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General Aviation Accidents Postcrash Fires and How to Prevent or Control Them

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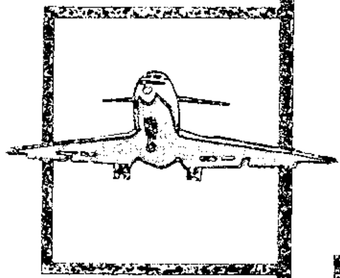

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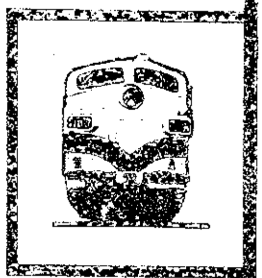

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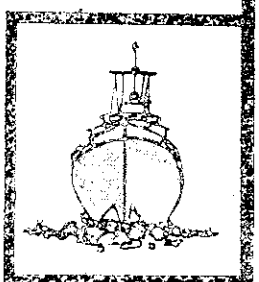
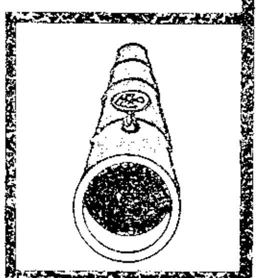


SPECIAL STUDY

GENERAL AVIATION ACCIDENTS: POSTCRASH FIRES AND HOW TO PREVENT OR CONTROL THEM

NTSB-AAS-80-2



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16. Abstract

A study by the National Transportation Safety Board showed that postcrash fires occurred in approximately 8.0 percent of the 22,002 general aviation accidents during 1974-1978. About 59 percent of the accidents involving postcrash fire resulted in fatalities, while fatalities were involved in only 13.3 percent of those accidents without fire.

A survey of state-of-the-art technology has demonstrated that feasible techniques for the containment of fuel exist. U.S. Army accident experience using similar technology has shown that fuel containment dramatically reduces fire injuries and deaths.

The study has shown that there are few regulations dealing with the postcrash fire problem in general aviation aircraft. The Safety Board has made six recommendations to the Federal Aviation Administration for corrective action.

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NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

SPECIAL STUDY

Adopted: August 28, 1980

GENERAL AVIATION ACCIDENTS: POSTCRASH FIRES AND HOW TO PREVENT OR CONTROL THEM

INTRODUCTION

A 1948 National Advisory Committee for Aeronautics (NACA) Research Memorandum stated: ". . .Two to three times as many people are killed in accidents followed by fire than are killed when no fire follows the accident." 1/ An analysis of the National Transportation Safety Board's general aviation aircraft accident data for the years 1974 through 1978 shows that postcrash fire is a more significant problem today than it was 30 years ago.

The hazards created by postcrash fire have long been recognized by the aviation industry. When powered flight was not yet 20 years old, research into the fire hazard was already underway. Much of the philosophy and many of the ideas developed during early research formed the foundation for today's preventive action.

During this special study, the Safety Board reviewed accident experience and the severity of postcrash fires in accidents involving general aviation aircraft, and examined possible preventive measures made available by new design philosophies and technological advances in materials and manufacturing.

STATISTICS AND CASE HISTORIES

Statistics

National Transportation Safety Board data show that from 1974 through 1978, 22,002 general aviation accidents occurred, 1,764, or 8.0 percent, of which involved postcrash fires. Although 8.0 percent seems insignificant, a disproportionately large number of accidents resulting in fatalities occurred when compared to accidents which did not involve fire. (See Table 1.) About 59 percent of the accidents involving postcrash fires resulted in fatalities, while fatalities were involved in only 13.3 percent of those accidents without fire. About 57.4 percent of the occupants of all aircraft involved in accidents with postcrash fire were killed while only 12.3 percent of the occupants of aircraft involved in accidents where no fire occurred were killed. (See Table 2.)

1/ Cleveland Laboratory Aircraft Fire Research Panel, Preliminary Survey of the Aircraft Fire Problem, RM No. E8B18, NACA Flight Propulsion Research Laboratory, Cleveland, Ohio, May 21, 1948.

Table 1.--U.S. General Aviation Accidents
1974 - 1978

	Accidents Without Fire	Accidents With Postcrash Fire
Total accidents	20,238	1,764
Fatal accidents[1/]	2,685	1,038
Percent fatal/total	13.3	58.8
Total severe accidents[2/]	11,207	1,413
Fatal severe accidents	2,053	872
Percent fatal/total	18.3	61.7
Total nonsevere accidents[2/]	7,381	159
Fatal nonsevere accidents	68	30
Percent fatal/total	0.9	18.9

1/ A fatal accident is one in which deaths determined to be a direct result of injuries sustained in the accident occur within a period of 30 days following the accident.
2/ The total number of accidents will not add up because some accident types were excluded from both categories.

Table 2.—Number of Fatalities in
U.S. General Aviation Accidents
1974 - 1978

	Accidents Without Postcrash Fire	Accidents With Postcrash Fire
All Accidents		
Total Aboard	40,220	3,903
Fatally Injured	4,948	2,240
Percent Fatal/Total	12.3	57.4
Severe Accidents		
Total Aboard	21,842	3,124
Fatally Injured	3,831	1,868
Percent Fatal/Total	17.5	59.8
Nonsevere Accidents		
Total Aboard	14,933	346
Fatally Injured	102	55
Percent Fatal/Total	0.7	15.9

One might hypothesize that postcrash fires occur more often in severe accidents. To examine this hypothesis, the data were divided into two accident categories -- relatively severe accidents and relatively nonsevere accidents. The severe accidents included collisions with the ground or other objects such as trees or poles, stall/spins, and some accidents following engine failures or malfunctions. The nonsevere accidents which usually occurred during landing, included ground loops, hard landings, gear-up landings, nose-overs, or under/overshoots.

Almost 80 percent of the 3,723 fatal accidents, or 2,925, were made up of the severe accident types. A comparison of these severe accident types show that fatalities occurred in about 62 percent of the accidents with postcrash fires; however, fatalities occurred in only 18 percent of the accidents without postcrash fires; less than 1 out of every 5 severe accidents resulted in fatalities if no postcrash fire was involved. When fire was involved, more than three out of every five severe accidents involved fatalities. Furthermore, the data show that even in relatively nonsevere accidents, there was a great disparity in the percentage of fatal accidents. Less than 1 percent of the nonsevere accidents involved fatalities when there was no postcrash fire. When there was a postcrash fire, almost 19 percent were fatal accidents.

A review of accident investigation reports and their associated statistics strongly indicate that fire was the only major variable between the accidents of a similar type. Using this assumption, it is reasonable to conclude that, since only 13.3 percent of all nonfire accidents are fatal, only 235 of the 1,764 accidents involving postcrash fires would have been fatal if there had been no fire. Following this reasoning, 803, or 77.4 percent, of the 1,038 fatal accidents involving postcrash fire should have been survivable had there been no postcrash fire. With an average number of fatalities of about 2.16 persons for every fatal accident involving postcrash fire, as many as 1,734 lives could have been saved if postcrash fires had not occurred. Clearly, fire, rather than impact, is the major contributor to fatalities in those general aviation aircraft accidents which involve postcrash fire, and eliminating fires could save more than 300 lives per year.

Case Histories

The Safety Board chose the following case histories to illustrate accidents which were survivable, but because of postcrash fire, death, injury, or property damage resulted. The aircraft in these case histories were type certificated and are being manufactured under the following:

Case 1, single-engine aircraft - Civil Air Regulations (CAR) Part 3.
Case 2, twin-engine jet - Federal Aviation Regulations (FAR) Part 25.
Case 3, twin reciprocating-engine aircraft - CAR Part 3 and some provisions of FAR 23.

Case No. 1.--A single-engine aircraft with four persons on board encountered a power loss after takeoff and had to make a forced landing. As a result, the aircraft struck the ground in a slight left wing-low attitude and slid about 240 feet along level terrain. (See figure 1.) Witnesses stated that fire and smoke erupted immediately after impact. A surviving passenger in the rear seat said that when the aircraft stopped, he saw no fire on the wings or around the aircraft.

He suddenly became aware of fire under his feet, and he escaped immediately through the left rear window. He stated that, as far as he could recall, the fire was only under the belly of the aircraft.

The airport crash/fire/rescue personnel were notified of the crash by the tower and responded immediately. By the time they arrived, the passenger in the right front seat had escaped through the door and the pilot had escaped through the left front window. None of the three survivors received any impact injuries, but all were burned seriously. The fourth occupant, who was sitting in the right rear seat of the aircraft, died from the effects of smoke and fire. It was not determined why she did not escape. (See figure 2.)

Case No. 2.--A twin-engine jet on a flight from Paton, New Mexico, to Houston, Texas, was being used to train the copilot, who had only 3.7 hours in this make and model aircraft.

As the aircraft reached rotation speed on the takeoff roll, the pilot retarded the power lever for the right engine to flight idle and announced a simulated power failure. The copilot continued to rotate the aircraft, and as it left the ground, the aircraft yawed to the right and the right wing dropped. The pilot took control, but was too late. The right wing tip tank hit the ground about 50 feet to the right of the runway, and the aircraft caught fire immediately.

The aircraft then hit on its main landing gear and, still burning, continued to slide along the ground for about 1,500 feet, collapsing the landing gear. After it stopped, the aircraft was quickly engulfed in flames. The pilot, copilot, and passenger exited the aircraft through the main door; no one was injured. Even though the airport crash/fire/rescue personnel arrived within minutes, the aircraft was destroyed by fire. (See figures 3 and 4.)

Case No. 3.--A twin reciprocating-engine aircraft departed Riverside, California, for Grand Canyon, Arizona, on a pleasure flight; nine persons were on board. When the aircraft was about 35 miles from Grand Canyon, the pilot reported losing an engine. He was unable to maintain altitude and told the Grand Canyon tower controller that he would have to make an emergency landing.

During the emergency landing, the aircraft's right wing struck the ground, and then the nose of the aircraft struck the ground. The aircraft slid for 300 feet over gently rolling, brush-covered ground. Fire erupted after the aircraft came to a stop. (See figure 5.)

Investigation determined that, except for those occupying the pilot and copilot seats, the accident was survivable. However, five persons died and four were seriously injured by fire. One of the survivors described the crash as follows:

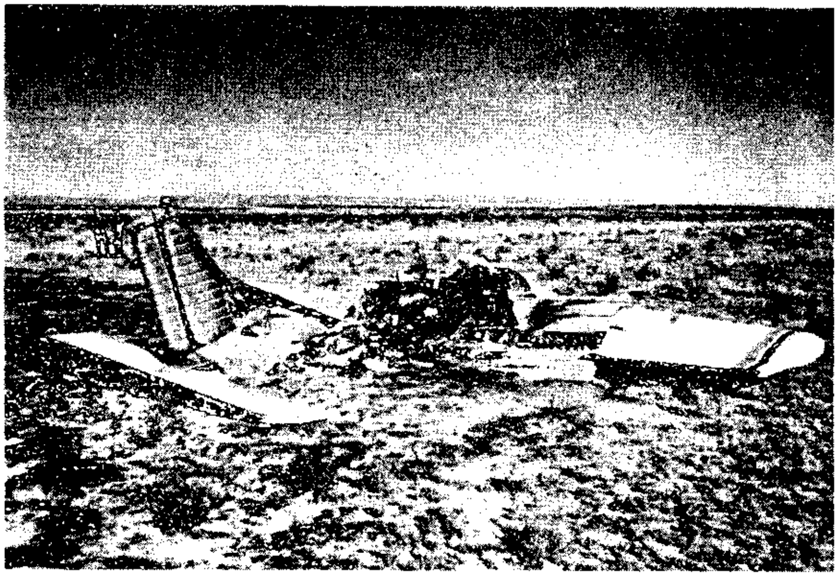

Figure 1.--Main wreckage of single-engine aircraft.

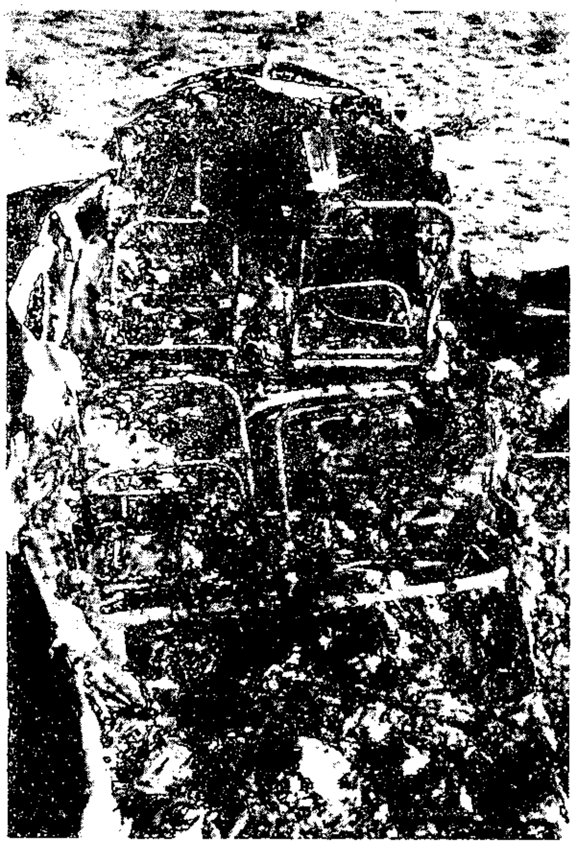

Figure 2.--Cabin area of single-engine aircraft.

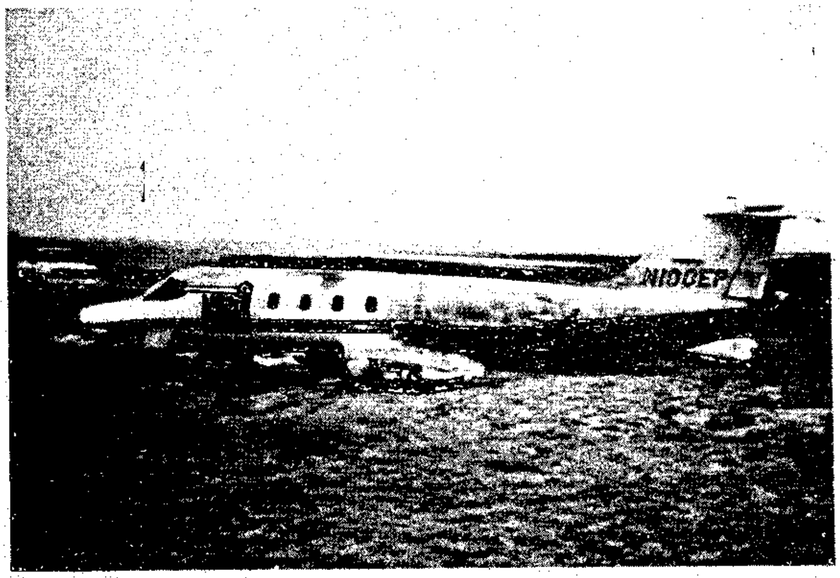

Figure 3.--Left side of aircraft.

Figure 4.--Right side of aircraft.

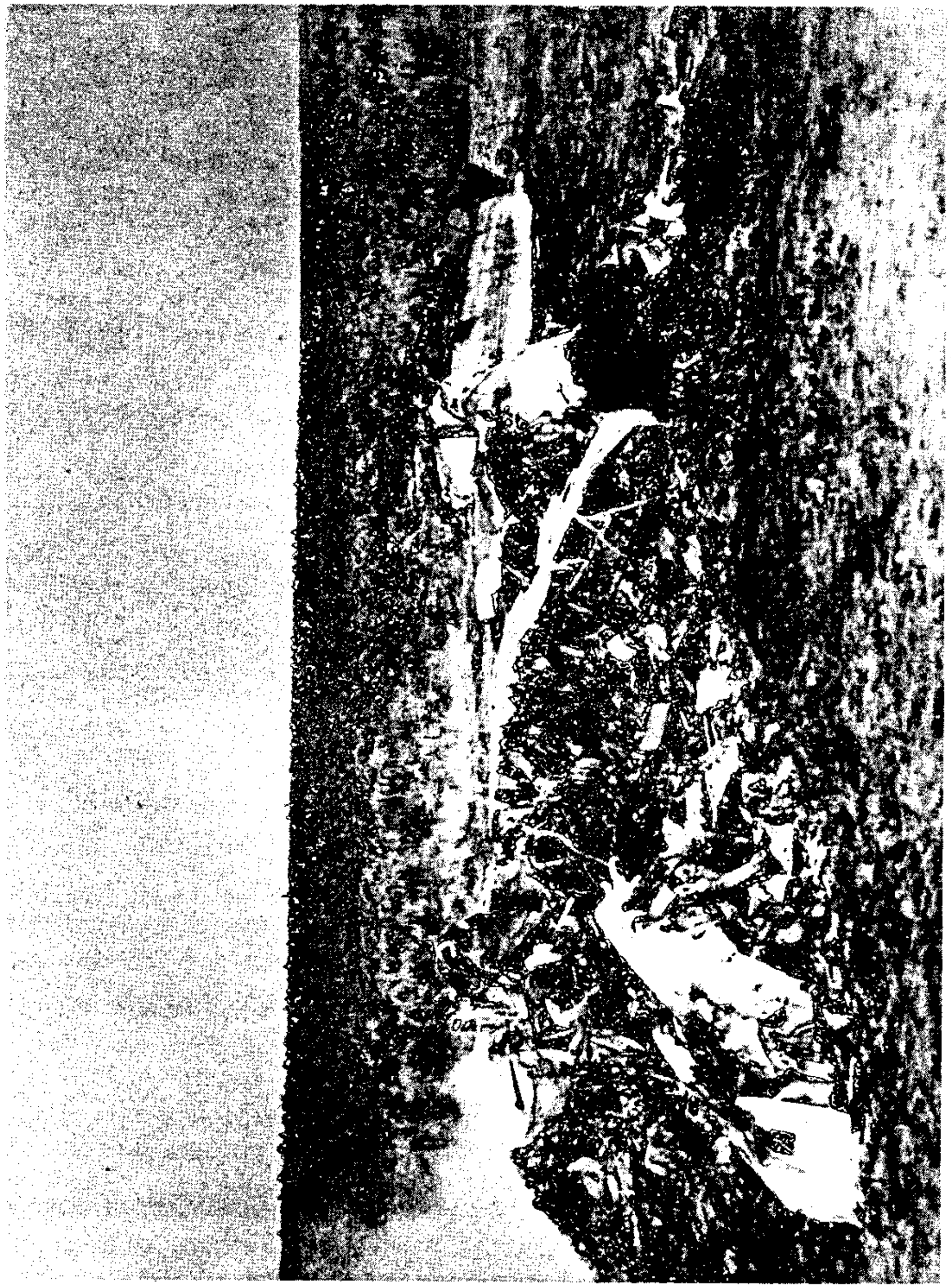

Figure 5.--Main wreckage of twin-engine aircraft.

"At the time of the crash I felt tremendous pressure, like something was pushing me forward, just doubling me over. I felt pressure in my lungs as if I were being pulled apart inside and then I passed out. When I came to I felt myself buried under something heavy and I was unable to breathe. By moving my arms I discovered that I was covered by a thick layer of ashes. Opening my eyes the first thing I became aware of was a bright orange color. It was fire burning all around me. I saw that nothing was left of the interior compartment of the tail section. All that was left on my left side were pieces of burning metal that looked like struts of some sort. The seat next to mine, where my son Michael had been sitting was gone. Looking towards the front passenger compartment I saw nothing except flames. To get up I had to grab the burning metal in front of me and I pulled myself out of the plane."

These cases have illustrated the following:

- o There is no way to predict the occurrence of postcrash fires based on the type or severity of the crash.

- o The time available for occupants to escape is limited severely.

- o Improvements in airport crash/fire/rescue capabilities alone may not adequately reduce the loss of life and property in these crashes.

- o Postcrash fire occurs in survivable crashes -- where the forces are well within the human tolerance range, where the occupiable area is not crushed, and where the seats and restraint systems have not failed.

The statistics and case histories presented thus far have illustrated the extent of the problem of postcrash fires in general aviation accidents, with the main emphasis on fatal accidents. However, even the less serious burn injuries, unlike most impact injuries, are permanently disfiguring and leave many psychological as well as physical scars.

HISTORY OF AIRCRAFT FIRE PREVENTION METHODS

After World War I, the aviation industry in the U.S. and abroad directed its efforts toward industry expansion and improvement of aircraft. One of the main areas of concern was fire -- in flight, on the ground, and after crashes.

Studies were performed and papers were written on the hazards of fire, its causes, and preventive measures to be taken. These early efforts attempted to identify ignition sources and other contributors to fire and to propose design improvements and uses of materials to eliminate or minimize fire and its effects. Most of the data used were from accident and combat experience. The most prominent potential sources of fires identified were leaking fuels and oils which came into contact with hot engine parts or poorly insulated or short circuited electrical components. Friction sparks from structural breakup during a crash also provided ignition sources.

Suggestions for eliminating or minimizing the potential for fire and its effects included containing fuels and oils in self-sealing or energy absorbing tanks and using shielded, flexible fuel lines. The use of fuel drop tanks or dumping chutes was also suggested. Other ideas included cooling hot engine parts with a nonflammable liquid and insulating electrical components and locating them above and as far away from fuels as possible. The installation of manual or automatic switches was suggested to allow the electrical system to be deenergized.

The years after World War II saw renewed efforts to identify causes and eliminate postcrash fires. A new generation of research expanded on the work already done and incorporated the knowledge gained during the war.

One landmark study in the post-World War II era was performed at the NACA's Lewis Flight Propulsion Laboratory. 2/ The 1953 study sought to answer two questions: (1) how and when ignition sources appear in the crash sequence, and (2) how fuel comes into contact with those sources. In full-scale crash tests of various aircraft types, the possible sources of ignition were studied separately from, then concurrently with, fuel spillage. The ignition sources identified were placed into seven categories: (1) hot surfaces, (2) friction and chemical sparks from abraded airplane metals, (3) engine-exhaust flames, (4) engine induction system flames, (5) electric arcs and electrically heated wiring and lamp filaments, (6) flames from chemical agents, and (7) electrostatic sparks.

The tests revealed that, in a crash, fuel was released in three forms: liquid, mist, and premixed fuel vapor and air from the engine induction system. The latter, however, was found less frequently.

As the study progressed, the characteristics of the movement of the fuel were recorded and mapped. The study revealed that many variables influenced the spread of fire, including wind direction and velocity, type of terrain, and moisture. In addition, in many cases, there was little difference in fire safety between low volatility fuels and gasoline.

To assure that no ignition sources were being overlooked, the known sources were inerted and new crash tests were carried out. The experimental inerting was extremely successful, and no fires occurred in further tests. However, when the method of crashing the airplane was changed, even though the inerting system worked properly, a previously unidentified ignition source was uncovered: electrostatic discharge, in this case from a wheel-strut assembly which had broken off of the test airplane.

The report of the study suggested new methods of designing aircraft to minimize the possibility of a postcrash fire. The results of the study were more useable than previous studies because of improved testing capabilities and techniques. Some of the design changes suggested by the study were:

- Use drip fences on the wings to keep fuel from running toward the engine compartment.
- Use some method, such as a series of small interconnected fuel cells, to impede the escape of fuel when the tanks are breached.

2/ Pinkel, I.I., Preston, G. Merritt, Pesman, Gerard J., Mechanism of Start and Development of Aircraft Crash Fires, Report 1133, NACA Lewis Flight Propulsion Laboratory, Cleveland, Ohio, 1953.

- o Locate the fuel as far as possible spanwise, aft, and down, from the engines.
- o Use nonsparking materials for hardware and aircraft parts most likely to contact the ground during a crash, and use special paint to reduce electrostatic sparks.
- o Arrange nacelle fluid lines so they can accommodate crash distortions without separating.

By the early 1960's, the use of rotorcraft and light fixed-wing aircraft by the U.S. Army had increased. The U.S. Army Board for Aviation Accident Research (USABAAR) 3/ reviewed accidents involving these aircraft and found that postcrash fire was important to occupant survival.

Its report on helicopter accidents for the years 1957 through 1960 showed that 42, or 7 percent, of the total 579 accidents involved postcrash fires. However, these 42 fire accidents accounted for 63 percent of the fatalities. The review further revealed that in more than 78 percent of the accidents where postcrash fire occurred, the fire was caused by fuel released from ruptured fuel cells or lines.

In early 1960, the Army awarded a series of contracts to Aviation Safety Engineering and Research (AvSER) to study the crash fire problem and other survival aspects of aircraft crashes. Its reports on this work, together with information and data from other agencies, were consolidated into the Aircraft Crash Survival Design Guide. 4/ This resulting guide represented the state-of-the-art in design in five areas: (1) crashworthiness of aircraft structure, (2) tie-down chain strength, (3) occupant acceleration environment, (4) occupant environment hazards, and (5) postcrash hazard.

Since its release by the Army in 1967, the design guide has been periodically revised to reflect changing technology in crash survivability. The most recent revision, completed in the fall of 1979, has expanded the single volume into five separate volumes: (1) Design Criteria and Checklists, (2) Aircraft Crash Environment and Human Tolerance, (3) Aircraft Structural Crashworthiness, (4) Aircraft Seats, Restraints, and Litters, and (5) Aircraft Postcrash Survival.

FIRE PREVENTION METHODS

Volume V, Aircraft Postcrash Survival, of the U.S. Army's design guide proposes methods to reduce the postcrash fire problem through fuel modification, ignition source control, and fuel containment. The Safety Board has reviewed these postcrash fire prevention methods for their potential application to general aviation aircraft.

3/ Army Helicopter Accidents Involving Fire, Report No. HF 2-60, United States Army, Board for Aviation Accident Research, Fort Rucker, Alabama.
4/ Aircraft Crash Survival Design Guide, USARTL-TR-79-22, Applied Technology Laboratory, U.S. Army, Research and Technology Laboratories, Fort Eustis, Virginia.

Fuel Modification

Fuel is modified to decrease the atomization and vaporization of spilled fuel during a crash. This, in turn, inhibits the start and propagation of postcrash fires. Most of the work on fuel modification has been done with kerosene-type fuels used in turbine engines. Great progress has been made with an antimisting additive, FM-9, developed in the United Kingdom, and now being tested in the U.S. Unfortunately, this additive loses effectiveness when used in the highly volatile, wide cut fuels such as JP-4 and gasoline. At best, the availability and use of antimisting kerosene are some years away and ultimately would affect only that small part of the general aviation fleet powered by turbine engines. The Safety Board has not been able to uncover any work, either current or anticipated, on the modification of gasoline.

Ignition Source Control

Although it is impossible to eliminate all possible ignition sources, ignition source control can serve to reduce the probability of fire. The potential for postcrash fire is reduced because as many ignition sources as possible are eliminated before and during the crash. Through design of electrical systems and components to separate them from flammable fluids, or through deenergization of the electrical system and its components, many ignition sources can be eliminated. By using devices such as baffles, drip fences, or flexible paneling, flammable fluids can be kept away from the ignition sources.

Ignition from engine flames and hot metal surfaces can be controlled to some extent by the use of fuel cutoff devices, shields, and inerting. Inerting systems can be used in the engine induction system or to surround hot surfaces with an atmosphere incapable of supporting combustion. They can also be used to spray the hot surfaces with a cooling liquid. Inerting systems which provide limited control of ignition sources are being used in some military aircraft. However, the size, weight, and complexity of inerting systems preclude their practical use in most general aviation aircraft.

Friction sparks can be controlled through the use of certain materials. In 1957, NACA 5/ reported on friction sparking characteristics of the most common aircraft metals. Metals, such as aluminum, that give off low thermal energy sparks under high-speed and high-pressure should be used on areas of the aircraft likely to come into contact with the ground in a crash.

Fuel Containment

As early as 1965, AvSER, working with Goodyear Tire and Rubber Company, had developed a fuel system capable of containing fuel in a crash in which the forces were beyond the limits of human survivability. 6/ The design requirements

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5/ Campbell, John A., Appraisal of the Hazards of Friction-Spark Ignition of Aircraft Crash Fires, RME57B26a, NACA Lewis Flight Propulsion Laboratory, Cleveland, Ohio.

6/ Robertson, S.H., and Turnbow, James W., Aircraft Fuel Tank Design Criteria, Technical Report AvSER 65-17, Aviation Safety Engineering and Research, Phoenix, Arizona.

for this system, called a crash-resistant fuel system, are described in the design guide and in military specification MIL-T-27422B. 7/

The basic component of this crash-resistant fuel system is a crash-resistant tank made from materials that are highly resistant to cuts and tears and that possess some ability to absorb energy by stretching and deforming without allowing fuel to escape. The shape of the tank also is important. Smooth, regular shapes (cylindrical or rectangular) with corners of large radii are recommended because they are less likely to become entangled and torn when surrounding structure is displaced. Also, they are less susceptible to failure when subjected to high internal fluid pressures.

The tank should be located as far as possible from occupants and as far as possible from at least the primary ignition sources, such as the engine and battery. Since the crash forces on the tank must be minimized, it must be placed away from those areas of the structure most likely to be subjected to impact forces. Placement of the tank should also take advantage of surrounding structure to protect it from direct impacts. Placement of the tank must also provide for some space for the tank to shift or deform when the surrounding structure is crushed.

The fuel lines are the other major component of the fuel system. The design guide for the crash-resistant fuel system recommends that flexible hoses, armoured with braided steel, be used. The lines should be routed near larger structural members which are less likely to deform in a crash. Extra length lines should be used to allow shifting and displacement and, like the fuel tank, the fuel lines should have expansion space in which to deform.

Some lines and fittings will inevitably fail in a crash. However, allowances can be made for these failures by designing controlled failures into the system, by anticipating areas of complete separation and by using frangible, self-sealing valves at those areas. These valves should also be used for fuel tank fittings and at bulkheads.

Although the tanks, lines, and valves comprise the major portion of the fuel system, there are other details which must be incorporated in the design of a crash-resistant system, such as high-strength fittings for the tank and methods of attaching the tank and lines to the structure. The design guide explains these concepts in detail.

In summary, the basic idea of the crash resistant fuel system is to have an energy absorbing system that incorporates controlled failures to ensure that the escape of flammable fluid in a crash is minimized or eliminated. Once this is accomplished, the aircraft occupants will have sufficient time to escape or be rescued without the threat of fire.

Unlike the concepts of ignition-source control and fuel modification, the concept of fuel containment is both feasible and achievable now. In fact, the crash-resistant fuel system has been in use in Army helicopters since 1970, and

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7/ Military Specification Tank, Fuel, Crash-Resistant, Aircraft, MIL-T-27422B, 24 February 1970.

it has been extremely successful. The findings from a study of Army accidents between April 1970 and July 30, 1973, 8/ showed that 80, or 8.94 percent, of the 895 helicopter accidents that occurred without crash-resistant fuel systems resulted in postcrash fires. However, of the 702 accidents with the crash-resistant fuel system, only 14, or 1.99 percent, resulted in fire. Without the crash-resistant system, postcrash fire occurred more than four times as often. (See Table 3.)

Table 3.--Postcrash Fire Accidents in Army Helicopters
April 1970 - July 30, 1973.

	Without Crash Resistant Fuel System	With Crash Resistant Fuel System
Total Accidents	895	702
Postcrash Fire Accidents	80	14
Percent Fire/Total	8.94	1.99

According to the study, those fires that did occur in aircraft with the crash-resistant fuel system were small and localized. Propagation was "delayed significantly to allow occupants to escape or be rescued."

By far the most impressive finding of the study was that there were 52 fatalities and 31 injuries caused by fire in the accidents without crash-resistant fuel systems. However, in the accidents with the crash-resistant system, there were no injuries or fatalities caused by fire. (See Table 4.) These data provide dramatic evidence of the effectiveness of fuel containment in reducing fire related deaths and injuries in helicopter accidents.

Table 4.--Fire Fatalities and Injuries in U.S. Army Helicopters
April 1970 - July 30, 1973.

	Without Crash Resistant Fuel System	With Crash Resistant Fuel System
Thermal Fatalities	52	0
Thermal Injuries	31	0

Although the crash-resistant fuel system has been used almost exclusively in helicopters, it can be adapted to fixed-wing aircraft as well. In fact, the system can be adapted to different sizes and configurations of vehicles. For instance, since the 1974 racing season, the United States Automobile Club (USAC) has required that crash resistant fuel systems be used in all championship racing cars, the type driven in the Indianapolis 500. These systems have proven to be just as successful in the race cars as in the Army helicopters.

8/ Gabella, William F., and Young, Wade L., Summary of U.S. Army Crashworthy Fuel Systems Accident Experience, 1970-1973, System Safety Newsletter, Vol. 2, No. 3, 1973, U.S. Army Agency for Aviation Safety.

Even if crash-resistant fuel systems were only partially successful in general aviation aircraft, the savings in injuries, deaths, and property damage would be significant. Therefore, the Safety Board believes that the regulations should be amended to require the incorporation of crash-resistant fuel systems in general aviation aircraft.

THE IMPACT OF FEDERAL REGULATIONS ON FIRE PREVENTION

Many of the general aviation aircraft in use today were originally designed and certificated in the 1950's under Civil Air Regulations (CAR) Part 3. At that time, there were few regulations relating to fire safety, and these were directed mainly at making the cabin safer for smokers and at keeping the aircraft combustion heater from catching fire. Handheld fire extinguishers were not required in nontransport category airplanes.

Regulations for powerplant fire protection specified that lines and fittings in the engine compartment, except those that were an integral part of the engine, be fire resistant. Another early regulation called for a means by which flammable fluids could be kept from flowing into, within, or through the engine compartment. The regulation, however, only applied to multiengine aircraft with a stall speed (V_{so}) greater than 70 mph or with a maximum weight greater than 6,000 pounds.

Those regulations for fuel systems addressed only the ability of the systems to provide the engine(s) with fuel under normal, predictable operating conditions, and specified requirements for various components of fuel systems. Unfortunately, the most stringent structural loads that the fuel system components were required to withstand were those loads associated with flight operations.

Structural crashworthiness and occupant protection were also addressed in the early regulations. The provisions set forth were for "minor crash conditions," in which the occupants would be subjected to ultimate acceleration forces as follows:

	Normal (N) Utility (U) g's	Acrobatic (A) g's
Upward	3.0	4.5
Forward	9.0	9.0
Sideward	1.5	1.5

Further, the structure of aircraft with retractable gear had to afford protection to the occupants in a wheels-up landing. If "reasonably probable" that an aircraft might completely turn over, the fuselage structure also had to afford protection to the occupants. In both of these cases, an ultimate vertical (downward) acceleration of 3.0g was assumed. No provisions existed in the 1950's for regulating the integrity of the fuel system under even minor crash conditions.

Currently, almost 25 years later, fire safety regulations for general aviation aircraft have changed very little. Almost all newly certificated general aviation aircraft flown today are certificated under Title 14 CFR Part 23 - Airworthiness

Standards: Normal, Utility, and Acrobatic Category Airplanes (formerly CAR Part 3); Part 25 - Airworthiness Standards: Transport Category Airplanes; Part 27 - Airworthiness Standards: Normal Category Rotorcraft; or Part 29 - Airworthiness Standards: Transport Category Rotorcraft.

The regulations governing fuel systems and components still require that they operate reliably in all flight conditions likely to be encountered, and that the system components withstand all vibration, inertia, fluid, and structural loads encountered throughout the aircraft flight envelope, without leaking or failing.

Regulations for powerplant fire protection, which have been successful in preventing most serious in-flight fires, have been expanded. The expanded regulations deal more effectively with engine compartment fire safety. However, there are no provisions in the regulations for minimizing the engine compartment fire problem under crash conditions.

Under the general requirements section of Part 25, aircraft fuselage fuel tanks must be resistant to rupture and must retain their fuel in a minor crash landing. (See Table 5.) Under Part 29 there is a similar general requirement for all fuel tanks. More specifically, each tank in these transport category rotorcraft that is close to the personnel compartment, engines, or combustion heaters must be designed or protected and installed so that it contains fuel under the minor crash landing conditions. Part 23 fuel tanks for nontransport category aircraft also must retain their fuel under the minor crash landing conditions of that part. There is no comparable regulation regarding fuel tank construction or installation for Part 27 rotorcraft.

Table 5.--Comparison of Occupant G Forces Allowed in Minor Crash Landings for Aircraft Certificated Under Each Part of FAR's.

Direction	CAR Part 3, and Part 23 23.561 N, U	CAR Part 3, and Part 23 23.561 A	Part 27 27.561	Part 25 25.561	Part 29 29.561
Up	3.0	4.5	1.5	2.0	1.5
Forward	9.0	9.0	4.0	9.0	4.0
Sideward	1.5	1.5	2.0	1.5	2.0
Down	3.0	3.0	4.0	4.5	4.0

The only other crashworthiness requirements for the fuel system components are that they must be protected from damage which could cause fuel to be released as the result of a wheels-up landing, statistically one of the least serious accident types. The requirement, however, applies only to Part 23 and Part 25 aircraft. Aircraft certificated under all four parts must have fuel system drain valves located in such a way or protected in such a way as to prevent fuel spillage in a wheels-up landing.

A close examination of the development of the fuel containment provisions in Part 23 illustrated the time lag between state-of-the-art and promulgation of new regulations. Section 23.994, the provision for the prevention of fuel release in a wheels-up landing, was not promulgated until 1967 and did not become effective until 1969. The requirement that fuel tanks be designed to contain fuel in a minor crash landing (23.967(e)) was not promulgated until 1971 and did not become effective until 1973. Therefore, all small, fixed-wing aircraft designed and certificated before these dates were not required to meet the more stringent requirements for fuel containment and can be manufactured today without complying with these rules.

SUMMARY AND CONCLUSIONS

Summary

Safety Board data show that postcrash fires are causing fatalities in accidents where the occupants would otherwise have survived. This fact and the fact that advances in light aircraft design technology over the last 10 years have not been incorporated into regulations on crash/fire survivability indicate that the promulgation of adequate regulations is overdue.

Equally important, as the Safety Board noted recently in a special investigation report, 9/ the "grandfather clause" aspect of the regulations is of major concern. A considerable number of aircraft being manufactured currently do not have to meet the current Part 23 regulations. The case histories illustrate the inability of current and past regulations to provide for fire protection in survivable accidents. The Safety Board believes that as the state-of-the-art progresses, regulations for newly type-certificated aircraft should be updated periodically. The Safety Board also believes that aircraft type certificates should be reissued periodically to ensure that they reflect significant regulatory improvements. We have noted with interest the Administrator's stated intent 10/ to issue a Notice of Proposed Rulemaking which would allow the Federal Aviation Administration (FAA) to review the type certification basis of aircraft in service and to require necessary changes. The Board will strongly support such rulemaking.

The general aviation aircraft manufacturers have initiated some safety design changes voluntarily. However, this is an extremely competitive industry, and because of the penalties of additional cost and weight there is a reluctance to design aircraft to other than the minimum standards prescribed by the FAR's. To date, only one manufacturer offers a crash resistant fuel system in some production models. It also offers kits to improve the crashworthiness of existing fuel systems in an earlier model.

For many years, the FAA has been involved in fire safety research and development. Most recently, the FAA has been working with industry on the Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee. Membership of the SAFER Committee included experts from government and the aviation community, and representatives from other segments of the aviation community affected by the committee's work. The objective of this committee was "to examine the factors affecting the ability of the aircraft cabin

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9/ Special Investigation--Design-Induced Landing Gear Retraction Accidents in Beechcraft Baron, Bonanza, and Other Light Aircraft, Special Investigation Report Number NTSB-SR-80-1, National Transportation Safety Board, Washington, D.C., 1980.

10/ Statement of Mr. Bond before Senate Committee on Commerce, Science, and Transportation, Subcommittee on Aviation, August 25, 1980.

occupant to survive in the post-crash environment and the range of solutions available." Unfortunately, this research addresses only aircraft certificated under Part 25, Transport Category Aircraft. Although the results of this committee's efforts may be applicable to general aviation aircraft, especially in the area of cabin interior materials, little or no emphasis is being placed on this application. The Safety Board believes that any pertinent information from the SAFER committee, as well as from other formal advisory committees, should be applied to all aircraft.

The FAA's research into fuel containment for Part 23 aircraft has shown that ". . . crash-resistant fuel cells used with self-sealing frangible fuel-line couplings can effectively reduce postcrash fuel fires in general aviation aircraft. . . ."11/ Furthermore, the research has shown that the safety advantages of crash-resistant fuel systems outweigh the penalties of weight and volume. 12/ Finally, the research has shown that impact resistant tanks "could provide useful benefits at moderate costs." 13/

Crash resistant fuel system technology has been demonstrated with great success by the U.S. Army, and some this technology has voluntarily been incorporated in civilian aircraft as well. The Board believes that the rationale against incorporating crash-resistant fuel system designs in general aviation aircraft—weight, cost, and state-of-the-art — are no longer valid. For example, a crashworthy fuel system could be incorporated in the civilian version of one particular aircraft for an estimated weight increase of only 25 pounds; this system will far exceed the requirements currently under consideration for general aviation aircraft. Thus, the Board believes that the regulations should be amended to provide for crash-resistant fuel systems in general aviation aircraft.

Conclusions

1. Postcrash fire is a serious problem in general aviation accidents, and escape time from small aircraft is extremely limited.

2. Control of ignition sources and fuel modification techniques would enhance the fire safety of the aircraft, but they will not eliminate the potential for fire and are not feasible for use in general aviation aircraft based on the current state-of-the-art.

3. Research into the postcrash fire problem has illustrated that containment of fuel is the most promising avenue for prevention of fires and is both feasible and achievable now.

11/ Perella, William M., Jr., Tests of Crash-Resistant Fuel System for General Aviation Aircraft, FAA-RD-78-28, Federal Aviation Administration, Washington, D.C., 1978.

12/ Scheuerman, Hugo P., Crash Resistant Fuel Systems Demonstrations and Evaluation, FAA-RD-71-27, Federal Aviation Administration, Washington, D.C., 1971.

13/ Bergey, Karl H., Assessment of New Technologies for General Aviation Aircraft, FAA-RD-78-132, Federal Aviation Administration, Washington, D.C., 1978.

4. The regulations under which many aircraft were designed and certificated, and are still being manufactured, do not address fuel containment in crash conditions.

5. Existing regulations are not adequate to provide the minimum standards necessary to improve crash/fire survivability of newly certificated aircraft.

6. Previously expressed reasons against using crash-resistant fuel systems--cost, weight, and state-of-the-art -- are no longer valid.

RECOMMENDATIONS

As a result of its special study, the National Transportation Safety Board has recommended that the Federal Aviation Administration:

> "Amend the airworthiness regulations to incorporate the latest technology for flexible, crash-resistant fuel lines, and self-sealing frangible fuel line couplings at least equivalent in performance to those used in recent FAA tests and described in Report No. FAA-RD-78-28 for all newly certificated general aviation aircraft. (Class II, Priority Action) (A-80-90)

> "Amend the airworthiness regulations to incorporate the latest technology for light weight, flexible crash-resistant fuel cells at least equivalent in performance to those used in recent FAA tests and described in Report No. FAA-RD-78-28 for newly certificated general aviation aircraft having nonintegral fuel tank designs. (Class II, Priority Action) (A-80-91)

> "Require after a specified date that all newly manufactured general aviation aircraft comply with the amended airworthiness regulations regarding fuel system crashworthiness. (Class II, Priority Action) (A-80-92)

> "Fund research and development to develop the technology and promulgate standards for crash-resistant fuel systems for aircraft having integral fuel tank designs equivalent to the standards for those aircraft having nonintegral fuel tank designs. (Class II, Priority Action) (A-80-93)

> "Assess the feasibility of requiring the installation of selected crash resistant fuel system components, made available in kit form from manufacturers, in existing aircraft on a retrofit basis and promulgate appropriate regulations. (Class II, Priority Action) (A-80-94)

"Continue to fund research and development to advance the state-of-the-art with the view toward developing other means to reduce the incidence of postcrash fire in general aviation aircraft. (Class II, Priority Action) (A-80-95)"

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JAMES B. KING
Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ PATRICIA A. GOLDMAN
Member

/s/ G. H. PATRICK BURSLEY
Member

ELWOOD T. DRIVER, Vice Chairman, did not participate.

August 28, 1980