

JET AIRCRAFT CRASH-FIRE RESEARCH
AND CRASH-IMPACT SURVIVAL

presented by

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This talk on the origin of crash-fire covers the work conducted with jet aircraft. This work followed an extensive research program with piston-powered aircraft in which we learned how the airplane combustibles — oil, fuel, and hydraulic fluids — spill in a crash, when and where ignition sources appear, and how the combustibles move from where they spill to the ignition sources to start the fire.

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 this 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 following motion pictures you will see the flames that issue from the operating test-stand engine following ignition of the fuel sucked into the engine inlet. (Motion pictures of test-stand engine.) 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. 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 actual crash, turbojets 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 engines powered the airplane into a crash barrier to take-off speed. Extensive fuel spillage was produced by poles which ripped open the wing fuel tanks that contained 1,000 gallons of jet fuel. 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. (Slow motion pictures of crash.) The action here is 1/5 normal speed. The engines are mounted under the wings at these locations. Upon crash impact, 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.

When we face the problem of what may be done to reduce the likelihood of fire upon crash, it is evident that provision should be made to shut off the engine combustor fuel at the moment of crash impact. In the discussion that follows we shall assume that the engine is equipped with this crash-actuated fuel shut-off. This valve eliminates the continuous combustor flame as an ignition source and leaves the hot engine metal as the remaining engine fire hazard.

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 air 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. (Demonstration.) Since the 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.

The points of application of water in the engine are shown on this schematic engine cutaway (first slide). Two quarts of water are discharged into each of the combustors of an engine the size of a J-47, one pint is applied to the outside surface of each of the transition liners, and one gallon is delivered to each face of the turbine wheel. In some engines the combustible atmosphere moving through the engine may enter the inner tail cone through vent holes in the cone. Ignition may occur on the hot walls of the quiescent interior. A fine water spray amounting to one quart, provides a steam atmosphere in the cone and prevents ignition.

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. The tail pipe is cooled with about three gallons of water. A total of nine gallons of water is required for inerting the entire engine.

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.) This engine carries a complete water system fully charged. When this switch is closed, indicating the moment of crash impact, the water system discharges. (Close switch.)

In six crashes of the type shown previously but with the engines carrying this water system, no fires were obtained. Four of the most interesting 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. (Slow motion films as described.)

Crashes of jet fighters equipped with engines protected by the water system gave the same results. Here is a slow motion picture of one of the fighter crashes with protected engines. (Slow motion films of crash.) Crash impact occurs at 110 miles per hour. In spite of extensive airplane damage no fire occurs.

The next slow motion pictures show the fire that develops when the same type of airplane is crashed without protection. (Slow motion pictures of F-84 crash.) More than six separate engine explosions are evident.

The last crash involves another fighter carrying protection. This time the action is shown at normal speed. (Crash films at normal speed.) Notice the complete wetting of the airplane with red-dyed fuel.

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 we will consider another phase of the crash-survival problem. Mr. _____ will speak on crash-impact survival.

Preventing a crash fire is worthwhile only if the people involved can survive the crash impact. NACA's research on this problem of reducing injury in a crash involves laboratory studies and full-scale crashes of instrumented airplanes. In this discussion we will describe briefly some of the preliminary results of this study.

When we consider the problem of impact survival, it is obvious at once that there is no chance for survival when the passenger compartments collapse and living space disappears. However, even though living space remains in the fuselage the passenger can be severely injured by the crash impact. In general two seating environments are recognized with regard to injury in crash-- in the first, the pilot fills most of the cockpit and has little room for movement, such as in the fighter and light airplane; and in the second, the space allocated to the passenger allows him considerable freedom for movement, as in the case of the transport.

Let us consider first the condition in which the pilot fills most of the available cockpit volume. Unless he is properly held with seat belt and shoulder harness, he will move enough during a crash to be severely injured by striking objects within the cockpit. The question then arises: How strong must this restraining harness be to limit the pilot's movement safely? However, a properly harnessed pilot may be

injured by the decelerations he experiences, wholly apart from blows to vital parts of the body. A necessary companion question is therefore: What are the decelerations experienced by a properly harnessed pilot? This information used in conjunction with the data on tolerance of humans to deceleration provides a clue to possible changes in harness and seat design for improved crash-impact survival.

In order to obtain this information, a series of crashes were conducted with decommissioned fighter airplanes provided by the Navy. These airplanes carried instrumented dummies as pilots. The fighters were crashed in ways to duplicate a variety of accidents experienced in military service. Slow motion pictures of two of these crashes will now be shown to illustrate the type of information being obtained in this study. In the first crash, the airplane strikes the ground at an impact angle of $22-1/2^{\circ}$, simulating an unflared landing. (S-5)

Superimposed on the actions are the horizontal decelerations measured on the seat. The data line on the graph will develop in phase of with the airplane's action. Notice the deceleration peaks accompanying the two impacts of the airplane with the ground. The airplane enters the crash at 110 miles per hour. Notice the high deceleration peaks accompanying the first and second impacts. Such data tell the designer how strong the harness has to be. The same sequence is repeated showing the vertical decelerations encountered in the crash. These vertical decelerations can produce major spine injuries if not reduced by seat design.

Now for contrast, let us compare these results with those obtained in a cartwheel crash. Again the decelerations are superimposed on the action. The horizontal, vertical, and lateral decelerations will all be shown on the same motion picture sequence. Notice the deceleration peaks that accompany each contact of the airplane with the ground. Because of the tumbling of the airplane, these peak decelerations are low. Aeromedical data indicate that the pilot would receive little or no injury from these decelerations.

In general the information obtained in this fighter crash program showed that the decelerations, particularly in the vertical direction, exceeded human tolerance without collapsing the living space in the cockpit. Harness that supports the pilot properly and seats that cushion the crash blow can make real gains in reducing crash injury. The measurements made in these studies are useful in the development of seats and harness.

In contrast to the fighter pilot, the transport passenger is restrained only by a seat belt which is attached to the seat. If the seat belt fails or the seat rips from the floor, the passenger becomes a missile within the airplane. A passenger striking broken seats or other objects within the cabin can be severely injured by blows and cuts on vital parts of the body. Survival in a transport crash requires belts and seats that will not fail.

Seat and their floor attachments that are strong enough to hold against peak crash loads may be too heavy for aircraft use. It would be desirable, therefore, to reduce the magnitude of these peak loads imposed on the seat by the decelerating passenger.

One way to obtain this load reduction is represented by this flexible seat shown on the stage. The seat is flexible and deforms in the direction of the load applied by the passenger in the crash. In this way the crash forces imposed on the passenger and seat are reduced. The load on the seat floor attachments are reduced correspondingly.

Seat flexure is achieved by making the seat pedestal of two cylindrical members joined by this elastic band. The elastic band is stretched when installed to pull the cylindrical members together with a 1,000 pound force. The lower cylinder is attached to the floor and the upper member to the seat pan and seat belt. In the crash the passenger pulls the upper cylinder which displaces elastically with respect to the airplane floor and cushions the crash blow. When the crash load subsides the stretched elastic band restores the seat to its normal shape and it is prepared for the next crash blow. A rubber sheet between the two cylinders introduces sufficient frictional damping to avoid an additional blow to the passenger when the seat rebounds. This friction also keeps the seat pedestal rigid in rough air. All of the seat parts above the seat pan are made of air-inflated self-supporting members that are safe for head and body blows.

The response of this seat to a single blow was studied by mounting the seat with a dummy on a swinging platform. In this study, the platform swings and strikes a target. Impact with the target produces platform decelerations up to 25 g's. Here is a slow motion picture of the movement of a seat and dummy receiving a blow from the rear.

Instrumentation on the platform and dummy gives these deceleration data. This slide shows the deceleration of the swing and the dummy's hip in flexible and rigid seats plotted against time. While the platform deceleration has a peak of 18 g's, the dummy's hip in the flexible seat shows a peak of only 10 g's spread over a longer period of time. Data on rigid seat of standard design subjected to the same platform deceleration shows deceleration peaks of about 1.5 times that of the platform. This amplification of the platform deceleration is characteristic of rigid seats.

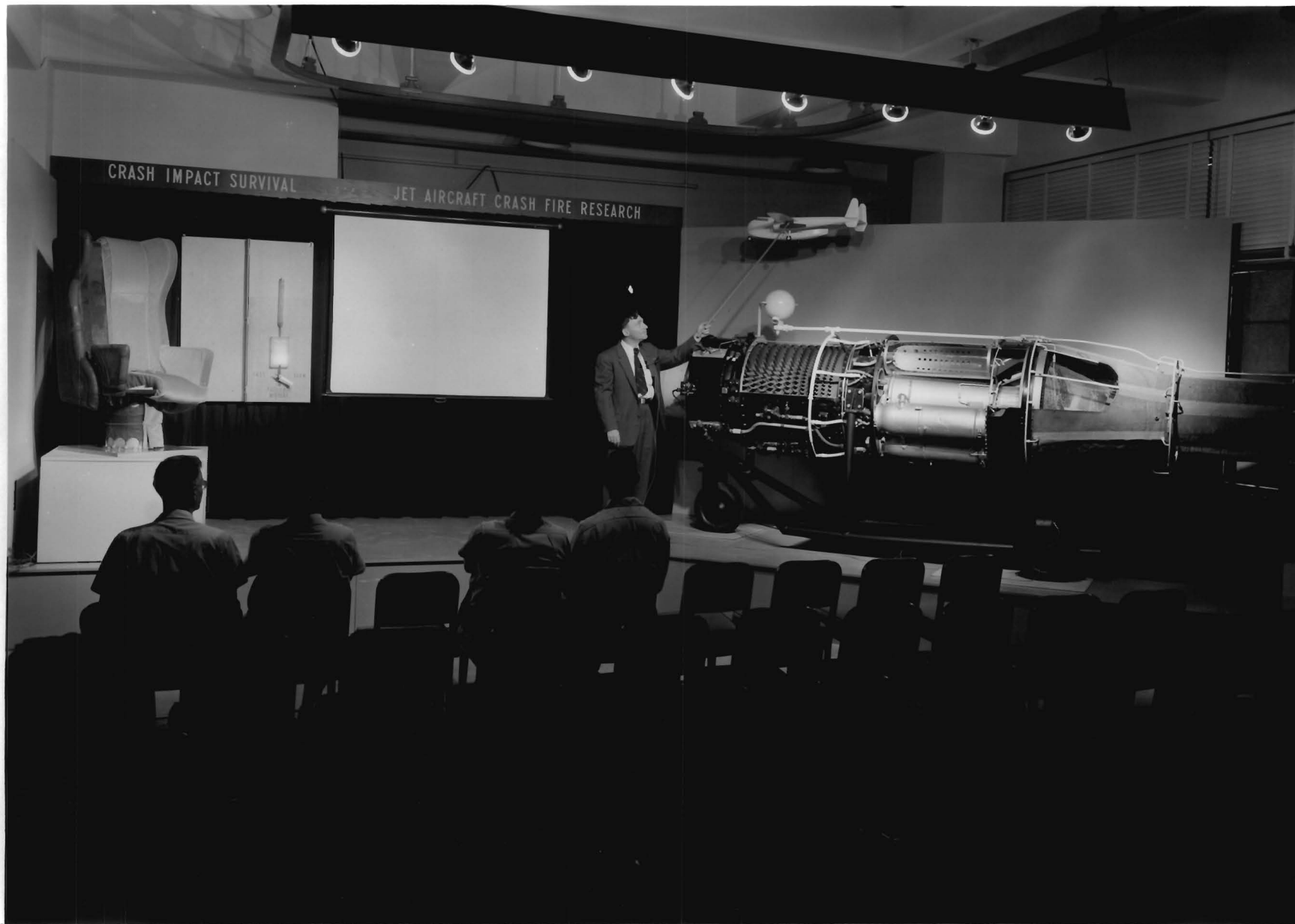
Flexible and rigid seats were installed in a transport airplane to obtain a comparison of their performance in a crash. All seats and their occupants were instrumented. Here is the crash in slow motion. The approach speed is 110 miles per hour. The airplane first strikes this bank and bounces into the air. It hits a second bank in the middle of the fuselage. Cameras taking pictures inside the airplane show the action of both rigid and flexible seats during the first impact of the airplane with the ground.

The next motion picture shows this action at about 1/9 normal speed. Notice that the dummy in the rigid seat has very little movement while the dummy in the flexible seat has considerable movement.

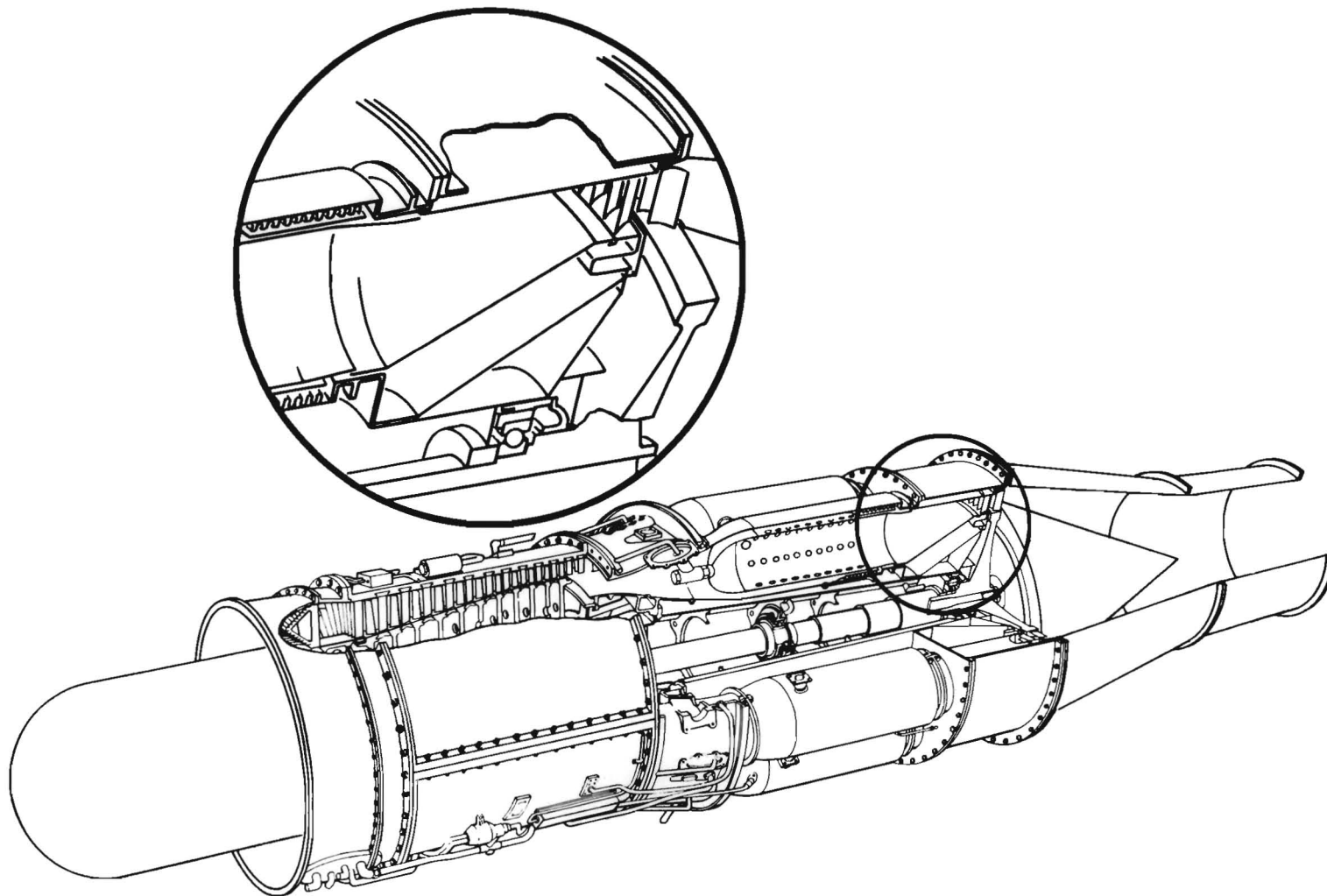
Here is the dummy in the rigid seat, and here is the dummy in the flexible. Now, notice the large movement of this dummy in the flexible seat and the little movement of the dummy in the rigid seat.

The data presented on the next slide shows a comparison of the resultant of the vertical and horizontal decelerations measured in the dummies' chests in the rigid and flexible seats. A peak deceleration of 78 g's was experienced by the dummy in the rigid seat whereas the dummy in the flexible seat experienced a peak deceleration of only 18 g's. It is recognized that the flexible seat deformation in this crash is excessive; however, these data do show the extent to which the crash forces can be reduced by flexible seats.

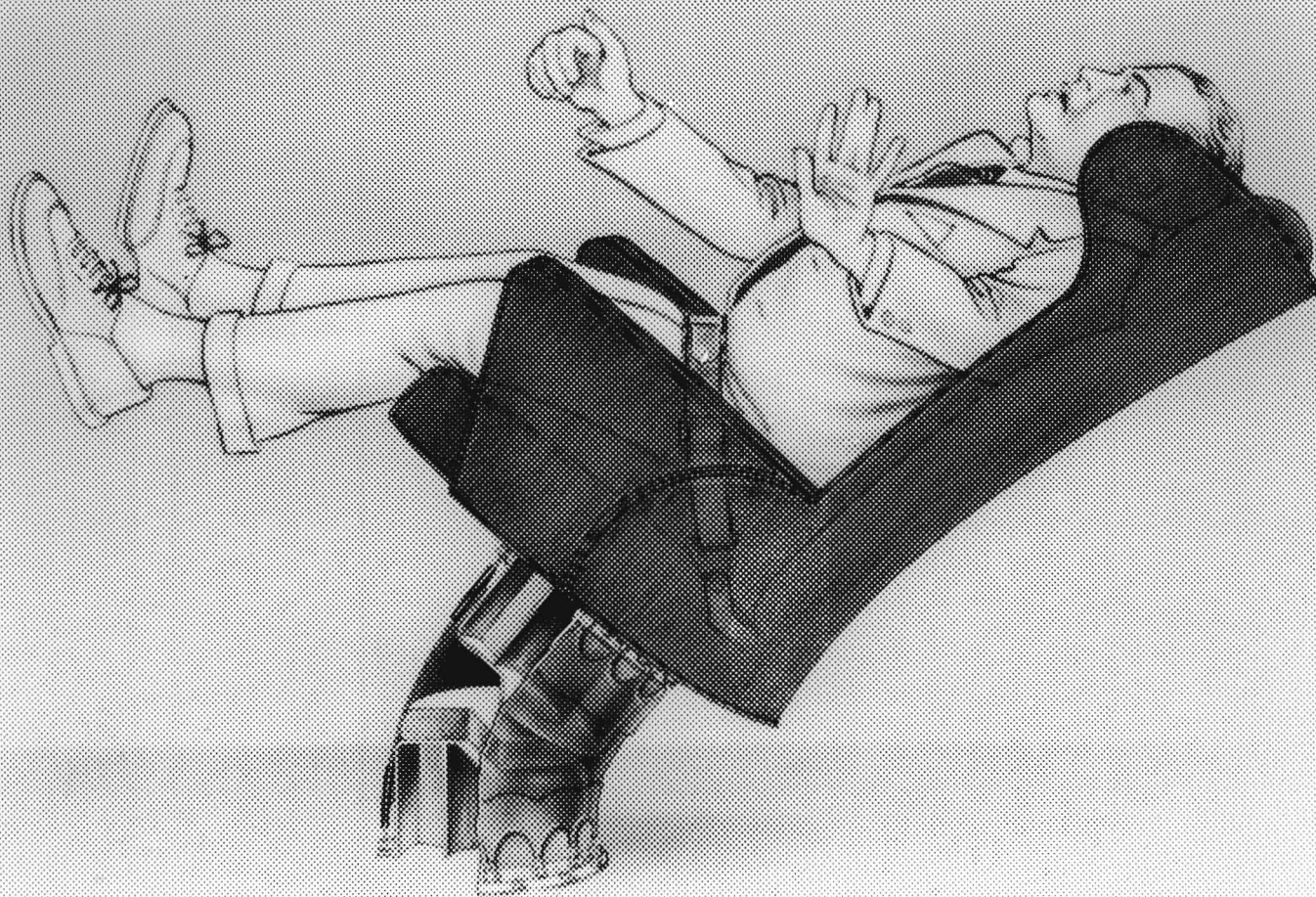
The shock absorption principle demonstrated with the flexible seat represents a solution to only one of the problems of reducing injury during a transport crash. A complete study of crash-impact survival, must include consideration of the design of floor attachments for maximum strength with minimum weight, and the effect of airplane design on the crash loads transmitted to the occupants in the airplane.



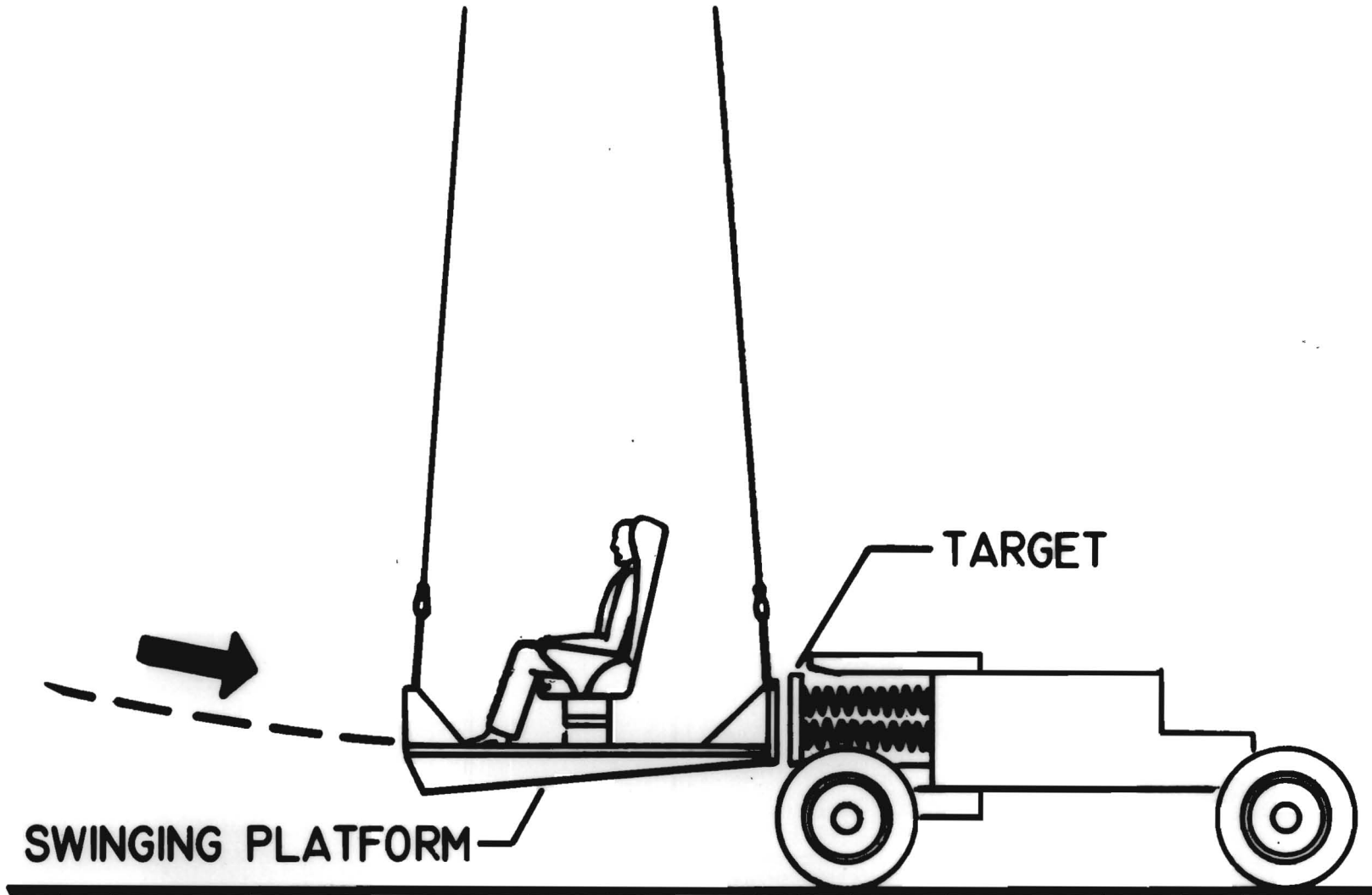
TURBOJET CUT AWAY



NACA EXPERIMENTAL FLEXIBLE SEAT IMPACT FROM REAR



IMPACT SWING



CHEST ACCELERATION

REAR FACING SEATS

