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ABSTRACT: A general approach for selecting polymers to increase fire safety in aircraft is described. It is shown that polymer flammability and thermal protection capability are related to the molecular structure of the polymer and its thermochemical properties. These criteria are used to develop advanced fire resistant materials that can achieve increased survivability in both post-crash and in-flight fires. The degree of fire hardening of materials depends greatly on the available heat load and fire threat present. It will be shown that improvements in fire safety can be achieved by the use of polymers possessing certain basic thermochemical parameters such as high char yield.

INTRODUCTION

ENHANCEMENT OF human survivability and reduction of aircraft vulnerability to accidental aircraft fires are the objectives of aerospace fire research and related studies for the development of fire-resistant materials, components, and structures. Losses of life and aircraft have resulted from recent disasters representative of the principal kinds of fires encountered in aircraft operations: the in-flight fire, the ramp fire, and the post-crash fire. Analysis of these events has called attention to the potential threat to survivability produced by the combined effects of heat of combustion, smoke, and toxic gases that can be generated by most of the polymeric materials so commonly used in all modern aircraft construction. However, to improve aircraft fire safety, replacement materials should be cost effective, comparably functional, and timely. For these reasons aircraft fire safety must be considered a complex systems problem that requires trade-offs between kinds of materials, design parameters, reduction of ignition sources, early fire detection, extinguishment, and fire isolation. Only a partial solution can be obtained from use of fire hardened materials and structures; this paper emphasizes this particular aspect of aircraft fire safety.

Although there are many laboratory test methods for evaluating the flammability of materials, they cannot, at present, be used to qualify materials for fire

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safety in a real fire environment [1]. The same assessment must also be made about the excellent basic studies on smoke and toxic gas production [2]. There are no reliable analyses that relate material properties to survivability in aircraft fires. Only full-scale component testing gives meaningful answers to survivability assessments of specific systems. What is needed for long-term improvement is the definition of survivability criteria to guide the evolution of aircraft fire safety.

The objectives of this paper are to present a methodology for assessing the effects of fire threats in aircraft by first considering an appropriate fire dynamics logic and to point out, with specific examples, in the case of both military and domestic aircraft, reasonable opportunities for breaking the fire dynamics chain to increase the probability of survival by the application of new materials and structures. Criteria for developing new materials and test methods for materials selection will also be presented.

FIRE THREAT VERSUS FIRE HARDENING

A general approach for specifying fire survivability is shown in Figure 1 in which the fire threat level is plotted as a function of the degree of fire hardening for aircraft structures. The size of the imposed ignition source has been plotted as a fire threat criterion and for a given system such as a contemporary interior aircraft wall paneling. This fire threat is compared to the degree of fire hardening required in a full scale component test.

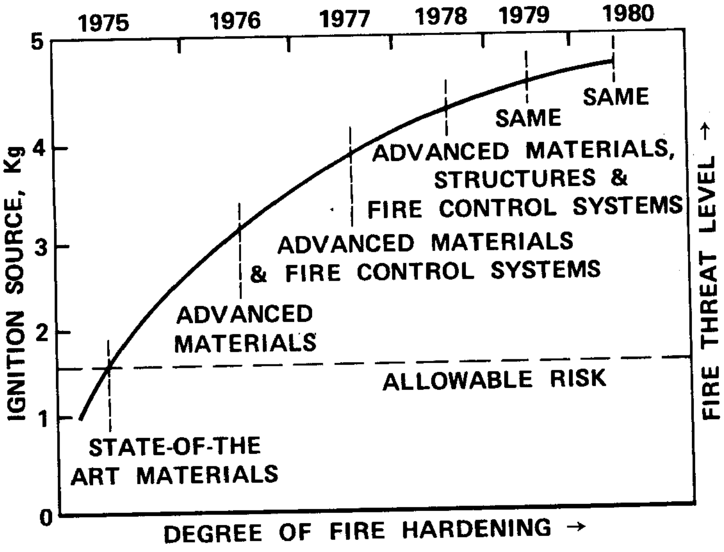


Figure 1. Comparison of fire threat level and fire hardening.

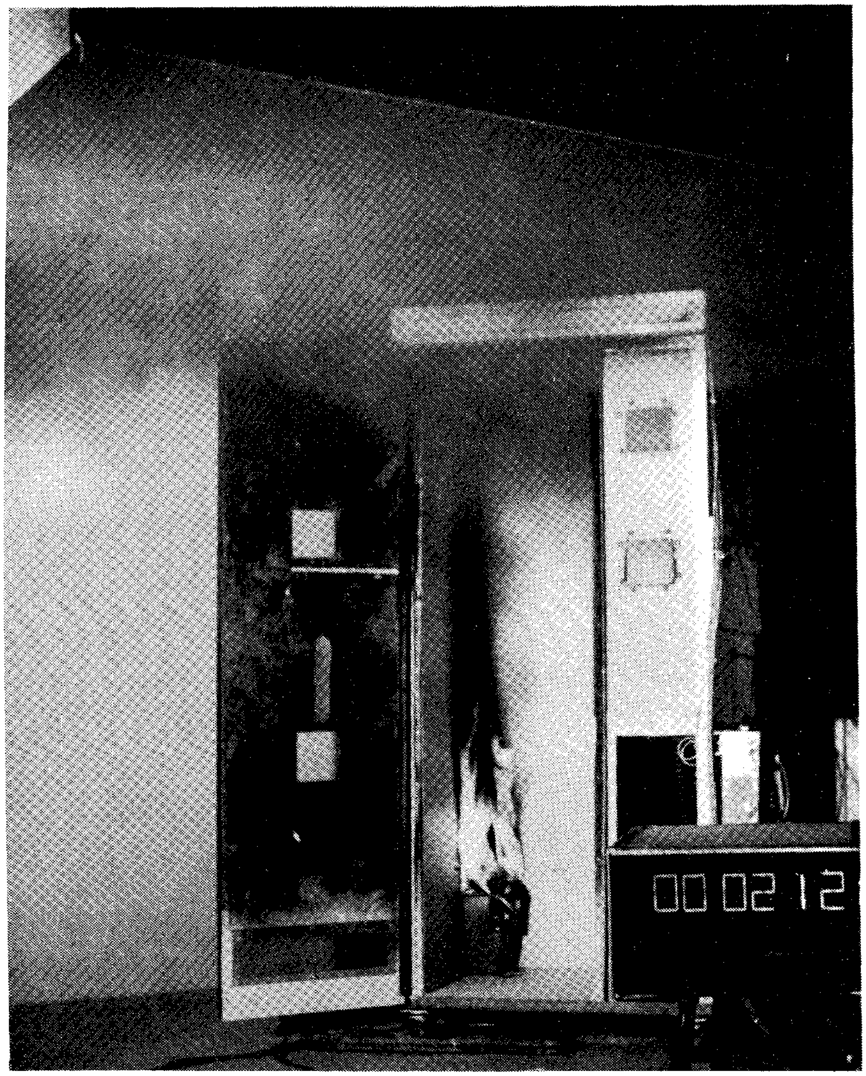


Figure 2. Fire resulting from 1-kg ignition source.

Figures 2 and 3 incidate the effect of ignition source size on flashover. The effect of a 1 kg and 2 kg hydrocarbon ignition source on a prototype, wide-body jet aircraft lavatory fitted with state-of-the-art lavatory wall paneling is shown. Previous statistics [3] have indicated that ignition sources of approximately 5 kg can be encountered in an aircraft lavatory under maximum passenger load conditions. It can be seen that the larger ignition source produced a catastrophic flashover in 2.2

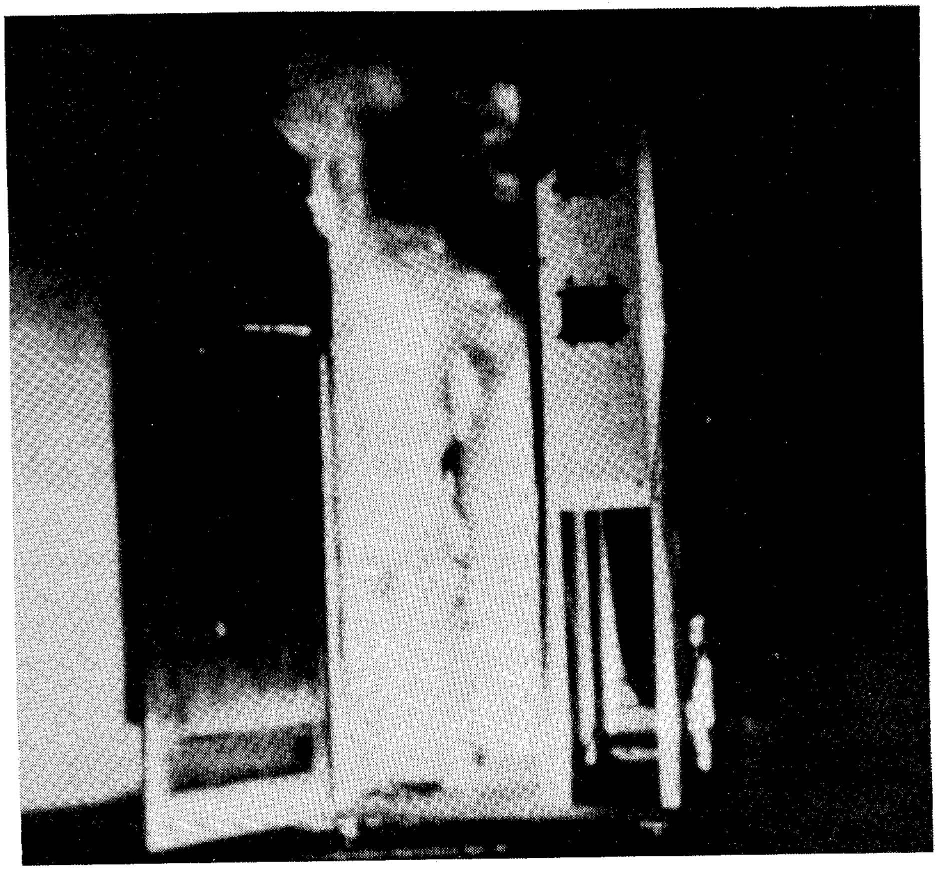


Figure 3. Fire resulting from 2-kg ignition source.

minutes, whereas the smaller ignition source produced a fully contained fire which was observed to burn itself out in 10 minutes. The door was open in both tests. It was observed that even the small ignition source caused the wall panel to produce considerable smoke and gas. In this study smoke and gas production was not considered in the fire hardening criteria.

The limit of the degree of fire hardening for the structure indicated in Figures 2 and 3 can be designated in Figure 1 as an allowable fire threat level produced by an ignition source between 1 kg and 2 kg. It is also indicated in Figure 1 that by the application of the advanced materials technology that will be available by 1978, a large improvement can be achieved in the degree of fire hardening for this particular system. From this simplistic example it is evident that the specification of survivability in terms of the interaction of the thermal environment with the materials system, requires specific information about the interaction of anticipated fire threat levels with aircraft subsystems such as unattended modules, (lavatories, cargo bays, and galleys), interiors of passenger compartments, fuselage structure, engine bays, and fuels. In order to establish an allowable threat level, as shown in Figure 1, it remains to obtain an agreement among aircraft manufacturers, airline operators, and regulatory agencies, through appropriate risk assessment studies.

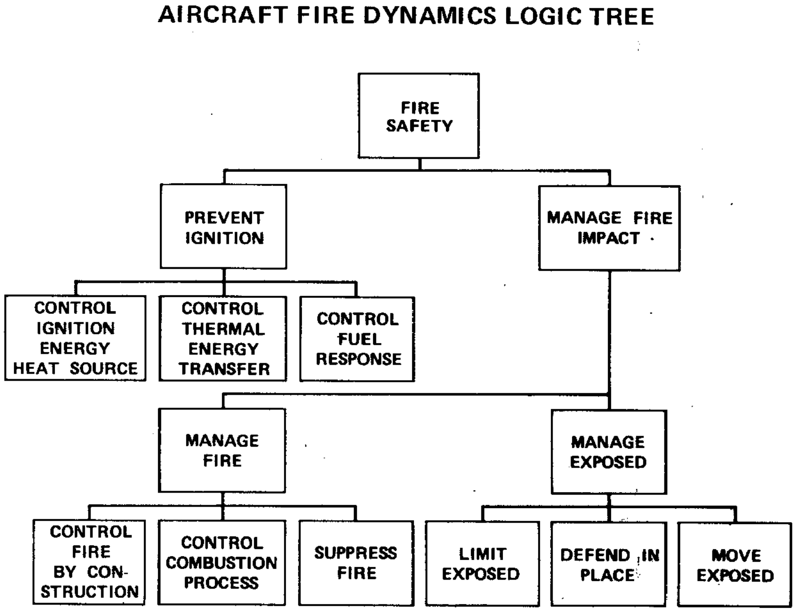


Figure 4. Fire dynamics logic tree.

The general fire dynamics logic tree shown in Figure 4 may be used to identify opportunities to improve aircraft fire safety. It is shown that fire safety depends on two principal functions: namely, prevention of ignition and management of the fire impact. Overall fire safety and survivability for both military and civilian aircraft can be substantially improved by preventing ignition. This is the major factor in considering the survivability and vulnerability of close support combat military aircraft. Survivability has been achieved in some instances by ignition suppression of the ballistic incendiary threat and by protection of the fuel system with low density foams and composites.

In the case of military aircraft, management of the fire impact after ignition has occurred has received less attention. Analysis of most fire scenarios in aircraft fire disasters indicates that most of the fires could have been prevented by taking positive action to prevent ignition. Some of the aircraft fire disasters might have been controlled by adequate management of the fire impact. Since it is practically impossible to predict an accidental fire threat level accurately, both ignition and fire management must be considered together in fire hardening of aircraft components in order to address both threat mechanisms. For example, ballistic foams prevent ignition by controlling the energy heat source, and also control thermal energy transfer by virtue of their excellent insulation qualities. Certain foams can act through ablation mechanisms, by managing the fire, controlling the fire, and defending in place to manage the areas exposed. Low density foams, composites, unsupported films, and coatings can be modified by including components which produce volatile species, under the fire-impact, to suppress fire and control combustion processes.

Energy sources can be isolated and energy transfer prevented by inorganic insulation, reradiation and dissipation by conduction. The total thermochemical energy of potential energy sources can be managed by the judicious selection of materials that are essentially noncombustible in the fire environment; for example, silica, silicates, magnesium oxides, and high char yield organic polymers, such as the aromatic heterocyclics, polyimides, and polyquinoxalines. Design modifications of components and special structural configurations to control ventilation, to limit convection, and to reduce radiant energy transfer are also important considerations in managing the fire impact. Although it is technically possible to fire-harden the structural and functional materials which are an integral part of the aircraft, at present there is little hope of eliminating the fuel contribution from sources in cargo bays and passenger carryon materials. The latter alone can amount to between 2500–5000 kg in a wide-body jet with a fuel load contribution of 4000–7000 Btu/kg. Unlike the aircraft fuel which, with the exception of the engine fire (in-flight) and post-crash fire, is well managed, the passenger carryon materials and frequenctly the aircraft cargo are not controlled. For these reasons the probable fire threats must be anticipated accurately, and the system must be designed and tested with a clear understanding of the fire impact if the fire is to be managed at all.

In examining the logic tree, it is clear that the first line of defense against any fire threat is to prevent ignition and subsequently to achieve fire suppression if ignition occurs. This action generally involves the concerted functions of detection and extinguishment. In the occupied areas of the aircraft it is believed that the passengers and crew are the best detectors, and fire fighting procedures are adequate. But when the fire starts in inaccessible areas, for example, in the plenum volume or unattended modules such as lavatories, cargo bays, and galleys, this human response to fire control is of little value as has been recently demonstrated in full scale tests conducted by NASA [3]. The same concern applies to the external fuel-fed fire associated with the post-crash case where survival depends on external fire fighting and assistance in egress. For these reasons, it appears that the largest short-term payoff for enhancing aircraft fire survivability is in the area of fire hardening of unattended, inaccessible aircraft modulus to cope with the in-flight and ramp fire, and fuselage fire hardening to provide protection against the impact of the external fuel fire. The use of fire hardened, nonsmoking, nontoxic materials and structures offers an effective fire management tool.

Aerospace research and development have yielded a large number of high-strength low-density composites, fire-suppression and fire-resistant coatings, ablative foam insulation, and char-forming transparent polymers, in the form of unsupporting free films and glazings for both space vehicles and military applications. Most of these new polymers, materials, and derivative components are now limited in commercial volume, and for this reason are relatively high in cost. They all provide extremely high efficiency as ablative thermal protection materials; that is, they resist burn-through and minimize back-face temperature rise under both aerodynamic heating and fire impact. Unlike most nonmetallic contemporary aircraft materials, these newly developed polymer systems and component derivatives provide resistance to ignition, limited flame spread to prevent flashover, and maximum thermal protection to isolate fires; they also prevent burn-through and produce little or no toxic gas or smoke when exposed to a sustained ignition source. These new polymers and their component derivatives may be ideal candidates, from a fire safety point of view for use in the development of fire barriers to replace conventional aircraft materials and in providing new kinds of construction materials to prevent ignition and manage fire impact.

FIRE-RESISTANT MATERIALS TECHNOLOGY BASE FOR AIRCRAFT APPLICATIONS

The technology base provided by NASA-Ames to design, fabricate, test, and select new polymeric materials for enhancing aircraft safety has evolved from two basic requirements for manned space vehicles: (1) char-forming polymers as materials for entry technology, and (2) ignition suppressing materials for protection of crew members from fires. Both of these technologies are unique in a thermochemical sense. The high-char yield polymers such as phenolics, imides and imidazoles, have provided a basis for applying the concepts of reentering spacecraft thermal protection to aircraft fire containment and isolation [4]. Thermally stable fluoro polymers, such as teflon and vinylidene fluoride derivatives, have provided materials especially suited to the prevention of ignition in aircraft fire accidents [5]. Both of these definite polymer classes of aerospace materials require considerable modification and assessment to be applied in a cost-effective manner to improve aircraft survivability. Both classes of materials are now relatively expensive. A one-to-one replacement of contemporary materials with these advanced aerospace materials could result in a three- to tenfold increase in cost.

The char forming materials are generally crosslinked polycylic aromatic polymers [6]; this molecular structural constraint places limitations on processing and limits application to relatively stiff, high molecular structures. The fluoro substituted polymers are limited to ignition suppression and may pose a serious toxic threat due to the toxicity of the pyrolytic gases produced from a sustained ignition source. This result is generalized in Figure 5. The flammability, including ignition resistance and flame spread are compared to the estimated toxic threat. It can be seen that the conventional use of effective fire suppressant additives and the fluoro substitution of polymers to achieve reduction in flammability may increase both

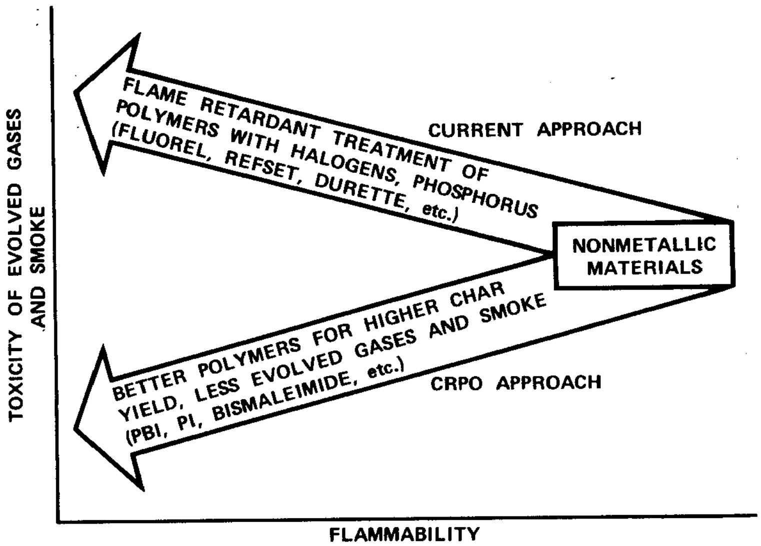


Figure 5. Contrasting methods of reducing flammability of nonmetallic materials.

the toxic and smoke threats; on the other hand, the char-forming polymer can reduce flammability and at the same time reduce smoke production. There are opportunities to apply both of these new classes of advance; state-of-the-art materials to aerospace vehicles with appropriate systems constraints and safeguards.

HEAT REJECTION MECHANISMS OF CHAR-FORMING POLYMERS

Figure 6 represents the principal heat rejection mechanisms characteristic of char-forming ablative polymers. These involve the response of a low density foam or composite to an externally applied heating environment. The figure shows the extent of char formation produced by one dimensional heat transfer to the surface at a heating rate q, applied for a fixed length of time. When the heat is applied convectively, it is blocked in part by aerodynamic blowing in the boundary layer by diffusive coupling of the pyrolytic gases formed from the decomposition of the constituent polymers (which also produces residual char). The amount of char formed under steady state conditions is bounded by a surface temperature, T_s, and

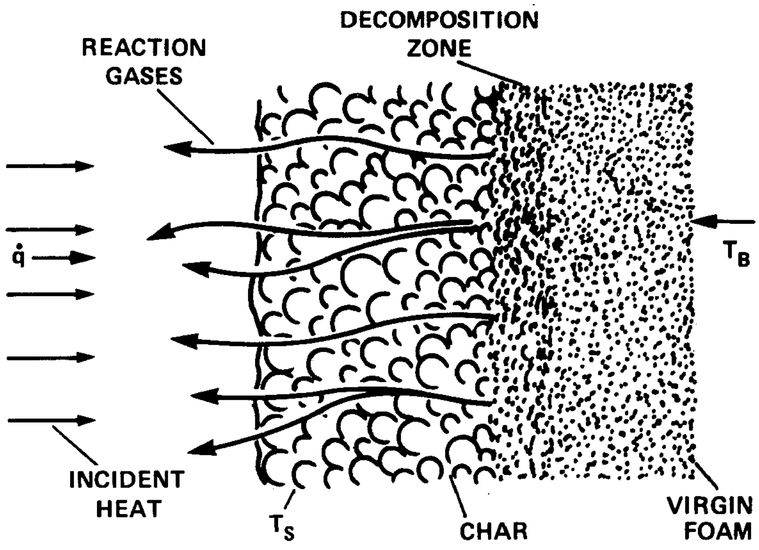


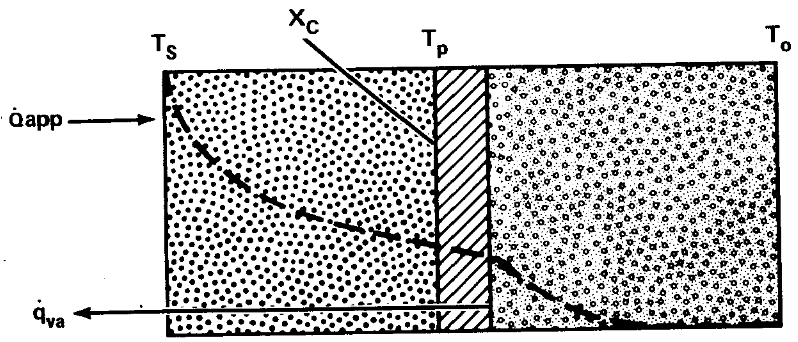
Figure 6. Typical reaction of char-forming foams due to thermal loads.

a decomposition temperature of the char-forming polymer. Heat is rejected at the surface by radiation, which for a black char with an emissivity approaching unit, is at a rate proportional to the fourth power of the temperature.

In the fire environment where there is a large radiative component of the heat load, the thermal reradiation from the hot char surface is one of two principal modes of heat rejection. The other principal mode depends on low thermal conductivity of the virgin substrate to provide heat blockage in the mass and energy balance relationship of this process. Additional heat is absorbed by the pyrolytic gases as they are heated from the decomposition temperature to the wall temperature as the gases pass through the char layer. It is the objective of this ablative application of char forming material to maintain as low a back-face temperature as possible, for the largest period of time under an impacting heat load, with a minimum weight of ablative material per square foot of protective surface. For heat loads that are mainly radiative — those encountered in most fuel fire environments — it was found empirically that low-density organic foam insulation with a density of 40–60 kg/m^3, provided optimum fire thermal protection from fuel fires when the constituent polymer exhibited 30–50% char yield in an anaerobic environment as measured by thermogravity.

THERMODYNAMIC ANALYSIS OF ONE DIMENSIONAL CHAR-FORMING PYROLYSIS

This correlation with thermal performance was further examined analytically as shown in Figure 7. The net heat rate applied to the surface results in an equilibrium



$$Y_C :: \int_0^t \dot{X}_C \, dt :: \int_0^t \dot{Q}\mathrm{app} \, dt$$

$$\dot{X}_C :: \frac{1}{\dot{q}_{va}}$$

$$\therefore Y_C :: \frac{1}{\dot{q}_{va}} \bigg|_t$$

Figure 7. Thermodynamic analysis of one-dimensional char-forming pyrolysis.

surface temperature T_s, and a constant vapor production rate $\dot{q}_{va}$. This vapor production rate results from the pyrolysis of the amount of polymer bounded by T_s and T_p, the pyrolytic temperature required to form a stable char from the virgin polymer. The amount of char formed Y_c (that is, the polymer converted to stable char), is proportional to the linear rate of char production $\dot{X}_c$ acting through time t, as given by

$$Y_c :: \int_0^t \dot{X}_c \, dt :: \int_0^t \dot{Q}\mathrm{app}_1 \, dt \tag{1}$$

which is also proportional to the applied heating rate acting for the same time, t, as given by:

$$\dot{X}_c :: \frac{1}{\dot{q}_{va}} \tag{2}$$

In this linear mass and energy transfer process, the linear rate of char production is evenly proportional to the rate of vapor production. It follows that the rate of vapor production, $\dot{q}_{va}$, is evenly proportional to the amount of char produced in the interval, t, as given by:

$$\therefore Y_c :: \frac{1}{\dot{q}_{va}} \bigg| \; t \tag{3}$$

It has been found that the char yield, Y_c, obtained from the anaerobic pyrolysis in a simple thermogravimetric analysis of a char-forming polymer, is identical with the carbonaceous debris layer obtained by the one-dimensional pyrolysis in both the fire and other radiation environment. It has been shown [6], that in the absence of significant char removal from the surface by oxidation, spalling, or carbon sublimation these processes do not occur in the fuel fire environment. This mechanism is true for all char-forming polymers and is independent of the heating rate over a range of three orders of magnitude in a radiation-only environment.

The char yield obtained anaerobically is a definite reproducible thermochemical property which can be obtained simply by thermogravimetric analysis carried out at modest heating rates to 800°C in pure nitrogen. A typical thermogram for a polyisocyanurate foam plastic is shown in Figure 8. It can be easily estimated at 800°C and for the polymer amounts to about 45%. It can be seen that this polymer begins to decompose at approximately 200°C, and that its decomposition is essentially completed by the time a temperature of 700°C is reached.

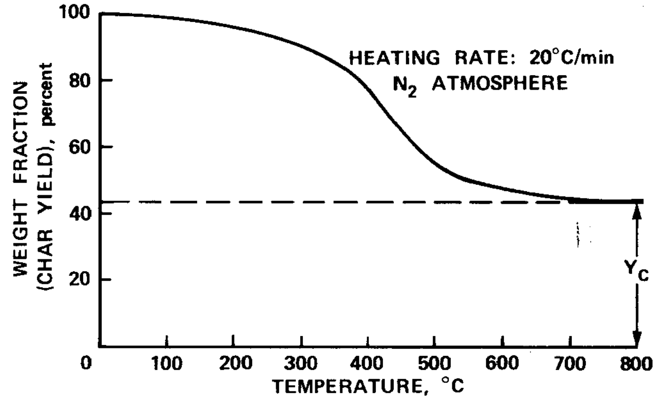


Figure 8. Dynamic thermogram for polyisocyanurate foam.

In order to evaluate this char yield of char-forming ablative polymers as a correlation parameter for both flammability properties and their efficiency as thermal protection systems for fire containment, a number of different polymers were obtained in foam form with densities in the range of 30–60 kg/m^3 and char yields in the range of 20–80%. These were evaluated by standard test methods, by measuring ignition, smoke obscuration, and flame spread. The relative toxicity of the pyrolytic gases was assessed by using an in situ enzyme preparation [7]; thermal efficiencies were determined in a T-3 burner [8]. Costs were estimated as of 1973 and are based on published monomer and polymer costs including processing to a finished product or form. The results are plotted in Figure 9.

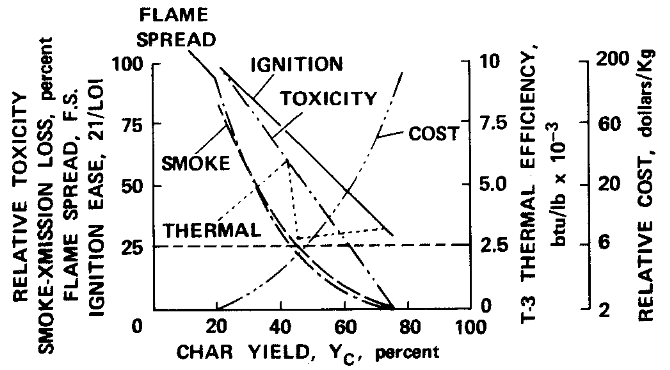


Figure 9. Summary of properties of char-forming foamed polymers.

It can be seen that all the flammability properties decrease monotonically, and almost linearly .with increasing char yield or with decreasing vapor production rate at the wall (Equation 3). The thermal protection efficiency appears to go through a maximum 40–45% char yield. This may be explained by the contribution of the enthalpic contribution of the transpiring gases which would be expected to decrease with a decreasing rate of vapor production at higher values of the char yield. Due to the difficulty in processing and unavailability of monomers for systems with high char yield (when values are > 65%), the costs presently become very unfavorable.

It can be seen from the results indicated in Figure 9, that the best combination of properties and costs for selecting char-forming polymers for the development of aircraft material systems lies in arange between 40 and 60%. It should be noted that the char yield index as a selection criterion for materials also sets the limits on the expected values of the flammability tests. These values have yet to be correlated with full-scale component test data, a final requirement for completing general materials selection criteria. It also should be pointed out that, unlike the high temperature fluoro substituted polymers, which have limited applications as thin coatings on fire sensitive substrates, the char-forming polymers exhibit both ignition suppression and hardening with regard to fire penetration and are intended to be applied as primary structures rather than thin overlays for flammable substructures.

PREDICTION OF THE CHAR YIELDS OF POLYMERS FROM MOLECULAR STRUCTURE

Each macromolecule has a unique pyrolysis mechanism. For high-temperature-stable, char-forming polymers, however, it is possible to predict these characteristic thermochemical parameters stoichiometrically, from the polymers' known molecular structure, with sufficient exactness to be extremely useful in selecting polymers for development as fire-resistant materials. The thermochemical process characteristic of the anaerobic pyrolysis of a number of char-forming polymers is shown in Figure 10. It is sufficient to point out that for the most part it is the aromatic rings — which are either inherently multiple-bonded or become so during the early stages of the thermoanalysis process — that ultimately donate their carbon atoms to the final stable char. The dominant mechanistic feature of these processes is the existence of aromatic ~ carbon levels that are sufficiently stable to persist — during the elimination of substituent hydrogen atoms followed by ring coalescence — to yield polycondensed ring systems with graphite-like structures. This general reaction mechanism makes it possible to correlate the primary thermochemical char yield with the molecular structures of polycyclic aromatic polymers as shown in Figure 11. The experimentally determined anaerobic char yield is plotted as a function of the calculated number of multiple-bonded aromatic ring equivalents initially present in the polymer. It can be seen that this relationship is surprisingly linear over a wide range of useful polymer types. Consequently, in accordance with Figures 9 and 10, it is possible, having a knowledge of the molecular structure of polymers, to predict the flammability and thermal protection properties of polymers. In general the epoxy resin systems and polyurethanes do not meet the flammability selection criteria established above. The isocyanurates at 40% or more char-yield give the best combination of fire isolation properties and flammability characteristics. Polymers like the phenolic, polybenzimidazoles and polyphenylene are extremely hard to the impact of fuel fire ignition although they are less efficient as thermal ablators.

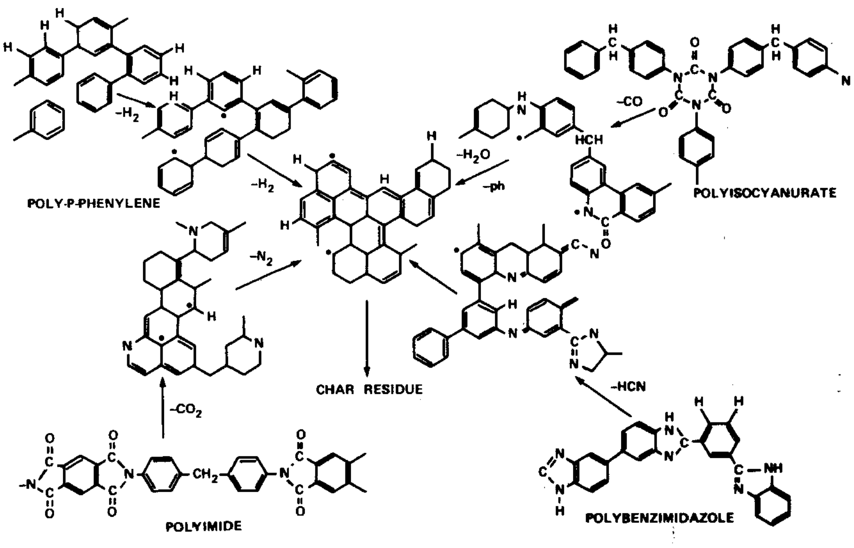


Figure 10. Thermal degradation of high temperature polymers.

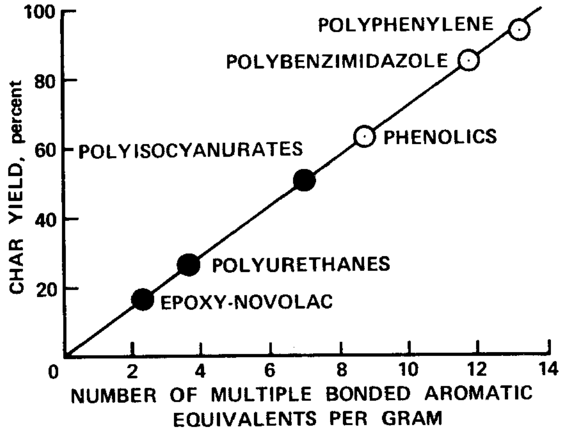


Figure 11. Correlation of primary thermochemical char yield with molecular structure.

APPLICATION OF POLYCYLIC AROMATIC POLYMERS AS BASIC MATERIALS FOR AIRCRAFT FIRE PROTECTION

Applying the aforementioned selection criteria, a semirigid closed-cell polyisocyanurate foam at a density of 30–60 kg/m^3 was selected for evaluation for fuselage protection in a large scale test using the airframe of a C-47 [3]. The aircraft fuselage was divided into two sections. One section was protected with the foam, which was applied 7.5 cm thick internally against the skin of the aircraft, and the other section was of standard aircraft construction. The entire fuselage was subjected to a fire environment produced from 18,500 liters of JP-4 fuel. Figure 12 depicts the result at the end of the test after approximately 12 minutes showing the fuselage section protected by the isocyanurate foam, charred but still intact, while the unprotected section has melted and flowed out on the ground. Also included in Figure 12, is a plot of the cabin interior temperatures for both the unprotected section is in the order of 250°C in less than 2 minutes and has gone off scale in 3 minutes. The interior cabin air temperature of the protected section shows little or no change for up to 6 minutes, with little smoke or gas evolved in the interior. This protection may provide time to put the fire out. It can be seen that as the fire burns itself out, the cabin interior temperature is still at a survivable level. Complete details and results of this test are given in Reference 3. The potential benefits from fire hardening of aircraft are limited by the severity of impact and whether the fuselage remains intact or sustains minor damage during impact. It is estimated that 35% of the fatalities in fire-related aircraft accidents have occurred in crashes which were judged to be impact survivable [9].

It can be concluded from these results that it is possible to make a reasonable prediction of aircraft fire performance from laboratory test methods and to ex-

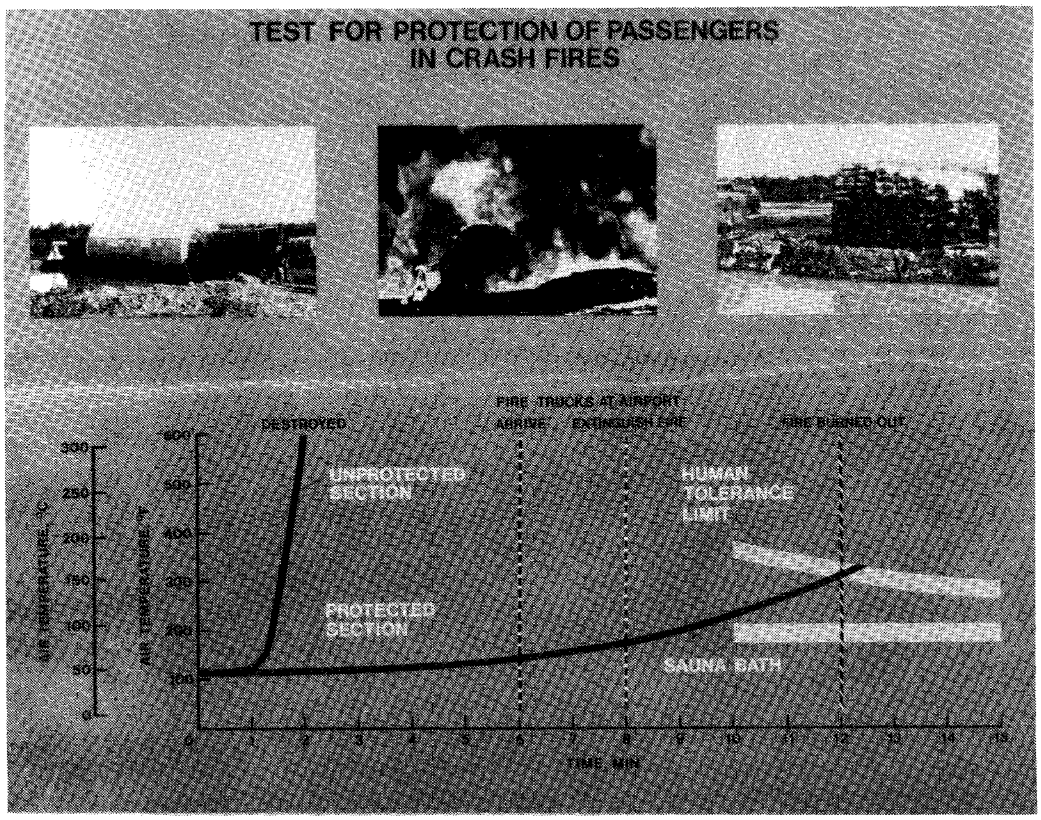


Figure 12. Thermal history of C-47 aircraft test.

trapolate these to full-scale test conditions in the case of providing fuselage thermal protection from the action of a fuel fire in a simulated post-crash scenario.

It is evident from this test result that the materials selection criteria, based on correlation of laboratory thermal protection efficiency data with predictable basic thermochemical parameters, can be reasonably extrapolated to full-scale tests. It remains to be demonstrated that similar agreement can be achieved in the case of flammability tests related to aircraft fire safety.

APPLICATION OF HIGH CHAR-YIELD POLYMERS FOR THE DESIGN AND CONSTRUCTION OF AIRCRAFT MODULES

To determine the relationship between laboratory flammability tests and the capacity of char-yield materials selection criteria for predicting the performance of aircraft interior materials (including ignition, flame spread, smoke, and toxic threats to full-scale components testing) the opportunity of increasing the level of fire hardening of unattended aircraft modules such as lavatories, cargo bays, and galleys has been considered. In these cases two dominant failure modes, flashover and degree of fire containment or fire endurance, have been considered and wall panels have been selected for fire hardening. The construction details of these load-bearing, lightweight wall panel constructions comprising state-of-the-art and advanced materials are shown in Figure 13. The state-of-the-art panels were evaluated against two fire threat levels as shown in Figures 2 and 3. In these tests, it was established that flashover occurred with this wall paneling in 2.3 minutes and apparent burn through in about 5 minutes from a 2 kg hydrocarbon fuel source placed against the base of the wall panel.

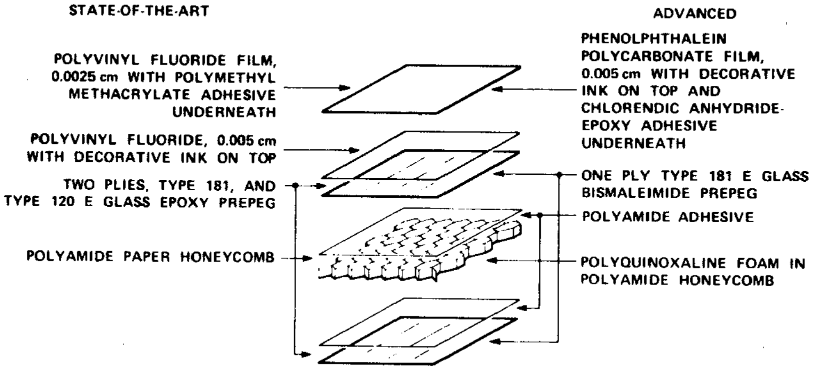


Figure 13. Composite configuration of aircraft interior panels.

Each of the polymeric materials comprising the state-of-the-art composite was evaluated by both conventional flame spread, limiting oxygen index, and smoke generation. With the exception of the phenolic impregnated polyamide paper honeycomb, none of these polymeric components met the flammability criteria established for char-forming polymers with thermochemical char yields of more than 40%. The thermochemical char yields of all of the polymer components, with the exception of the high char yield honeycomb, were found to be less than 25%.

A group of advanced polymeric materials [10] was selected to increase the degree of fire hardening of the total composite panel on the basis of thermochemical parameters and the fire test criteria established above. All of the candidate replacements gave thermogravimetric char yields in excess of 40%. The transparent polyvinyl fluoride film, which gave a char yield of 10%and a corresponding limiting oxygen index of 20, was replaced by a phenophthalein polycarbonate transparent free film [11] with a char yield of 40% and limiting oxygen index of 38. The highly flammable acrylate adhesive was replaced with a fire retardant chlorendic anhydride epoxy adhesive. The low char yield laminated epoxy resin was replaced with a high char yield bismaleimide resin with a char yield of 50% and a limiting oxygen index of 50. The honeycomb structure which met the flammability criteria was further hardened to heat penetration by filling the honeycomb with a high char yield, low density (20 kg/m^3) polyquinoxaline foam formed from the in situ polymerization of p-nitroaniline bisulfate.

Table 1 indicates the properties of this new prototype aircraft interior structural panel fabricated from advanced materials selected for evaluation by the thermochemical criteria set forth in this paper. Panel properties are compared with the properties of contemporary panels found on most domestic transport aircraft. It is shown that at equivalent density the fire containment or fire endurance capability of this panel has been improved by a factor of five. This improvement is believed to be due to the thermal protection efficiency of the high char yield foam filling the honeycomb structure. It may also be seen in Table 1 that these panel modifications have resulted in a great reduction in the specific optical smoke density. Examination of the smoke density values for the constituent components of these composites clearly shows that the principal contributor to smoke is the epoxy resin laminating resin in the contemporary panel. This is predictable from the materials selection criteria set forth above. Replacing the epoxy laminating resin with the high char yield bismaleimide resin effectively reduces the total smoke evolved to the low value of 16. It is interesting to note that with the advanced composite the specific optical density is also an additive property of the individual component values.

Figure 14 [10] compares the fire endurance of containment capability of the advanced aircraft interior panel B which is compared with the state-of-the-art panel A under the conditions of the T-3 test [8]. In this figure, the backface temperature rise is plotted as a function of the time in minutes under the impact of front-face heat flux of 11×10^4 W/m^2 which is a reasonable simulation of a full-scale fuel fire. It can be seen that the back-face temperature of the conventional composite reaches an arbitrarily chosen survival temperature of 200°C in 2 minutes but takes as long as 9 minutes to reach a comparable back-face temperature with the advanced material B. By extrapolating the results obtained from the T-3 test facility to a full-scale fuselage burn-through test it is to be expected that similar fire containment capability can be expected in full-scale component testing of interior panels fabricated from these high char yield polymer systems.

The assessment of the full-scale component flammability, including time to flashover, toxic threat assessment, and ignition characteristics from high energy ignition sources, must wait full-scale component testing of these new panels in aircraft structural configuration.

CONCLUSIONS

It has been shown that it is possible to predict the values of laboratory flammability tests and the thermal protection capability of char-forming polymeric materials from basic thermochemical parameters. Two examples — fuselage hardening

Table 1. Comparison of Flammability Properties of Aircraft Interior Panels.

•Composite properties	PVF, epoxy-glass, polyamide honeycomb, epoxy-glass		Phenol-polycarbonate, bismaleimide-glass, polyamide honeycomb filled with polyquinoxaline foam, bismaleimide-glass	
Density (ASTM D 71)	96 kg/m^3		96 kg/m^3	
Flatwise tensile strength (ASTM C307), 24°C	0.02-0.05 N/m^2		—	
Fire endurance, NASA AMES T-3 Thermal test facility, time (min) to reach backface temperature of 204°C, front face heat flux 11 X 10^4 W/m^2	2		10	
Smoke density (NBS), (D_S 4 min) Specific optical density	87		16	
FAR 25.853 (vertical test method standard 191, method 2903)	Passes		Passes	
•Component smoke density	Polyvinyl fluoride	7	Phenol polycarbonate	5
Maximum specific optical density (NBS smoke chamber)	Polyamide	2	Polyamide	2
	Epoxy Resin	90	bismaleimide resin	9
	Glass	—		—
•Composite material balance	Polyvinyl fluoride	7.6	Phenol polycarbonate	5.0
% by weight	Polyamide	20.5	Polyamide	20.5
	181,120 glass	41.9	181 glass	30.0
	Epoxy resin	30.0	Bismaleimide resin	30.0
			Polyquinoxaline	14.5

and fire hardening of interior aircraft modules — have been presented in which materials selection criteria and designs employing these materials have been defined. In the case of fire isolation and containment these examples demonstrate the effectiveness of this methodology in improving fire safety in aircraft fires. Further full-scale component testing is required to apply this methodology to flashover and toxic threat predictions based on laboratory test methods now available.

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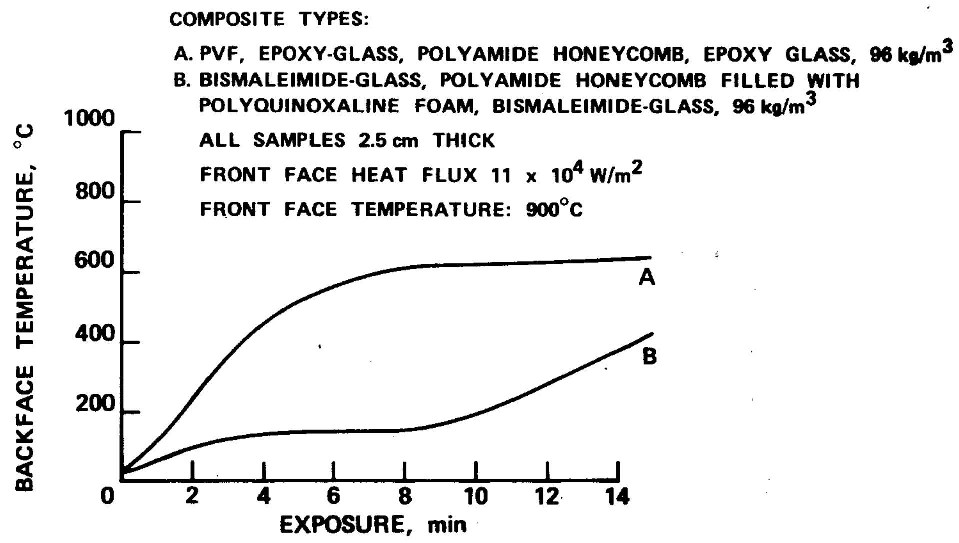

Figure 14. Comparison of fire containment capability of aircraft interior panels.

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