5:0.5	Methyl	2.5	408-413	15.1	52.48	45.5 x 10^3	21.0	73.5 (2)
6	BTDA:2,6DAP:4,4'DADPS	1:0.5:0.5	Propyl	2.5	395-409	20.9	–	22.47 x 10^3	14.3	46.9 (4)
7 & 8	BTDA:2,6DAP:4,4'DADPS	1:0.5:0.5	Methyl	0	405-412	15.6	–	55.15 x 10^3	15.33	108.5 (3)
9	BTDA:2,6DAP'4,4'DADPS	1:0.5:0.5	Ethyl	0.8	405-413	17.7	29.8	42.7 x 10^3	17.0	56.0 (2)
10	BTDA:2,6DAP:4,4'DADPS	1:0.5:0.5	Methyl	5	417-424	16.2	49.54	38.14 x 10^3	11.3	73.5 (3)
11	BTDA:2,6DAP:4,4'DADPS	1:0.5:0.5	Methyl/Ethyl	0.8	428-433	15.8	39.2	57.33 x 10^3	20.6	91.0 (2)
12	BTDA:2,6DAP:4,4'DADPS	1:0.5:0.5	Methyl/Ethyl Propyl	0.8	401-408	18.0	21.4	38.6 x 10^3	27.0	52.5 (2)
13 & 14	Repeat of No. 1 and 2	–	–	–	–	–	–	–	–	–
15	BTDA:2,6DAP:4,4'DADPS	1:0.75:0.25	Ethyl	0	408-413	18.7	28.48	57.8 x 10^3	32.4	157.6 (1)
16	BTDA:2,6DAP:4,4'DADPS	1:0.25:0.75	Ethyl	0	403-409	16.0	39.08	72.97 x 10^3	24.0	166.3 (1)
17	BTDA:2,6DAP:MDA	1:0.5:0.5	Ethyl	0	429-439	14.6	–	27.5 x 10^3	8.0	– (5)
18	BTDA:2,6DAP:MDA	1:0.75:0.25	Ethyl	0	414-419	17.9	–	10.11 x 10^3	8.0	– (5)
19	BTDA:2,6DAPmPDA	1:0.5:0.5	Ethyl	0	463-483	17.9	–	25.5 x 10^3	11.5	– (5)
20	BTDA:2,6DAPmPDA	1:0.75:0.25	Ethyl	0	433-448	19.1	–	– (5)	– (5)	– (5)
21	BTDA:2,6DAP:mPDA:4,4'DADPS	1:0.5:0.25:0.25	Ethyl	0	411-418	18.0	43.2	31.2 x 10^3	4.66	– (5)
22	BTDA:2,6DAP:mPDA:MDA	1:0.5:0.25:0.25	Ethyl	0	433-438	16.4	29.5	–	–	– (5)
23	BTDA:2,6DAP,mPDA,TDA	1:0.5:0.25:0.25	Ethyl	0	412-418	17.7	42.4	56.99 x 10^3	24.6	– (5)
24	BTDA:0.26DAP,TDA,MDA	1:0.5:0.25:0.25	Ethyl	0	447-456	15.5	–	–	–	– (5)
25	BTDA:2,6DAP:4,4'DADPS	1:0.85:0.15	Ethyl	0	411-418	18.6	32.5	91.0 x 10^3	38.6	192.6 (1)
26	BTDA:2,6DAP:TDA	1:0.5:0.5	Ethyl	0	445-453	16.0	41.36	46.0 x 10^3	17.6	– (5)
27	BTDA:2,6DAP:TDA,mPDA	1:0.75:0.15:0.	Ethyl	0	413-418	18.9	31.68	94.2 x 10^3	19.0	145.3 (1)
28	BTDA:2,6DAP:TDA:mPDA	1:0.6:0.3:0.1	Ethyl	0	418-423	17.1	36.16	73.07 x 10^3	28.0	110.3 (2)
29	BTDA:2,6DAP:TDA	1:0.85:0.15	Ethyl	0	414-417	19.4	43.7	113.7 x 10^3	30.5	288.9 (1)
30	BTDA:2,6DAP,4,4'DADPS	1:0.5:0.5	Methyl/Ethyl/ Propyl	0	417-419	17.8	38.27	47.7 x 10^3	23.5	133.0 (2)
31	BTDA:2,6DAP:4,4'DADPS	1:0.95:0.05	Ethyl	0	397-409	21.6	15.2	69.9 x 10^3	37.5	127.8 (2)
32	BTDA:2,6DAP:TDA	1:0.95:0.05	Ethyl	0	399-401	23.2	13.2	61.8 x 10^3	16.3	110.8 (2)
33	BTDA:2,6DAP:TDA	1:0.75:0.25	Ethyl	0	414-419	18.7	17.9	62.0 x 10^3	14.0	87.6 (4)

(1) Resilient, good cellular structure.

(2) Marginally resilient.

(3) Brittle, poor structure.

(4) Brittle, easy to crush manually.

(5) Very brittle, broke on clamping in tear and/or tension testing.

Abbreviation	Name
BTDA	Benzophenone - 3,3',4,4' tetracarboxylic acid dianhydride
2,6DAP	2,6 - Diaminopyridine
4,4'DADPS	4,4' - Diaminodiphenyl sulfone
mPDA	meta Phenylenediamine
MDA	Methylene Dianiline
TDA	Toluene Dianiline

Figure 3.

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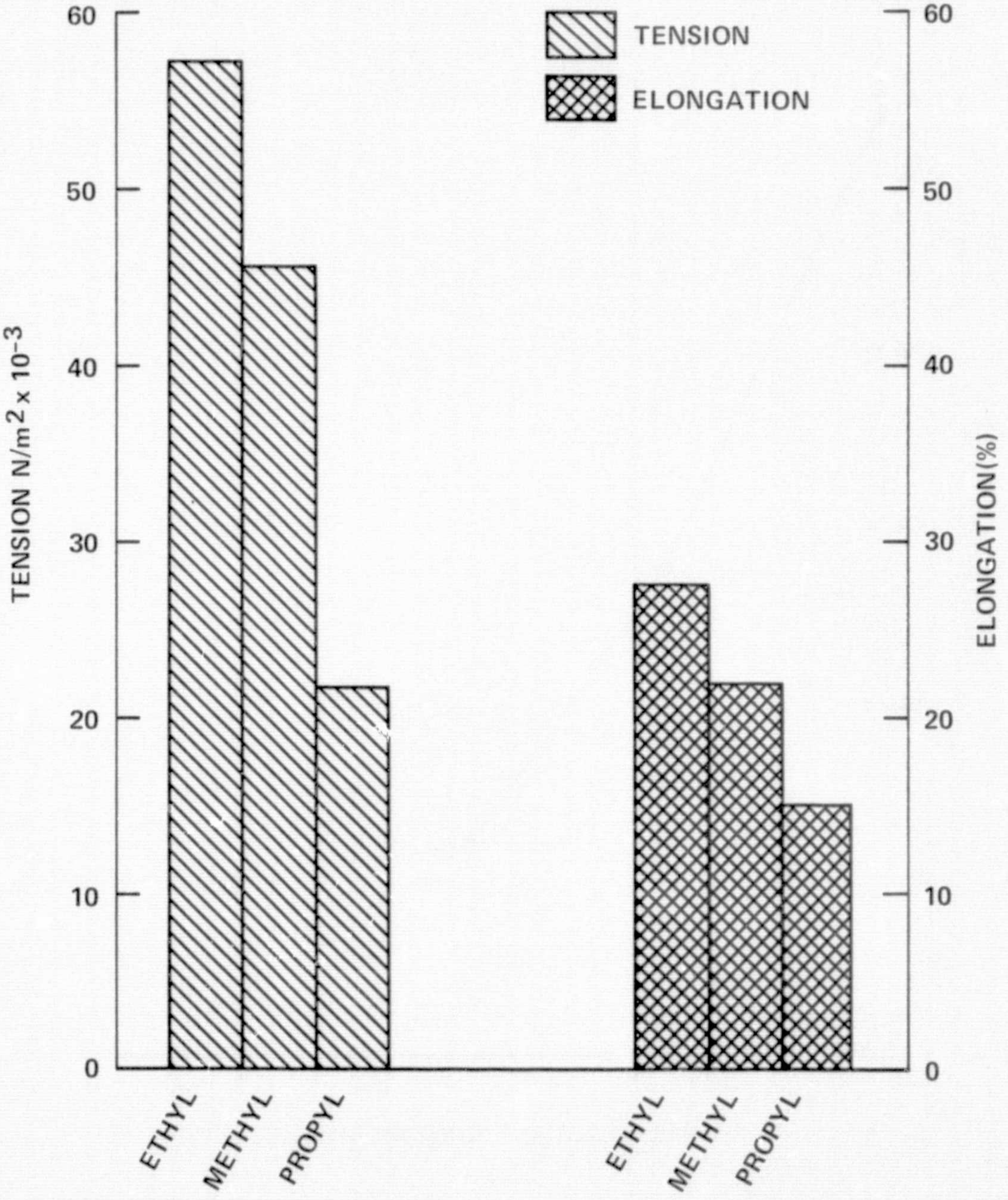


EFFECT OF HALF ESTER ON MECHANICAL PROPERTIES OF POLYIMIDE FOAMS; BTDA:2,6DAP:4,4'DADPS SYSTEM

Figure 4.

SILICONE SURFACTANT EFFECT ON MECHANICAL PROPERTIES OF POLYIMIDE FOAMS; BTDA:2,6DAP:4,4'DAPS SYSTEM

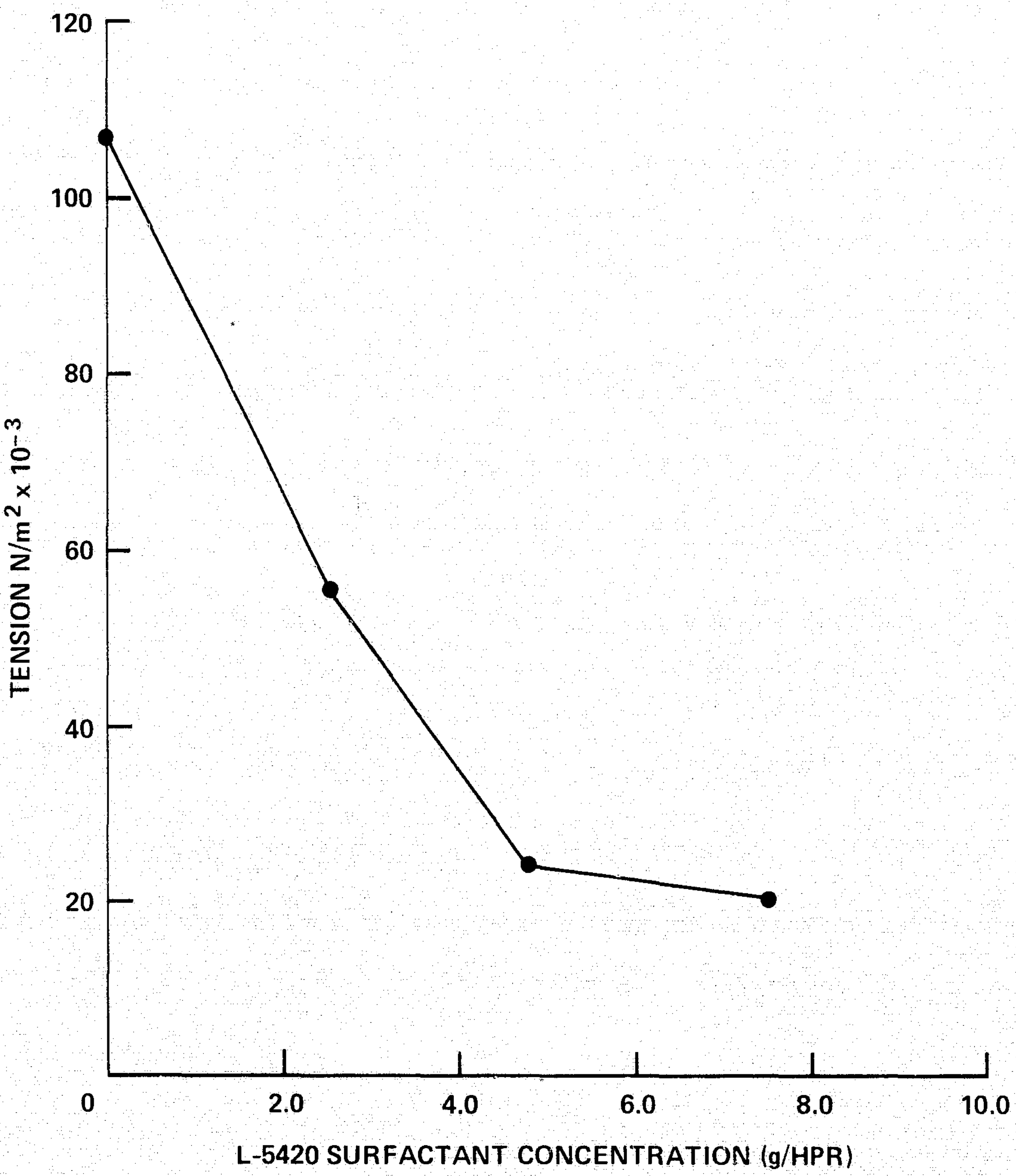


Figure 5.

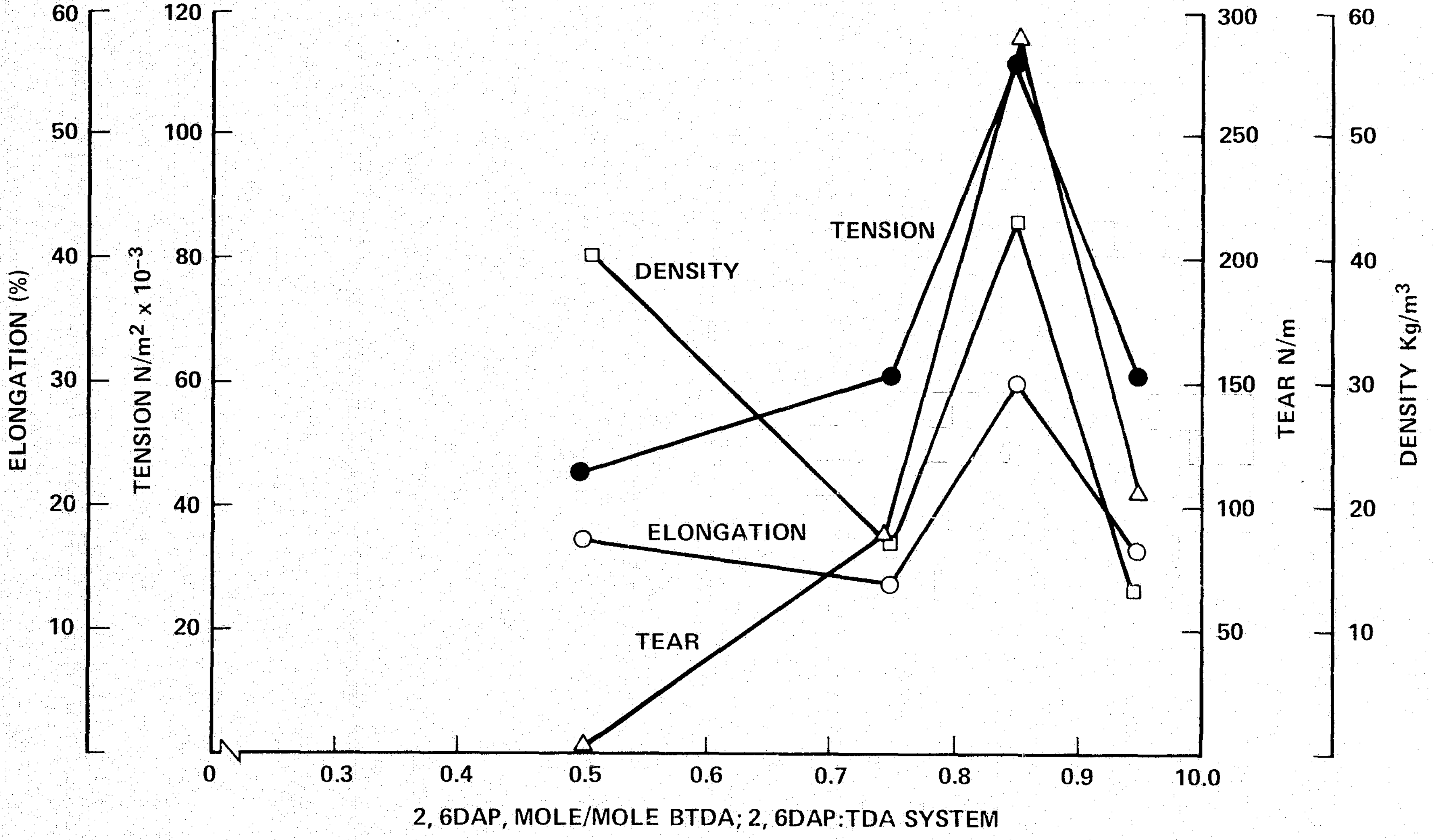

ELONGATION (%)
60
50
40
30
20
10
TENSION N/m² x 10⁻³
120
100
80
60
40
20
TEAR N/m
300
250
200
150
100
50
DENSITY Kg/m³
60
50
40
30
20
10
TENSION
DENSITY
ELONGATION
TEAR
0
0.3
0.4
0.5
0.6
0.7
0.8
0.9
10.0
2, 6DAP, MOLE/MOLE BTDA; 2, 6DAP:TDA SYSTEM

Figure 6.

INFLUENCE OF FOAMING TEMPERATURE ON PROPERTIES

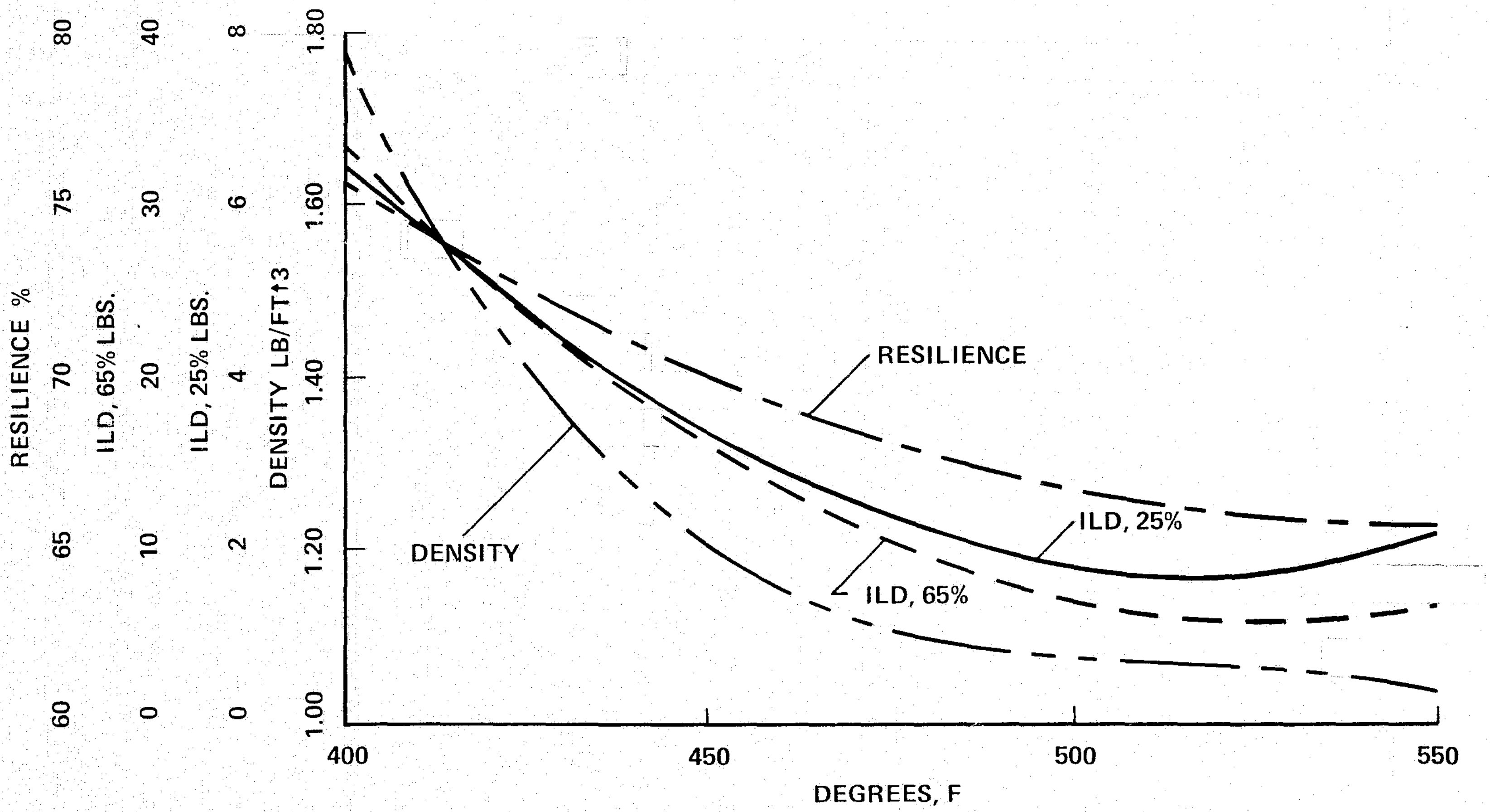


Figure 7.

SUMMARY OF RESULTS

Property	Goal	Resin #29	Resin #25
Density			
kg/m^3	40.0 max.	22.56	20.32
lb/ft^3	2.5 max.	1.41	1.27
Tensile Strength			
N/m^2	82.7×10^3 min.	90.3×10^3	67.56×10^3
psi	12.0 min.	13.1	9.8
Elongation			
Percent	80.0 min.	23.0	19.8
Tear Resistance			
N/m	175.0 min.	181.0	171.0
lb/in.	1.0 min.	1.03	0.976
Fatigue			
Loss I.L.D.-percent after 20,000 cycles	20.0 max.	Failure by delamination at 2000 cycles	Failure by delamination at 7000 cycles
Indentation Load Deflection I.L.D.			
25%-N/3.2 dm^2	111-155	132.1	145.4
lb-force/50 in^2	25-35	29.7	32.7
65%-N/3.2 dm^2	289-400	587.5	1116.4
lb-force/50 in^2	65-90	175.0	251.0
Compression Set			
50 percent	7 max.	6.5	15.0
90 percent	12 max.	36.3	37.0
Steam Autoclave			
Loss I.L.D.-percent	20 max.	Failure by degradation	Failure by degradation
Corrosion (Aluminum)	None	No evidence	No evidence
Odor			
Room Temperature	None	Not detectable	Not detectable
344°K-160°F	None	Not detectable	Not detectable
Dry Heat			
Loss Tensile Strength-percent	20 max.	7.3	4.0 (increase)
Resilience			
Rebound Value	55 min.	58.0	54.0
Oxygen Index	40 min.	44.4	54.0
Smoke Density			
NMS Uncorrected			
Nonflaming-percent	50-70	1.0	0.0
Flaming-percent	50-70	0.5	0.0
Toxic Products of Combustions (tentative)			
HCI-ppm	10	None present	None present
HF -ppm	10	None present	None present
H$_2$S-ppm	10	None present	None present
HCN-ppm	10	1.0*	1.0*
Thermostability			
Loss at 477°K (400°F)	No loss	No loss	No loss

*NASA LBI Data

Figure 8

OFFICE MEMORANDUM

NORTHROP-HOUSTON

TO:	Dr. H. L. Kaplan	15 March 1975
FROM:	Dr. D. A. Bafus, Toxicology	0070-750-03.12
SUBJECT:	SABLON Polyimide Foam Pyrolysis	

Two samples of a SABLON polyimide foam of the same composition, labelled F-137-29-3 and F-338-FR-29, were received from Mr. Dan Supkis of NASA/SMD for toxicity testing. A 1.10 mg sample of F-137-29-3 was examined by Thermal Gravimetric Analysis (TGA) at 1 atm of flowing air at 20 ml/min. The onset to thermal degradation was found to be 873±5°K (600°C) and complete degradation was observed at 923±5°K (650°C). From the TGA data, an experimental pyrolysis temperature of 973°K (700°C) was chosen. The results of fifteen animal exposures and carbon monoxide produced during those pyrolyses is given in Table I.

As can be seen in Table I, all samples over 0.6 g exhibited measurable amounts of residue after pyrolysis for 30 minutes. The length of pyrolysis was increased to 1 hour at 700°C and residue was still observed under these conditions.

An estimate of the LC_{50} is about 1.9 g before correction for residue and about 1.45 g after correction for the residue. All deaths can be attributed to carbon monoxide poisoning although there may be other contributory agents in the pyrolysate atmosphere. Investigation of the organics produced during the pyrolysis is being carried out via gas chromatography and has not been completed. Histological preparation of animal organs from animals which survived the exposures were carried out, however, clinical pathology has not been completed at this time.

D. A. Bafus
Toxicology Section
Life Sciences Laboratory

DAB:llm

Attachment

Figure 9

TABLE II

SABLON POLYIMIDE FOAM PYROLYSIS

Grams Pyrolyzed	Pyrolysis Time	CO(ppm)	Residue	Deaths[c]
0.3291	30 min	407	No[a]	0/10
0.6376	"	1277	No[a]	0/10
0.8008	"	1716	Yes[a]	0/10
1.005	"	1677	Yes[a]	0/10
1.200	"	1575	Yes[a]	0/10
1.400	"	1545	Yes[a]	0/10
1.400	60 min	1838	No[a]	0/10
1.600	"	1645	?[a]	0/10
1.900	"	2018	Yes[b]	1/7
1.900	"	2272	0.426 g[b]	10/10
1.900	"	2277	0.504 g[b]	9/10
1.950	"	2408	Yes[b]	10/10
2.000	"	2190	Yes[a]	5/7
2.100	"	1965	Yes[b]	8/8
3.000	"	3891	Yes[a]	10/10

[a] Sample No. F-137-29-3

[b] Sample No. F-388-FR-29

[c] Deaths that occurred during the 30-min-chamber exposure

Figure 9.- Continued

TABLE III

Percent, %

Bottle	Oxygen	CO_2	CO	HCN	CH_4	C_2H_4
Polyimide Material						
Bkg.	21.0	0.03	---	---	---	---
1 min.	18.1	2.4	0.07	65	43	54
2 min.	14.7	5.1	0.10	225	126	116
3 min.	14.7	5.7	0.11	245	131	131
4 min.	14.5	5.5	0.11	195	90	105
Polyurethane Material						
Bkg.	21.0	0.03	---	---	---	---
1 min.	6.2	14.5	.86	895	495	240
2 min.	15.0	5.1	.28	500	575	200

Figure 9.- Concluded.

POLYPHOSPHAZENE SEAT CUSHION APPLICATIONS

Dr. J. A. Parker

Ames Research Center

The use of polyphosphazene for seat cushions for aircraft passenger seats was described. The subject was introduced by noting that a model had been developed for heat shield material behavior. This has been put into a computer code which can be used for seat materials. The critical parameter in the char forming reactions in foams is the heat load. Factors such as heat loss by gas evolution, char formation, reradiation from the char are completely modeled. One can predict char formation from the number of aromatic rings in the molecule; therefore, char yield varies as to the degree of aromaticity. The problem associated with char yield is that as the char yield is increased, the material becomes more rigid and brittle. Polyphosphazene is the polymer of choice for seat cushion applications. However, the polymer should be selected according to mission requirements and one should always keep that fact in mind.

Figure 1.- Synthesis of polyphosphazene polymers. The problem of control of chain length was examined by S. Rose (De Soto Co.). The system is stable when all the chlorine is removed from the molecule. Elasticity of the material is determined by the ratio of aliphatic to aromatic groups in the molecule. Present density is about twice that of the desired value.

Figure 2.- Describes the synthesis of polyphosphazene polymers.

Figure 3.- Shows compression resistance of the polymer.

Figure 4.- Comparison of polyphophazene foam properties with a typical fire-retardant-treated polyurethane foam specification. The polyphosphazene limiting oxygen index is very high, but density is twice the desired value.

Figure 5.- Typical polyphosphazene foam formulations are shown.

Figure 6.- Flammability and smoke production are described.

Figure 7.- Physical properties of open cell foam are described.

Figure 8.- Foam formulations are shown.

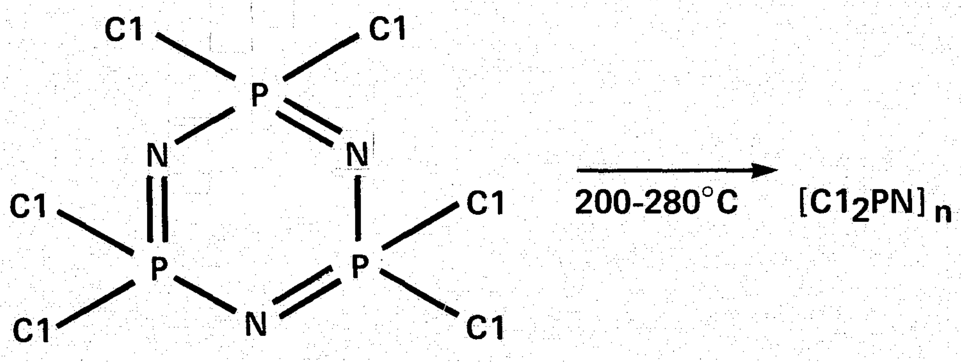
Figure 9.- Polyphosphazene open cell foam gum stock formula.

Figure 10.- Thermal/physical properties of open-cell P-N polymer.

Figure 11.- Thermal/physical properties of closed-cell P-N polymer formulation.

Figure 12.- Flammability and smoke production of P-N foams.

SYNTHESIS

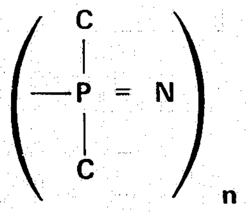


$$[Cl_2PN]_n + 2nNaOR \longrightarrow [(RO)_2PN]_n + 2nNaCl$$

Figure 1.

SYNTHESIS OF POLYPHOSPHAZENE POLYMERS

1. $(-Cl_2PN-)_3 \xrightarrow[\text{VACUO}]{250°C}$



$$\left(-\overset{\displaystyle C}{\underset{\displaystyle C}{P}}=N\right)_n$$

DICHLOROPHOSPHONITRILE TRIMER
WHITE SOLID, M.P. = 114°C

POLYPHOSPHONITRILE
n = 15000 – 20000

25 – 40% CONVERSION
PURIFICATION BY SOLVENT EXTRACTION (DIGLYME)

2. $$(-Cl_2PN-)_n + \left[\begin{array}{l} C_6H_5ONa\ (1) \\ 4-C_2H_5C_6H_4ONa\ (1) \end{array}\right] \xrightarrow[\text{IN DIGLYME, 30 – 50 hrs}]{125°C} [(C_6H_5O)_2PN-(4-C_2H_5C_6H_4O)_2PN]_n + NaCl$$

   a. PPT PRODUCT WITH METHANOL
   b. WASH ON MILL WITH H_2O TO 0.01% NaCl
   c. DRY IN VACUO

3. POLYMER IS A RANDOM HYBRID COPOLYMER, ELASTOMERIC, LINEAR
   $T_g = -27°C$, $M_n = 250{,}000 - 300{,}000$ $M_w = 2 - 6 \times 10^6$

Figure 2.

COMPRESSION RESISTANCE AT 25% DEFLECTION AFTER ISOTHERMAL AGING AT 300° F

	TYPICAL COMMERCIAL FR URETHANE FOAM	FOAMED POLY(ARYLOXY-PHOSPHAZENE
HRS. AT 300° F		
0	2.5 psi	1.7 psi
2	1.9	1.6
6	2.3	1.7
24	12.0 (RECOVERED)	0.7
96	25.7 (NO RECOVERY)	1.7
168	–	1.6
600	–	12.5

Figure 3.

COMPARISON OF POLY(ARYLOXYPHOSPHAZENE) FOAM PROPERTIES WITH A TYPICAL FIRE-RETARDANT URETHANE FOAM SPECIFICATION

PROPERTY	TYPICAL $[(C_6H_5O)_2PN$- $(4-C_2H_5C_6H_4O)_2PN]_n$ FOAMS	F.R. URETHANE (MIL-P-0015280F)
DENSITY, lb/ft^3	4.0 to 9.0	4.5 to 8.5
COMPRESSION RESISTANCE AT 25% DEFLECTION	2.1 to 4.8	2.0 to 6.0
SMOKE DENSITY, FLAMING, D_m	40 to 150	250
OIL RESISTANCE	NO SOFTENING OR VISIBLE SWELL	NO SOFTENING OR VISIBLE SWELL
TENSILE STRENGTH, psi	20 to 80	40
ULTIMATE ELONGATION, %	80 to 125	100
TENSILE STRENGTH OF CEMENTED JOINTS BEFORE & AFTER AGING	NO BOND FAILURE	NO BOND FAILURE
FLEXIBILITY AT 28°F INITIAL	NO CRACKING	NO CRACKING
FLEXIBILITY AT 28 F AFTER HEAT AGING 7 DAYS/180°F	NO CRACKING	NO CRACKING
THERMAL CONDUCTIVITY BTU in/hr sq. ft., °F AT MEAN TEMPERATURE 75°F	0.32	0.30
FLAME SPREAD INDEX, FLAMING, I_s	14	30
LIMITING OXYGEN INDEX	43 to 45	20

Figure 4.

TYPICAL POLYPHOSPHAZENE FOAM FORMULATIONS

FORMULATION OF 2281-04C, 2201-46C

$[(C_6H_5O)_2PN-(4-C_2H_5C_6H_4O)_2PN]_n$ COPOLYMER	100 phr
HYDRAL 710, $Al_2O_33H_2O$	200
ELASTOMAG 170, MgO	5.0
VAROX POWDER	8.0
BENZOYL PEROXIDE	2.0
ZINC STEARATE	14.0
CELOGEN AZ130, AZODICARBONAMIDE	30.0
BIK, SURFACE TREATED UREA	20.0

FORMULATION OF 2201-46A, 2201-46B

$[(C_6H_5O)_2PN-(4-C_2H_5C_6H_4O)_2PN]_n$ COPOLYMER	100.0
HYDRAL 710, $Al_2O_33H_2O$	100.0
ELASTOMAG 170, MgO	5.0
VAROX POWDER	6.0
BENZOYL PEROXIDE	1.5
ZINC STEARATE	4.0
CELOGEN AZ130, AZODICARBONAMIDE	21.0
BIK, SURFACE TREATED UREA	14.0

Figure 5.

FLAMMABILITY AND NBS SMOKE DATA ON POLYPHOSPHAZENE CLOSED CELL FOAMS

FOAM SAMPLE NO.	2161-21A	2161-25H ⓐ
DENSITY (lbs/ft^3)	6.7	8.9
TENSILE STRENGTH (psi)	20.0	48.0
ELONGATION (%)	90.0	100.0
COMPRESSION RESISTANCE AT 25% DEFLECTION (psi)	2.1	3.8
LOI	43.0	45.0
SURFACE FLAMMABILITY ⓑ ASTM E-162-67		
FLAME-SPREAD FACTOR, F_S	2.6	4.4
HEAT EVOLUTION FACTOR, Q	5.5	3.9
FLAME-SPREAD INDEX, I_S	.14	17.0
NBS SMOKE CHAMBER:		
MAXIMUM SMOKE DENSITY, D_m	49.0	—
TIME TO D_S = 16 min	1.5	—
MAXIMUM RATE, R_m min^{-1}	10.0	—
WEIGHT LOSS, (%)	15.9	—
CO (ppm)	100.0	—
CO_2 (%)	.3	—
HCN (ppm)	10.0	—

Figure 6.

PHYSICAL PROPERTIES OF POLY(ARYLOXYPHOSPHAZENE) OPEN CELL FOAM

FOAM	I	II	VALUES DESIRED
DENSITY, LBS/FT^3	4	5.5	2.5
TENSILE STRENGTH, PSI	5.7	7.5	≥ 12
ELONGATION, %	50	44	≥ 80
TEAR RESISTANCE, PPI	0.35	0.4	≥ 1
ILD, LBS/50 IN^2			
AT 25% DEFLECTION	6.1	18	≤ 25 - 35
AT 65% DEFLECTION	13.6	80	≤ 65 - 90
COMPRESSION SET, C_T, %			
AT 50% DEFLECTION	13	17	≤ 7
AT 90% DEFLECTION	70	65	≤ 12
STEAM AUTOCLAVE, LOSS OF COMPRESSION LOAD DEFLECTION	130% GAIN	50% GAIN	≤ 20% LOSS
ODOR	NONE	NONE	NONE
DRY HEAT TENSILE STRENGTH	30% GAIN	70% GAIN	≤ 20% LOSS
RESILIENCE, % AT 25°C	3	6	≥ 55%
LOI	36	35	≥ 40

Figure 7.

POLY(ARYLOXYPHOPHAZENE) FOAM FORMULATIONS

POLYMER	100	100
HYDRAL 710	150	150
DOW SILICONE FLUID 704	10	10
DIGLYME	30	30
POLYZOLE AZDN	25	25
$NaHCO_3$	10	10
CELOGEN RA	4	4
VULCUP 40KE	2	3
BENZOYL PEROXIDE	8	8
LUPERCO ANS-50	2	–
DENSITY LBS/FT^3	3.5	5.5

Figure 8.

POLY(ARYLOXYPHOSPHAZENE) OPEN CELL FOAM GUM STOCK

RATIO OF $\approx 2C_6H_5O:3C_2H_5C_6H_4O$

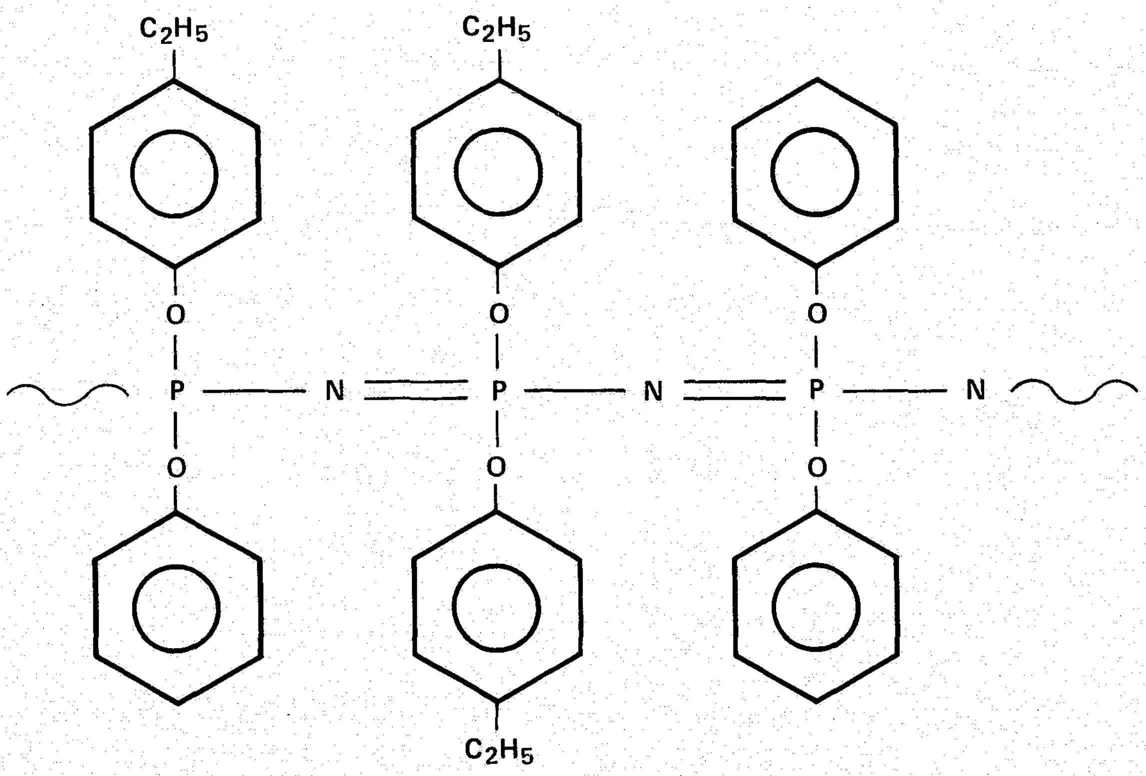


Figure 9.

THERMAL/PHYSICAL PROPERTIES OF OPEN-CELL PN POLYMER FORMULATION

Formulation Number	Apparent Density (lb/ft^3)	Limiting Oxygen Index (ASTM: D-2863 (% Oxygen)	Compressive Strength (parallel) (ASTM: D-1056) (lb/in^2)	Compression Set Percent %
2435-13C	4.240	36.5	0.3740	4.43
2435-14D	3.765	34.0	0.9650	0.0
2435-15D	3.158	35.0	0.7791	0.51
2435-16D	6.498	35.5	0.4554	11.01

Figure 10.

THERMAL/PHYSICAL PROPERTIES OF CLOSED-CELL PN POLYMER FORMULATION

Formulation number	Apparent density (lb/ft^3)	Limiting oxygen index (ASTM: D-2863) (% oxygen)	Compressive strength (parallel) (ASTM: D-1056) (lb/in.^{2})	Compression set percent (%)
2281-04C	9.626	53.5	9.3285	11.50
2201-46C	9.718	51.5	5.3664	3.81
2201-45A 2201-46B	12.995	36.5	5.8206	3.81
2435-06C	13.923	34.0	5.2678	3.16

Figure 11.

NBS SMOKE (FLAMING) FOR POLY(ARYLOXYPHOSPHAZENE) FOAMS

SAMPLE	OPEN CELL A	 B	CLOSED CELL (TYPICAL)
D_{MC}	81	122	49 - 71
$T_{0.9}$, MIN.	4.73	5.06	-
$T_{D=16}$, MIN.	0.68	0.39	1.4 - 1.5
R_M, MIN^{-1}	-	-	10 - 12
SON_4, MIN^{-1}	48	75	-
LIMITING OXYGEN INDEX	38	37	44 - 48

SON_4 = AVERAGE RATE OF SMOKE GENERATION OVER FIRST FOUR MINUTES.

R_M = MAXIMUM RATE OF SMOKE GENERATION.

Figure 12.

PBI IN FIRE-RESISTANT AIRCRAFT PASSENGER SEATS

Dr. Robert H. Jackson

Celanese Fibers Marketing Company

INTRODUCTION

Polybenzimidazole — or PBI as it is more commonly known — is the only textile fiber, either commercial or experimental, which is nonflammable in air, emits little or no smoke, emits virtually no toxic offgases, and, yet, has the textile properties of polyester, and the comfort of cotton.

PBI has a useful temperature limit of about 560°C, which is about 200°C higher than commercial high-temperature fibers.

I am convinced that PBI, with this unique set of properties, could be the key component of the future fire-resistant aircraft passenger seat.

BACKGROUND

By way of history, PBI fiber was developed by the Celanese Research Co. in conjunction with the AFML. The objective of this program was to develop a flight suit material that would afford a pilot the maximum possible personal protection from a fire. All of the data I will present for PBI are based on its performance as a 4 oz/yd^2, flight suit material evaluated during the joint Celanese/AFML program. We would expect that the heavier fabrics used for commercial aircraft upholstery (typically 14-16 oz/yd^2) would exhibit superior performance characteristics.

SMOKE GENERATION

Experience to date indicates that PBI fabric generates little or no smoke when heated or exposed to a flame source.

Smoke generation of PBI foam has been studied in greater depth in programs both here at NASA-Ames and elsewhere (refs. 1 and 2). It has been concluded that PBI "foam is one of the lowest smoke-producing polymers examined...to date" (ref. 2). PBI fiber, which is made from even purer polymer than is foam, would likely have even lower smoke generation characteristics than foam.

OFFGASES

Unlike some other high-temperature fibers, the offgases of PBI are not toxic up to about 600°C. The Celanese Research Co. has studied the oxidative degradation process of PBI in detail using a combination of thermogravimetric — mass spec analyses. These tests show that the offgases of the virgin (undyed, untreated) material are composed predominantly of carbon dioxide and water up to 560°C.

THERMAL STABILITY

Associated with its high degradation temperature, PBI has excellent thermal stability. For example, PBI has a degradation temperature of about 560°C vs commercial aramid with a degradation temperature of about 370°C. If heated above its degradation temperature, PBI will eventually char. But this char will remain intact, supple, and reasonably strong. As an example of PBI's thermal stability, fabric exposed to 400°C in air for 15 min still retains 22 percent of its original tenacity vs less than 1 percent for aramid.

DIMENSIONAL STABILITY

Untreated PBI fabric exhibits good dimensional stability when heated. There is less than 1 percent shrinkage between room temperature and 275° and a total of 10 percent shrinkage up to about 540°C.

The dimensional stability of PBI can be improved still further by a post-extrusion treatment of the filament or tow using sulfuric acid. Fabric made from acid-treated PBI exhibits only about 10 percent shrinkage up to 640°C. Let me emphasize this point, PBI fabric (treated or untreated) has only a minimal shrinkage at temperatures that are well above the operating limits of other high-temperature fibers.

The dimensional stability of a fabric is a particularly important property for protective clothing, for example, where excessive shrinkage could severely restrict the movement of the individual and, eventually, lead to rupture of the fabric and exposure of the wearer.

I believe good dimensional stability is equally important for fire-resistant aircraft seat fabric. If the seat covering material remains physically intact, it will continue to protect the underlying structure when exposed to heat or flame. Thus the degree of flame retardancy required for the other seat components as well as their cost may be significantly reduced.

FLAMMABILITY

PBI has a limiting oxygen index of about 40. But, more importantly, PBI requires 28 percent oxygen to sustain burning vs 17 percent for aramids. Therefore, PBI will not burn in air. Even if PBI were ignited in an oxygen-rich environment, it would not afterburn in air the way most other high-temperature fibers do.

The high-temperature performance of PBI was demonstrated during the extensive fuel fire pit tests conducted by the Air Force Materials Laboratory. Mannequins dressed in flight suits of PBI or one of the other candidate materials were drawn across a pit of burning JP-4 fuel. Exposures of 3 and 6 sec were used. Temperatures of 1000-1200°C were recorded. PBI clearly outperformed every other material tested according to the AFML reports.

Even after a 6-sec exposure to these extreme conditions, the PBI flight suits emerged totally intact, with little or no smoke, no afterburning, and with a char which still had good structural integrity and which was almost as supple as the virgin material. The cotton underwear worn by the PBI-clothed mannequins was virtually unaffected by the exposure to these extreme conditions.

Included in these tests were PBI, Kynol, Nomex, HT-4, and Durette. The AFML concluded that PBI fabric "provides superior thermal protection when compared to (all other high-temperature materials tested)" (refs. 3 and 4).

As mentioned before, PBI fabric will eventually carbonize (or char) if it is exposed to sufficient heat for a long enough period of time. But even after the char has formed, the charred fabric still retains its integrity and pliability. In this characteristic it is markedly superior to the other heat-resistant fibers which melt and/or produce a stiff, hard, or friable char.

TEXTILE PROPERTIES

PBI can be produced in either filament or staple form. The primary emphasis to date has been on fine dpf's to maximize the comfort for Air Force flight suits, so that now dpf's as fine as 1.5 can be produced.

PBI staple is characterized by a tenacity of 4-4.5 gpd, an elongation of 22 percent, and a modulus of 90 gpd. In other words, the physical properties of PBI are generally equivalent to those of polyester which is usually regarded as "the performance fiber" in today's textile and industrial worlds.

PBI staple is easily spun into yarn at commercially acceptable levels of efficiency. Yarn counts as fine as 42's cotton count (about 5 mils diam.) have been achieved.

PBI filament and spun yarns have been fabricated successfully into a wide variety of materials and products including: (1) woven goods for shirting, parachute packs and canopies, handkerchiefs, flight suits, ribbon; (2) knit goods for gloves, insulated underwear, "T" shirts, socks; and (3) braid for rope and strapping.

COMFORT

PBI's outstanding moisture-regain makes fabrics exceptionally comfortable. At 65 percent RH and 70°F, PBI has a regain of greater than 13 percent. Corresponding regain figures are <1 percent for polyester and 10 percent for cotton.

The high moisture regain of PBI has significance beyond just comfort. It has been proposed that one reason flight suits of PBI provide better thermal protection than those of other high-temperature fibers is "because the heat required to dissipate the greater moisture content of the PBI fabrics is not available to cause burns" (ref. 4).

PBI's high moisture regain may also account for its low surface resistivity. As a result, static not be a problem with PBI materials. PBI fabric has a surface resistivity ranging from 10^9 ohms per square at 65 percent RH to 10^{11} ohms per square at 20 percent RH. This means that PBI is even better than cotton (10^{11}-10^{12} ohms per square) and much better than polyester ($>10^{13}$ ohms per square).

ABRASION RESISTANCE

The abrasion resistance of PBI is very good. As measured by both the Schiefer abrasion test and Stoll flex cycles, the abrasion resistance of PBI is better than any other high-temperature fiber. The comfort and abrasion resistance of PBI were confirmed in extensive wear trials conducted by the AFML comparing flight suits of PBI and other high-temperature fibers.

DYEABILITY

The natural color of PBI is a pleasing gold shade. PBI can be stock dyed, solution dyed, or skein dyed almost any medium or dark color using conventional dyes. The resulting colors are pleasing and attractive and offer a reasonable, although somewhat limited, range of colors for styling.

PBI fabric (natural or dyed) will not fade, but sufficient exposure to ultra-violet light will cause it eventually to photo-oxidize or darken slightly. This slight darkening can be reduced by using solution-dyed filament or staple.

These, then, are the two present styling limitations of PBI — its color range and tendency to darken.

STATUS OF PBI

PBI is not currently available. However, Celanese has elected to begin a modest market development program with PBI. The first small development quantities will be available in about 9 to 12 months. We will be happy to make a reasonable quantity of PBI available for the NASA development program.

PBI IN COMMERCIAL AIRCRAFT SEATS — SUMMARY

To summarize, the properties of PBI which should make it a prime candidate for evaluation in commercial aircraft upholstery are its nonflammability, low smoke emission, and non-toxic offgases.

REFERENCES

1. Kourtides, D. A., et al.: Low Density Polybenzimidazole Foams. Soc. of Plastics Engineers 32nd Annual Tech. Conf., May 1974.

2. Einhorn, I. N., et al.: Thermo Chemistry and Flammability Characteristics of Polybenzimidazole Foams. Final Report to WRD July 15, 1975.

3. Stanton, R. M., Schulman, S.: Evaluation of Candidate Fabrics for Air Force Flight Suits in JP-4 Fuel Fire Pit Test. AFML-TR-72-139, 1972, p. 40.

4. Stanton, R. M.: The Thermal Response of PBI and Nomex II Fabrics Exposed to a JP-4 Fuel Fire. AFML-TR-73-27, 1973, p. iii.

TEST OF AIRCRAFT SEAT CUSHION MATERIALS

Richard W. Bricker

Lyndon B. Johnson Space Center, NASA

Five component level flammability tests were conducted in a 400 cubic foot chamber to determine the products of combustion and relative destruction of coated (with fire-retardants) and uncoated polyurethane foams during exposure of the foams to a large flaming ignition source for 5 min.

All of the foams tested produced similar maximum concentrations of hydrogen cyanide, carbon monoxide, carbon dioxide, and smoke; however, the onset rates for the gases produced by the treated and coated foams were significantly retarded during the first 1 to 2 min of the test as compared to the untreated foams. The JP-4 fuel also contributed to the gas production.

Relatively high levels of hydrogen cyanide (over that produced by the JP-4 fuel) were detected in each test, indicating that the polyurethane foam may be the major contributor to similar high levels found in the full-scale tests.

The hydrogen cyanide levels detected by infrared spectroscopy were approximately five to nine times the hydrolyzable cyanides measured by a specific ion electrode, indicating that an interfering species affected the specific ion electrode technique.

The lack of any measured fluoride for the Fluorel coated foams may have been due to differences in the collection techniques used in these tests in comparison with the techniques used in the full-scale tests and does not necessarily indicate the absence of fluoride compounds.

Total destruction for the two treated and coated foams was much less than for the three untreated foams, one of which was of the same material as the protected foam.

Temperatures measured on the upper portion of the front side of the seat back were significantly lower during the tests for the protected foams when compared to the unprotected foams.

Loss of visibility due to smoke production did not vary significantly between tests. This could partially be due to the large quantity of smoke produced by the JP-4 ignition source.

To summarize the foregoing conclusions, the results indicate that under the conditions tested, the improved state-of-the-art polyurethane foams without the added fire retardant and coating treatments were not significantly better than untreated older, less fire-resistant polyurethane foams. However, by treating and coating the state-of-the-art foams, the production of toxic gases as delayed and the destruction of the foam limited.

The following are figures and representations from which the conclusions were drawn for this study.

Figure 1 is a table of foam samples and their weight loss.

Figure 2 is a table of hydrogen cyanide and hydrolyzable cyanides produced by the respective foam samples during the test.

Figure 3 shows the set-up and test apparatus.

Figure 4 shows the backface temperature of the top portion of the seat back.

Figure 5 is a graph of the hydrogen cyanide concentrations during the test.

Figures 6 and 7 are graphs of the carbon monoxide and carbon dioxide concentrations respectively produced during the test.

Figure 8 is a graph of the smoke density levels during the test.

Figure 9 is a graph of the oxygen concentrations during the test.

PRETEST- AND POST-TEST WEIGHTS

Test	Foam material	Treated and coated	Density, lb/ft^3	Pretest weight, g	Post-test weight, g	Weight loss, g	Weight loss, percent
1	Scott	Yes	3.3	2260	1050	1210	54
2	Mobay	Yes	5.3	3620	2015	1605	44
3	Upjohn CPR 9700	No	2.5	1710	430	1280	75
4	Mobay	No	2.9	1947	495	1452	75
5	Pre-1968	No	1.8	1220	0	1220	100

Figure 1

HYDROGEN CYANIDE AND HYDROLYZABLE CYANIDES

Test	Foam material	Treated and coated	Maximum hydrogen cyanide measured by infrared spectrometer, ppm	Maximum hydrolyzable cyanides measured by specific ion electrode, ppm	Ratio of IR measured HCN to hydrolyzable cyanides
1	Scott	Yes	778	129	6
2	Mobay	Yes	986	113	8.7
3	Upjohn CPR 9700	No	1603	338	4.7
4	Mobay	No	1084	160	6.7
5	Pre-1968	No	1408	271	6.2

Figure 2

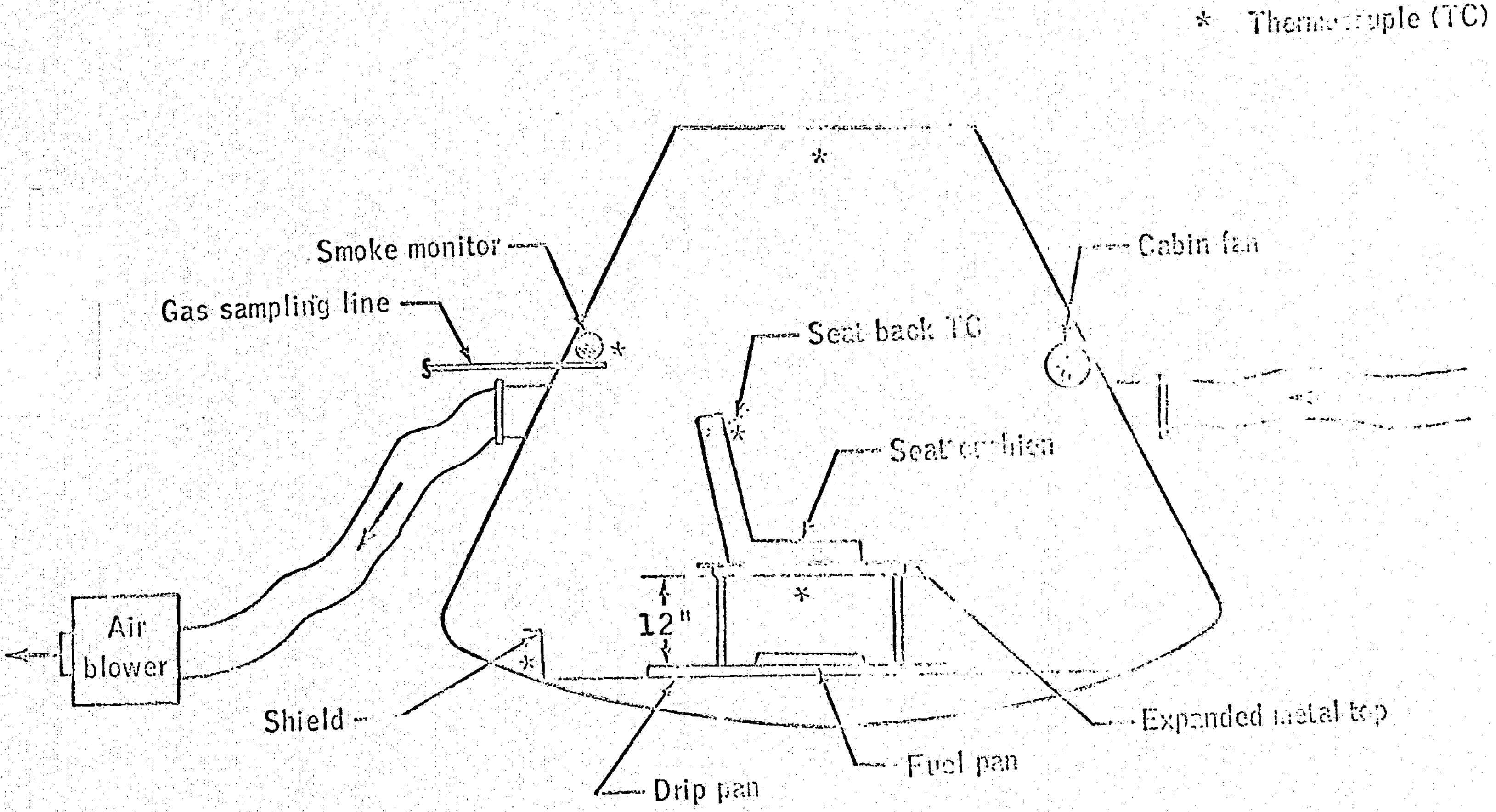

* Thermocouple (TC)
Smoke monitor
Gas sampling line
Cabin fan
Seat back TC
Seat cushion
12"
Air blower
Shield
Expanded metal top
Fuel pan
Drip pan

Figure 3.

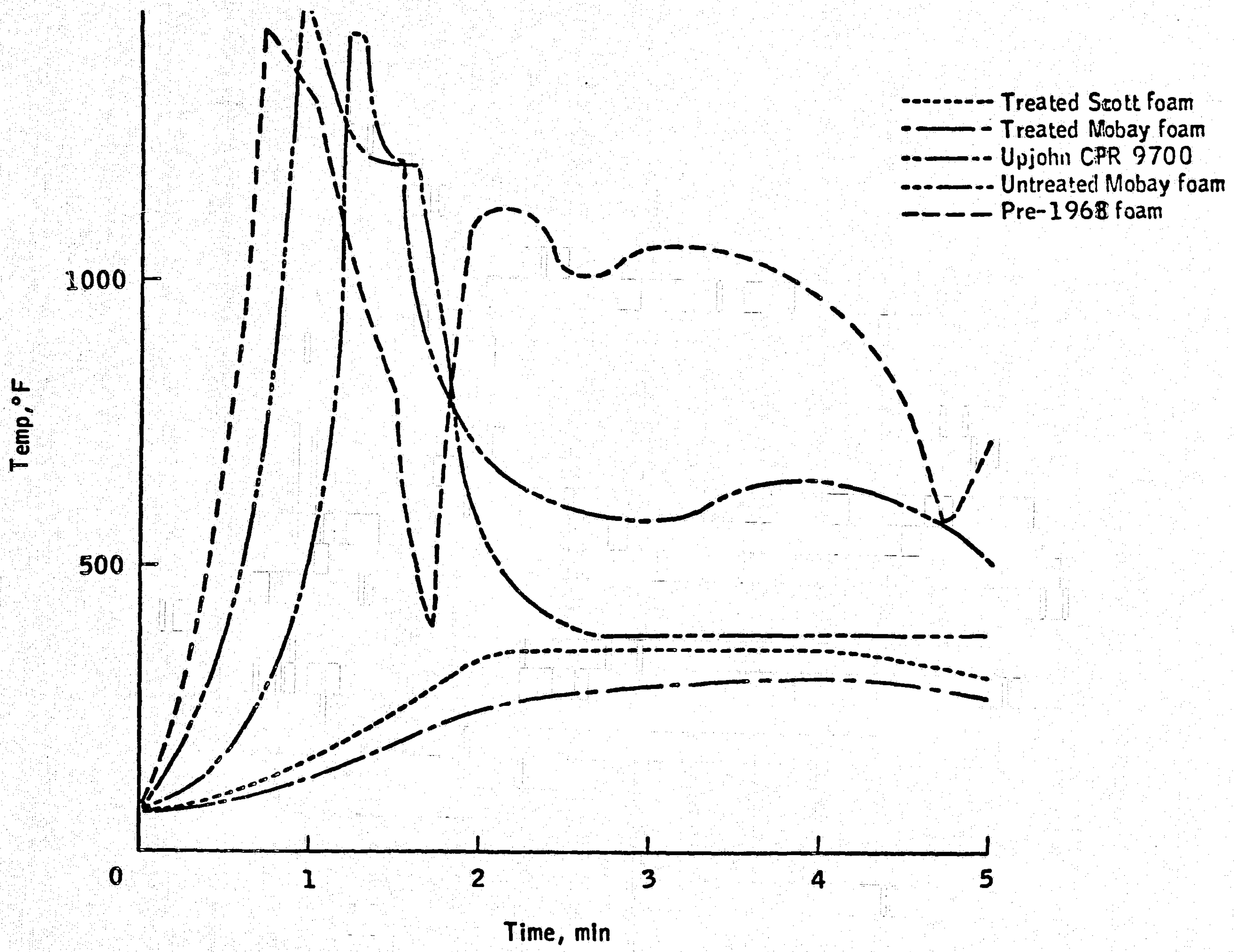
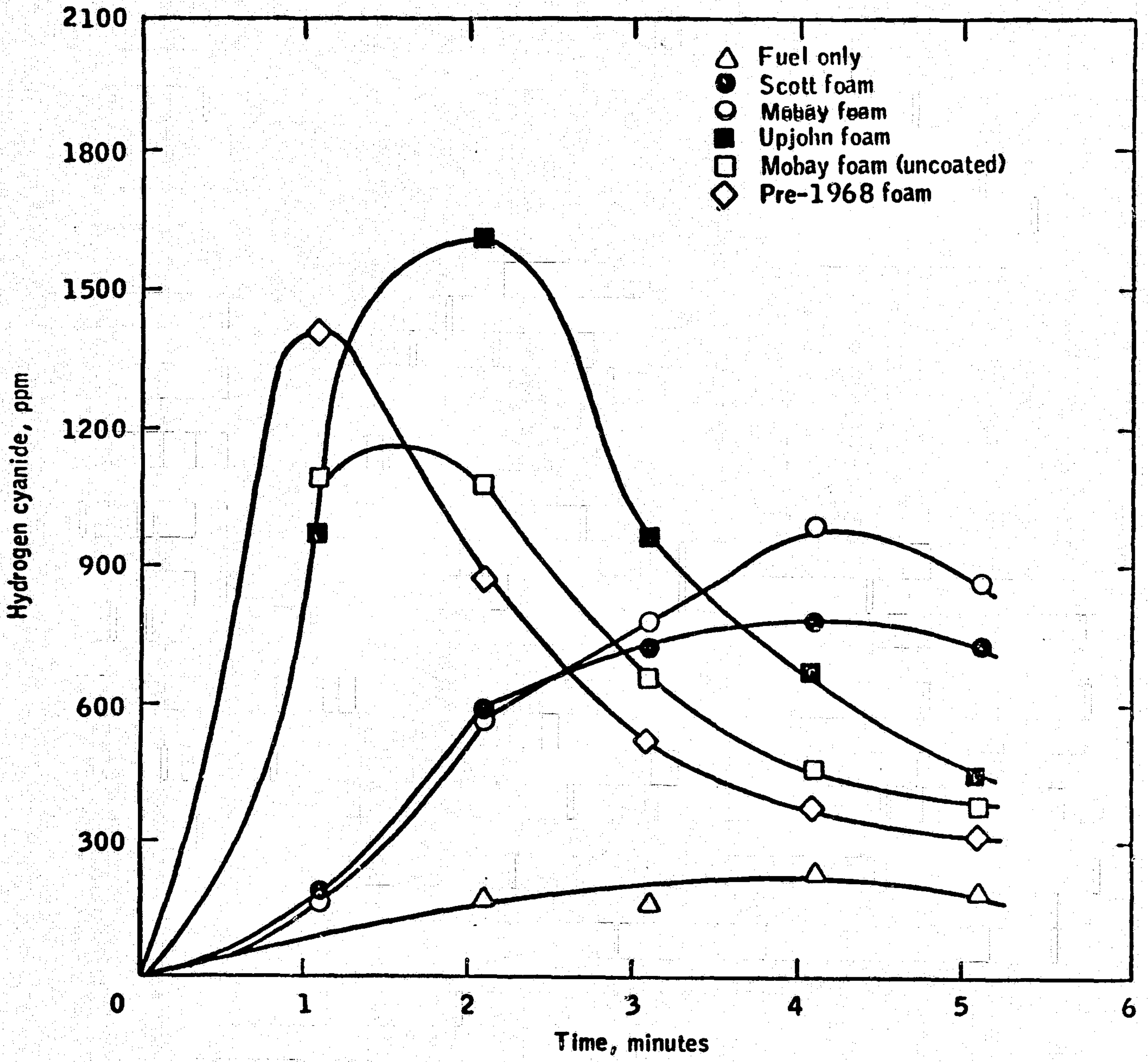

Treated Scott foam
Treated Mobay foam
Upjohn CPR 9700
Untreated Mobay foam
Pre-1968 foam
Temp, °F
1000
500
0
1
2
3
4
5
Time, min

Figure 4.



△ Fuel only
● Scott foam
○ Mobay foam
■ Upjohn foam
□ Mobay foam (uncoated)
◇ Pre-1968 foam
Hydrogen cyanide, ppm
2100
1800
1500
1200
900
600
300
0
1
2
3
4
5
6
Time, minutes

Figure 5.

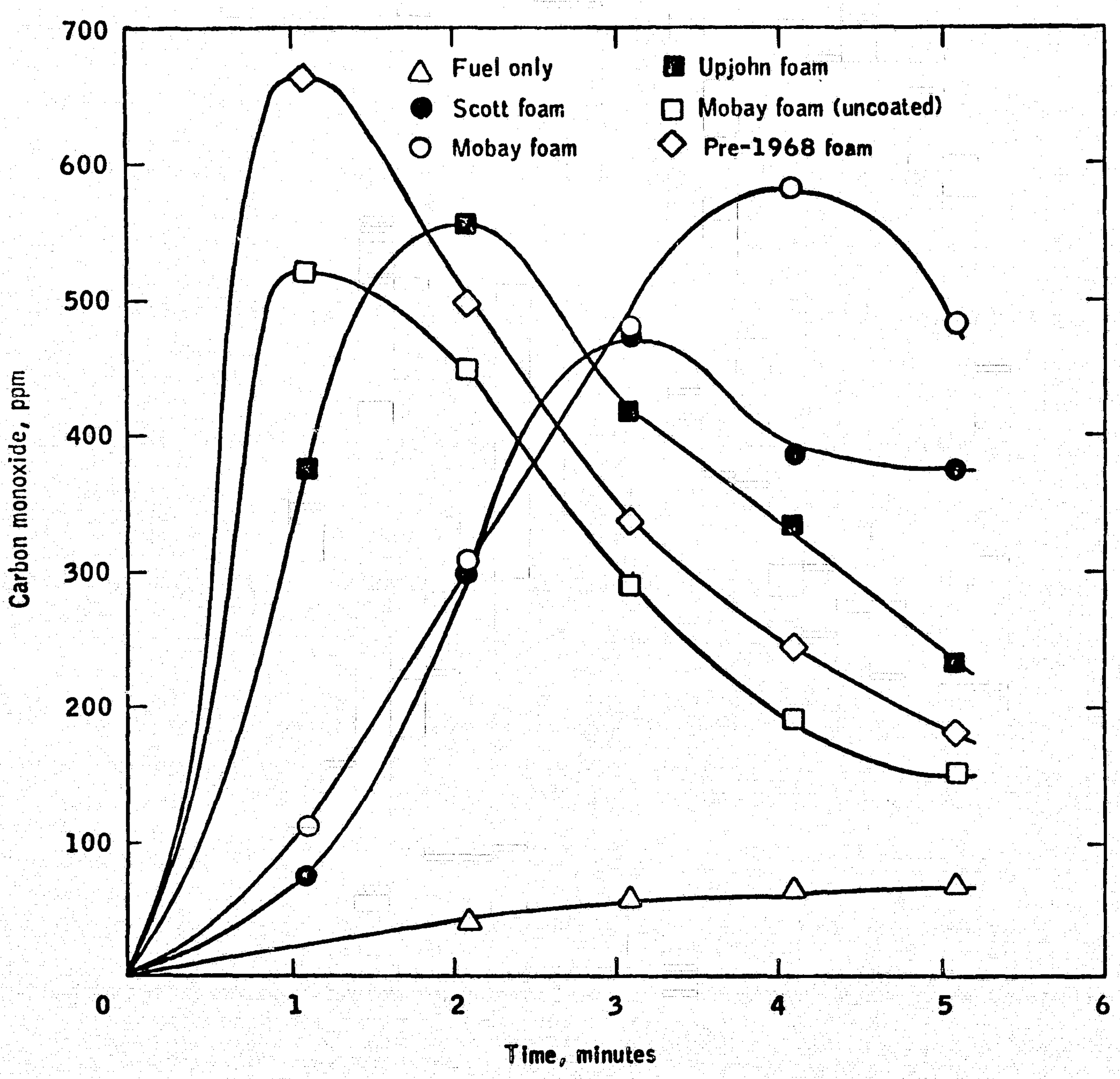

700
600
500
400
300
200
100
0
1
2
3
4
5
6
Carbon monoxide, ppm
Time, minutes
△ Fuel only
● Scott foam
○ Mobay foam
■ Upjohn foam
□ Mobay foam (uncoated)
◇ Pre-1968 foam

Figure 6.

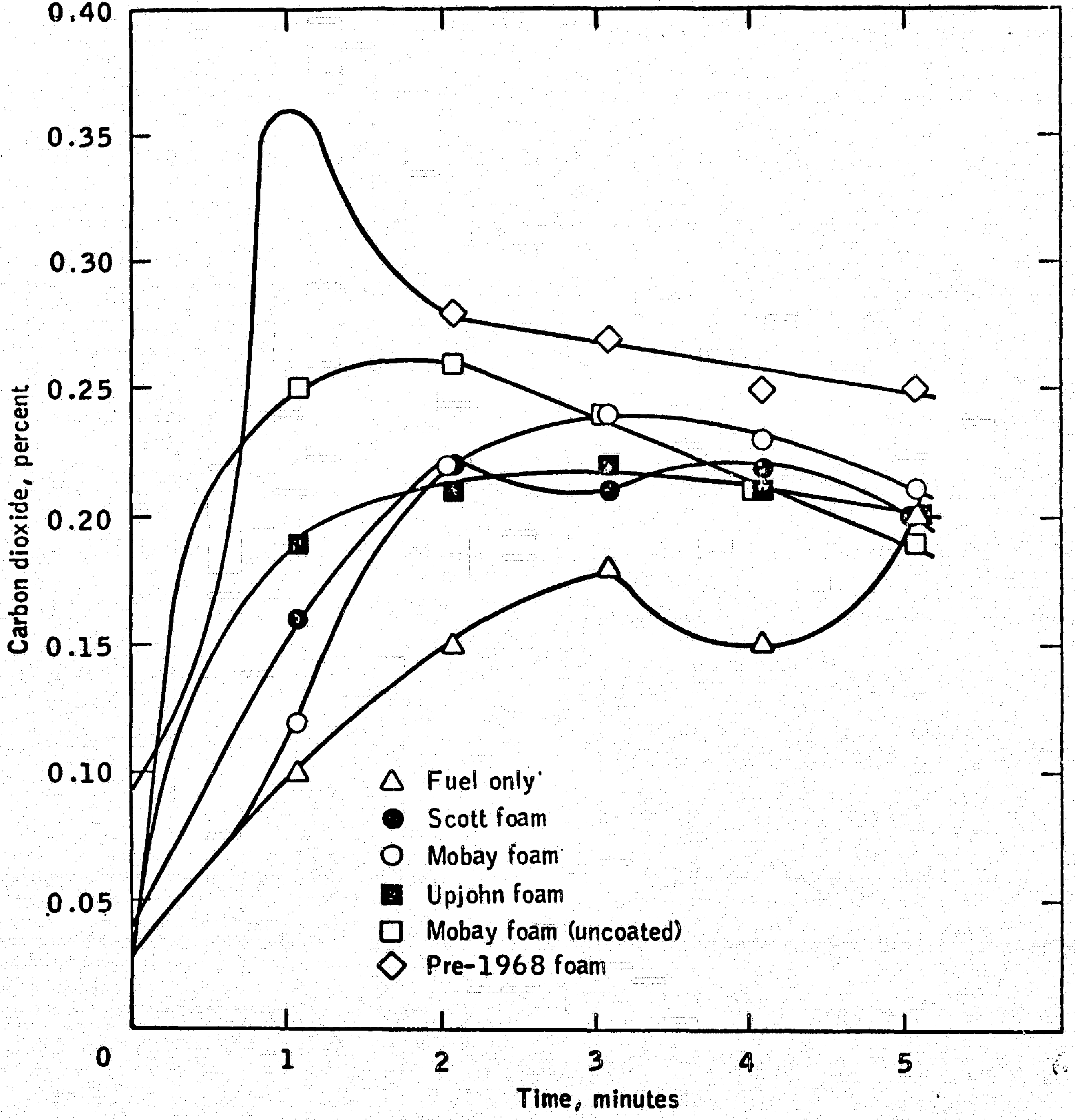

0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
Carbon dioxide, percent
1
2
3
4
5
Time, minutes
△ Fuel only
● Scott foam
○ Mobay foam
■ Upjohn foam
□ Mobay foam (uncoated)
◇ Pre-1968 foam

Figure 7.

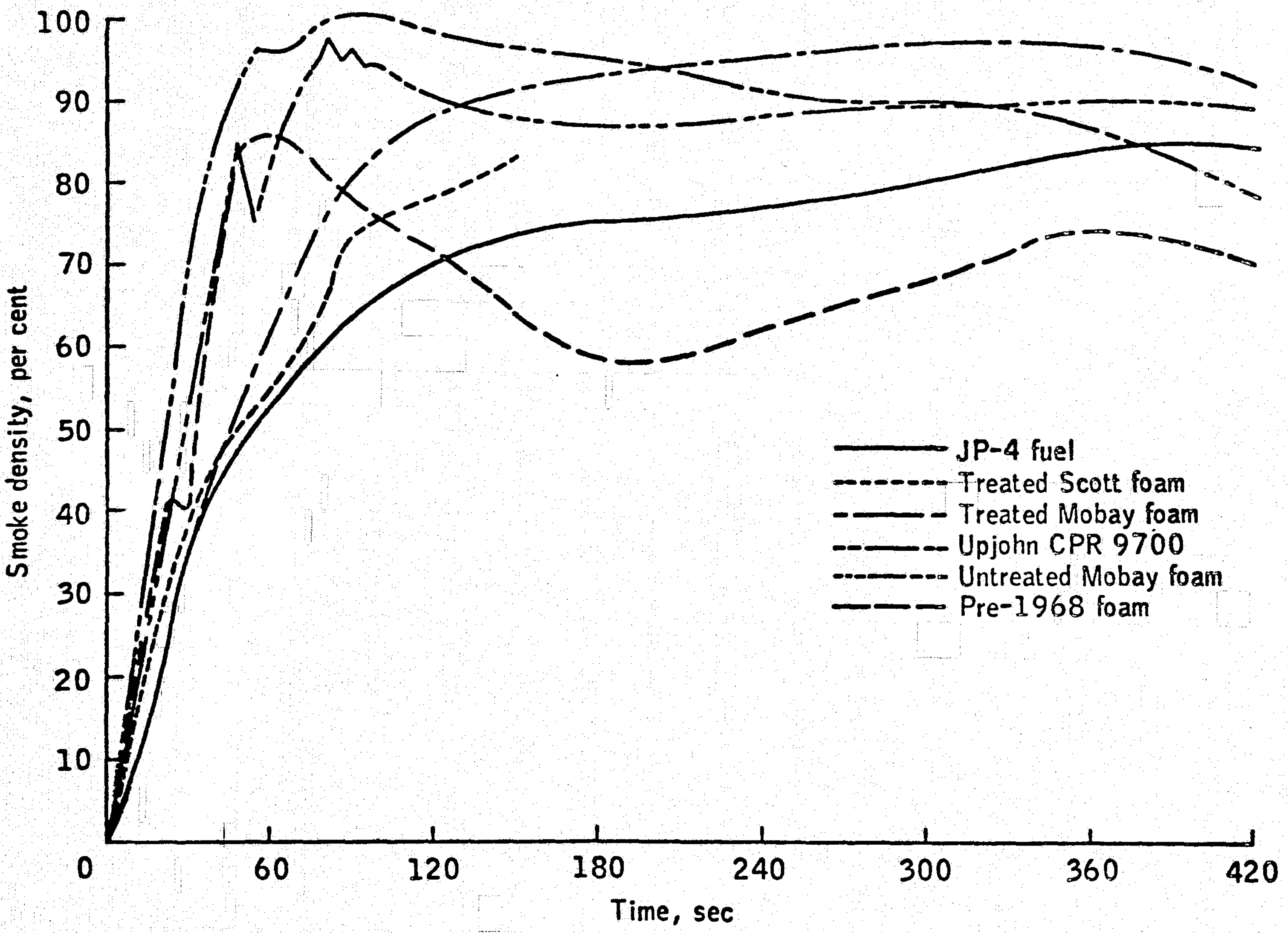
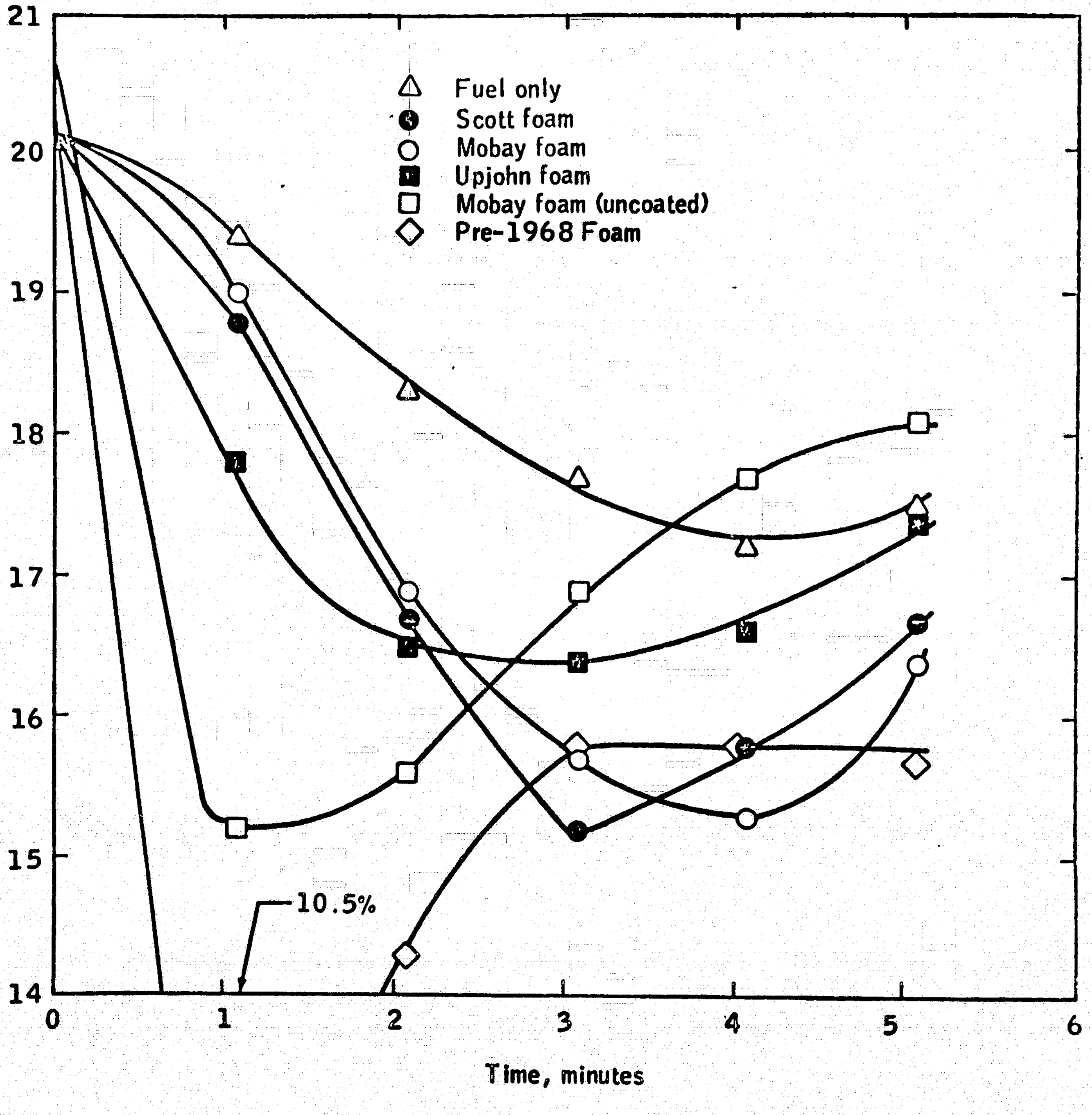

Smoke density, per cent
100
90
80
70
60
50
40
30
20
10
0
60
120
180
240
300
360
420
Time, sec
JP-4 fuel
Treated Scott foam
Treated Mobay foam
Upjohn CPR 9700
Untreated Mobay foam
Pre-1968 foam

Figure 8.



21
20
19
18
17
16
15
14
0
1
2
3
4
5
6
Time, minutes
△ Fuel only
● Scott foam
○ Mobay foam
■ Upjohn foam
□ Mobay foam (uncoated)
◇ Pre-1968 Foam
10.5%

Figure 9.

Mr. Flack, Weber Aircraft Company, asked what role the seat manufacturers should play in the program. Dr. Parker suggested that the following might be the seat manufacturers role: (1) supply wisdom to distinguish options for Dr. Tesoro, (2) establish whether seats can be made from candidate materials, (3) make a factual economic input, and (4) supply prototype seats for testing.

Dr. Parker went on to present his curves of fire threat versus material availability in the future. Using these curves (drawn on the blackboard) he compared fire hardness or fire resistivity and cost as a function of currently available materials and materials as they would be available in time increments.

A question arose as to where the airlines were in developing the program since they play the largest role in selecting materials. Dr. Parker noted that they had been invited. He further noted that Dr. Bara had assured him that aircraft manufacturers had a predominant role in the choice of materials. Dr. Bara then said that it appeared that more constraints must be put on the airlines. The situation cannot be allowed to be as random in the future as in the past.

A question arose from the floor as to the time element involved in the initiation of the program. The reply to the question was that two contracts had already been let: namely, one to McDonnell-Douglas Aircraft Company and one to MIT (Dr. Tesoro, principal investigator). A 3-year milestone chart would be available about 25 April 1976.

The general question of fire hardening in the absence of control of the passenger-originated fire load was recognized as a large area that needed attention.

The question of whether seat manufacturers will be directly funded was answered by a statement that this was up to McDonnell-Douglas Co. which gets the general FIREMEN funding for seats and which will also fund R&D.

A question was raised as to the interface with FAA and Congress. This could not be answered definitively, but it was felt that they would hold off until NASA accumulates necessary data. NASA will produce (1) material and process specification for new kinds of seats in about 3 years, and (2) a performance specification for seats. Then the FAA and others can proceed. Dr. Bara suggested that the seat makers could go back to FAA to find out what the agency plans are. However, it was also suggested that FAA has been told what the cost of retrofit is. Nevertheless, if one or two major disasters occur, the entire presently planned course of events may be changed through congressional involvement.

Demetrius Kourtides chaired the workshops. He opened the session by listing the topics: categories of seat materials (foam, fabric, structural materials); mechanical property data base; effect of the environment (humidity, temperature, ultraviolet light, etc.); and maintenance, cost, and availability of materials.

Dr. Gagliani, Solar Corp., was asked about price projections for polyimide foams. He noted that the monomer material was $1.95/lb in 1973, was $0.65-1.95/lb now, and was estimated to shortly be $0.55/lb. He noted that using P.I. foam would only add about 5 percent to the cost of the seat. He felt that it was most cost-effective now.

Dr. Tesoro stated that hard cost figures are not currently available for new advanced materials.

Dr. Parker suggested that for the short-term (3 yr) FIREMEN Program phenolics were more cost-effective than polyimides particularly when compared to the polyurethanes.

It was recognized that McDonnell-Douglas would have to obtain firm prices for materials resulting from the FIREMEN Program.

Mr. Chase, Wever Aircraft Co., cautioned against forgetting the comfort factor during material developing and testing.

Mr. Milligan noted that Aerotherm had acquired the Whittaker business on polybenzimidazoles, including all patent rights and other rights.

Dr. Tesoro chaired the second workshop on the effective use of fire-resistant materials in aircraft passenger seats. She introduced the subject by noting two problems: First, industrial companies find it difficult to undertake significant programs without the prospect of large volume sales. It should be noted that progress in aircraft seats will also apply to the market for seats in buses, trains, cars, etc. Second, each developer of an advanced material frequently tries to have maximum amounts of his material used to the exclusion of others. This makes it difficult to achieve an optimum mix or match.

To a question, Dr. Tesoro replied that it was not in her assignment to take on the task of expanding markets. Dr. Parker said that promising new materials will be brought to the attention of the Department of Transportation; Dr. R. Shane will act in a liaison capacity for Ames information on advanced seat materials. Other contracts will also be used to publicize technology advances. NASA has funds for technology transfer and utilization.

Dr. Tate of Firestone made the point that price is dependent on volume. If the aircraft industry cannot stand a 5:1 increase in cost for advanced materials, it has a serious problem in how to get advances started into its technology. It may be necessary to consider subsidizing advanced materials for aircraft. Polyphosphazene is available for $100/lb now, but Firestone is making a long-term commitment to the product and sees many markets other than seats.

Dr. Parker contrasted short-term fixes versus long-term fixes. If we concentrate on short-term fixes, new material development is hopeless. It is necessary to structure projections of performance and costs and to do this for society's best interests. For example, DeSoto is working on polyphosphazene coatings and films which may be available soon. We need to consider cost and availability also. Further, we must consider little specialty firms and the credibility of the market.

Dr. Batha, A.K.I., noted that A.K.I. is working actively on a low-cost Kynol material with seat manufacturers. Active testing is producing very favorable results. A protective barrier approach is being utilized.

Thin Kynol mats in furniture and other uses were discussed that implemented the barrier concept.

Dr. Shane suggested using ASTM F-15, Consumer Product Safety, as a mode of enlarging markets through voluntary product safety standardization.

Dr. Batha said that he was pleased to find the desired design properties by using Kynol.

Dr. Parker thanked all the conference participants. He suggested that the next meeting on the subject might be scheduled after Dr. Tesoro advises NASA on material selection. He cautioned that all data presented at the Conference is tentative.

The meeting adjourned.