Report No. FAA-RD-71-75

AN INVESTIGATION OF METHODS TO CONTROL POST-CRASH FUEL SPILL FROM INTEGRAL FUEL TANKS

K. D. Robinson
The Goodyear Tire and Rubber Company
1144 E. Market Street
Akron, Ohio 44316

U.S. International Transportation Exposition
Dulles International Airport
Washington, D.C.
May 27-June 4, 1972

DECEMBER 1971

FINAL REPORT

Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151, for sale to the public.

Prepared for

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington D. C., 20591

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FAA-RD-71-75	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle AN INVESTIGATION OF METHODS TO CONTROL POST-CRASH FUEL SPILL FROM INTEGRAL FUEL TANKS		5. Report Date December 1971
		6. Performing Organization Code
7. Author(s) K. D. Robinson		8. Performing Organization Report No. FAA-NA-71-32
9. Performing Organization Name and Address The Goodyear Tire and Rubber Company, 1144 E. Market Street, Akron, Ohio 44316		10. Work Unit No. Project No. 503-101-01X
		11. Contract or Grant No. DOT-FA69NA-432
12. Sponsoring Agency Name and Address Federal Aviation Administration, Systems Research and Development Service, Washington, D. C. 20591		13. Type of Report and Period Covered Final Report 1 July 1969 through January 1971
		14. Sponsoring Agency Code

15. Supplementary Notes The work effort on this project was part of a program of the Aircraft Division, Systems Research and Development Service, Washington, D. C. Engineering liaison and technical review were furnished by the Structures Section, Aircraft Branch, Test and Evaluation Division, National Aviation Facilities Experimental Center, Atlantic City, New Jersey.

16. Abstract

This study was undertaken to investigate the use of elastomer coatings, curtains and other more novel materials as containment methods to eliminate or control post-crash spill from aircraft integral fuel tanks.

Through use of comparative screening tests, elastomeric liner, curtain, and multilayer liner, and contractor selected boot type liner concepts were selected for evaluation in aircraft wing sections."

Results of aircraft wing section drop tests show that very little improvement was realized with the various systems installed. The structural damage to the wing sections was of such magnitude as to preclude success of any of the systems evaluated.

17. Key Words Crash Fire Safety, Fuel Tanks, Crashworthiness, Fuel Containment	18. Distribution Statement Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Va. 22151, for sale to the public.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	70	

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

	PAGE
INTRODUCTION	1
DISCUSSION	2
Materials Selection	2
Test Program	3
Elastomeric Liner Concepts, 1 thru 5	20
Curtain Concepts	29
Multilayer Liner Concepts, 6 thru 11	36
Wing Section Tests	40
CONCLUSIONS	43
APPENDIX A (8 pages) - **Test Data On Components Used In FAA Program**	1 - 1
APPENDIX B (3 **pages**) - **Multilayer Liner Concept Sketches**	2 - 1
APPENDIX C **(10 pages) - Test Photographs**	3 - 1

LIST OF ILLUSTRATIONS

Figure		Page
1	Drop Tower	4
2	Drop Tower Buckling Test on DC-7 Wing Tank Section	6
3	Typical Damage Sustained by DC-7 Tank After Buckling Test	7
4	Drop Tower Slashing Test on DC-7 Wing Tank Section	9
5	Typical Damage Sustained by DC-7 Tank After Slashing Test	10
6	Drop Tower Penetration Test on DC-7 Wing Tank Section	12
7	Typical Damage Sustained by DC-7 Tank After Penetration Test	13
8	Fuel Flow Test Fixture	15
9	Side View of Fuel Flow Test Showing Curtain Position At Initial Valve Opening	16
10	Fuel Flow Test Showing Curtain Position After Substantial Loss of Fluid	17
11	Slosh Test Tank on Tilting Table	19
12	Simulated Wing Section Test Tank With Leading Edge	21
13	Penetration Test on Simulated Wing Section (Outside View)	27
14	Penetration Test on Simulated Wing Section (Inside View)	28
15	Fuel Flow Test Showing Curtain in Position Over Wound	30

INTRODUCTION

This program was initiated to investigate the use of elastomer coatings, curtains, and other more novel materials to eliminate or reduce the amount of post-crash fuel spill from aircraft fuel tanks.

It was felt that selective application of the above materials while not completely eliminating fuel spill could provide some control of the spillage. Reduction in fire potential resulting from control of fuel spillage might allow those passengers able to survive the crash impact, sufficient time to safely evacuate the aircraft.

This report is divided into six sections and outlines the program followed in the evaluation of the various containment methods. The first section pertains to materials selection, the second to test program, the third to elastomeric liner concepts, the fourth to intermittently supported curtain concepts, the fifth to multilayer liner concepts, and the sixth section to actual aircraft wing section tests.

DISCUSSION

Materials Selection

As directed in the statement of work, the data contained in the final report of Contract No. FA 67NF-245, "An Engineering Investigation and Analysis of Crash-Fire Resistant Fuel Tanks", were used as a guideline in the selection of materials for evaluation. Materials selected for this program were those currently in use and known in the industry as being suitable for immersion in, or exposure to, all types of aircraft fuels. Descriptions of the different materials are included in the discussion of specific containment concepts in which they are utilized. Physical test data of the materials used are included in Appendix A of this report.

Test Program

The vertical drop tower at the Wingfoot Lake Test Facility was utilized in screening tests conducted on the elastomeric and multilayer liner concepts while a static test fixture was designed and fabricated for fuel flow screening and slosh test of the curtain concepts. All aircraft wing section tests were conducted on the vertical drop tower.

The vertical drop tower, reference Figure 1, is capable of lifting and dropping test articles of up to 5 tons by quick release at heights of up to 85 feet maximum. The drop pad is a 10 - x 10 - x 4 - foot thick block of reinforced concrete under a 1-inch thick steel plate. Vertical cables are provided for attachment of guide plates to control test article attitude during drop. Impact "G's" are measured and recorded through use of accelerometers and a Honeywell Visicorder having a chart speed of 50 inches per second.

Three types of impact tests, buckling, slashing and penetration were conducted on the vertical drop tower. All simulated wing section tests were conducted with the tank filled two-thirds full with water (40 gallons) while all aircraft wing section tests were conducted with the fuel cavity filled with 68 gallons of water which was approximately two-thirds the tank capacity of the sections used in the control tests. This figure was used regardless of actual tank size to allow determination and comparison of the rate of loss of test fluid. **Simulated wing sections were fabricated from 0.062-inch thick 2024-T4 aluminum alloy and used for preliminary screening tests in**

FIGURE 1   DROP TOWER

order to conserve on the short supply of DC-7 wing tank sections which were used in the final acceptance tests of each concept.

Buckling Test - The buckling test was conducted on the simulated wing sections with a 15-foot drop and on the aircraft wing sections with a 40-foot drop. The buckling obstacle was a vertical stack of railroad ties approximately 7 inches wide. Crushable corrugated fiberboard columns were used each side of the obstacle to limit penetration to approximately one-half the depth of the forward fuel cavity. Guide plates were attached to the forward and trailing edges of the test sections and to the vertical cables to insure impact at the approximate center and at an angle of 90° to the front spar of the wing section and to the forward surface of the simulated wing section. See Figures 2 and 3.

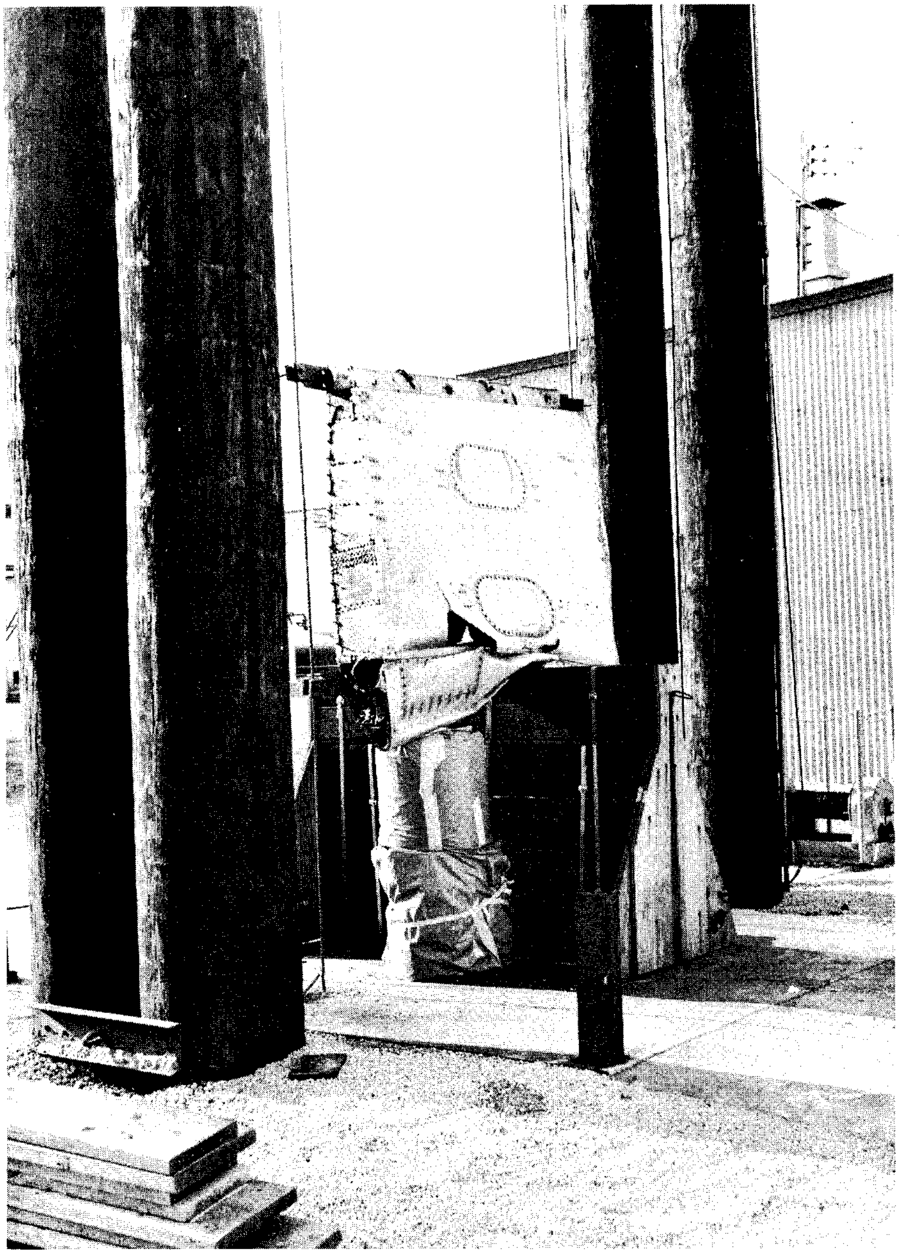

FIGURE 2 DROP TOWER BUCKLING TEST ON DC-7 WING TANK SECTION

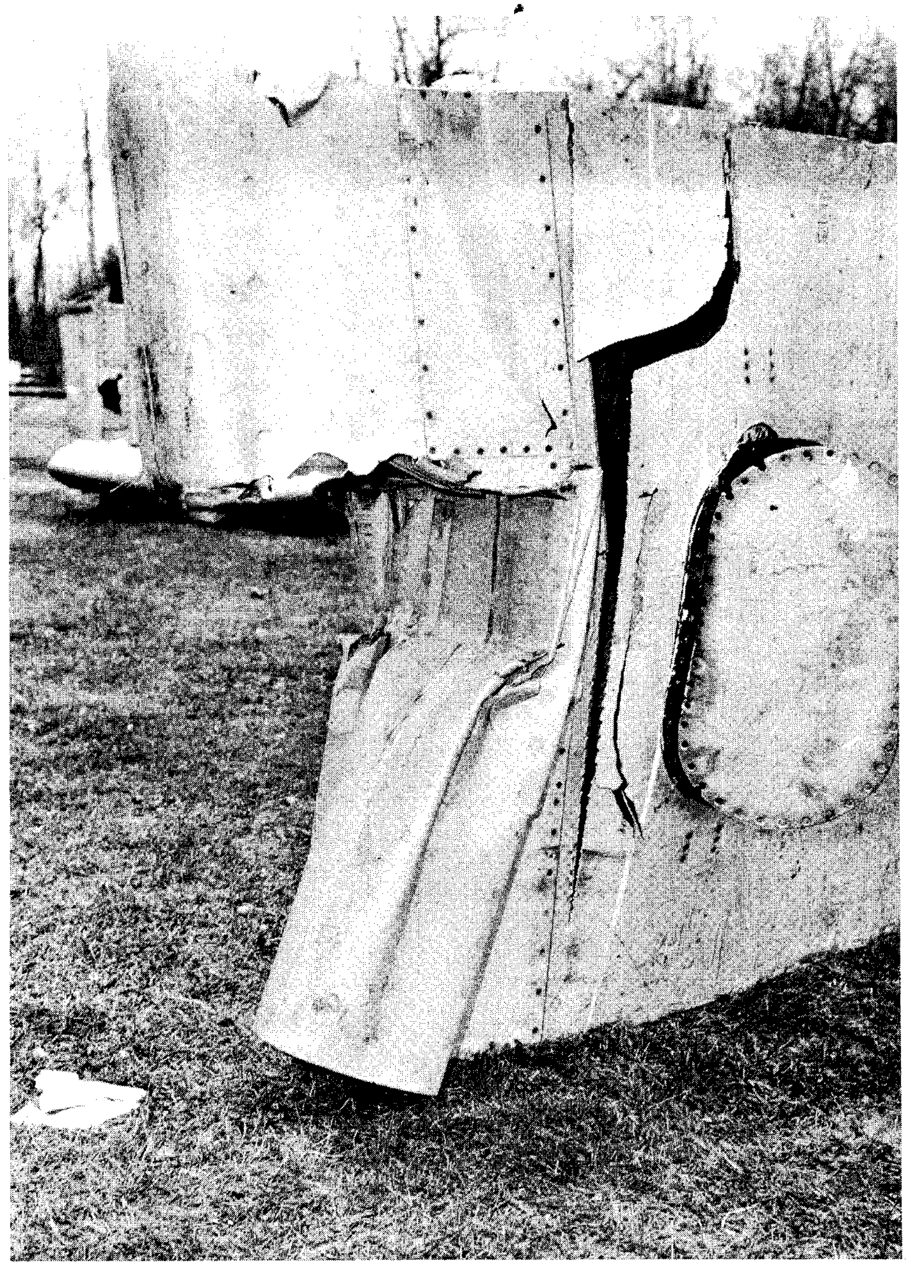

FIGURE 3 TYPICAL DAMAGE SUSTAINED BY DC-7 TANK AFTER BUCKLING TEST

Slashing Test - The slashing test was conducted on the aircraft wing sections only. The drop height was 20 feet. The slashing obstacle is the buckling obstacle with a 4-inch "I" beam attached to the top and extending beyond the end of the ties approximately 12 inches. The guide plates were attached to the wing so as to insure impact at the center lower half of the leading edge. Impact was normal to the wing bottom causing slashing of the wing bottom one-half to two-thirds the depth of the forward fuel tank. Depth of penetration was controlled by corrugated fiberboard columns located each side of the impact obstacle. See Figures 4 and 5.

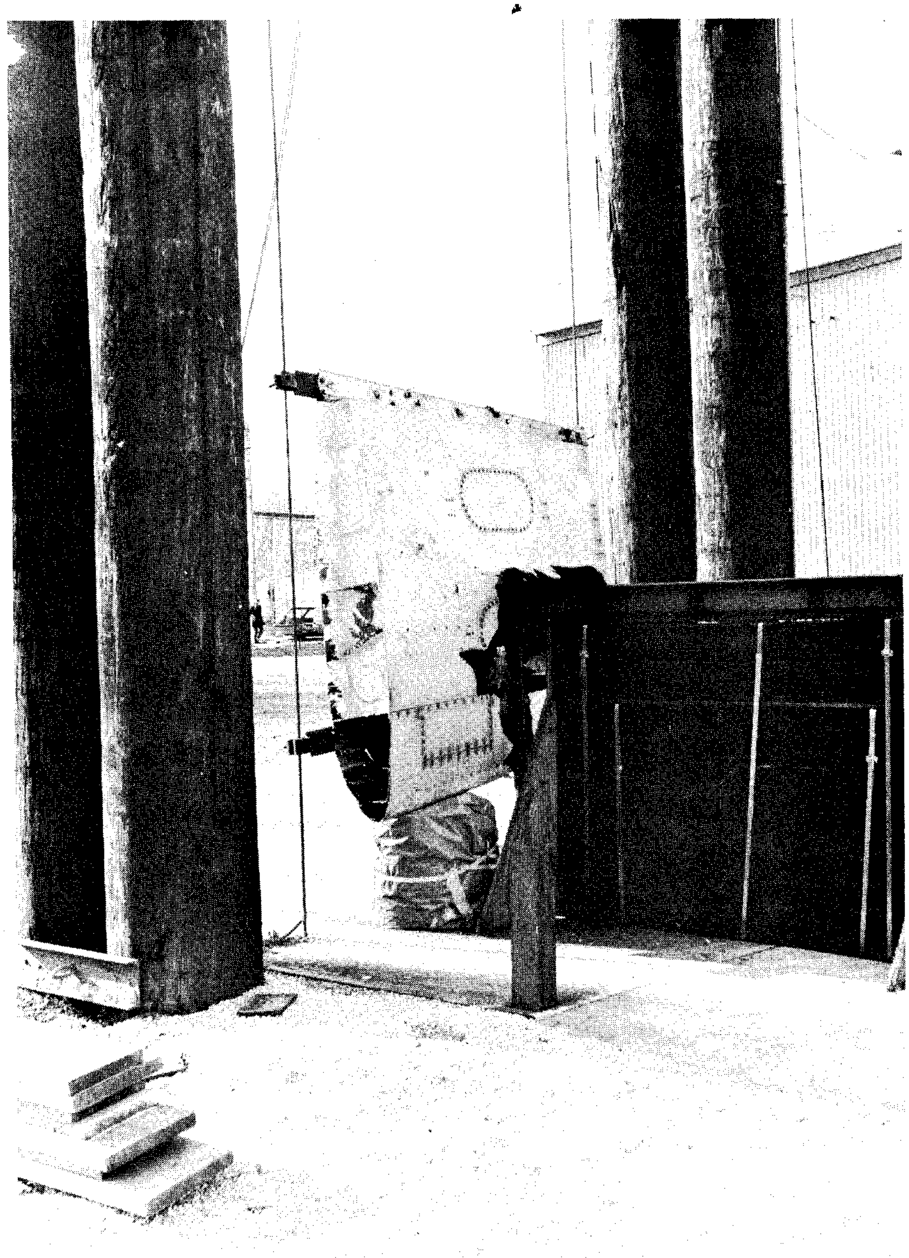

FIGURE 4 DROP TOWER SLASHING TEST ON DC-7 WING TANK SECTION

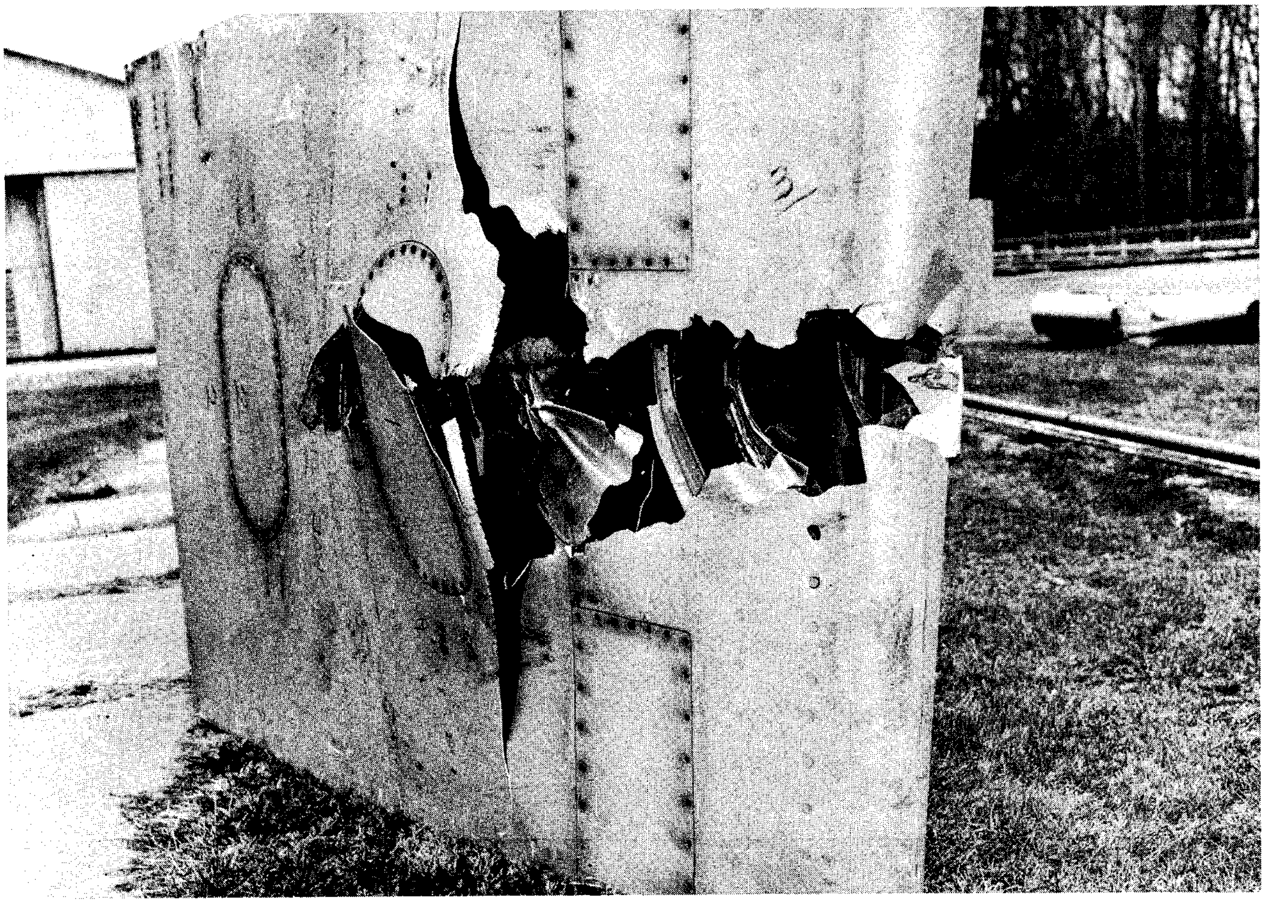

FIGURE 5 TYPICAL DAMAGE SUSTAINED BY DC-7 TANK AFTER SLASHING TEST

Penetration Test - The penetration test was conducted on the simulated wing sections with a 10 foot drop and on the aircraft wing sections with a 20 foot drop. The penetration obstacle was a 22-inch length of 4-inch pipe welded to a base plate and having a 2½-inch pipe placed inside and extending 7 inches above the 4-inch pipe. Guide plates were attached to the wing section so as to cause impact to occur on an axis extending through the front lower edge and the aft upper edge of the fuel cavity. The DC-7 wing tank sections had an impact angle of approximately 75° so that the penetrating obstacle fractured the lower forward wing spar before entering the fuel cavity. However, because of the comparatively small size of the simulated wing sections, the impact angle was set at 90° to the forward surface to insure impact and penetration. Corrugated fiberboard columns were used to limit penetration damage to the forward fuel cavity only. See Figures 6 and 7.

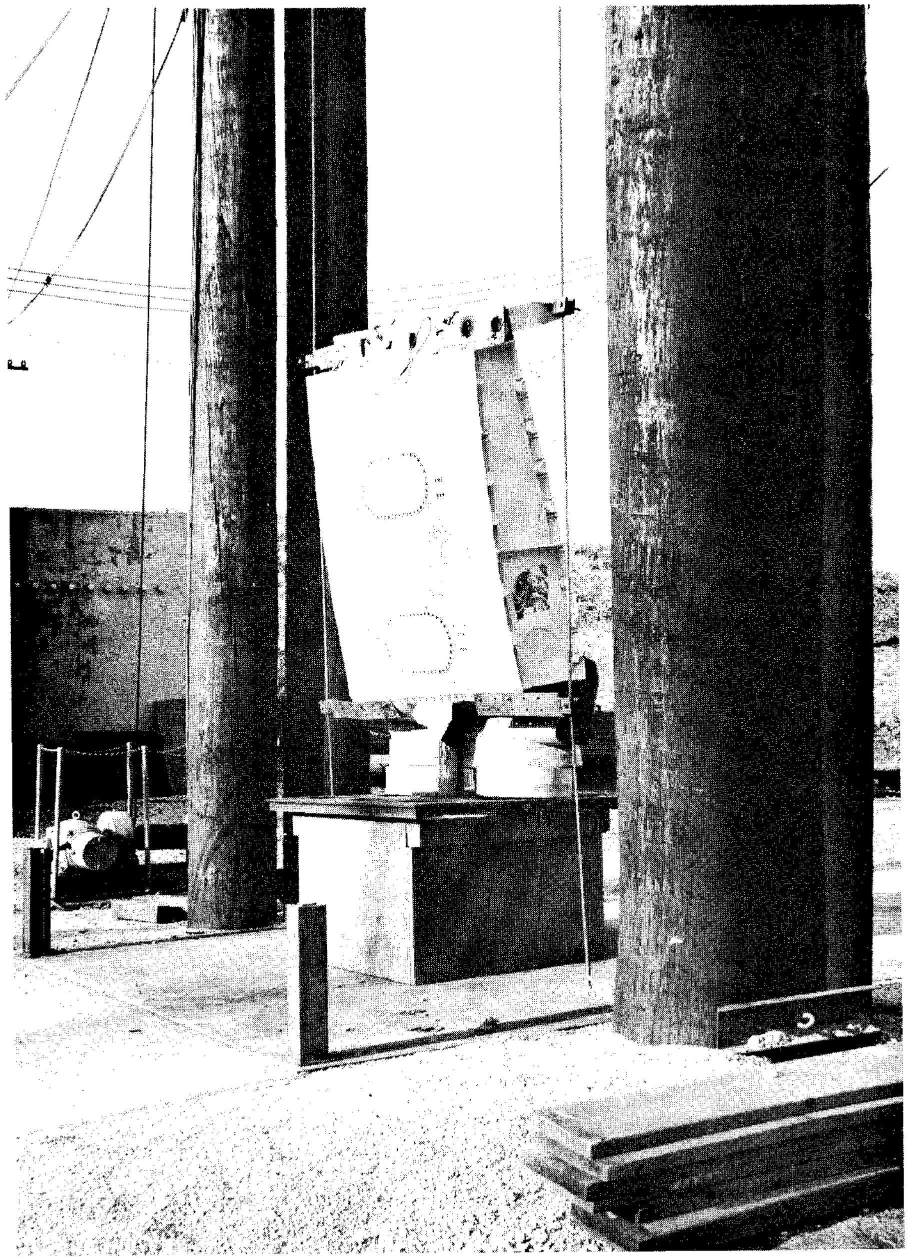

FIGURE 6 DROP TOWER PENETRATION ON DC-7 WING TANK SECTION

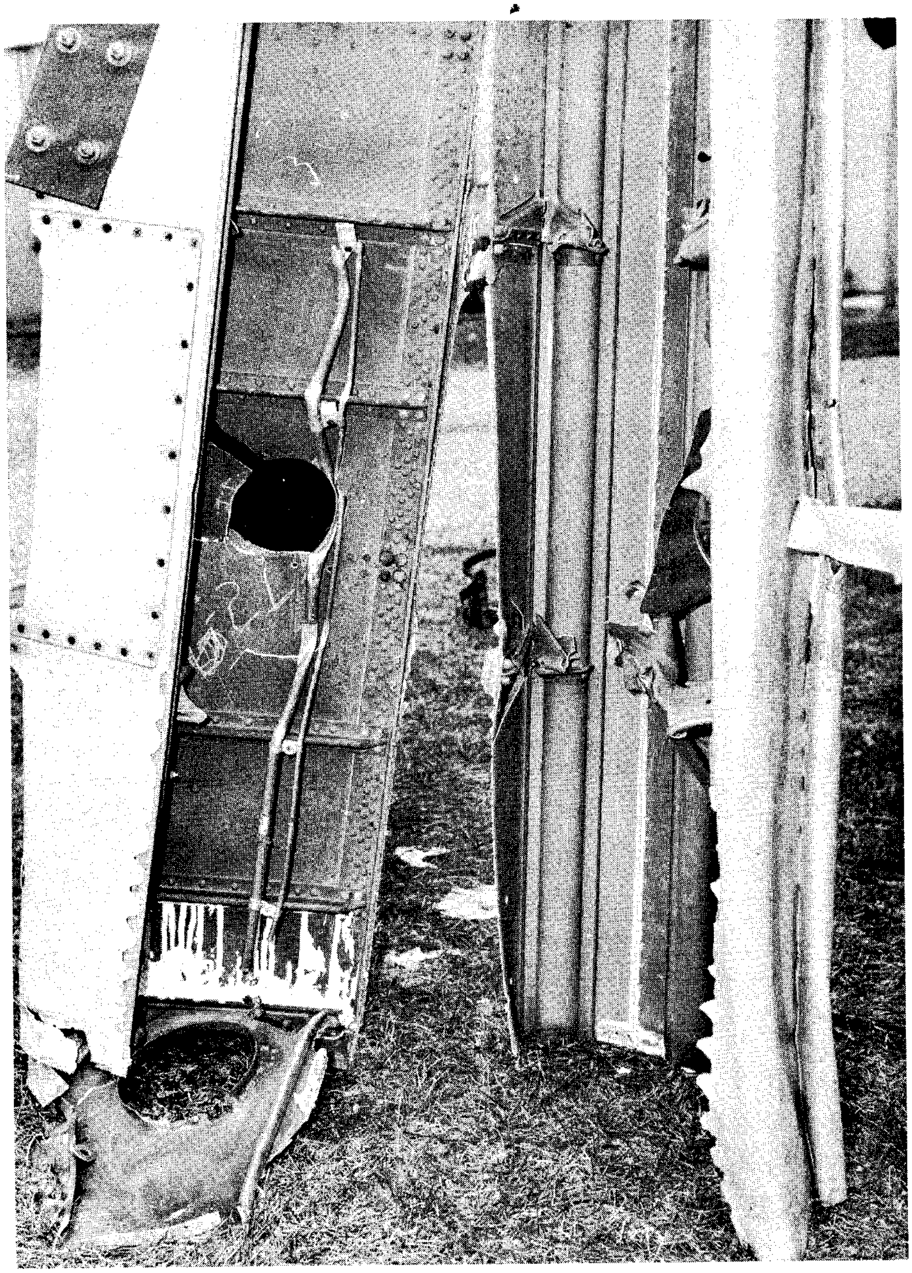

FIGURE 7 TYPICAL DAMAGE SUSTAINED BY DC-7 TANK AFTER PENETRATION TEST

Fuel Flow Test - The fuel flow test fixture utilized in screening curtain concepts was a simulated wing test structure having a prearranged penetration wound. A quick disconnect fitting with a 4-inch inside diameter with jagged sheet metal tabs approximately 3 inches long attached to the fuel side was installed in the tank forward face to simulate the penetration wound. A clear plastic side and forward face were installed to allow visual observation of curtain action during fluid dumping tests. The test fixture with curtain installed was set on drums with the forward face oriented horizontally approximately 30 inches from the ground. The tank was filled with 40 gallons of test fluid (water). Upon opening the quick disconnect valve the fluid was dumped, the curtain action was observed and the total time to drain was noted. See sequence of flow test photographs, Figures 8, 9, and 10.

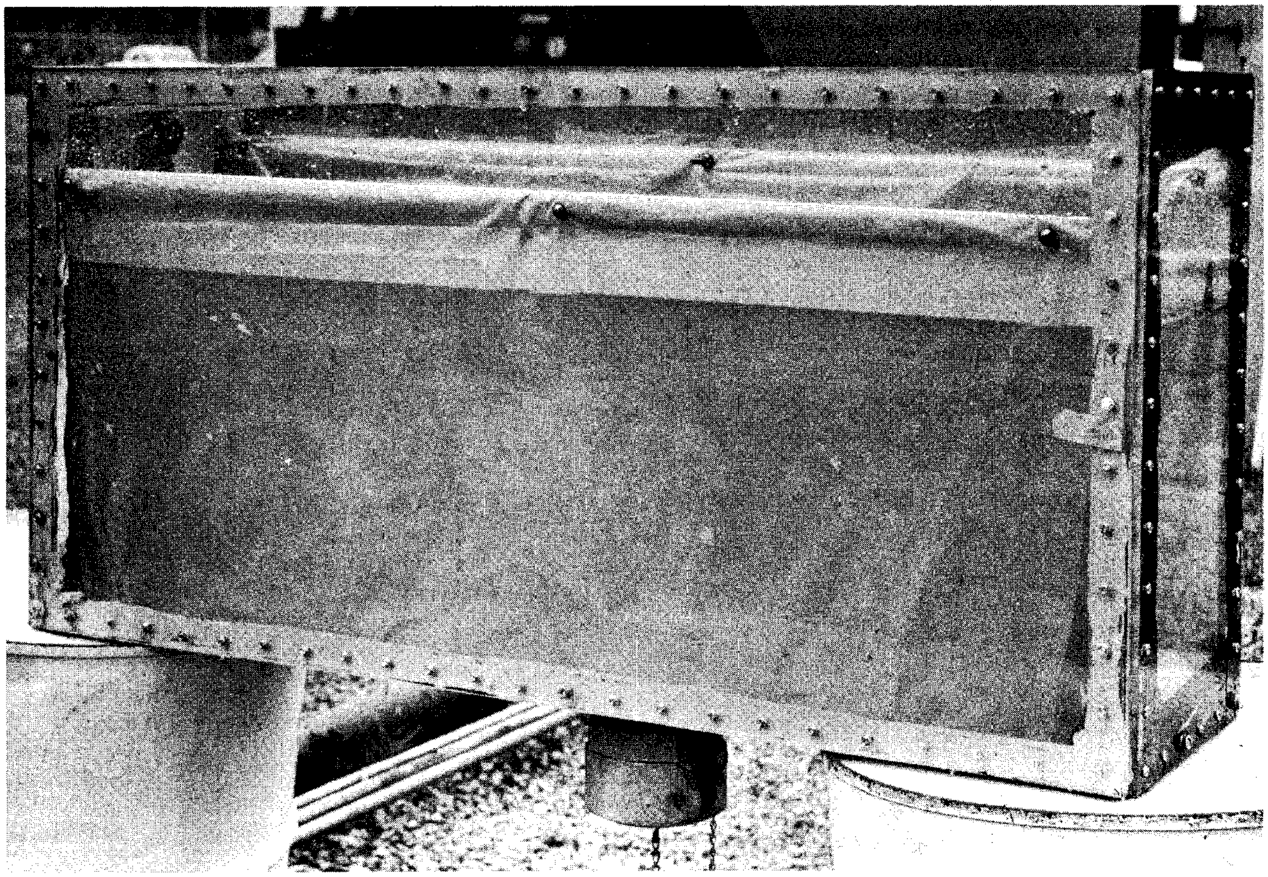

FIGURE 8 FUEL FLOW TEST FIXTURE

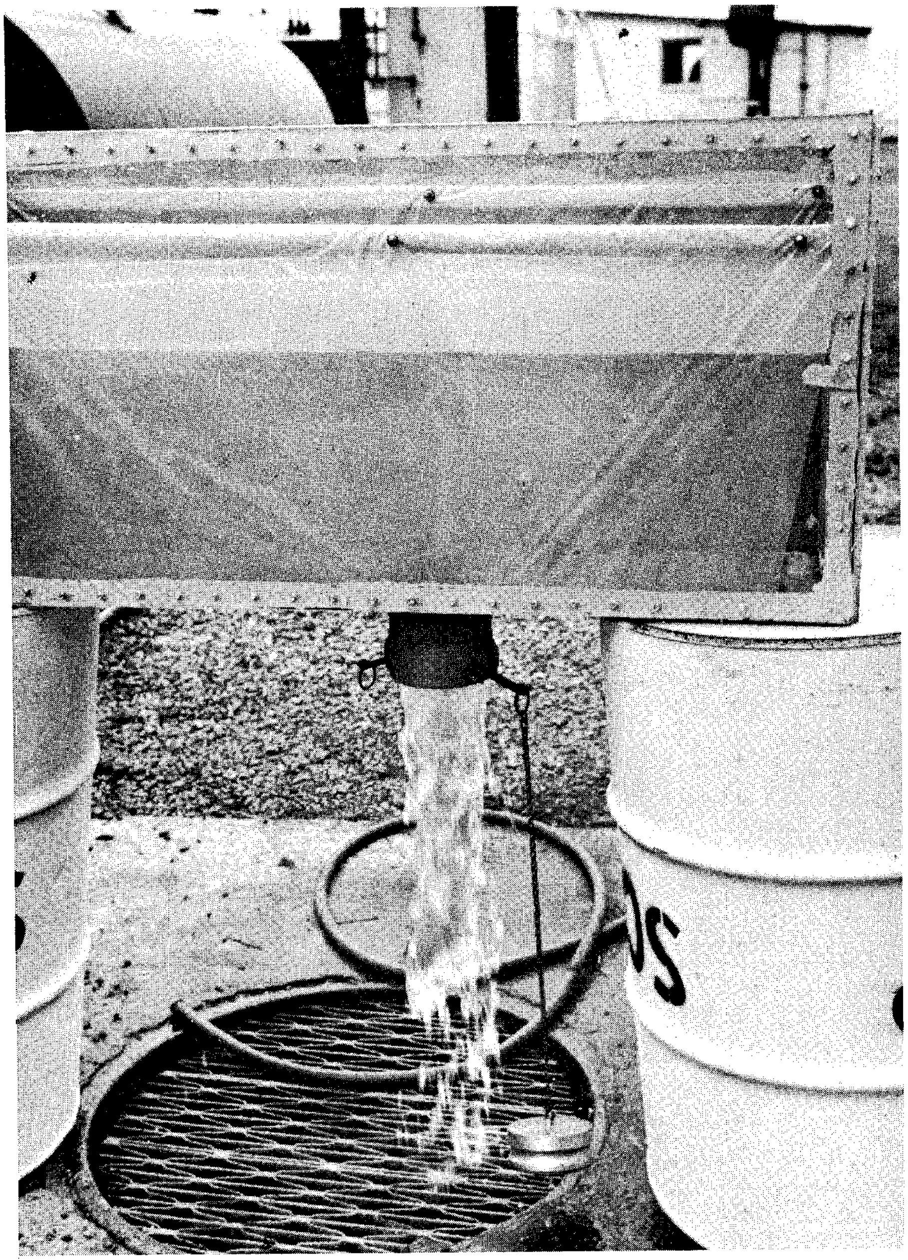

FIGURE 9 SIDE VIEW OF FUEL FLOW TEST SHOWING CURTAIN POSITION AT INITIAL VALVE OPENING

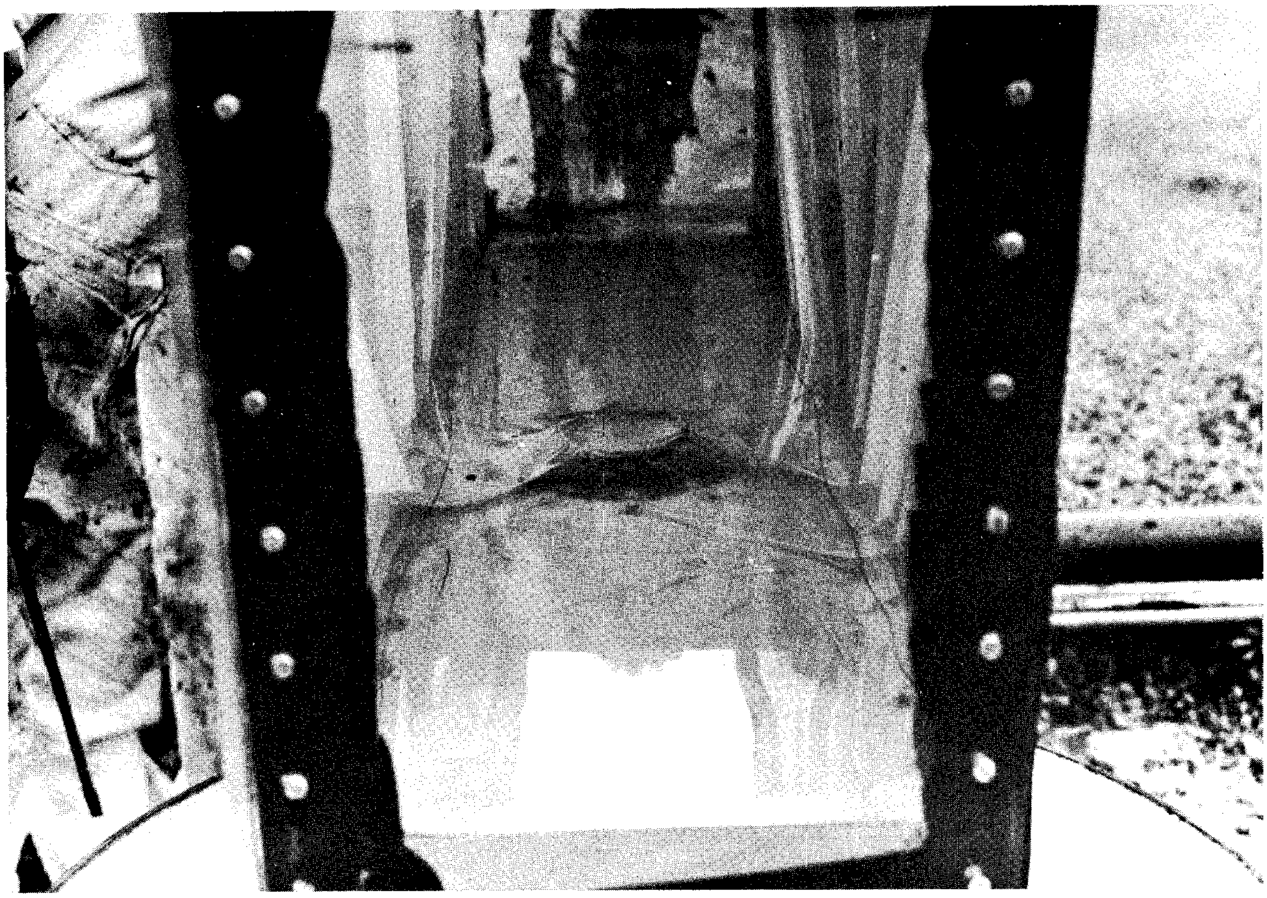

FIGURE 10 FUEL FLOW TEST SHOWING CURTAIN POSITION AFTER SUBSTANTIAL LOSS OF FLUID

Slosh Test - The slosh test was conducted on the most promising curtain concept as determined from results of the fuel flow tests outlined above. The fuel flow test fixture was used in this test. With curtain installed, it was filled with 40 gallons of test fluid, mounted on the slosh table with the forward surface perpendicular to the axis of rotation and rocked at 17.25 cycles per minute, 15° each side of horizontal, for a total angle of 30°. The purpose of this test was to determine attachment requirements and slosh characteristics of the curtain. See Figure 11.

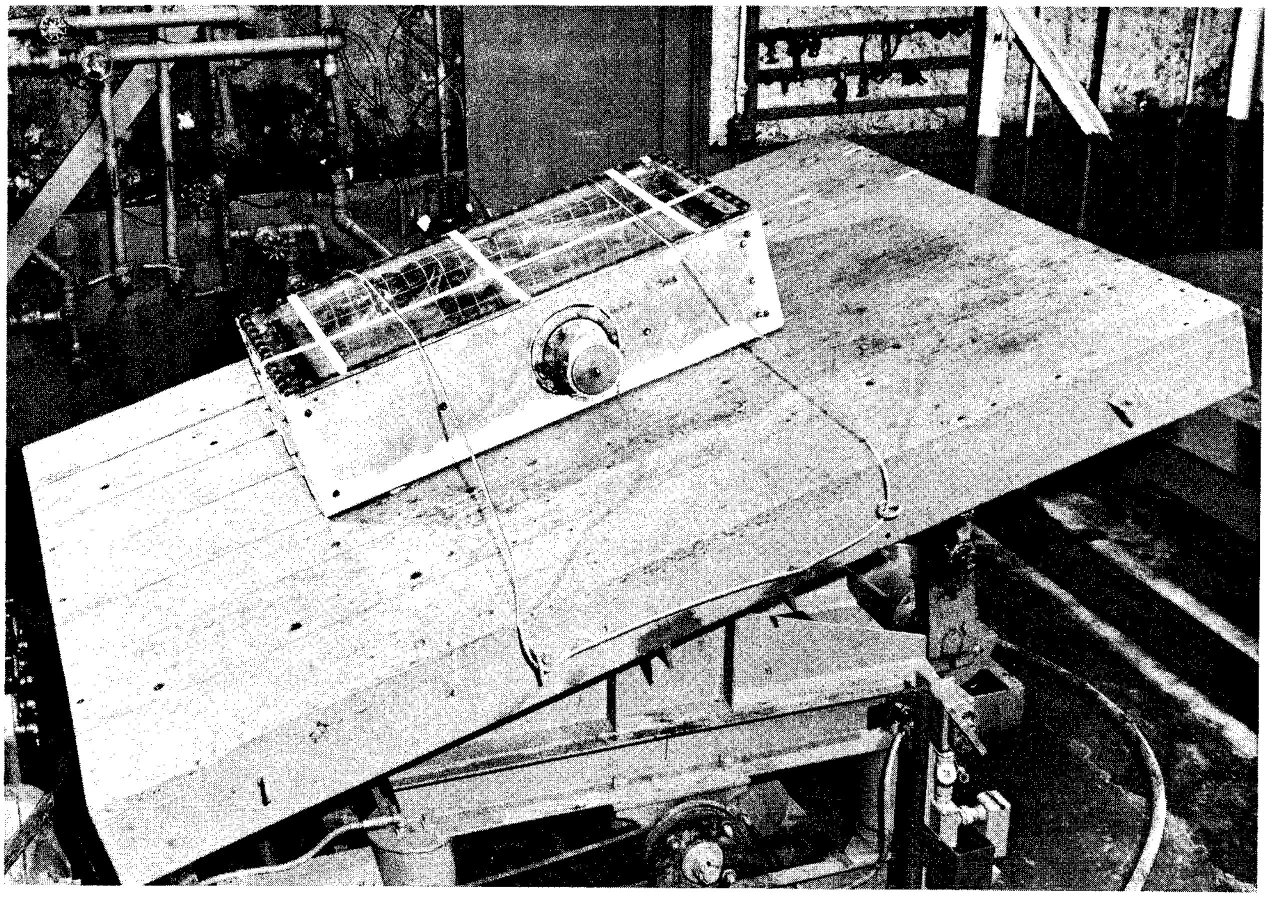

FIGURE 11 SLOSH TEST TANK ON TILTING TABLE

Elastomeric Liner Concepts

A total of five different elastomeric liner concepts were subjected to screening tests to determine the system most suitable for evaluation in aircraft wing section tests. These tests were conducted utilizing the simulated wing structure. Figure 12 shows one of these structures with leading surface fairing as,first used. The following is a description of each of the elastomeric liner concepts followed by a brief discussion of the test results and the selective changes incorporated in subsequent liner concepts.

Liner Concept No 1 - Liner material was a Goodyear "Vithane" aircraft fuel tank innerliner material 2329C (physical properties contained in Appendix A), built up to 0.030-inch thickness by spray coat application. Total weight was approximately 0.1875 psf. The liner was attached to the structure at the top and bottom surface trailing edges using a metal strip and machine screws. This method of attachment was used for all liner and curtain concepts evaluated in this program. Position within the fuel tank cavity was maintained through use of nylon hook and eye material which has a high shear strength, but relatively low peel strength.

Buckling Test - Instrumentation recorded a peak load of 300 G's. The tank was ruptured at one of the forward corners with approximately 15 inches of vertical and 20 inches of horizontal seam opened up. The leading surface of the tank was indented approximately 4 inches. The liner pulled in approximately 1-inch from each end and was found to be undamaged. The test fluid (40 gallons of water) drained from the tank in 120 seconds.

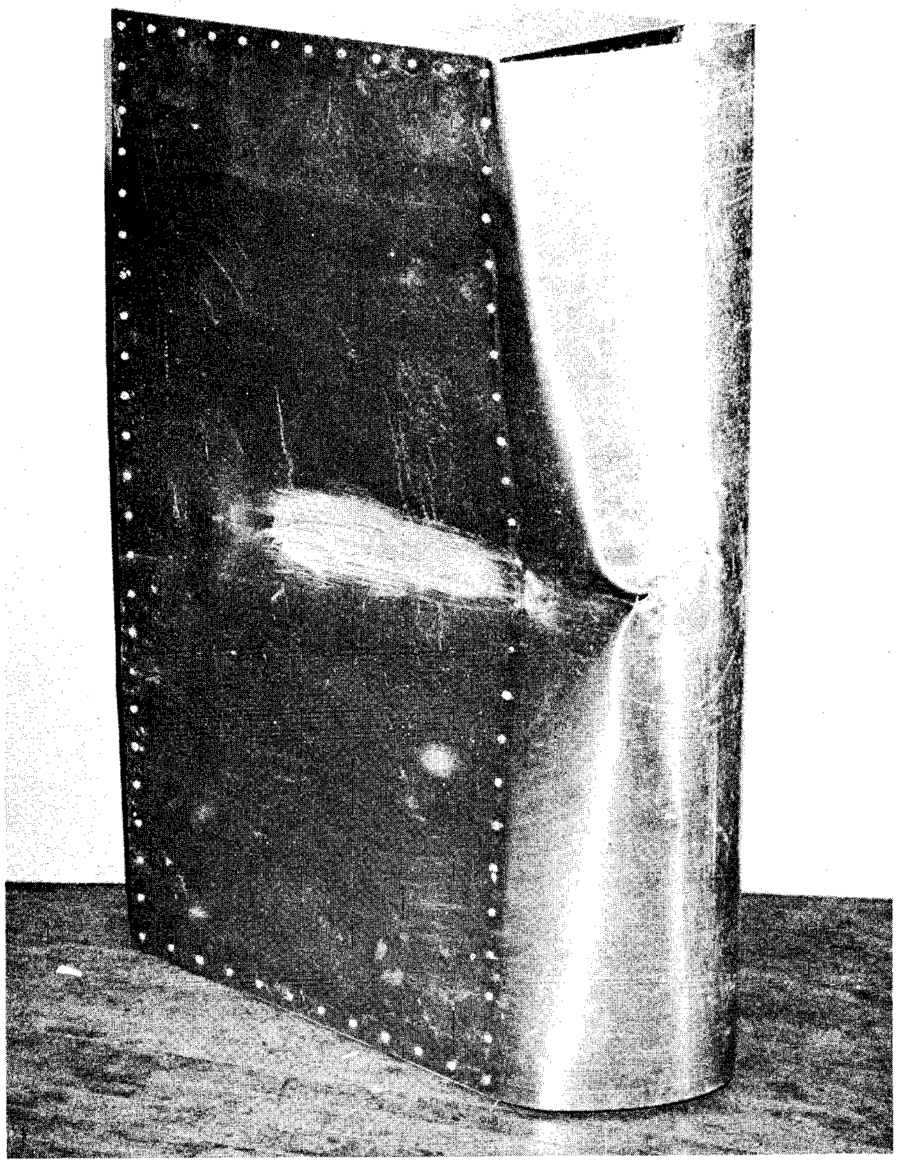

FIGURE 12 SIMULATED WING SECTION TEST TANK WITH LEADING EDGE

Penetration Test - Instrumentation recorded a peak load of 270 G's during impact. The forward fairing (simulated leading edge) was penetrated producing a 4-inch diameter hole and the front surface of the tank pushed back about 4 inches breaking loose the entire seam along one edge and both end seams. The test fluid drained from the tank in 40 seconds.

The inability of the penetration obstacle to penetrate both the fairing and the fuel cavity with any degree of reliability as demonstrated in the above and control tests necessitated eliminating the fairing for all subsequent tests. It was felt that in as much as the tests were comparative in nature and that penetration of the cavity was desirable the most suitable means of attaining penetration was to remove the fairing and thereby provide a flat impact surface.

An additional structure (no fairing) with Liner Concept No. 1 installed was subjected to penetration test. The obstacle penetrated the simulated wing section 1-inch from the leading edge coring out a 3-inch diameter piece of structure, leaving a 4-inch diameter hole with a 4-inch tear extending from it. The liner was pulled in from the inboard and outboard edges approximately 1-inch and was pierced by the impact obstacle leaving a 6.5-inch tear. The test fluid drained in 120 seconds. Instrumentation recorded 30 G's.

As a result of the above tests it was felt that use of the reticulated foam, frangible bond as outlined in the final report Contract No. FA-67NF245 in conjunction with the Vithane liner would be an improvement over Liner Concept No. 1.

Liner Concept No. 2 - A 1.5-inch thick protective layer of reticulated polyurethane foam was adhered to the inside leading, top and bottom surfaces of the tank cavity using a polyurethane adhesive. The 0.030-inch thick Vithane liner was adhered to the foam using a polyurethane adhesive. Total weight was approximately 0.5010 psf.

Buckling Test - Instrumentation recorded a peak load of 100 G's. The lead surface of the tank 12 by 48 inches had seam failures in both the top and bottom seams. The bottom seam opened 24 inches at the tank center while the top seam opened 14 inches near one end. A 6-inch by 1.5-inch hole was torn in the bottom surface approximately 3 inches from and adjacent to the 24-inch seam failure. The test fluid drained from the tank in 55 seconds.

Penetration Test - Instrumentation recorded a peak load of 32 G's during impact. The center of the obstacle impacted the tank approximately 3.5 inches from the edge, punching a 5-inch hole through the lead surface. The obstacle penetrated the liner leaving a 4-inch long crescent tear upon removal. The test fluid drained in 85 seconds.

During the tests conducted on Liner Concept No. 2 it was found that while the foam did seem to improve the puncture resistance of the liner, on recovery after impact it provided an efficient path for escape of the test fluid. As a result of preceding tests it was decided to switch to a lower modulus material, nitrile gumstock, in an attempt to provide a liner less suceptible to tearing upon puncture.

Liner Concept No. 3 - Liner material was Goodyear nitrile gum stock M863 compound approx 0.050-inch thick and weighing 0.312 psf. Liner position within the fuel tank cavity was maintained through use of nylon hook and eye fasteners.

Buckling Test - Instrumentation recorded 75 G's during impact. The entire forward surface of the tank broke loose on impact. The test fluid drained from the tank in 45 seconds. There was no damage to the liner.

Penetration Test - Instrumentation recorded 45 G's during impact. The impact obstacle penetrated the structure leaving a 4-inch hole. Seam failure occurred at a corner of the top surface of the structure, 10 inches along the top seam and 6 inches along the end seam. The test fluid drained in 50 seconds. There was no damage to the liner.

Analysis of test run to this point revealed that the liners appeared able to survive impact with little or no damage. However, forces created in deformation of the tank leading surface were sufficient to pull the liner loose from the frangible bond or fasteners which allowed the test fluid to flow out between the liner and the tank liner wall.

It was decided to build all future liners with ends to prevent loss of fluid due to displacement of the liner at impact, and also to weld all structures in an attempt to limit structural failures to the immediate area of impact.

Liner Concept No. 4 - Liner material was Goodyear nitrile gum stock M863 compound approximately 0.050-inch thick and weighing 0.312 psf. The liner was built with ends. The ends were not fastened to the structure. Liner position within the cavity was maintained through use of nylon hook and eye fasteners.

Buckling Test - Instrumentation recorded 120 G's during impact. Both the top and bottom faces of the structure had 3-inch and 4-inch tears approximately 7 inches apart. A seam failure 7 inches long occurred adjacent to the impact area. No appreciable amount of test fluid was lost. There was no damage to the liner.

Penetration Test - The penetration obstacle penetrated both the structure (5-inch diameter hole) and the liner (2-inch diameter hole). Rate of test fluid loss was approximately 1.5 quarts per minute. Instrumentation recorded 39 G's during impact. As a result of this test and subsequent review of results with NAFEC, it was decided to conduct an additional penetration drop test on Liner Concept No. 4 with additional protection in the impact area to prevent puncture of the liner.

Liner Concept No. 5 - Same as Liner Concept No. 4, except a 24 oz square woven nylon fabric was installed between the liner and the structure in the area of impact.

Penetration Test - The pipe penetrated the structure but did not pierce the liner. There was no loss of test fluid. The test structure was dropped a second time with impact occurring approximately 12 inches from the first impact area. Depth of penetration was deeper than the previous drop. There was no damage to the liner in the area of the second impact; however, a jagged piece of structure at the original impact area cut the fabric and the liner (2-inch cut). Fluid loss on the second drop was 6 gpm. A 4-inch diameter hole was punched in the structure on the first drop and a 5-inch diameter hole on the second drop. The welded seams, top and bottom edge of the leading surface, failed between the two impact areas during the second drop. Instrumentation recorded 15 G's during both drop tests. Figures 13 and 14 show the results of the above penetration test performed on a structure with the leading surface fairing removed and seams welded.

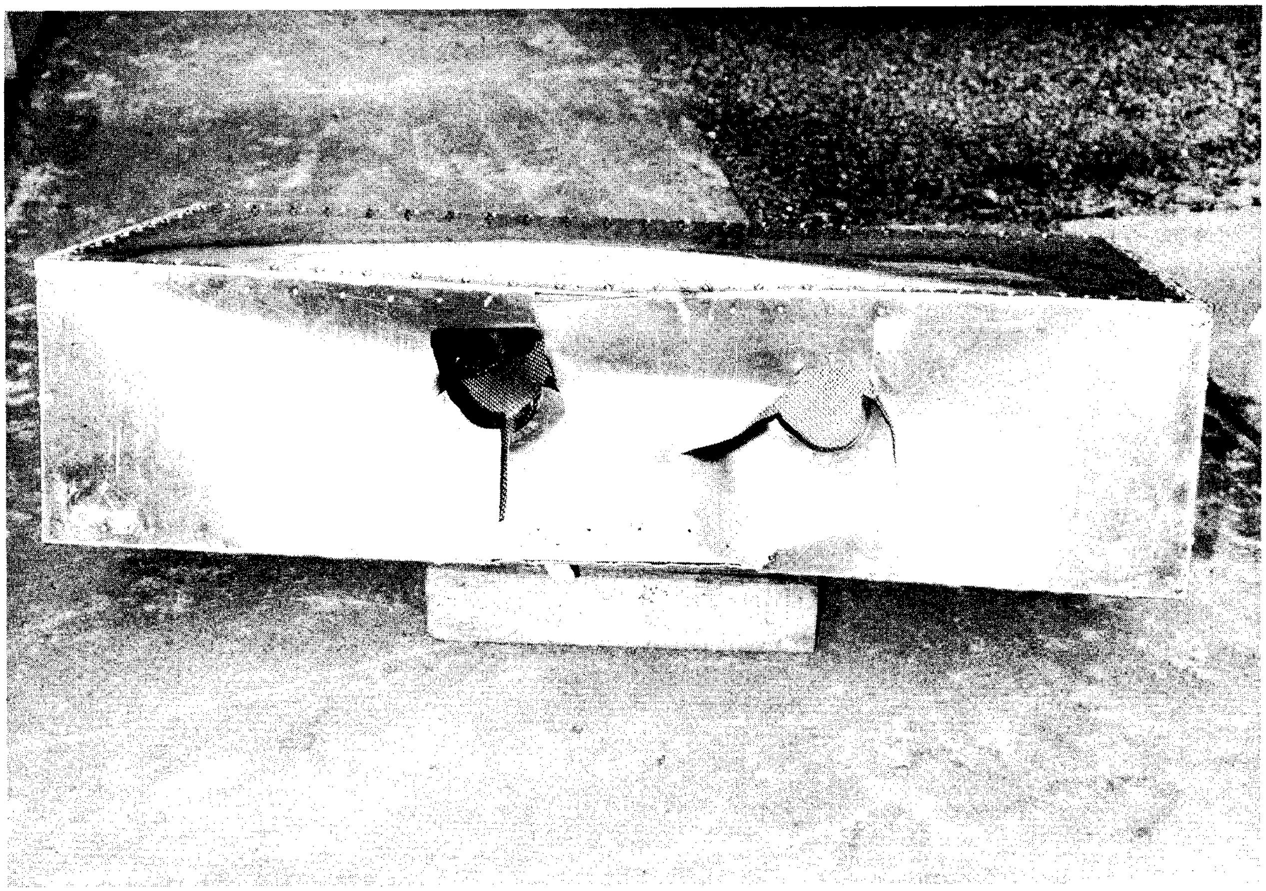

FIGURE 13 PENETRATION TEST ON SIMULATED WING SECTION (OUTSIDE VIEW)

FIGURE 14 PENETRATION TEST ON SIMULATED WING SECTION (INSIDE VIEW)

Curtain Concepts

The objective of the curtain concept of fuel containment was to utilize fluid flow in conjunction with flexibility of relatively thin (less than 0.030-inch) intermittently attached lightweight curtains to inhibit loss of fluid and prevent or minimize fuel spray or misting upon impact.

A total of eight different concepts varying from unreinforced flexible films to elastomeric coated fabrics were fabricated and subjected to the fuel flow tests to determine the best candidate for further evaluation on slosh test. The following is a description of each of the curtain concepts and results of the fuel flow testing.

Curtain Concept No. 1 - A polyethylene film curtain 0.002-inch thick was fastened in the structure and covered the top, forward, and bottom surface to within 4 inches of the aft end of the cavity. No fastenings were used to maintain curtain position within the cavity. Upon opening the quick disconnect there was a full stream for 1 minute. A 50 percent reduction in flow for an additional 1.5 minutes emptied the structure. The curtain floated freely in the test fluid and did not move into position over the wound as a result of the test fluid movement. Two small punctures occurred in the curtain on contact with sharp edges of the wound.

A second 0.002-inch thick polyethylene film was installed as before and the curtain positioned so as to lay relatively close to the front, bottom, and top surface of the structure. Position was maintained by securing the top and bottom leading edges with piano wire across the full width of the tank. Upon release of the quick disconnect there was full flow for approximately 2 minutes and 30 percent flow for an additional 2 minutes. Figure 15 shows the curtain in position over the wound, also shown are the piano wires used to maintain curtain position prior to test.

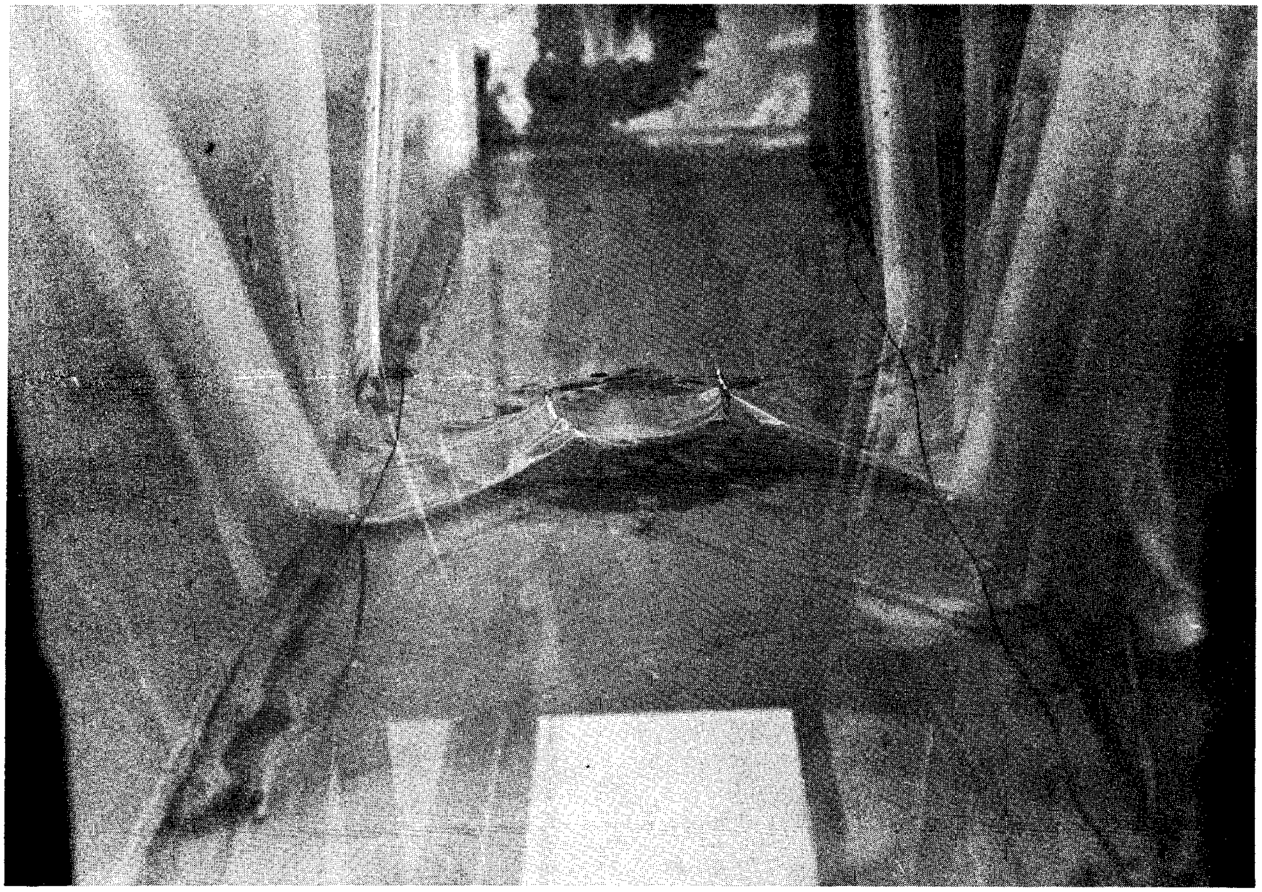

FIGURE 15 FUEL FLOW TEST SHOWING CURTAIN IN POSITION OVER WOUND

As a result of the above tests it was felt that curtain position within the structure would have to be maintained in close proximity to the wound to insure any degree of success. Subsequent tests were conducted with curtain position maintained through use of piano wire as was done for Test No. 2 of Curtain Concept No. 1.

Curtain Concept No. 2 - Polyethylene film curtain 0.003-inch thick. Upon release of the quick disconnect there was full flow for 25 seconds dumping approximately 50 percent of the test fluid. The remaining fluid required 6.08 minutes to drain.

The curtain while of sufficient length to cover the inside top, bottom and forward surface of the structure was too short to encapsulate and seal the wound area effectively. Approximately 10 percent of the length of the area to be protected was added to curtain length for the remaining tests.

Curtain Concept No. 3 - Blue polyethylene film 0.006-inch thick - Upon release of the quick disconnect there was full flow for 10 seconds reducing to 50 percent flow for an additional 30 seconds at which time the curtain was completely covering the wound. Total time to drain was 5 minutes. Holes were punched in the film where the curtain lay across the jagged edges of the wound.

The susceptibility of the unreinforced films to puncture as demonstrated in the testing of Concepts No. 1 and No. 3 resulted in a decision to terminate evaluation of this type material for curtains. All additional tests were run on curtain concepts employing fabric reinforcement.

Curtain Concept No. 4 - Neoprene coated nylon fabric having a total thickness of 0.007 inches. Upon release of quick disconnect there was full flow for 10 seconds. The flow diminished to approximately 25 percent in 2 minutes at which time one-half the test fluid had been lost. Total time to drain was 4.5 minutes. The curtain was observed to fold across the wound, thereby, providing a channel for the fluid to escape.

The neoprene coated fabric chosen for Curtain Concept No. 4, while not particularly suitable for long term exposure to aircraft fuels, was readily available and was selected solely to allow comparison of a spread fabric curtain with one that was spray coated. It was noted that the neoprene coated curtain was more flexible than the spray coated fabric comparing favorably with Curtain Concepts Nos. 7 and 8 of approximately one-half the gauge and weight.

Curtain Concept No. 5 - Five oz nylon fabric spray coated (mist) with Vithane, 2329C, one side only. Total thickness was 0.024-inch. Upon release of the quick disconnect there was full flow for 25 seconds, diminishing to 50 percent flow for the remainder of the test. Total time to drain was 3 minutes.

Curtain Concept No.6 - Eight and one-half oz nylon fabric spray coated (mist) with Vithane 2329C, one side only. Total thickness was 0.015-inch. Upon release of the quick disconnect there was full flow for 15 seconds and approximately 40 percent flow for the remainder of the test. Total time to drain was 3 minutes.

Both Concepts No. 5 and No. 6 were relatively stiff. The force created by the fluid flow was insufficient to cause either curtain to conform to the wound. Lighter curtains utilizing 2 oz nylon fabrics were selected for Curtain Concepts No. 7 and No. 8.

Curtain Concept No. 7 - Two oz nylon fabric spray coated (mist) with Vithane (2329) one side only; Thickness 0.003-inch. Upon opening the quick disconnect there was an immediate slow down in fluid flow. The curtain moved over and encapsulated the wound completely. Total time to drain was 5 minutes.

It is felt that most leakage was through and not around the curtain in the preceding test, therefore, additional coating was applied for Concept No. 8.

Curtain Concept No. 8 - Two oz nylon fabric mist coated with Vithane, 2329C, one side only to a thickness of 0.004-inch. Upon opening the quick disconnect there was full fluid flow for 7 seconds. The curtain then covered the wound as did Concept No. 7. Total time to drain was 4.5 minutes.

It was evident from observation that the added Vithane coating had decreased flexibility of the curtain and decreased effectiveness considerably.

As a result of the above tests, Curtain Concept No. 7 was selected for slosh tests to determine attachment requirements and to provide a visual record of slosh characteristics. A total of four different slosh tests was conducted and three different attachment methods were evaluated.

Test No. 1 - The curtain was installed in the structure using metal strips and machine screws. No fasteners or attachments were used to maintain curtain position during the first test. Upon start of sloshing, the curtain moved from the forward face of the structure to the center area. Movement of the curtain due to fluid motion was similar to that of a flag in gusting winds.

Test No. 2 - Three glove snap fasteners, provided at each end of the curtain forward face, were attached with male part installed in the structure. During the first few minutes of slosh, the fluid movement in the tank disengaged the center and top glove snap on both ends of the curtain. The test was discontinued at this point.

Test No. 3 - A curtain was installed using nylon hook and eye fasteners at both ends the length of the top, bottom and forward surfaces. The force of the fluid was sufficient to pull the curtain free from the structure on the top and forward surfaces during the first minute of testing.

Test No. 4 - A curtain was installed using soft wire across the entire leading surface top and bottom edges to maintain position similar to the system used in the fuel flow tests.

Considerable curtain movement was noted during the slosh test; however, the position within the structure remained substantially the same throughout the test.

It should be noted that while the use of wire or cord to maintain curtain position in a small structure (60 gallons) was satisfactory, the reliability of such a system in aircraft fuel tanks would be questionable. The forces created by the fuel trapped behind a containment device during slosh are of sufficient magnitude to fail most conventional types of fuel cell attachments.

The design of a system to maintain the position of this type fuel containment device under in-flight conditions, while not an insurmountable task, would entail considerable effort and was beyond the scope of this program.

Multilayer Liner Concepts

A total of 6 multilayer liner concepts was subjected to the penetration drop test in simulated wing sections to determine the system most suitable for evaluation in DC-7 wing section tests. The objective of this phase of the program was to investigate more novel materials than those used in the liner concepts. These materials included impregnated nonwoven fabrics and multi-layered elastomeric/film/fabric combinations. The following is a description of the concepts tested and the results obtained from the penetration drop test. Cross section sketches of the multilayer liner concepts are included as Appendix B of this report.

Liner Concept No. 6 - Liner Concept No. 6 was a two component system utilizing a 12.50 oz-per-sq-yd nonwoven nylon fabric for penetration protection and a 0.005-inch thick nylon film for fluid containment. The nonwoven fabric was adhered to the inside of test structure and the nylon film spot adhered to the nonwoven fabric. A polyurethane air cure adhesive was used for both applications.

Instrumentation recorded 60 G's upon impact. The structure was penetrated coring out a 5-inch diameter section. The nonwoven cloth was torn around the wound and the nylon film punctured. The test fluid drained in 1.66 minutes.

Liner Concept No. 7 - Liner Concept No. 7 utilized 33 oz-per-sq-yd and 9.75 oz-per-sq-yd nonwoven fabrics and 2329C Vithane spray coat. The 33 oz-per-sq-yd fabric was adhered to the top, forward and bottom surfaces of the wing using 2329C. The end caps were fabricated of 9.5 oz fabric and adhered to the structure using 2329C. The entire inside surface of the nonwoven fabric was then sealed by spray coat application of 2329C.

Instrumentation recorded 47 G's upon impact. The structure was penetrated leaving a 5-inch diameter hole. The nonwoven fabric stretched then tore approximately 10 inches dumping the test fluid. Time to drain was approximately 40 seconds.

Liner Concept No. 8 - Liner Concept No. 8 was a two component system utilizing a 24 oz-per-sq-yd square-woven nylon fabric for penetration protection and a 0.005-inch thick nylon film for fluid containment. The liner was installed in the structure using the same procedure as that used for Liner Concept No. 6.

Instrumentation recorded 43 G's upon impact. The structure was penetrated leaving a 5-inch diameter hole with 4-inch and 5-inch long tears to a top and bottom corner. The fabric was undamaged; however, examination of the nylon film revealed an 8-inch tear at the point of impact and 3-inch and 24-inch tears at the junction of the forward and the end surfaces.

Liner Concept No. 9 - Liner Concept No. 9 was a four component system utilizing both 9.75 oz nonwoven and 24 oz square-woven fabrics for penetration protection and a 0.005-inch thick nylon film and a 0.020-inch thick 2329C innerliner for containment. The nonwoven fabric was adhered to the inside of the structure, A Vithane innerliner 0.020-inch thick was then applied to the inside of the nonwoven fabric by spray coat. The square-woven fabric was cemented to the Vithane innerliner and the nylon film spot adhered to the square-woven fabric.

Instrumentation recorded 45 G's upon impact. The structure was penetrated as in previous tests. The liner was not penetrated. However, the adhesive bond of the nylon and Vithane films to the structure ends was sufficient to cause these components to tear at the junction of the forward and end surfaces upon penetration by the obstacle. Time to drain was 1.8 minutes.

Liner Concept No. 10 - Liner Concept No. 10 was a three component system utilizing a 0.020-inch thick 2329C Vithane film, a 33 oz-per-sq-yd nonwoven fabric and 0.005-inch thick nylon film. A light coat of release agent was applied to the inside of the test structure and a 0.020-inch thick 2329C Vithane film applied by spray coat application. The nonwoven fabric was cemented to the Vithane and the nylon film spot adhered to the nonwoven fabric.

Instrumentation recorded 45 G's upon impact. The structure and all components of the liner concept were penetrated; however, the Vithane liner sealed on the penetration obstacle preventing leakage of the test fluid.

Liner Concept No. 11 - Liner Concept No. 11 was a three component system utilizing a 0.020-inch thick 2329C Vithane film, a 24 oz-per-sq-yd square woven nylon fabric and a 0.005-inch thick nylon film. Installation in the structure was accomplished using the same procedure outlined for Liner Concept No. 10.

Instrumentation recorded 24 G's upon impact. The structure and Vithane gumsheet were penetrated with the fabric and nylon film undamaged in the area of impact. However, loss of support resulted when the obstacle penetrated, pulling in the square woven fabric. This coupled with test fluid "G" load was sufficient to tear the nylon film at both ends of the forward surface. Time to drain was approximately 4 minutes.

Based on a review of the data obtained from the penetration test conducted on Liner Concepts 6 through 11 and on DC-7 wing test previously conducted on Liner Concept No. 5, Liner Concept No. 10 was selected for installation and testing in aircraft wing sections.

Wing Section Tests

A total of 15 wing sections, three each, with the following containment methods installed was tested.

Containment Method No.	Description
1	Controls - no containment method installed (Ref. (Test Reports AFB 5098, 6004, and 6001)
2	Goodyear Liner Concept No. 5 (Ref. Test Reports AFB 8046, 8047, and 8048)
3	Goodyear Curtain Concept No. 7 (Ref. Test Report AFB 9290)
4	Goodyear Multilayer Liner Concept No. 10 (Ref. Test Report AFB 9290)
5	Firestone Liner Concept (Ref AFB 9290)

Descriptions of each of the above containment methods with the exception of the Firestone method are included in the preceding applicable sections of this report.

The Firestone containment method evolved from the work done on Contract No. FA-67NF245. In the actual wing sections tested, a polysulfide rubber caulking compound was spread onto the metal with 40 pores per inch (ppi) polyurethane reticulated foam, ½-inch thick, tightly adhered to this caulk. A frangible (breakaway) adhesive was used to adhere a 0.090-inch thick, low modulus, high-elongation nitrile compound innerliner to the foam. The entire top, bottom and forward surfaces of the forward cavity of the wing section were protected. All edges of the liner were fastened to the wing structure or skin using metal strips and machine screws. Installation was accomplished by The Firestone Tire & Rubber Company under modification to the contract.

The aircraft wing sections used for installation and test of above containment concepts were approximately 4 - to 6 - foot-wide sections cut from DC-7 wings. Interconnecting openings between the aft and forward tank cavities were left open while the inboard and outboard ends of each section were closed. The resulting wing section had a test fluid capacity of approximately 100 gallons.

The data obtained from the impact tests conducted on the aircraft wing sections has been compiled in Table I, and are presented by types of test to facilitate comparison of results.

As can be seen in the photographs, Appendix C, the wide variation in amounts of structural damage which occurred in the same types of tests precludes drawing any objective conclusions as to the merits of one method of containment over another. This becomes readily apparent when we compare results of the buckling tests of control sections having no containment methods with those of Containment Methods 4 and 5 where little damage occurred to the liner itself.

TABLE I

TEST RESULTS OF THE FIVE DIFFERENT CONTAINMENT METHODS

Test No.	Obstacle	Containment Method No.	Rate of Fluid Loss	Splash Distance	Weight Empty	G's	Comments
1	Buckling	Control	102 gpm	-	190 lb.	350	The wing section impacted squarely on the obstacle. The lower skin fractured loose from the forward edge of the tank 26 inches from the impact point on one side and 12 inches on the other side. The obstacle penetrated 7 inches beyond the forward wing spar. The top skin split open approximately 20 inches each side of a 14-inch opening made by the obstacle. The top skin split 19 inches back from the forward wing spar. The upper two-thirds of the forward wing spar fractured at the point of impact.
2	Buckling	2	See comments		190 lb.	110	The wing section impacted squarely on the obstacle. Fluid loss was rated as a heavy flow approximately 25 gpm during the first minute, and approximately 6 gpm during the second minute after impact. Thirty-six gallons of fluid remained in the tank. The lower skin had complete fracture from the forward spar. The center of the forward spar was pushed back 3 inches. The top skin split in the aft direction 15 inches from the forward spar at the center of the wing. There was no damage to the liner, with the exception of a 1/8-inch hole 4 inches down from the top of the liner in one side. The water splashed 19-1/2 feet perpendicular to the bottom side of the wing, and 17 feet perpendicular to the top side of the wing.
3	Buckling	3	408 gpm	25'	180 lb.	38	The forward spar fractured at the center. The top and bottom wing surfaces broke loose at the forward spar. The upper wing surface had a 7 by 12-inch hole at the point of impact while the bottom skin had a 30-inch long opening to the fuel cavity at the spar. The curtain was torn at the forward spar dumping the test fluid.
4	Buckling	4	408 gpm	32'	260 lb.	37	The top and bottom wing surfaces were broken loose at the forward spar. One-half of the forward spar and leading edge were completely loose from the remainder of the wing. The liner had two 2-inch diameter holes and one 3/4-inch diameter hole in the impact area. The end of the liner was torn out on the end where the spar and leading edge were torn away.
5	Buckling	5	408 gpm	24'	250 lb.	36	A 3 by 15-inch tear occurred in the top skin at the forward spar. The entire skin was broken loose at the forward spar. The fabricated end closure plate broke loose on impact and dumped the test fluid. The liner was not damaged.
6	Slashing	Control	185 gpm	-	190 lb.	170	The wing section lower edge impacted the I-beam which sliced to 8 inches behind the forward wing spar. A 10 by 17-inch section of the wing spar was pushed in. The lower wing skin had a 4 foot tear. The forward access door frame was broken, and the door had 10-inch and 9-inch tears.
7	Slashing	2	See comments	25'	190 lb.	78	The wing section lower edge impacted the I-beam which sliced a tear 20 inches long by 4-9 inches wide in the tank section of the wing. The forward spar had complete fractures in two places. The liner had a 3/4-inch tear in the lower forward edge. Rate of fluid loss was approx 20 gpm for the first 45 secs., 6 gpm for the next 1.5 minutes, diminishing to .25 gpm thereafter. Thirty-eight gallons of water remained in the tank after 5 min.
8	Slashing	3	275 gpm	33'	180 lb.	10	An 18 by 36-inch hole was torn in the wing at the point of impact and forward spar broken. The curtain was torn across the full width at the tank leading edge.
9	Slashing	4	45 gpm	27'	260 lb.	-	A 6 by 14-inch piece of the forward spar was broken out. The bottom wing surface was torn through the access door and back to the center spar. The top wing surface was torn from inboard to outboard end adjacent to and behind the forward spar. The liner had a 12-inch tear in the forward face.
10	Slashing	5	103 gpm	-	260 lb.	-	Lower edge of forward spar had a 10-inch tear. The lower wing surface was torn back to center spar with access door torn away. The liner had a 9-inch tear originating at the break in the spar.
11	Penetration	Control	163 gpm	-	190 lb.	100	The wing section impacted the obstacle 4 inches below the wing centerline. There was a 4 by 7-inch hole at the impact point. The forward spar fractured the full length adjacent to the lower wing surface. The lower skin pulled loose 12 inches at the side on the forward corner of the tank. The top of the nose fairing broke loose along the entire length of its joint to the tank.
12	Penetration	2	See comments	12'	190 lb.	123	The wing section impacted the obstacle 3 inches back from the leading edge of the wing on the underside. There was a 9 by 12-inch hole at the impact point. There was an 18-inch tear at the bottom of the main spar with additional skin cracks for a total length of 27 inches. There was an 11-inch vertical tear in the forward spar. Approximately 43 gallons of test fluid were dumped within .5 minutes. No additional fluid loss occurred. 25 gallons of water were retained in the containment liner. There was a 4-inch abraded area on the cloth reinforcement, but no hole in the liner.
13	Penetration	3	136 gpm	21'	230 lb.	26	The top surface of the wing broke loose adjacent to and forward of the front spar. A 7 x 10-inch hole was punched in the spar. A 12 by 12-inch "X" tear occurred in the curtain.
14	Penetration	4	34 gpm	18'	280 lb.	16	Leading edge of wing forward of spar separated from the rest of the section. A 4 by 8-inch hole was punched in the spar and a 2 by 6-inch hole punched in the liner.
15	Penetration	5	1.3 gpm	-	260 lb.	17	The top surface at the wing broke loose across the full width adjacent to and forward of the front spar. A 6 by 8-inch hole was punched in the forward spar and 3-inch diameter hole punched in the liner.

CONCLUSIONS

The work described in this report partially substantiates previous research findings in that a degree of crash protection is attained through use of extensible liners and other materials. However, the protection obtained from these systems would be ineffective in light of the amount of structural damage occurring at relatively low impact speeds and low average "G" loadings as experienced in the various tests.

A review of the test results and photographs, substantiates not only that the protection attained through use of the various systems is ineffective, but also that no system dependent upon continued support of the aircraft structure will be successful in eliminating or controlling post-crash fuel spills.

APPENDIX A

Test Data On Components Used In FAA Program

An Investigation Of Methods To Control Post-Crash Fuel Spill From Integral Fuel Tanks

Table 1-1	Physical Properties - Compounds (Average Values Only)
Table 1-2	Physical Data - Cloth and Film
Table 1-3	Fuel Contamination Data
Table 1-4	Physical Properties - Compounds
Table 1-5	Physicals After Soaking for 72 Hours in Type I Test Fluid
Table 1-6	Physicals After Soaking for 72 Hours in Type III Test Fluid
Table 1-7	Physicals After Soaking for 72 Hours in JP-4 Test Fluid

TABLE 1-1
PHYSICAL PROPERTIES - COMPOUNDS
(AVERAGE VALUES)

COMPOUND NUMBER		2329C	M-863*
TYPE		POLYURETHANE	NITRILE
Tensile (Psi)			
Original		2660	1957
After 72 hours soak Type 1 @			
(% Retained)	- 65°F	2697 (101.39)	2055 (105.01)
	70°F	2300 (86.47)	2117 (108.18)
	160°F	2888 (108.57)	2122 (108.43)
After 72 hours soak Type III @			
(% Retained)	- 65°F	2323 (87.33)	1607 (82.12)
	70°F	1207 (45.38)	1165 (59.53)
	160°F	1418 (53.31)	1210 (61.83)
After 72 hours Soak JP-4 @			
(% Retained)	- 65°F	3210 (120.68)	1970 (100.66)
	70°F	1903 (71.54)	1757 (89.76)
	160°F	2298 (86.39)	2053 (104.91)
Elongation (%)			
Original		353	543
After 72 hours soak Type 1 @			
(% Retained)	- 65°F	350 (99.15)	530 (97.61)
	70°F	327 (92.63)	513 (94.48)
	160°F	347 (98.30)	423 (77.90)
After 72 hours soak Type III @			
(% Retained)	- 65°F	347 (98.30)	400 (73.66)
	70°F	320 (90.65)	355 (65.38)
	160°F	330 (93.48)	333 (61.33)
After 72 hours soak JP-4 @			
(% Retained)	- 65°F	365 (103.40)	495 (91.16)
	70°F	343 (97.17)	493 (90.79)
	160°F	353 (100.00)	443 (81.58)

TABLE 1-2
PHYSICAL DATA - CLOTH AND FILM

CLOTH OR FILM	RF-035	RF-086	CAPRAN 77C
Type	Nylon Non-Woven	Nylon Square-Woven	Nylon Film
Weight (oz-per-sq-yd)	33.00	24.00	
Thickness (Inches)	0.320		
Tensile Strength			
1" Strip (Warp and Fill Direction)		1200 x 1200 lbs*	
PSI			11,000
Elongation %			400
Yield (sq-in-per-lb-per-mil)			24,500

*Minimum values. All other values typical.

TABLE 1-3
FUEL CONTAMINATION DATA

From Type III Test Fluid Extract Expressed in Mg-per-100 ml. (Per MIL-T-6396)		Non-Volatile Residue	Stoved Gum
Material			
2329-C Polyurethane Compound		13.4; 13.4	1.0; 1.4
	Average	13.4	1.2
M-863 Nitrile Compound		12.3; 13.7	3.8; 3.6
	Average	13.0	3.7
RF-035 Nylon Non-Woven Cloth		12.2; 12.0	4.0; 3.4
	Average	12.1	3.7
RF-086 Square-Woven Nylon Cloth		0 ; 0	0 ; 0
	Average	0	0
Capran 77C Film		0 ; 0	0 ; 0
	Average	0	0