Talk on

AIRPLANE CRASH-FIRE RESEARCH

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As part of a continuing program on aviation safety, the Lewis Flight Propulsion Laboratory of the NACA has been engaged in a study of the start of fires that sometimes accompany airplane crash. The purpose of this work is to provide a better understanding of the important factors involved in the setting of crash fires as a necessary first step leading to a reduction in the crash-fire hazard. This work was concerned primarily with the answer to two principle questions -- when and where do ignition sources appear in a crash; and how does the fuel move from the spillage point to the ignition sources to start the fire. A review of civil and military crash accident records failed to provide well-defined answers to these questions, and so it was necessary to crash full-scale aircraft to obtain the necessary information.

The aircraft that were employed in this study were twin-engine cargo planes of the type shown here. It is important to appreciate that the airplanes used in these studies were service-weary airplanes that were marked for decommission by the Air Force. Each of these airplanes were carefully instrumented to record the presence of combustible atmospheres or fire within the nacelles, wings, and fuselage, the time and location of fuel line ruptures, the time and location of electrical short circuits, the temperature histories of the various components of the airplane in the event fire should occur, and the decelerations experienced by component parts of the airplane in the crash.

A landing or take-off accident was chosen for study because this type of accident occurs at reduced airplane speed when the chance of human survival of the impact is high. The next movie will show how the crash operation was conducted. In these pictures, and all pictures shown during this discussion, the action is slowed to somewhere between 1/3 and 1/12 the normal speed; in other words, all action is in slow motion. Now the first motion pictures. The unmanned, instrumented airplane accelerates from rest under full engine power and is guided by this rail into a crash barrier. This barrier has a pair of abutments that strip the landing gear from the airplane. Here are the abutments that wipe out the landing gear. The propellers strike the same abutments at full engine power and disrupt the nacelle. A pair of poles slice into the wing fuel tanks to produce fuel spillage. The fuel has been dyed red for photographic purposes. Each of these airplanes carried 1,000 gallons of fuel in the wing tanks. The airplane attains a speed of about 95 miles per hour upon reaching the crash barrier. After the airplane passes through the crash barrier, it slides to rest along the ground.

Many of the ignition sources that were observed in this crash study setting fire to the airplane are found during normal airplane operation.

Next slide. For example, flames appear at the engine inlet in the familiar backfire, and flames appear at the exhaust tail pipe. Following engine operation at full powers the metal of the exhaust-disposal system becomes red hot. The electrical system represents the most extensive ignition source, ranging from the nacelles where the power is generated, into the wings, to power fuel pumps and lights, and into the fuselage for lights, navigational instruments, and airplane controls. While many of the ignition sources that appear in a crash are carried on the airplane, several are generated in the crash area. During this discussion some of the ignition sources that were observed in this study will be shown as the subject of fuel spillage and propagation in a crash is discussed.

Distinct from fires in flight, crash fire threatens human survival only when the fuel becomes involved in the fire because the other combustibles, such as the lubricating oil, hydraulic fluid, and alcohol, are present in such limited quantities. However, these lesser combustibles may be the first to ignite and, in turn, set fire to the fuel.

Consider now the subject of fuel spillage in a crash. When the fuel spills to the open air while the crashed airplane is in motion, the air streaming by the airplane atomizes this fuel to a mist. A part of the mist remains suspended in the air around the airplane. Next slide. This is a picture of the fuel mist as it appears in a crash. The airplane shown has already crashed through the barrier and is sliding along the ground. The fuel, which is dyed red, is pouring from a breach in the tank imposed by the poles of the barrier. This fuel develops into a dense mist. While some of the mist falls directly to the ground, a considerable portion streams into the wake of the airplane. See how the fuel mist rises above the airplane. Some of the fuel mist developing on the other side of the airplane appears above the airplane.

When the airplane decelerates rapidly in the crash and is moving at reduced speed, the fuel mist can propagate forward and spread spanwise. The fuel mist can spread to the nacelles where the ignition sources are located. The next motion-pictures sequence will show the development of this fuel mist forward and spanwise in a rather severe crash. Notice first that the fuel, which is dyed red, streams directly rearward from the breach in the tank while the aircraft moves through the crash barrier at high speed. When the fuselage strikes the ground, and the airplane slows, the fuel mist moves forward and spreads spanwise. Motion pictures. The first appearance of fuel spillage will be at this location under the wing. Notice how it streams directly rearward. When the airplane strikes the ground with high deceleration, the fuel spreads forward and spanwise to wet the wings from the fuselage almost to the tips. Even in a less severe crash, the forward and spanwise development of the fuel mist will occur as the airplane slows down. The next crash-fire sequence will show how the fuel that spills at this point on the wing, propagates as mist to the engine tail pipe where the flame from the engine tail pipe ignites the mist. Motion pictures. Here is an instance where the action is slowed to 1/5 normal speed. As the airplane passes through the crash barrier, notice a continuing series of flames at the tail pipe of the engine. Although fuel is spilling from the tanks, there is no contact between the fuel and the flame while the airplane moves at high speed, but as the airplane slows watch the forward development of fuel mist and its spread to the tail pipe where it is ignited by the flame. Another fuel-mist fire occurred on the other side of the airplane. Motion picture. Here is the same airplane. Notice how the nacelle breaks down when the propellers strike the barrier. The fuel mist propagates to the exposed exhaust-collector ring and fire starts at the top of the collector ring. In the three-second interval between impact with the barrier and ignition, the wings accumulated a combustible mixture of fuel and air which upon ignition gave this explosive distribution of flaming fuel.

Fuels of low volatility, sometimes called "safety fuels", have been proposed as means of reducing the likelihood of fire upon crash. Some of this fuel is contained in this beaker. A wick saturated with the fuel can be ignited by the steady application of the flame. The flame can be held over the liquid surface of the fuel without producing any ignition because the volatility of this fuel is so low that the concentration of combustible vapors in the air space over the fuel is too low for ignition; in fact, the fire can be put out by dipping it into the fuel. However, when this fuel is atomized to mist, as seen in these crash films, it burns readily. Even if a so-called "safety fuel" is carried into a crash and a large mist development which extends to an ignition source, fire is apt to occur. The next motion picture will show this in an actual crash. Motion pictures. This airplane carries 1,000 gallons of low-volatility fuel in the wing tanks and the same fuel powers the engines. Watch how the fuel mist moves toward the tail pipe of the engine as the airplane slows. A plume of flame out of the tail pipe ignites the fuel mist. Here is the ignition. Fire propagates through the low-volatility fuel mist about as fast as it does through mists of gasoline. This aerial view of the same crash shows the development of the fuel mist and then its ignition. The rapidity with which the flame passes through the low-volatility fuel mist is apparent. It is desirable to point out, though, that fuels of low volatility do provide a real safety advantage in those crashes where large volumes of fuel mist are not generated and the fuel spills as liquid. If a separation exists between the ignition source and the liquid fuel no ignition will occur, as was shown in the preceding demonstration.

With regard to fuel mists in general, it is desirable toappreciate that these fuel mists seldom persist around a crashed airplane for more than 15 seconds. The larger droplets of the mist rain to the ground and the smaller droplets, which are airborne, are swept from the area by the wind. Even after the fuel mist is dispersed, there still remains the fuel which id deposited on the ground in liquid form in the slide path of the airplane. The vapors coming from gasoline spilled on the ground in the open air are so rapidly diluted by normal air movement in the open air that the combustible atmosphere of fuel vapor and air associated with that fuel spillage is not much larger than the area of liquid spillage on the ground.

Because the fuel vapors have a higher density than air, this combustible atmosphere lies close to the ground. Ignition sources that would contact such a low-lying combustible atmosphere would be droplets of burning oil and fuel falling from the nacelles, or bits of broken, hot metal from the exhaust-disposal system, or sparks generated by the abrasion of magnesium or steel airplane parts on stoney ground, or concrete paving. The fuel that spills as liquid within the airplane structures, within the wings, for example, where the vapors can accumulate, provides extensive atmospheres within the airplane structures that are easily ignited.

In one crash ignition of the fuel spilled within the airplane structure was produced according to the following circumstances. The poles at the barrier that are used to rip open the full fuel tanks were set to smash the landing lights which are on the leading edge of the wing and drive the landing lights into the wing where the exposed incandescent filament sets fire to the fuel. Motion pictures. The landing lights on this airplane are located on the leading edge and they are lit. The first pole at the barrier will strike the light, drive it into the wing to give this ignition. The fuel being spilled is atomized to mist. This suspension of mist in air approximates a carburetted mixture of fuel and air giving this rapid development of the fire. So much for the fuel that spills in liquid form.

Consider now the ignition of fuel that spills as pre-mixed fuel vapor and air. When the propeller or the nacelle strikes an obstacle in a crash, the distortion of the nacelle may rupture the engine induction system. The carburetted mixture of fuel and air contained under pressure in the supercharger is then released into the nacelle, where the exhaust-disposal system and electrical system of the airplane are located. Ignition of the fuel-air mixture is likely. However, the amount of fuel in the engine induction system at any one time is so small that the fire which results is not hazardous in itself; however, the fire provided by the engine induction system fuel can propagate out of the nacelle and pick up other fuel being spilled remote from the nacelle which might not have caught fire otherwise. This method of fire development is shown in the next crash. When the airplane passes into the crash barrier, one nacelle fractures along a line passing through the supercharger case and the released fuel-air mixture is ignited at once. Motion pictures. Watch how the nacelle snaps open and the ignition that appears almost at once. The fire streams out of the nacelle to reach and ignite fuel being spilled from the wing. The ignition takes place back of the wing and propagates to the wing to produce the major fire. The action here is shown at about 1/12 the normal speed.

After the same ignition sources were observed to function repeatedly in this study, the question was raised whether the early fires that would be provided by the known ignition sources were masking other ways in which fire could develop that would take a little longer time. And so an ignition source inerting system was devised to prevent the known ignition sources from functioning in a crash. This ignition source inerting system is an experimental device installed on the airplane and is so arranged that the components of the inerting system functions after the airplane crashes into the barrier. On the next slide is shown the components of the inerting system. Shown here is a schematic of a reciprocating engine nacelle. One component of the inerting system is a pair of fuel valves, one at the engine and one at the fire wall, to shut off the fuel flowing to the engine and stop the engine. To prevent the appearance of flames at the engine inlet and the exhaust tail pipe, a 2-pound charge of extinguishing agent is introduced into the engine inlet. The rotation of the engine draws this charge through the engine and inerts the interior of the engine. The electrical system is shut off at the battery and generator by an electric system switch. Finally, a water-spray system, indicated schematically by this distribution manifold, is used to spray water on all of the hot metal of the exhaust-disposal system. The water cools the hot metal of the exhaust-disposal system to temperatures below the ignition temperatures of the liquid combustibles carried on the airplane. In the time it takes the hot metal to cool, steam generated by the evaporation of the water on the same hot metal envelops the metal and the inert steam atmosphere prevents any ignition from occurring.

Motion pictures. In the next series of crashes the inerting system is carried on the airplane. This airplane carries the inerting system just described. The inerting system comes into operation when the airplane strikes the barrier. The only visible sign of the functioning of the inerting system is the appearance of steam, described earlier, evaporated from the hot metal of the exhaust. The results shown here are typical of the results obtained with five airplanes which did not burn when equipped with the inerting system. Notice the dust being raised by the fuselage. It plays an important part in fire-setting processes to be described shortly.

After five airplanes were crashed in this way and no fires occurred, the question was raised whether ignition sources can be created by the crumpling and tearing of airplane structures in a severe crash. Although this was not expected to be the case, in order to make a complete study of the crash-fire problem, one crash was arranged in which the fuselage was crushed in a severe impact. The nacelles on the airplane carried the inerting system just described. The entire area around the crushed fuselage was wetted with the fuel in mist form. Nofire occurred around the crushed airplane structure or around the inerted nacelles; but fire did break out in the fuel-wetted wake of the airplane. Motion pictures. Notice how the fuselage collapses upon ground impact, bringing the wings to ground level. No fire occurs around the forward portion of the airplane. Note this wheel strut tumbling in the airplane wake and see the ignition when the metal end approaches the ground. Still no fire up forward. This fire now propagates through the fuel in mist form in the wake of the airplane, reaches the airplane, and ignites the fuel in the tanks.

The ignition source in this case developed in the following way. When the wheel strut tumbled through the dust and fuel in the wake of the airplane it accumulated an electrostatic charge. This charge provided a spark discharged to ground when the metal end of the strut approached the ground to give the ignition. It is fortunate that the circumstances required for an ignition of this type are not likely to appear in a crash.

In one last crash in this series, the airplane was made to ground loop in order that the fuel distribution in such a crash could be studied. Motion pictures. This crash is shown from the rear. To make the plane ground loop, only one of the landing gears is wiped out by a single abutment. Notice how the airplane moves into its own fuel spillage. On post-crash examination, the fuselage, wings, and nacelles were found to be heavily wetted by the fuel. However, this airplane carried the inerting system described earlier, and since no new ignition sources appeared, there was no fire.

Briefly summarized, this work showed that airplane component arrangement that increases the forward and spanwise distance, and the elevation, of the nacelles with respect to the fuel storage decreases the likelihood of contact between the fuel in mist form with the many ignition sources at the nacelle. The storage of fuel in tip tanks or on pods suspended below the wings represents current design trends in this direction. Because these studies showed how readily any of the combustibles, carried in the airplane, are ignited when they spill into the nacelles, it is desirable that the components of the fuel, hydraulic, and lubricating systems be located high in the nacelle, where crash damage is less likely to occur. If the pilot expects a crash landing and has time to take safety measures, he should deenergize as much of the electrical system of the airplane not required for airplane operation. He should practice engine operation that provides the coolest exhaust-disposal system, consistent with other safety considerations, of course. Just before the airplane touches down he should shut off all the fuel to the engines to allow the engines to be purged with clean air.

In view of the effectiveness of the ignition source inerting system in preventing crash fires experienced in this investigation, further study and development of this system with respect to special airplane application is indicated.

The work described here is covered in more detail in a sound film which is available upon request from our Headquarters Office.

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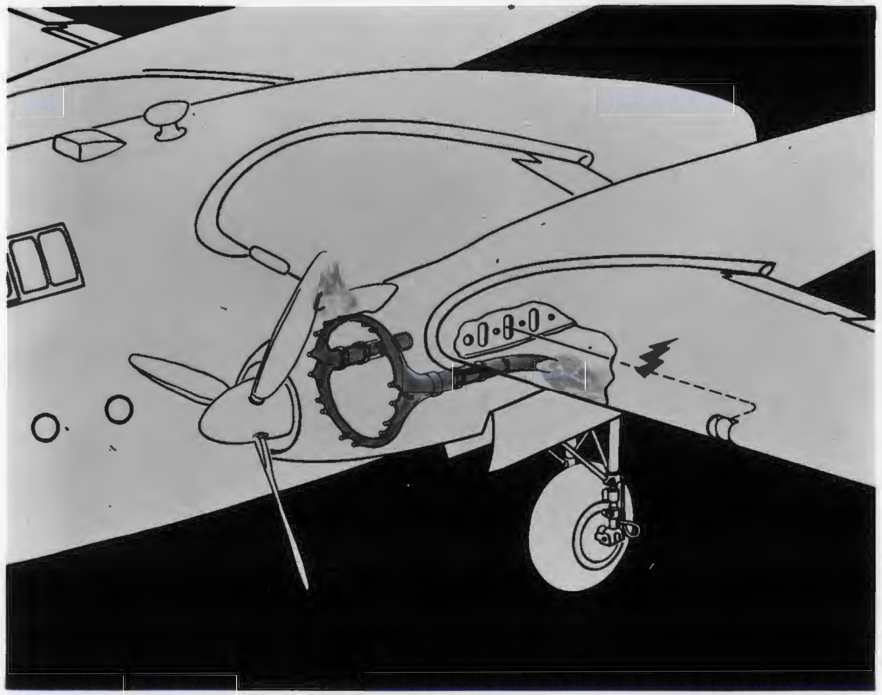


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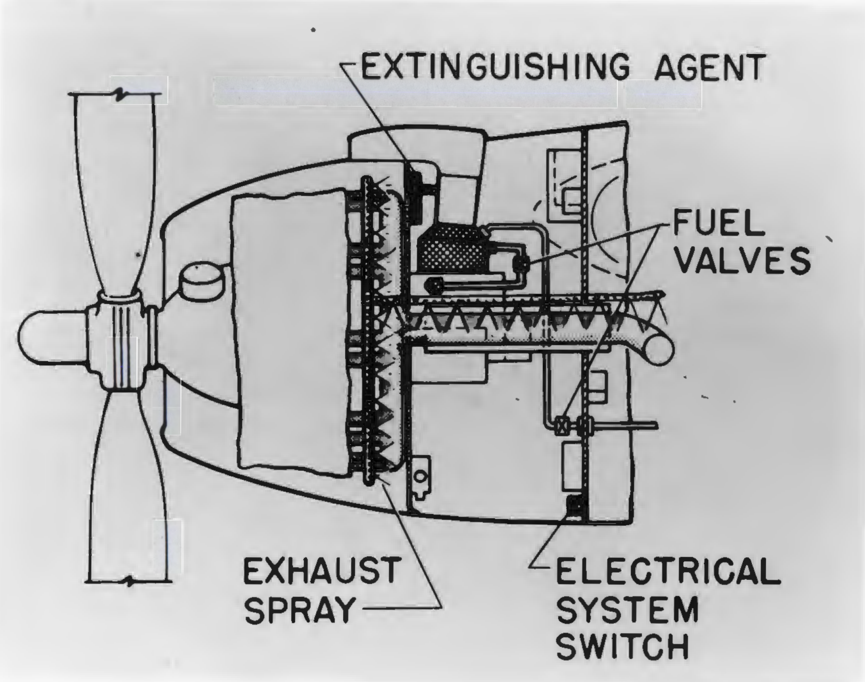
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