AIRCRAFT OPERATING PROBLEMS RESEARCH

Part I - Jet Aircraft Crash Fire Research

by I. Irving Pinkel and Solomon Weiss

During the last NACA inspection at Langley, the Lewis Laboratory described its full-scale research on the origin and development of crash fires conducted with aircraft powered by reciprocating engines. Today we shall describe an extension of this work to turbojet aircraft.

In the full-scale phase of this work, a fully instrumented airplane is accelerated from rest under its own power and guided into a crash barrier where damage is imposed typical of a landing or take-off accident. This kind of accident is studied because it occurs at low airplane speed and the chance for human survival of the crash impact is high. The crash, in slow motion, is shown on the first moving-picture sequence. (Show first movie sequence as in Langley inspection.)

The work with the reciprocating engine aircraft showed us how the airplane combustibles, oil, fuel, and hydraulic fluid, spill in a crash, the movement of the spilled combustibles to the ignition sources, and when and where these ignition sources are likely to appear. Much of what was learned applies to turbojet aircraft with some additional considerations. Because the turbojet has no propeller to strike the ground and bring the engine to rest, it continues to run after crash and draw large volumes of air into the engine inlet. Crash-spilled combustibles can be sucked into the engine inlet with the air and be ignited explosively within the engine.

This explosive ignition was studied in detail with a turbojet engine on the test stand. In the next motion pictures you will see the flames that issue from the engine following ignition of fuel sucked into the engine inlet. (Motion pictures of the pit, showing engine inlet.) This is the inlet of the operating test stand engine. Fuel is being sprayed into the air entering the engine. Here is the explosive ignition. Scraping of the compressor blades on the compressor case provides these flakes of magnesium burning in the flaming fuel. The flames that also appear at the engine tail pipe are shown in the next motion-picture sequence. Here are the flames accompanying the explosive ignition. The flames issuing from the engine inlet and tail pipe can reach fuel spilled around the crashed airplane and set the airplane on fire.

The test stand studies showed that the combustibles sucked into the engine can be ignited by the continuous flame in the engine combustors or by the hot metal of the engine interior for a short time after the combustor flame is extinguished.

To check these results in an actual crash, turbojet engines were pylon-mounted to the wings of a cargo airplane to simulate one type of jet bomber. The reciprocating engines were removed. The operating jet engine powered the airplane into the crash barrier and the airplane damage and fuel spillage was produced shown in the next motion-picture sequence. Arrangements were made to stop the fuel flow to the engines at the moment of crash impact. The flame in the engine combustor is thus extinguished, leaving only the hot metal of the engine as the ignition source. (Moving pictures of crash T-1.) The action here is 1/5 normal speed. The engines are mounted under the wings at these locations. When impact occurs, the fuel flow to the engines is stopped. The spilling fuel is dyed red; there is no fire yet. See the fuel enter the engine; then the flame at the tail pipe, and now the fire at the engine inlet. These results duplicate those obtained with the test-stand engine. Flames at the engine inlet and tail pipe ignite the fuel spilling from the wing to give this major fire.

Test-stand studies showed that ignition of spilled combustibles by the hot metal of the engine interior occurs only at those hot surfaces where the local velocity is low. Elsewhere, where the air velocity is high, the contact time between the hot surfaces and the combustibles sucked into the engine is too short to produce ignition. Since these ignition zones are small, it proved feasible to cool them by water streams applied directly to the surfaces. The steam generated by the water evaporating from the wetted hot surfaces protects against ignition while these surfaces are cooled to safe temperatures. Because the external surface of the tail pipe can ignite combustibles, water is sprayed on this surface. A stainless steel screen wrapped around the tail pipe maintains the water in contact with the tail pipe and promotes cooling.

In crash study of this use of water for preventing ignition by the engine, the water was carried under gas pressure and discharged upon crash impact. The water system employed is illustrated here in full scale. (Point to engine cutaway at right of stage.) This engine carries a complete water system fully charged. A separate charged water container is set on the hangar floor to provide a clear view of the water spray. When this airplane strikes the target, simulating crash impact, a crash-sensitive switch discharges both systems. (Release swinging airplane model into target at right center to set off crash switch.)

In four crashes of the type shown previously with the engines carrying this water system, no fires were obtained. Two of these crashes will be shown now. In the first of these the airplane ground-looped and was heavily damaged. In the second, one engine was pulled off the wing by arrangement and caused to tumble in the fuel spray suspended behind the crashed airplane. (Show crash T-2 and T-5 without interruption between them. Point out interesting features of the action.)

Further study of the crash-fire ignition hazard provided by a variety of aircraft gas turbine engines, including those of high compression ratio, is part of the future program. The mechanical condition and cleanliness of the engine will be among the factors covered.

And now let us consider the companion problem of safely absorbing loads imposed on personnel involved in a crash. This subject will be discussed by Mr. Pesman.

Part II - Absorption of Crash Impact Loads

by Gerard J. Pesman and Dugald O. Black

Experience shows that passengers who break away from their seats and are thrown about while an airplane is crashing generally are more severely injured than those remaining in their seats. The question then arises: How can a passenger be held in his seat during a crash and safely absorb the forces transmitted to him through the airplane structure?

During crash-fire research the cargo airplanes used were instrumented to give a continuous record of the crash forces. This record provides a partial answer to the question concerning loads transmitted to passenger compartments. Of particular interest are the data obtained in a crash in which the fore-structure of the fuselage collapsed completely, leaving living space in the rear of the fuselage only. This crash is shown in slow motion in the following motion-picture sequence.

(Movie, crash Y-7, station 13. Make appropriate descriptive remarks.)

The impact speed is about 100 miles per hour
Accelerometers for measuring crash forces are located on the rear floor
The angle between the airplane's path and the ground is 15°

Now, let us assume that a 200-pound passenger was securely fastened to a seat in the rear of the fuselage during this crash. The following slide (CS-8891) shows a time history of the forces the passenger would have imposed on his safety belt and the seat structure. Here we have plotted the imposed seat force versus time. Notice that the passenger and his seat would have been subjected to a succession of jolts as the airplane hit various obstacles. This action is similar to that resulting when an automobile hits various obstacles in a highway accident. The force of several of these jolts is over 1600 pounds. Such loads may break a passenger away from his seat by breaking the safety belt. If the safety belt holds, then the seat may break away from the floor. The forces below 1000 pounds are within the ultimate strength of most seats. It is recognized that the modern pressurized transport airplane is stronger than the unpressurized cargo airplane upon which these data were obtained. The transport may, therefore, transmit larger loads to the passenger. However, these data serve to establish an approximate order of magnitude for the loads in a severe transport crash.

A passenger may also be injured by striking adjacent seats, passengers, and airplane structure, as he flexes over the safety felt. It was desirable, therefore, to obtain slow-motion pictures of this passenger movement. This was done with dummies seated in light airplanes.

Here is an airplane with the dummies in place as it approaches the crash barrier (C-35937). Accelerometers for measuring the forces imposed on the dummy are carried in its head and chest. Forces were also measured at the seat pan and the floor. (Point to seat pan and floor.)

The following slow-motion picture will show a crash with only the rear dummy in place. The dummy is held by a safety belt alone. Notice how the dummy's body will swing forward as it flexes over the belt. (Movie, L-3 Fastax sequence.) The dummy's action shows that a passenger can swing forward and strike the seat ahead of him during a severe accident. Seats must then permit body blows without inflicting severe injury.

The crash loads measured in these studies and those shown previously from the cargo airplane are within the tolerable human limits established by aeromedical research. As previously stated, however, pressurized transport airplanes may transmit larger crash loads to the passengers than the cargo airplanes studied. Also, because of increased landing and take-off speeds, accidents may become more severe. Future seats must, therefore, be designed to safely absorb these larger crash loads. On the basis of the data obtained, the following seat design requirements are apparent:

1. Seat and passenger attachments should be strong enough to hold the passenger in place.

2. The seat should be capable of considerable elastic deformation in order to absorb the shock of peak loads. On this schematic model of a seat these rubber bands provide the elasticity (center, front of stage).

3. In order to keep the elastically deformed seat from rebounding and subjecting the passenger to an additional blow after the crash loads subside, considerable mechanical damping is required. (Illustrate with seat model.) On this model the friction surface, between these two sliding surfaces, provides the mechanical damping. This damping also prevents the seat from shaking in rough air.

4. Since the airplane may swing around in a crash and strike objects while moving sideways or backward, the seat should be able to deform in any direction. On this model a crash blow from the rear forces the seat back to tilt forward and preventsthe passenger from sliding up and over it.

5. If seats break, the structural components should not present sharp or pointed objects against which a passenger may strike. (Illustrate all of this with seat model.)

To determine whether these requirements can be met, an experimental seat was built for study under crash conditions. (Seat is on crash swing, off-stage right.) The seat pedestal was made according to the principles just mentioned. The passenger is held in place with a strong safety belt of standard design. All the structure above the seat pan is made entirely of self-supporting, air-inflated members that are safe for head or body blows. The seat back is designed to tilt forward and prevent passengers from sliding up and over it. This experimental seat, however, is not suited for aircraft use since it incorporates features of construction necessary for research.

The experimental seat, with the dummy in place (representing a forward-facing passenger arranged to receive a blow from the rear), is mounted on this swing. (Point to swing.) Upon release the swing will strike this target on wheels and impose a momentary 4000-pound stopping load on the seat. Watch for the deformation (pull swing back) of the pedestal and the movement of the dummy into the pocket formed by the tilting back (release swing).

Now let us see how this event appears to the slow-motion camera. (Film sequence. Make other appropriate remarks during film.)

This approach to seat design just described will be evaluated in full-scale airplane crashes.

Up to now we have discussed problems of survival in the event of crash. Now let us consider an area of work devoted to reducing the chance of crashing. Mr. Preston will now discuss some interesting aspects of jet thrust reversal as a means for shortening the ground run of landing airplanes.

Part III - Jet Thrust Reversal

by G. Merritt Preston and Robert C. Kohl

Airplanes landing on icy runways experience the same difficulty trying to stop that automobiles do on icy roads. Many of today's transports are equipped with reversible pitch propellers that change the normal forward thrust of the propellers to a rearward force. This force slows the landing airplane and reduces the ground run required to stop the airplane. Because the turbojet has no propeller, the braking of the airplane landing run has to be done by redirecting the exhaust jet, that normally issues rearward from the engine, to a forward direction. This reversal of the exhaust jet produces an airplane retarding force.

The data on the next slide (CS8894) shows how the reversal of the jet thrust shortens the required landing run. The length of the bar graph is proportional to the required landing run. When a jet airplane lands with the engines idling, some forward thrust is exerted on the airplane by the engines. Without a thrust reversal device the wheel brakes have to overcome this forward thrust in addition to slowing the mass of the airplane. The required stopping distance for a jet bomber or transport with only wheel brakes and idle power on the engines is about 11,000 feet on icy runways and about 6000 feet on dry runways. Even if the thrust is zero during the landing run, the stopping distance is 8000 feet on icy runways and 4500 feet on dry runways. In order for aircraft to stop safely on runways of existing major airports, the ground run should be reduced to about 4000 feet. This means that the reverse thrust for a jet bomber or transport must exceed 35 percent when landing on icy runways and 10 percent when landing on dry runways.

In addition to being effective and reliable, the thrust reverser must also

1. Be light
2. Have little effect on airplane or engine performance in flight, and
3. Must not allow the high-temperature gas of the reversed jet to strike airplane components that may be damaged by the heat.

Thrust reversal devices studied here and elsewhere fall into three broad types. The target type, which has undergone considerable development, can be illustrated with this model. (Model on backdrop, left of stage.) Consider this tube to be the tail pipe from which the high speed exhaust jet issues toward the rear of the airplane. When thrust reversal is desired, this cup-shaped target is placed squarely across the exhaust jet. (Speaker installs transparent tail pipe thrust reverser and turns on air blower.) See how the exhaust turns from a rearward to an almost forward direction (points to tufts at exhaust outlet). The reversing force acts on this cup which must be rigidly attached to the airplane. If the cup is too small (hold up small cup alongside tail pipe), little reversal of the jet is accomplished and the reverse thrust is reduced. If the cup is larger than necessary, it imposes an undue weight penalty on the airplane. If the cup is too close to the tail pipe (move cup close to end of nozzle), the gas flow through the engine is throttled down and the reverse thrust drops (point to tufts). When the target is too far from the tail pipe, some of the gas flows around the target and is not reversed. Good design requires a target to have a diameter and spacing from the tail pipe of approximately $1\frac{1}{2}$ to 2 tail-pipe diameters.

When not in use, target type reversers are retracted into adjacent airplane or engine nacelle structure. (Remove target type thrust reverser model. Pick up and install ring type thrust reverser model.)

A second type of thrust reverser uses a series of rings like this (pick up and display a typical metal ring) arranged behind the engine tail pipe to form a system of turning vanes (pull vanes into extended position). In use, the exhaust gases must engage the vanes and be directed forward. One form of this device developed by the French uses an air blast directed upstream to force the exhaust gases to move outward through the vanes. (Plug air hose in fitting in panel.) When the air blast is turned on, the exhaust gases are diverted laterally into the vanes and reverse thrust is obtained. (Point to tufts. Remove air hose.) In a second form of this device developed by the Swiss, a set of radial vanes is located in the tail pipe. When these vanes are given an angular setting with respect to the gas flow (adjust blades manually), the gas swirls. The centrifugal action on the swirling gas moves it through the turning vanes and the thrust reverses.

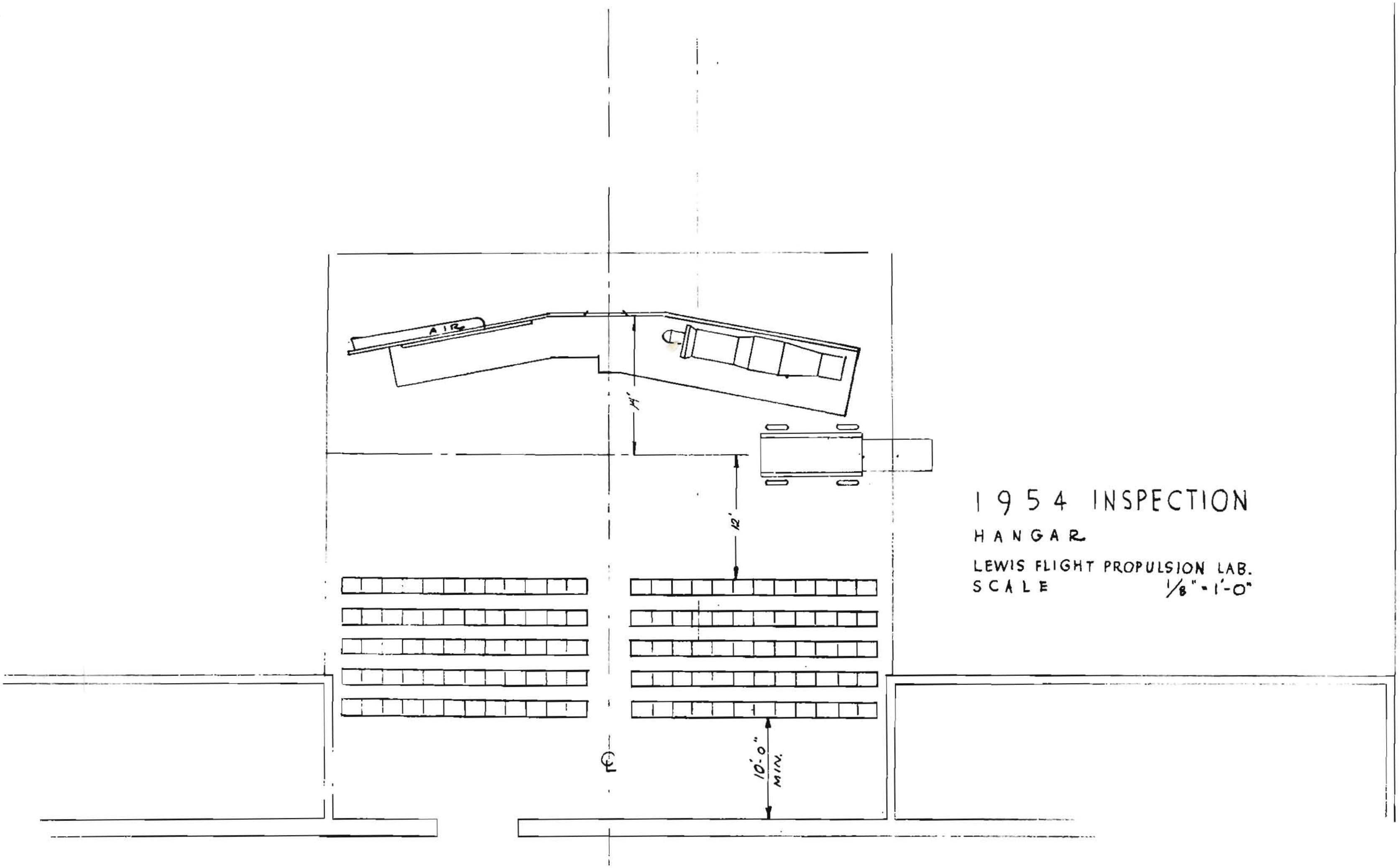
In flight, the cascade is retracted to this position. (Push vanes into collapsed position over nozzle.) However, the swirl vanes or the blast tube remain in the jet stream and reduce the thrust somewhat. (Remove ring type thrust reverser and install NACA type.)

In a third type now under study at the NACA, two sets of turning vanes are stowed in the engine tail pipe (point to blades nested along axis of tail pipe). When not in use they have the position and arrangement along the tail pipe shown here. When thrust reversal is desired this tail-pipe section splits into two half cylinders, each having one set of turning vanes. In contrast to the previous device, these vanes are set squarely across the tail pipe, and no auxiliary device is required to make the flow engage the vanes. However, because these vanes are stowed within the tail pipe when not in use, they, too, impose a thrust loss in flight similar to the previous device (point to tufts indicating reverse air flow).

Because the reversed exhaust gases appear as separate jets on each side of the engine, the hot gas in the reversed flow can be directed beneath the airplane tail surface, which usually cannot tolerate heat from the exhaust gases.

(Hangar doors are opened as engine in F-84 is started.)

As a demonstration of thrust reversal, we have equipped an F-84 airplane with this type of thrust reverser. The airplane is located outside the Hangar doors. (Side of canopy is opened to let audience move toward open hangar doors.) When this demonstration is given, notice the reversed jet issuing from the tail pipe and flowing beneath the horizontal stabilizer, also notice the rearward movement of the airplane. Following this demonstration you may inspect the airplane and the other exhibits in the Hangar that pertain to the three subjects we have discussed.



1954 INSPECTION

HANGAR

LEWIS FLIGHT PROPULSION LAB.
SCALE 1/8" = 1'-0"

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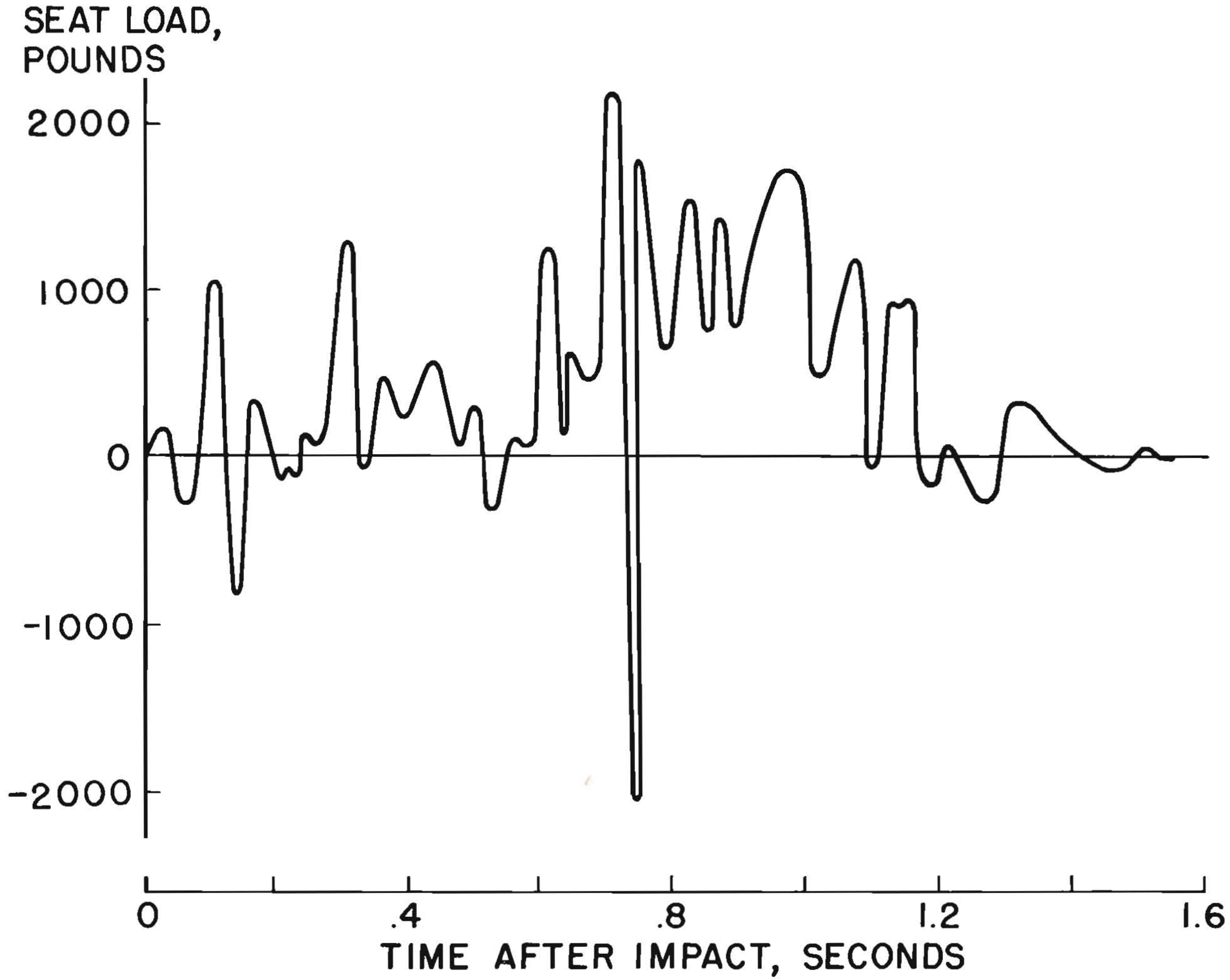
CRASH LOADS



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EFFECT OF THRUST ON LANDING RUN