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INVESTIGATION OF TWO METHODS FOR IMPROVING THE CRASHWORTHINESS OF INTEGRAL FUEL TANKS

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16. Abstract

F-86 droppable fuel tanks, fitted with reticulated polyurethane foam and filled to capacity with JP-4 fuel, were drop tested and catapulted to test the effectiveness of the foam in reducing fuel spray and leakage at impact. Also, structurally reinforced DC-7 integral wing tanks were impacted against an upright beam restrained by a steel shear pin to limit the loads. The forward spar caps were strengthened with aluminum alloy doublers and chordwise stiffeners to determine the effect of structural modifications on the crashworthiness of the structure.

It was determined that the 10 pores per inch and the 60 pores per inch polyurethane foam have little effect on the attenuation of fuel misting and spilling. The addition of a 0.040-inch-thick doubler strip to the upper and lower DC-7 wing skins did not appreciably decrease the vulnerability of the integral tank to leakage, but the front spar rails when reinforced by chordwise structural shapes did increase impact resistance.

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INTRODUCTION

Purpose

The purpose of this project was to investigate the effectiveness of materials and structural fabrication techniques designed to improve the crashworthiness of aircraft fuel tanks.

Background

Reticulated polyurethane foam has been used successfully in combat aircraft fuel tanks to reduce or eliminate explosions when the tanks were penetrated by gunfire. In practice the foam is installed in the fuel tanks in form-fitting pieces, and the entire void of the tank is filled. The foam used is generally 10 pores per inch (ppi) which reduced the total fuel carrying capacity of the tank by only 3 percent. It has been theorized that this same technique could be considered a potential deterrent to post-crash fires and explosions in commercial aircraft.

In this project the abilities of this reticulated foam to reduce fuel misting and fuel spillage from ruptured fuel tanks were investigated first by drop testing fuel tanks filled with foam and JP-4 fuel, and secondly by catapulting fuel tanks containing foam and fuel into an embankment in the presence of an ignition source; thus risking an explosion and/or fire on impact.

The effectiveness of structural reinforcement as a method of improving the crashworthiness of integral fuel tanks is discussed in FAA Report ADS-19, prepared by the Convair Division of General Dynamics. This was a study performed to investigate crash resistant design principles for integral fuel tanks. In the report the contractor recommended certain structural modifications that proved to be the most effective in his tests of simulated wing tanks performed on a pendulum swing. These design principles were incorporated on DC-7 outer wing panels at the National Aviation Facilities Experimental Center (NAFEC) and tested on the Drop Test Facility.

Test Methods and Procedures

The F-86 droppable fuel tanks were tested on both the NAFEC Drop Test Facility and the NAFEC Catapult and Track Facility. The Drop Test Facility is shown in Figure 1. Four tanks were dropped from a height of 35 feet onto the concrete

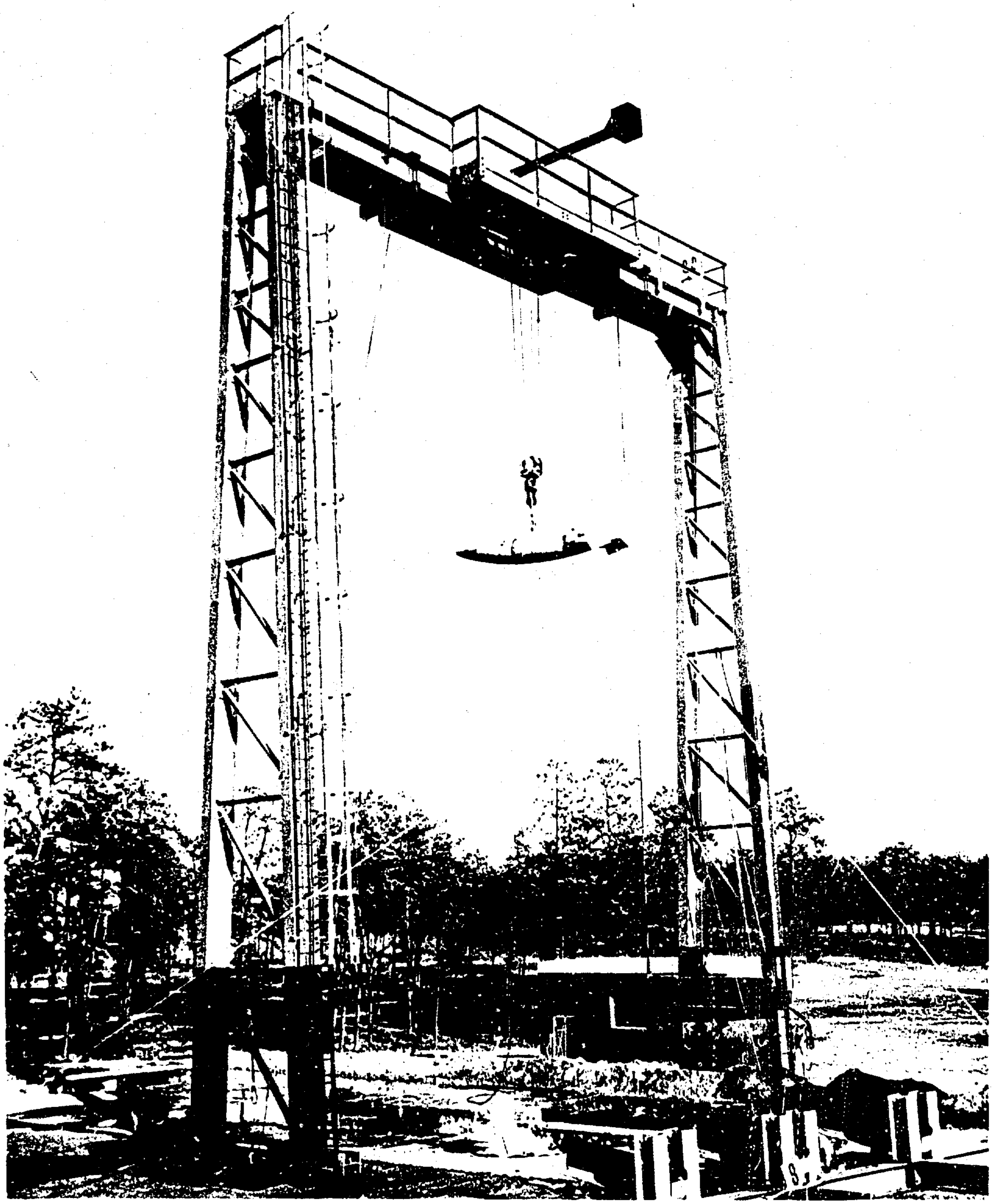

FIGURE 1 DROP TEST FACILITY FOR F-86 FUEL TANKS

pad below. This height produced an impact speed of 47.7 feet per second or 32.5 miles per hour. High-speed motion picture coverage of the impact was used to determine the extent of the spray pattern at impact. One tank contained just JP-4 fuel to act as a control; the other tanks were packed with 10 ppi foam or 60 ppi foam installed in the tanks in form-fitting pieces.

Five tanks were catapulted onto a steel plate resting on a sloped earthen bank at speeds of 80 miles per hour in the presence of an open fire. One tank contained JP-4 fuel only, to act as a control. The other tanks were packed with 10 ppi or 60 ppi foam and then filled with JP-4 fuel. High-speed motion pictures were taken as the tanks burst into flame at impact. Radiometer readings were taken at the impact point during the test. The radiometers were located around the impact point as shown in Figure 2.

The tests on the DC-7 outer wing tanks were performed on the Drop Test Facility which was modified as a pendulum swing with a 50-foot arc as shown in Figure 3. The wings impacted an upright steel pole restrained by a three-fourths-inch steel shear pin. This limited the impact load to 21,000 pounds on the wing. One unmodified wing was tested to act as a control and the other two wings that were swung were modified using design principles recommended by Convair in their report, ADS-19 of August 1964. The wings were swung from a height of 25 feet which produced an impact velocity of 40 feet per second or 27 miles per hour.

DISCUSSION

Test Results on Reticulated Polyurethane Foam

To test the effectiveness of the reticulated foam in reducing misting and spraying of the fuel under severe impact conditions, several F-86 tanks were fitted with foam fillers of different porosities and methods of installation. One tank had 10 ppi foam which was inserted in the tank in form-fitting pieces. Another tank was fitted with 60 ppi foam, and a third tank was fitted with 10 ppi foam; but in this instance all the separate pieces of foam were cemented to each other during installation to form one continuous piece.

The spray pattern of JP-4 fuel, resulting from the impact when these tanks were dropped from a 35-foot height, was recorded on high-speed film, and the results were assessed

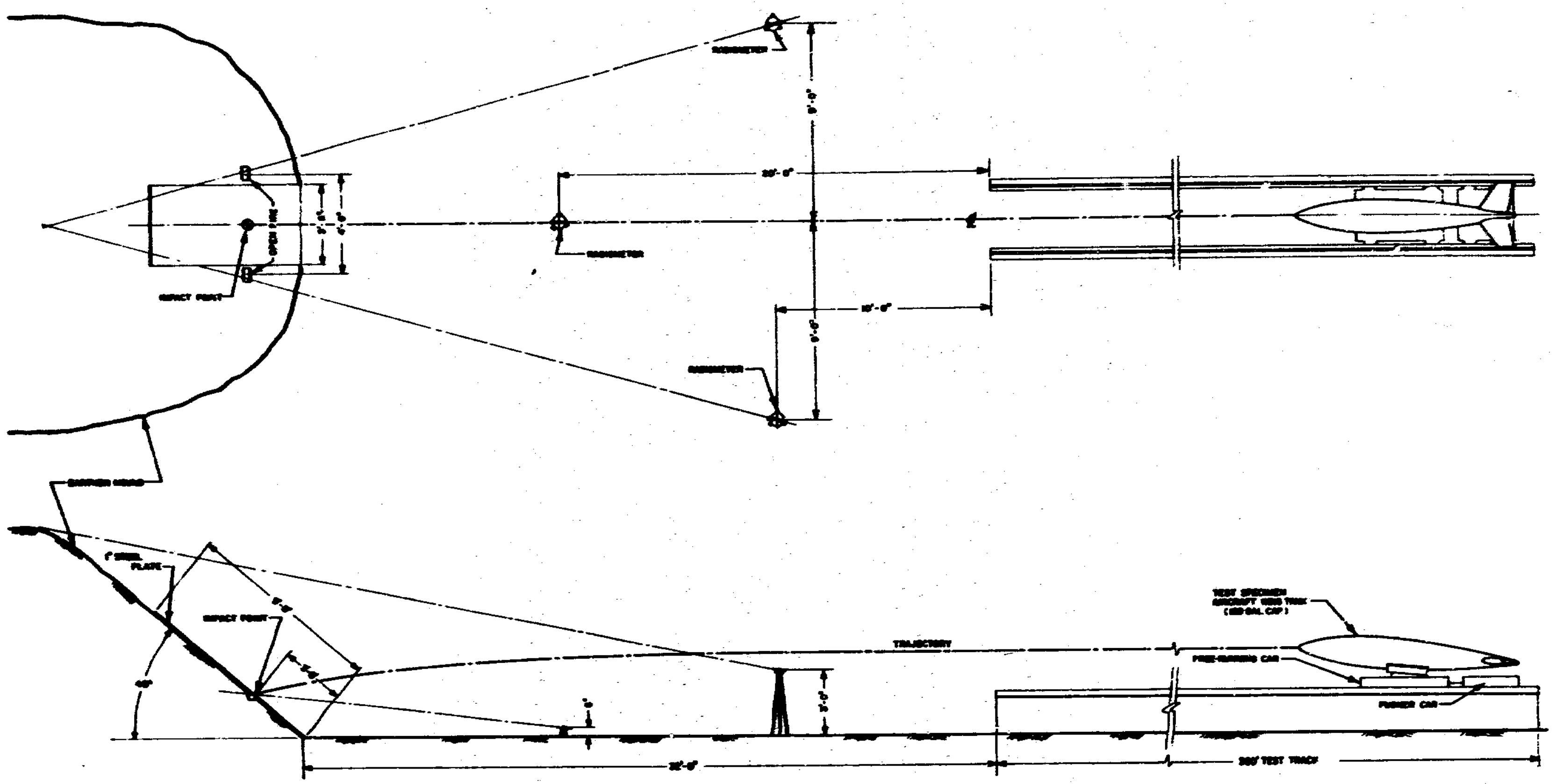

FIGURE 2 CATAPULT TEST FACILITY FOR F-86 FUEL TANKS

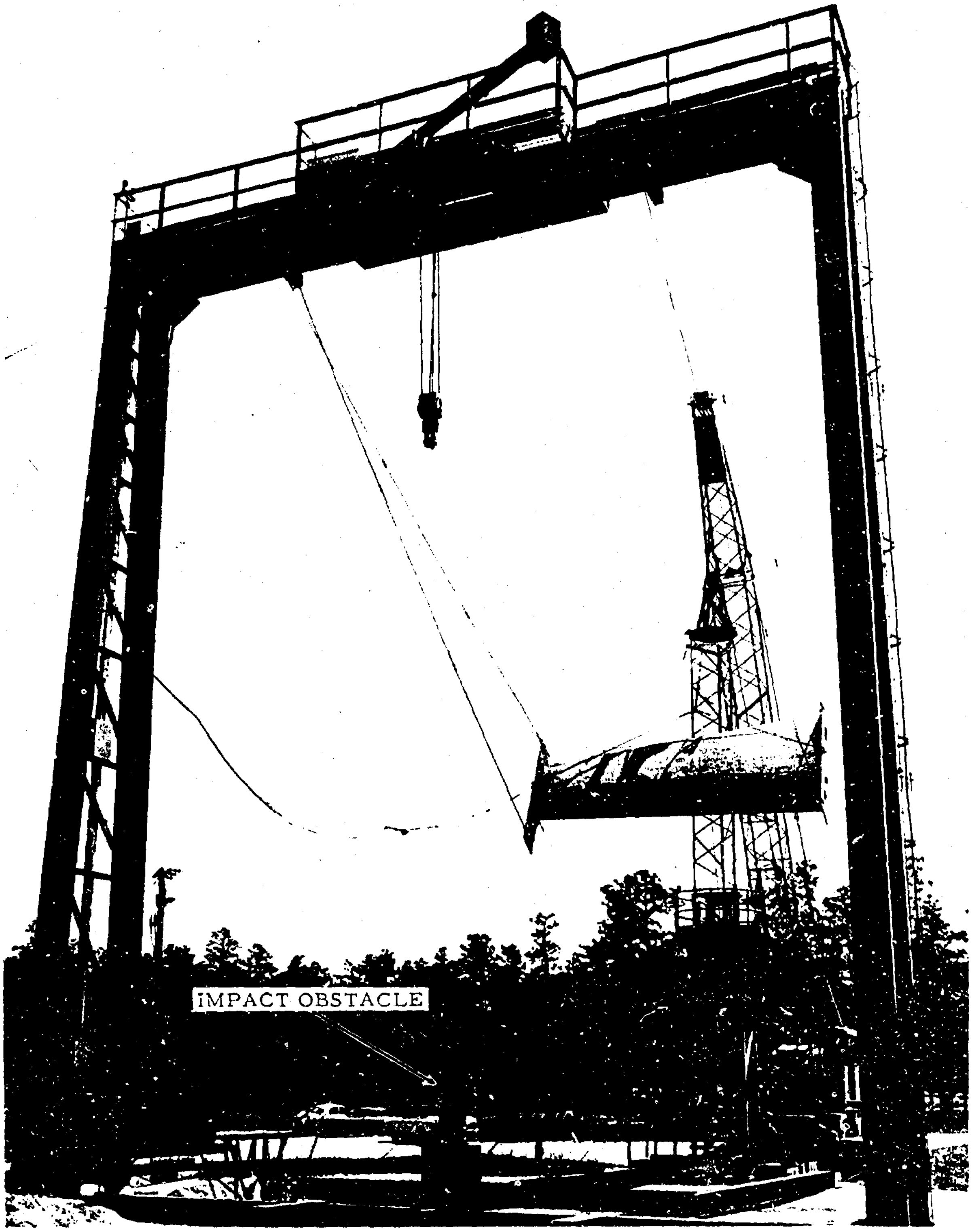

FIGURE 3 PENDULUM SWING TEST FACILITY FOR DC-7 INTEGRAL WING TANKS

to determine the effectiveness of the foam as compared to the spray pattern obtained with the control tank that was dropped with just JP-4 inside. Figure 4 shows a typical spray pattern obtained during these tests, and Figure 5 shows the damage one tank suffered from the 35-foot fall. The photographic analysis showed that the fuel spray patterns were similar for all drops relative to the depth of horizontal and vertical areas encompassed. In an attempt to estimate the relative amounts of fuel sprayed into the air, the time for the fuel spray to dissipate was determined. These quantitative results are shown in Table 1.

TABLE 1. - ELAPSED TIME FOR FUEL SPRAY TO DISSIPATE

Drop Test Number	Test Configuration	Dissipation Time Seconds
1	F-86 tank containing 120 gallons of JP-4 fuel and a full volume of 10 ppi polyurethane foam sections not cemented together	1.43
2	F-86 tank containing 120 gallons of JP-4 fuel	1.45
3	F-86 tank containing 120 gallons of JP-4 fuel and a full volume of 10 ppi polyurethane foam sections cemented together	0.95
4	F-86 tank containing 120 gallons of JP-4 fuel and a full volume of 60 ppi polyurethane foam sections not cemented together	1.01

Evaluation of these data indicated that less fuel was sprayed into the air where the foam was a continuous piece or where the smaller pore size foam was used. However, since the spray patterns were similar in depth, the possibility of the spray contacting an ignition source was the same for all configurations drop tested.

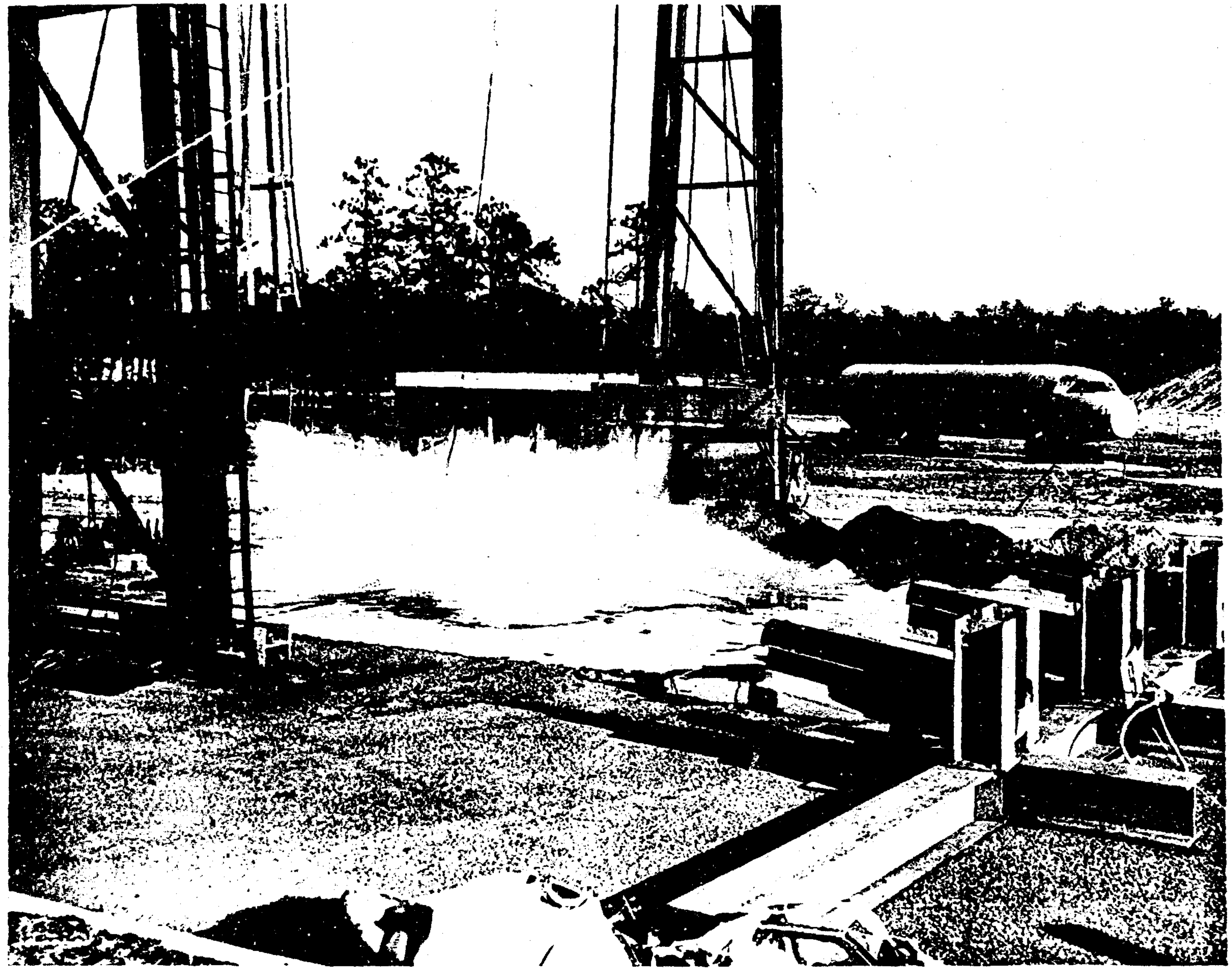

FIGURE 4 F-86 FUEL TANK DROPPED FROM A HEIGHT OF 35 FEET

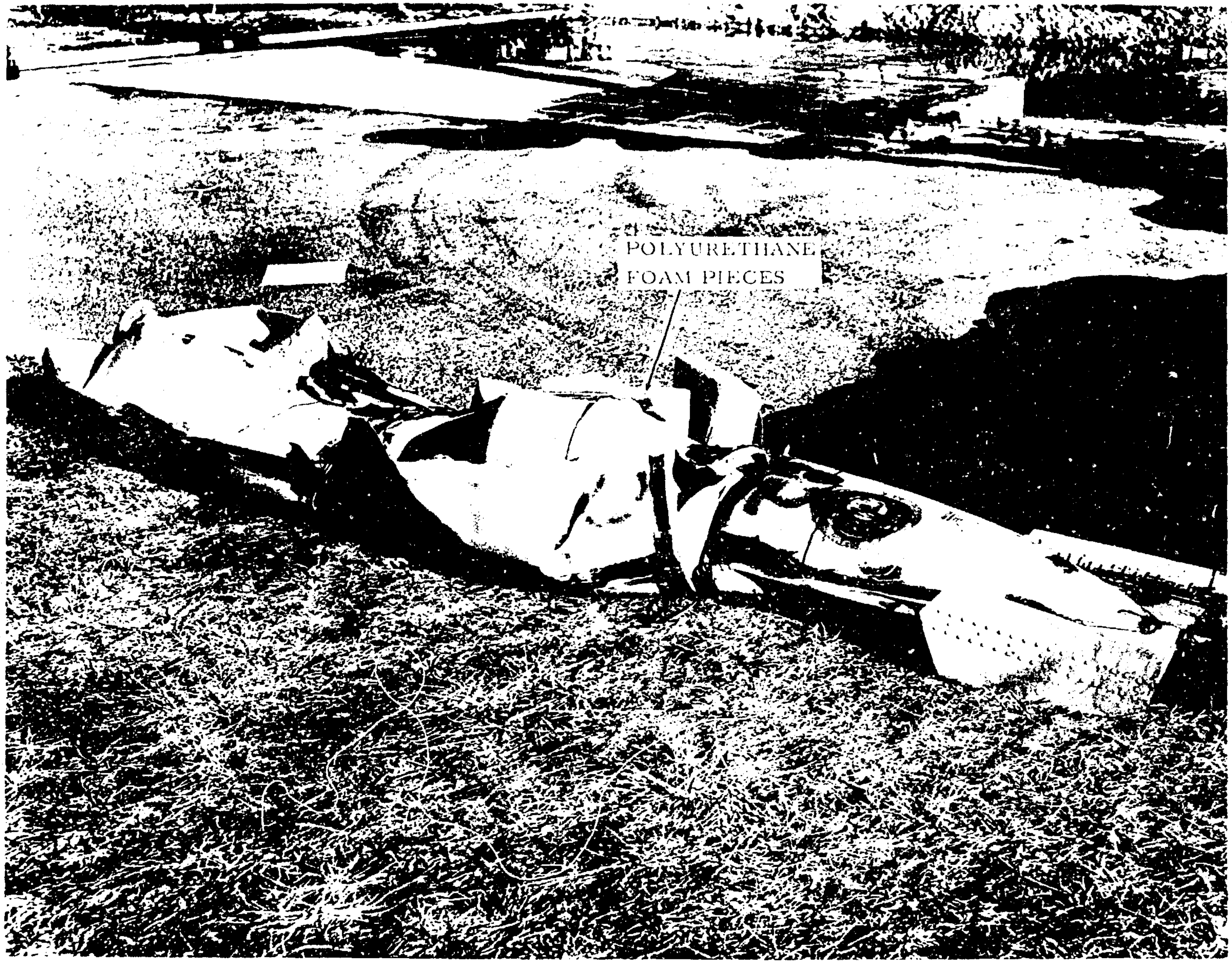

FIGURE 5 F-86 FUEL TANK WITH 10 PPI FOAM AFTER IMPACT

Various porosities and methods of installation were also used in the F-86 tanks that were catapulted into an earthen bank to test the effectiveness of the foam to control the intensity of post-crash fire. One tank contained only JP-4 fuel to act as a control. The second tank contained 10 ppi foam in form-fitting pieces. The third contained 10 ppi foam with the pieces cemented together. The fourth contained 10 ppi foam with pieces cemented to each other and also to the sides of the tank. The fifth tank contained 60 ppi foam in form-fitting pieces not cemented.

At impact the tanks broke open and the escaping fuel was ignited by burning smudge pots placed around the impact area. All of the fuel burned in the immediate vicinity of the impact area when the control tank containing JP-4 only was tested. On the other tests the fuel-soaked foam carried some of the burning fuel away from the impact area which accounts for the lower radiation readings for these tests as shown in Figure 6. Assessment of the high-speed photographs of these tests was made to determine if there was any substantial decrease in time for ignition of the fuel following impact. In all configurations tested, the fuel spray ignited within a time interval ranging from 40 milliseconds to 60 milliseconds after impact. This difference was considered to be quite insignificant.

Test Results on Structural Reinforcement

In FAA Report ADS-19, Convair recommended that the forward portion of the wing be strengthened in the chordwise direction from the front spar cap aft to the first or second spanwise stringer as a means of increasing the crashworthiness of the integral fuel tank in that area. Accordingly, two DC-7 outer wing panels were strengthened using this design principle and tested in comparison with an unmodified DC-7 wing panel which acted as a control. On one wing panel 0.040-inch-thick 2024 T3 aluminum alloy doublers were installed along the upper and lower skin surface in such a manner as to cover the width of the upper and lower spar caps and extending aft in the chordwise direction so as to engage the aft rivet line of the second spanwise stringer for the entire span of the panel. These doublers were fastened by riveting through the skin between existing rivets attaching the spar caps, portions of ribs and spanwise stringers covered. The other wing panel had a 0.020-inch-thick aluminum skin doubler installed in a similar manner, but in addition, incorporated chordwise tee sections of extruded 2024 T4 aluminum alloy which extended from the front edge of the forward spar caps to a point slightly aft of the rearmost rivet line for the second spanwise stringer. These tee sections were spaced at intervals of 6 inches on centers, and were installed externally for convenience.

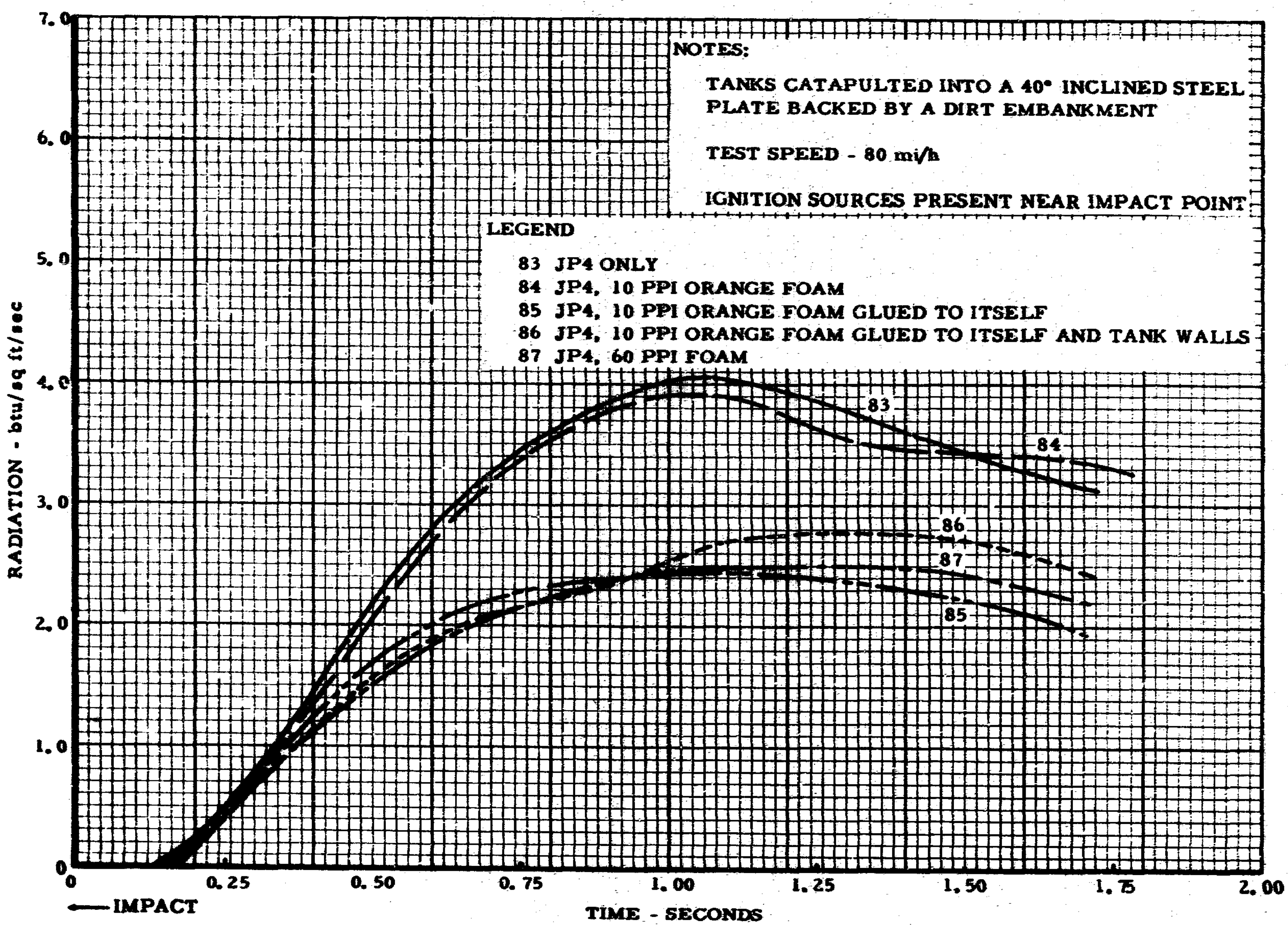

FIGURE 6 RADIOMETER RESULTS OF F-86 FUEL TANK CATAPULT TESTS

As shown in Figure 7, the tee sections were attached to the test specimen only in the immediate vicinity of the impact area. The actual weight of the tee was 8.24 pounds for this test, but extrapolation of this modification to the entire span of the outer wing panel would result in a total weight of tee sections of 45.5 pounds. The 0.020-inch-thick aluminum doubler weighed 15.5 pounds making the combined weight of structural reinforcement 61.0 pounds for the entire outer wing panel. Since the DC-7 outer panels weighed approximately 1000 pounds empty, this modification resulted in a 6 percent increase in weight. However, the 0.020-inch-thick doubler added no significant chordwise strength, and if retrofitted internal to the panel, the tees would be reduced in overall length by approximately the width of each stringer less its flange; thus decreasing the overall weight an additional increment so that at most the overall weight might be 40 pounds or only a 4 percent increase in dry wing weight.

The wings were filled to three-quarter capacity with 4000 pounds of dyed water for the test, and together with the aluminum support plates and the wings themselves, the test article weighed 6000 pounds. They impacted against an upright steel pole faced with a section of a wooden telephone pole. The three-fourths-inch steel shear pin size used in the upright pole was chosen by swinging unmodified DC-7 wing panels into the pole using various size shear pins and determining the shear pin size that caused sufficient damage to the front spar caps and cracking of the skin aft of the caps to cause the tank to leak. Figure 8 shows the damage sustained by an unmodified wing when a three-fourths-inch shear pin was used. The deceleration forces produced at impact were as high as 25 g's on the wing structure. Overpressure of the contained water caused by the inertia forces at impact was 9.3 pounds per square inch inside the wing tank.

The wing modified with the 0.040-inch-thick aluminum doubler ruptured almost as much as the unmodified control wing panel after impact, but the wing with the 0.020-inch-thick aluminum doubler and the 1 1/2-inch tee sections did not rupture upon impact.

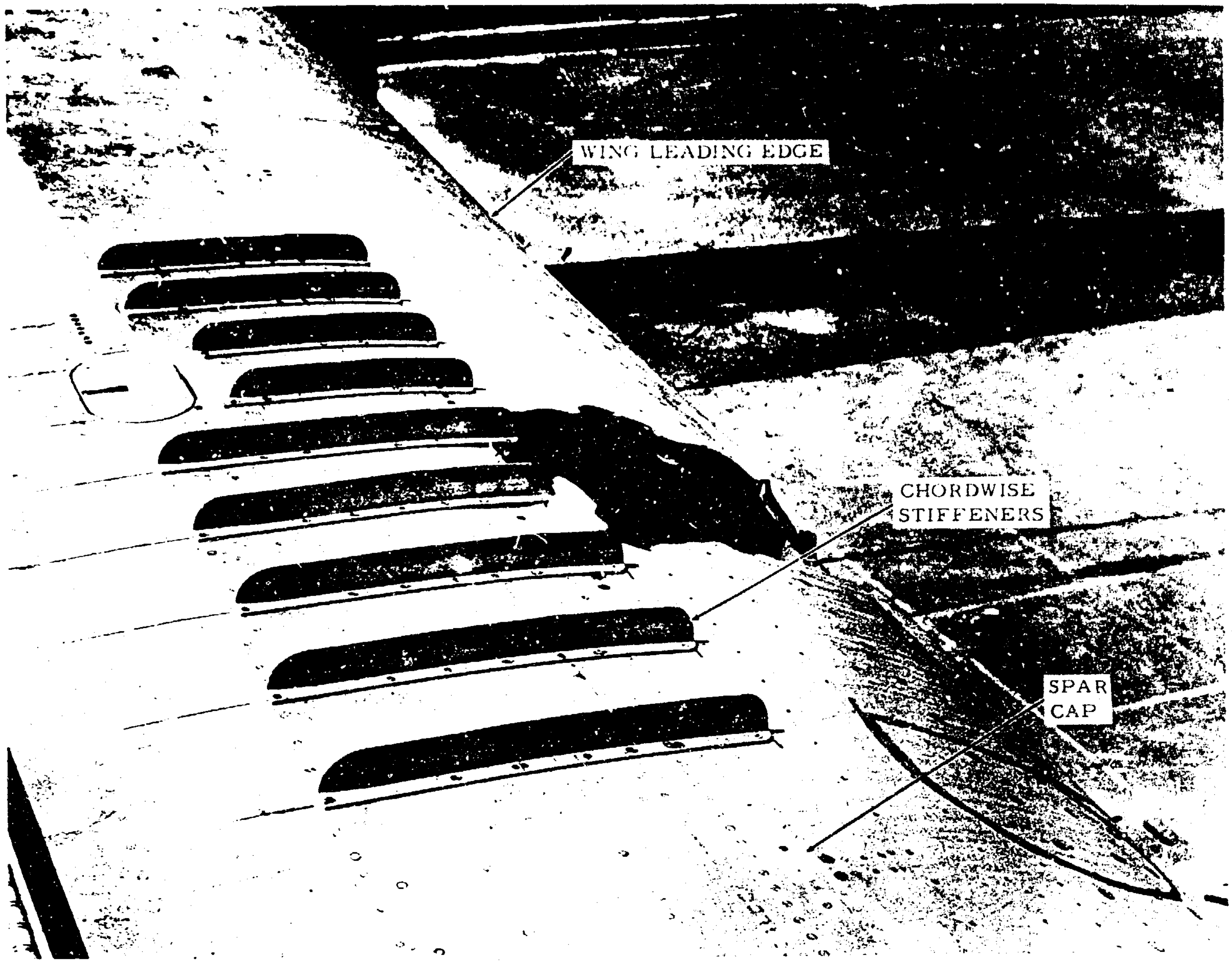

FIGURE 7 CHORDWISE STIFFENERS ON DC-7 INTEGRAL WING TANK

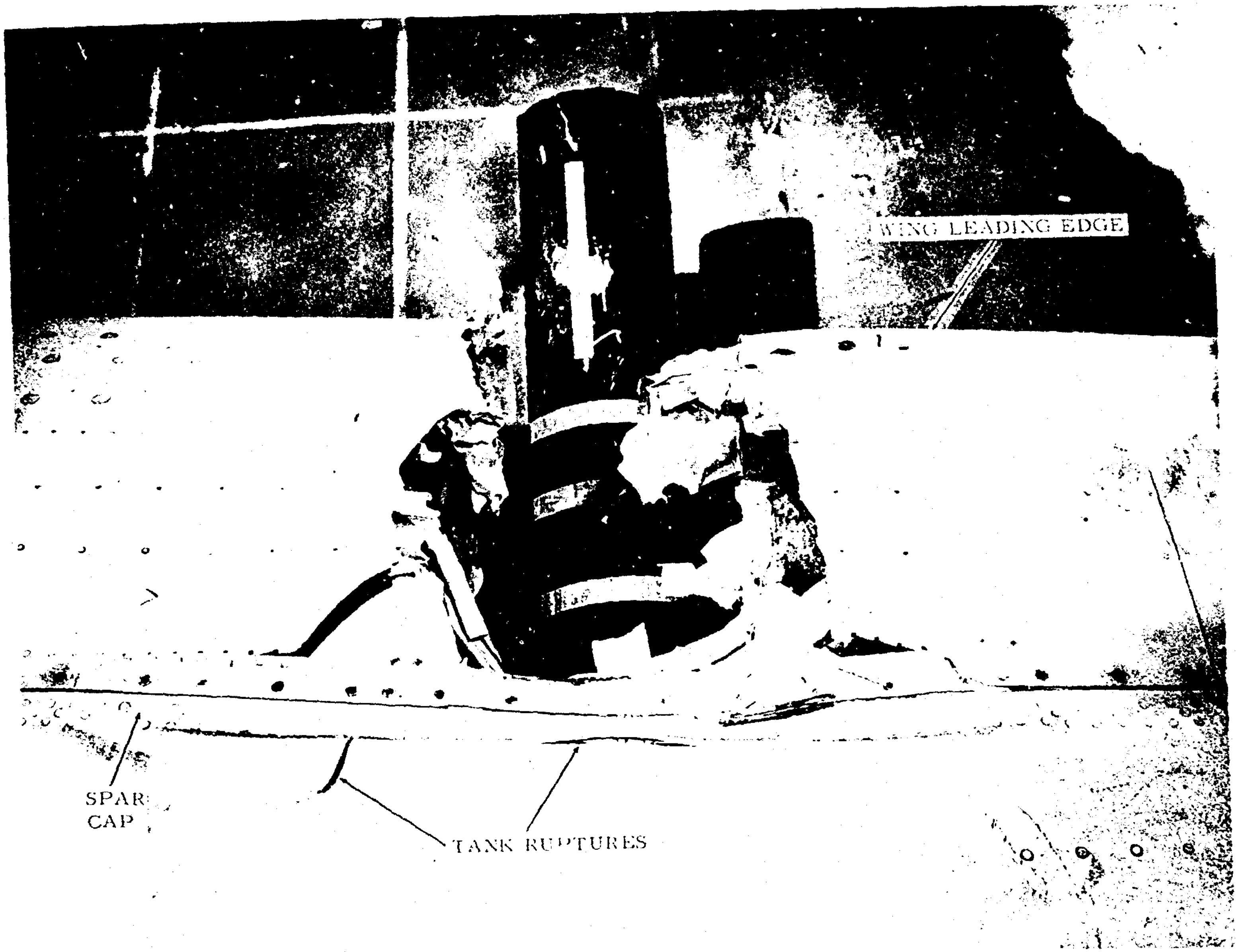

FIGURE 8 UNMODIFIED DC-7 INTEGRAL WING TANK AFTER IMPACT

CONCLUSIONS

Based on the analysis of the results of the tests, it is concluded that:

1. The 10 pores per inch (ppi) or the 60 ppi reticulated polyurethane foam when installed in fuel tanks does not effectively attenuate the fuel spray during impact, in terms of improved crashworthiness.

2. The addition of 0.040-inch-thick aluminum alloy doubler strips aft of the upper and lower front spar caps did not appreciably increase the resistance of the integral tank structure to damage by impact. However, reinforcement of the front spar caps and internal chordwise structure between ribs such as simulated in these tests, can reduce damage to the point of preventing fuel leakage after impact.

REFERENCE

"Structural Design for Fuel Containment under Survivable Crash Conditions" by P. M. Nissley and T. L. Heid, FAA Report FAA ADS-19, dated August 1964.