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Summary Report: Airplane Auxiliary Fuel Tank Tests

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June 2008

Final Report

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16. Abstract

From 1989 through 1999, the Federal Aviation Administration (FAA) conducted vertical and longitudinal tests of narrow-body transport fuselage sections with auxiliary fuel tanks onboard. The longitudinal tests were conducted at the Transport Research Center, Inc. in East Liberty, Ohio, and the vertical crash tests were conducted at FAA William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. The tests were structured to determine the impact response characteristics of typical items of mass installed onboard a transport airplane to provide a basis to assess the adequacy of the design standards and regulatory requirements for those components.

This report examines airplane auxiliary fuel tanks and their affect on the impact response characteristics of an airplane fuselage. The auxiliary fuel tank's potential dynamic amplification effects on the airplane's fuselage are also investigated. The impact tests were conducted on two types of airplane auxiliary fuel tanks, a cylindrical fuel tank and a conformable fuel tank. A simulated longitudinal impact test and a vertical impact test were conducted on each tank. The purpose of this research was to evaluate the crashworthiness characteristics of a cylindrical auxiliary fuel tank and a conformable auxiliary fuel tank.

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LIST OF ACRONYMS

ATD	Anthropomorphic test dummy
BS	Body station
CFC	Channel frequency class
CFR	Code of Federal Regulations
FAA	Federal Aviation Administration
FS	Fuselage station
SAE	Society of Automotive Engineers
TRC	Transport Research Center, Inc.

EXECUTIVE SUMMARY

From 1989 through 1999, the Federal Aviation Administration (FAA) conducted vertical and longitudinal tests of narrow-body transport fuselage sections with auxiliary fuel tanks onboard. The tests were performed at the FAA William J. Hughes Technical Center, Atlantic City International Airport, New Jersey and the Transportation Research Center, Inc., East Liberty, Ohio. The tests were structured to determine the impact response characteristics of typical items of mass installed onboard a transport airplane to provide a basis to assess the adequacy of the design standards and regulatory requirements for those components.

Several simulated longitudinal impact tests were conducted to measure the structural response of auxiliary fuel tanks that were mounted in the fuselage section. A series of tests were conducted on a Boeing 707 airplane test section with a cylindrical auxiliary fuel tank at 6.4, 10.9, and 13 g's. No damage was noted on the fuel tank, its mounting system, or the fuselage. Another series of longitudinal tests were planned at 6, 9, and 16 g's on a B-737 airplane fuselage test section with a conformable auxiliary fuel tank onboard. During the first 6-g test, the conformable auxiliary fuel tank broke free from its mounting system. No further tests in this series were conducted.

Two airplane test sections with auxiliary fuel tanks were dropped from a height of 14 feet, resulting in a vertical impact velocity of 30 feet per second. This resulted in what was considered a severe, but survivable, impact condition. The B-707 fuselage test section with a cylindrical auxiliary fuel tank onboard experienced no loss of habitable space in the cabin area. The cylindrical fuel tank remained firmly attached to its mounting system. There was minimal distress to the cabin floor to which it was attached. The simulated fuel leaked slowly out of the tank after the test.

The B-737 fuselage test section with the conformable auxiliary fuel tank onboard sustained severe damage after the test. Portions of the cabin floor were damaged due to impact with the auxiliary fuel tank located in the cargo compartment. The bottom of the auxiliary fuel tank was punctured in numerous locations causing fuel to leak out. The strength and rigidity of the conformable auxiliary fuel tank limited the inherent ability of the fuselage structure to crush and absorb energy during the impact.

1. INTRODUCTION.

Previous cabin safety research efforts have led to the definition of the survivable crash environment, the development of crash dynamic analytical modeling methodologies, and improved design standards and regulatory requirements for airplane seats and interiors. This report examines airplane auxiliary fuel tanks and their affect on the impact response characteristics of an airplane fuselage. The auxiliary fuel tank's potential dynamic amplification effects on the airplane's fuselage are also investigated. The impact tests were conducted on two types of airplane auxiliary fuel tanks, a cylindrical fuel tank and a conformable fuel tank. A simulated longitudinal impact test and a vertical impact test were conducted on each tank. The auxiliary fuel tanks were installed in narrow-body transport airplane fuselage sections. The longitudinal tests were conducted at the Transport Research Center, Inc. (TRC) in East Liberty, Ohio, and the vertical crash tests were conducted at the Federal Aviation Administration (FAA) William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. The purpose of this research was to evaluate the crashworthiness characteristics of a cylindrical auxiliary fuel tank and a conformable auxiliary fuel tank.

The Aviation Safety Research Act of 1988 (Public Law 100-591) directs the Administrator of the FAA to (1) issue an advance notice of proposed rulemaking to determine the feasibility of installing (in all air carrier airplane) rupture-resistant crashworthy fuselage fuel tanks and fuel lines that disconnect and seal in the event of an accident and (2) undertake research to develop technologies to prevent rapid fuel dispersal and combustibility after an air crash. It also directs the Administrator to initiate aviation maintenance and safety research, including fire and smoke resistance technologies.

In response, the FAA developed a Crash Dynamics and Engineering Development Program [1]. To support this program, a series of transport airframe section tests were conducted to evaluate the effect of airplane auxiliary fuel tanks on the impact response characteristics of an airplane fuselage. All tests were conducted to represent survivable impact conditions.

A simulated longitudinal impact test for a Boeing 707 narrow-body transport airplane fuselage section with a cylindrical auxiliary floor-mounted (suspended) fuel tank installed in the cargo area was conducted in June 1989 [2]. The objective of this test was to determine the dynamic response behavior of a fuselage installed auxiliary fuel tank system when subjected to a simulated longitudinal impact pulse.

In October 1993, a vertical drop test was conducted using a B-707 narrow-body transport airplane fuselage section with overhead stowage bins and a cylindrical auxiliary fuel tank system onboard [3]. The test showed the dynamic response characteristics of the fuselage section and the cylindrical auxiliary fuel tank system.

In November 1997, simulated longitudinal impact fuselage tests of overhead stowage bins and auxiliary fuel tank of a narrow-body transport airplane fuselage section [4 and 5] were conducted. The FAA conducted these longitudinal tests on a B-737-200 fuselage section equipped with a conformable auxiliary fuel tank system onboard. The test presented the

structural response and interaction between a transport airplane fuselage section, overhead stowage bins, and conformable auxiliary fuel tank system.

In October 1999, the FAA conducted a vertical drop test of a narrow-body transport airplane fuselage section with a conformable auxiliary fuel tank onboard [6]. This was a vertical drop test of a B-737-200 fuselage section with a fuel tank installed. The impact test showed the interaction between the transport airplane fuselage section, particularly its floor structure, and the conformable auxiliary fuel tank system.

2. TEST FACILITIES.

The longitudinal tests were conducted at the TRC Impact Simulator Facility (figure 1) in East Liberty, Ohio. This facility used a 24-inch-diameter HYGE™ shock tester to simulate the deceleration conditions of an impact by rapidly accelerating the test article.

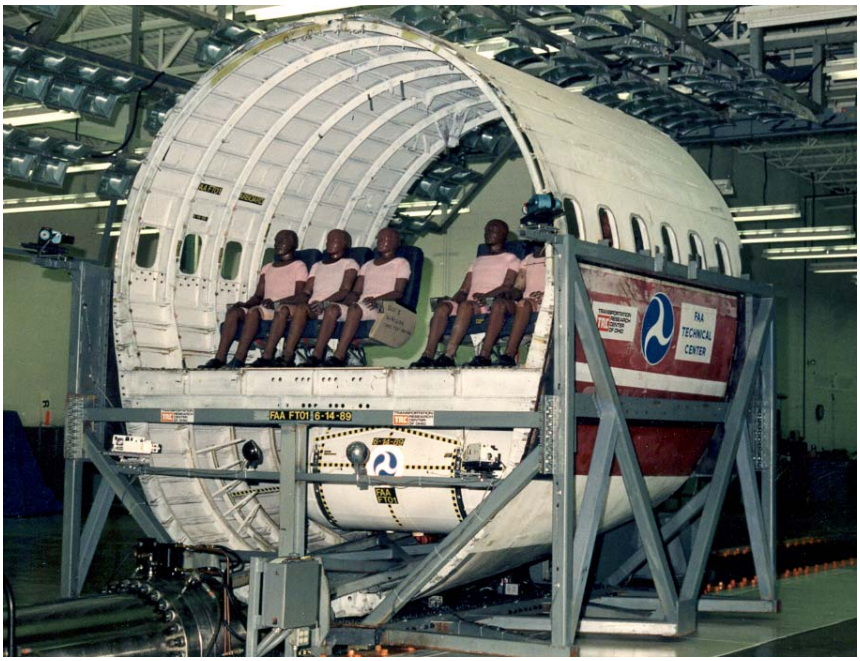


Figure 1. Transportation Research Center Impact Simulator Facility—Cylindrical Auxilary Fuel Tank Simulated Longitudinal Impact Test

The test articles were mounted in a steel fixture and the steel frame was attached to the test facility sled. The steel frame was fabricated and attached in a manner to minimize any effect on the load paths between the fuselage and the overhead stowage bins, fuel tank, and fuselage floor.

The drop test facility used for the vertical impact tests is comprised of two 57-foot vertical steel towers connected at the top by a horizontal platform (figure 2). The impact surface is located below the horizontal platform, and between the tower legs is a 15- by 36.5-foot wooden platform, which rests upon steel I-beams and is supported by 12 load cells.

Figure 2. The FAA Dynamic Drop Test Facility—Conformable Auxiliary Fuel Tank Vertical Impact Test

3. DESCRIPTION OF THE IMPACT TESTS.

3.1 LONGITUDINAL TESTS.

3.1.1 Cylindrical Auxiliary Fuel Tank.

A 10-foot tapered section of a B-707 airplane from body station (BS) 1120 to BS 1240 (figures 3 and 1) was used. The B-707 airplane fuselage section was also equipped with seats and anthropomorphic dummies (ATD).

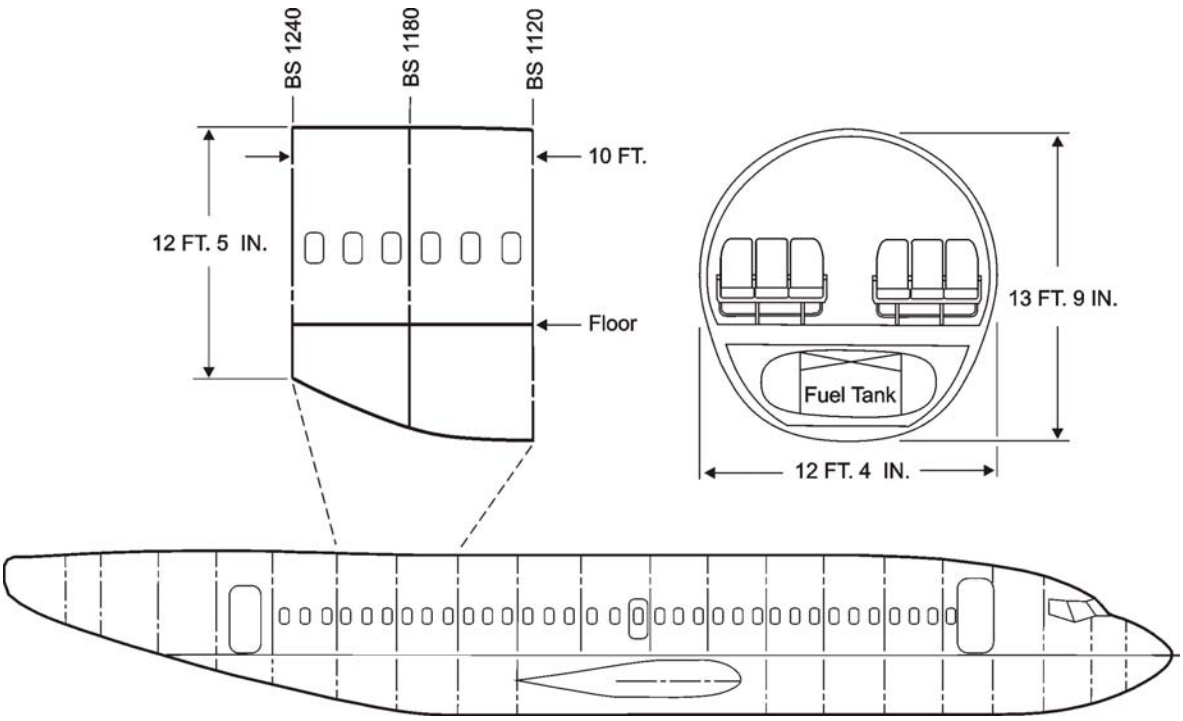


Figure 3. Airframe Test Section—B-707

The auxiliary fuel tank was a 330-gallon Sargent Fletcher Co. cylindrical tank (figure 4). The tank was mounted to the underside of the fuselage floor in the cargo area. The installation included reinforcement of five bays' floor beams from BS 1140 to BS 1240. The reinforcement consisted of adding intercostals between traverse floor beams in each bay and longitudinal stops at the cradle tracks. The mounting system is shown in figures 5 and 6. The tank contained 241 gallons of water, which simulated fuel. The weight of the tank and mounting system was 2400 pounds, and the total weight of the test section was 5874 pounds.

Accelerometers were mounted on the front left and right sides of the tank to measure longitudinal and vertical accelerations. Their placement is shown in figure 7. Two additional accelerometers were located on the stopper blocks in the longitudinal direction, as shown in figure 8.

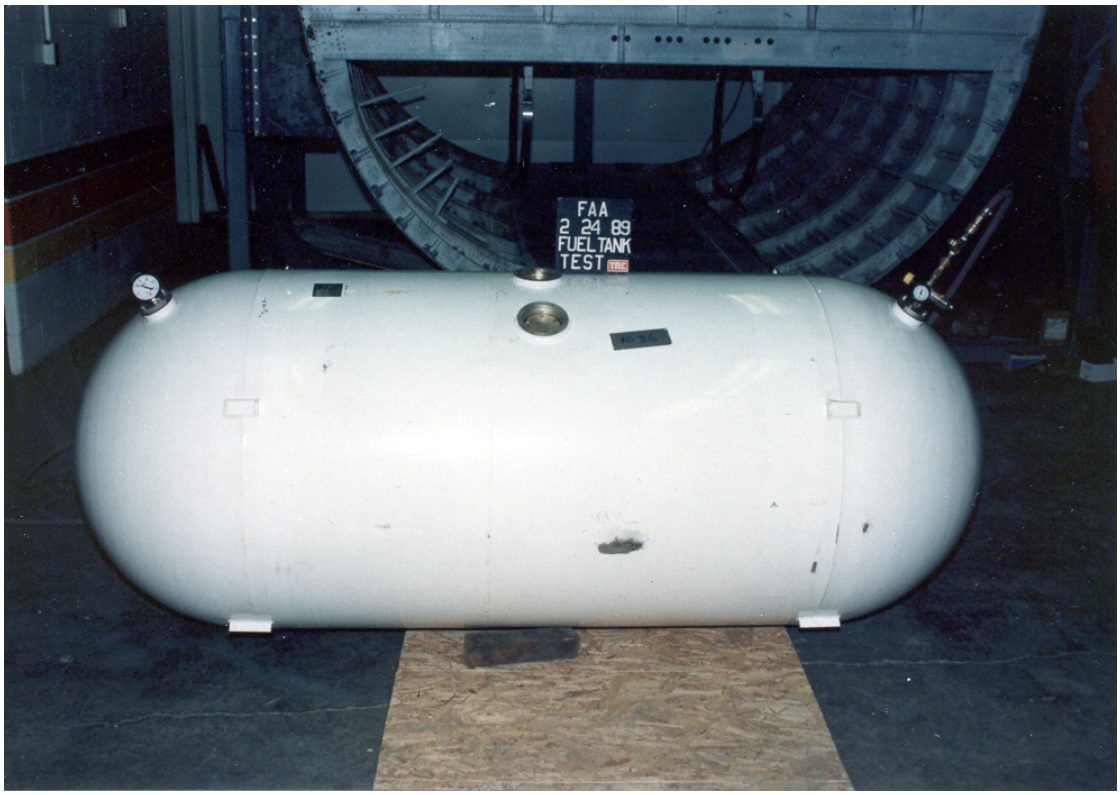


Figure 4. Cylindrical Auxiliary Fuel Tank

Figure 5. Cylindrical Auxiliary Fuel Tank Mounting System

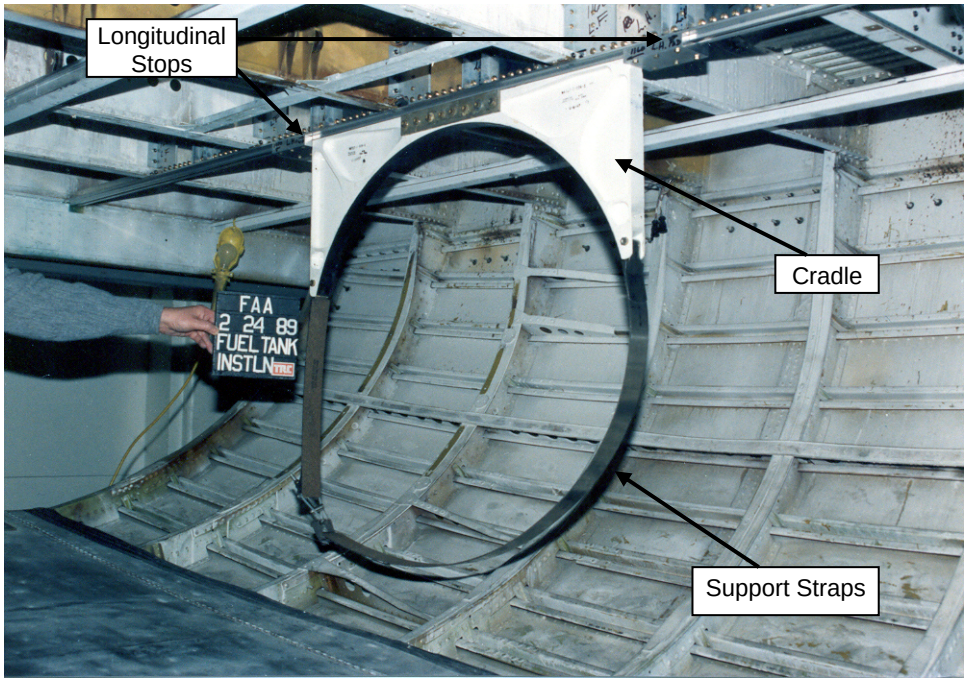


Figure 6. Cylindrical Auxiliary Fuel Tank Mount

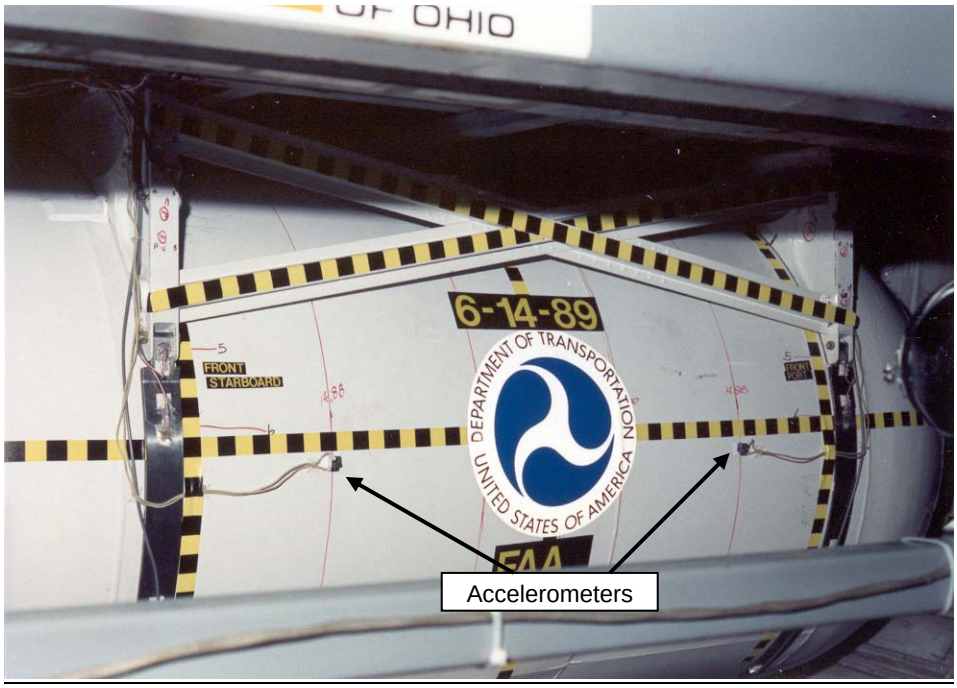


Figure 7. Cylindrical Auxiliary Fuel Tank—Accelerometer Locations

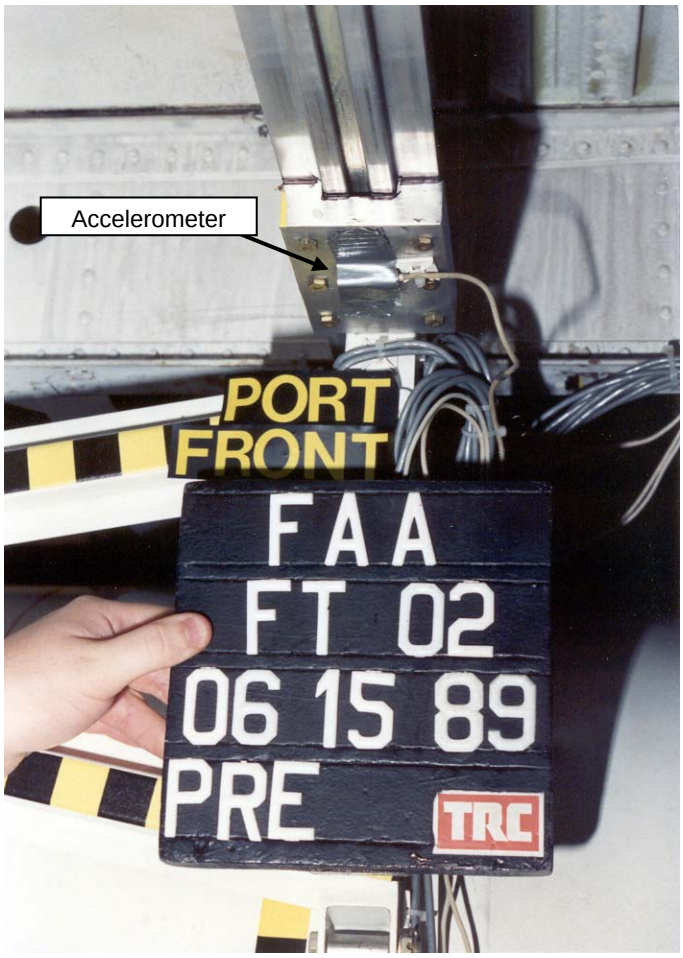


Figure 8. Stopper Blocks—Accelerometer Location

3.1.2 Conformable Fuel Tank.

The test article was a 10-foot, narrow-body transport category airplane fuselage section cut from fuselage station (FS) 400 to FS 500A from a B-737-200 transport airplane (figures 9 and 10). The total test article weight was 13,584 pounds, which includes the 7180-pound sled steel fixture to which the test article was mounted.

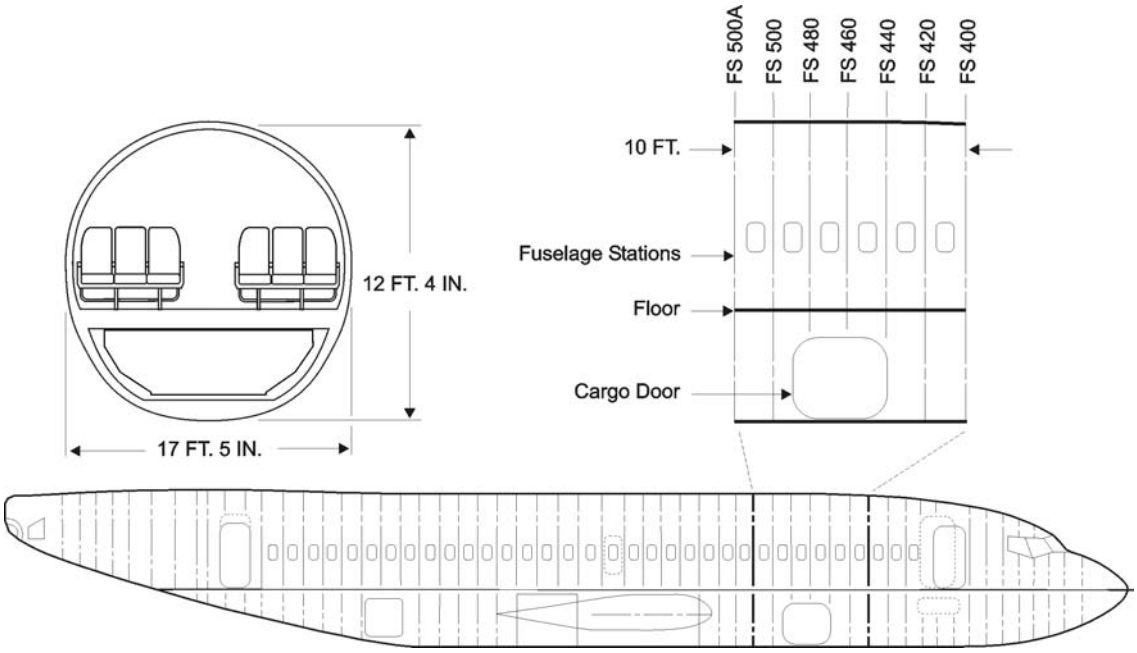


Figure 9. Airframe Test Section—B-737-200

Figure 10. Test Section—Conformable Fuel Tank Installed

A 500-gallon Patrick Aircraft Tank Systems, Inc. (PATS) auxiliary fuel tank (figure 11) was installed on the underside of the fuselage floor beams between FS 420 and FS 480. The fuel tank weighed 343 pounds and contained 3550 pounds of water. The fuel tank was mounted on two mounting rails running longitudinally along the bottom of the fuselage floor beams. The tank hangs on the rails by a flange running longitudinally along the topside of the tank. Bearing

blocks located at the four corners of the tank on the hanger rails prevent longitudinal movement along the rails. Figure 12 is a close view of the upper right corner of the fuel tank, which shows the floor beam, mounting rail, bearing block, and fuel tank. Forward loads and overturning moments are also reacted by two bottom straps. The two bottom straps are fastened to the bottom of the fuel tank and to the fuselage cargo floor under the tank. The bottom straps are shown in figure 13.

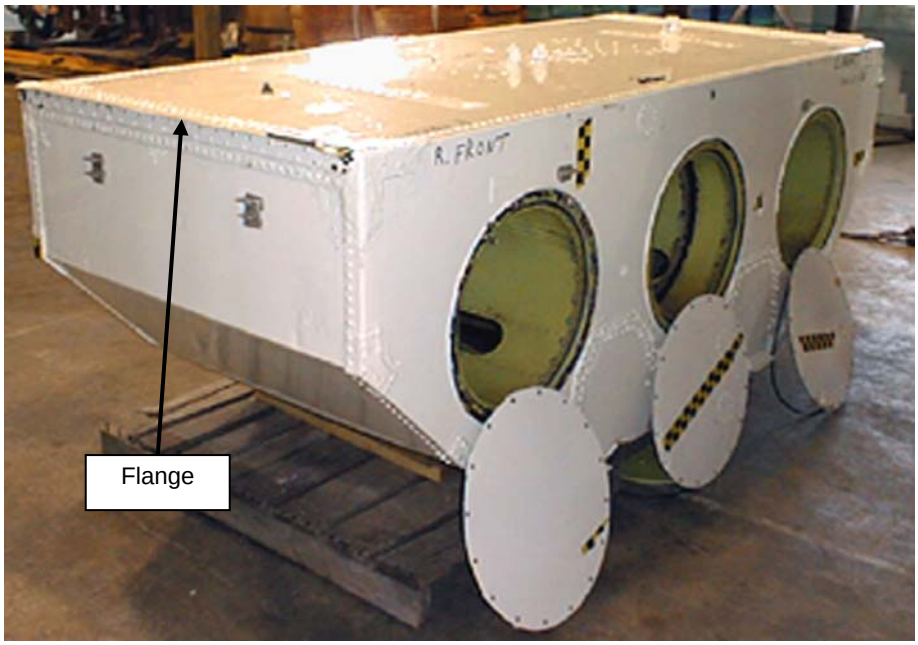


Figure 11. Auxiliary Fuel Tank

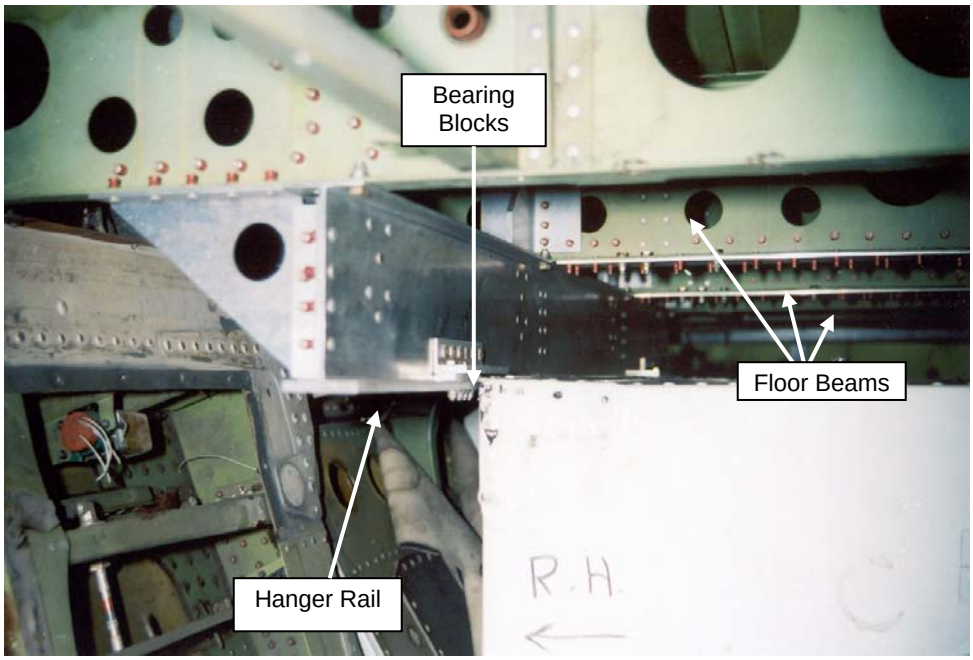


Figure 12. Auxiliary Fuel Tank Mounting System

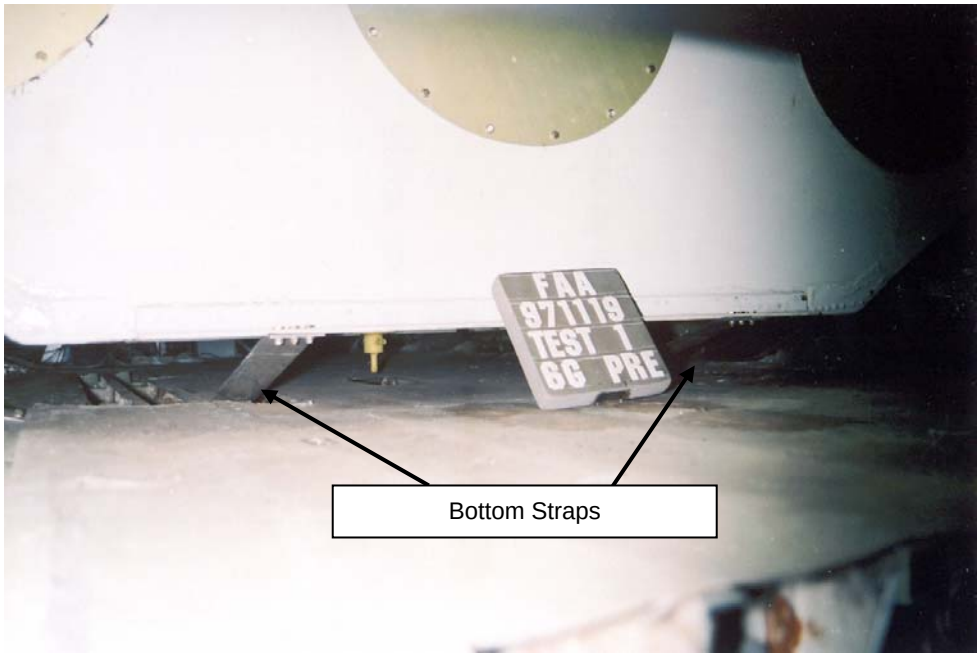


Figure 13. Auxiliary Fuel Tank Straps

The instrumentation on the conformable auxiliary fuel tank system included seven accelerometers (three longitudinal, two lateral, and two vertical) and one string potentiometer (figure 14). Two tri-axial accelerometers were mounted on the left and right sides of the tank, and one longitudinally oriented accelerometer was mounted on the top of the tank. The string potentiometer measured longitudinal displacement.

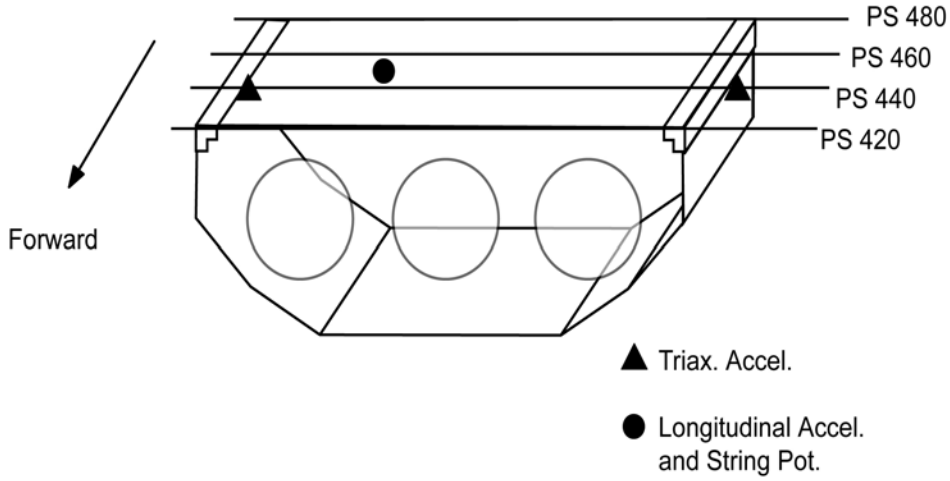


Figure 14. Conformable Auxiliary Fuel Tank Instrumentation Locations

3.2 VERTICAL DROP TESTS.

3.2.1 Cylindrical Auxiliary Fuel Tank.

Since no damage was sustained, the same 10-foot tapered section of the B-707 airplane (figure 15) that was used in the longitudinal test was also used for the vertical impact test. The B-707 fuselage section was equipped with seats, ATDs, and overhead bins. The total weight of the test article was 8097 pounds.

Figure 15. B-707 Test Article and Cylindrical Auxiliary Fuel Tank

The cylindrical auxiliary fuel tank was mounted as described in section 3.1.1. The 242-pound tank contained 247.5 gallons of water (2055 pounds) to simulate the weight of a full tank of fuel and was pressurized to 2.5 psi. The total weight of the fuel tank system was 2469 pounds.

The auxiliary fuel tank and mounting system was instrumented with accelerometers and strain gages. Six accelerometers were attached to the tank, with four recording in the z direction and two in the x direction, as shown in figures 16 and 17. Four accelerometers were attached to the cradle and recorded data in the z direction. The four upper cradle corners were strain gauged on the vertical and diagonal supports, along with the support strap, for a total of 12 channels. The mounting system instrumentation locations are shown in figure 18.

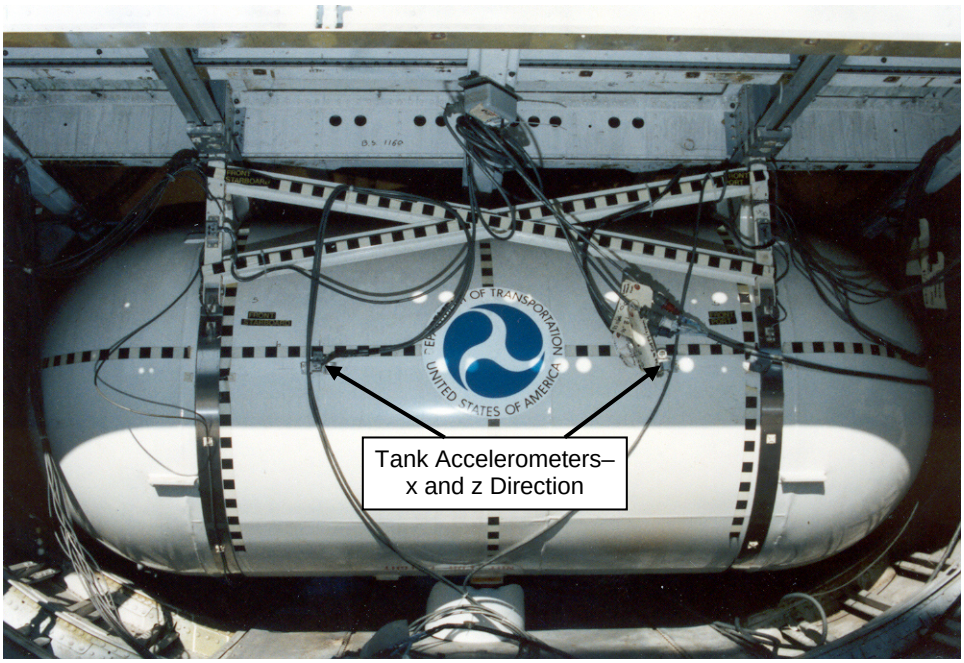


Figure 16. Cylindrical Auxiliary Fuel Tank System and Instrumentation—Front View

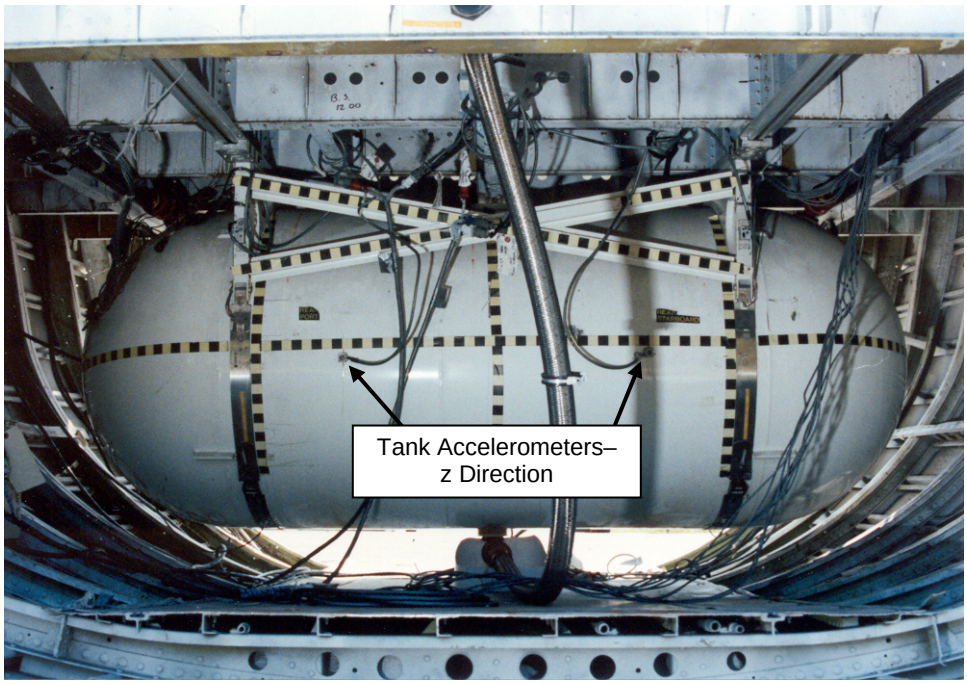


Figure 17. Cylindrical Auxiliary Fuel Tank System and Instrumentation—Rear View

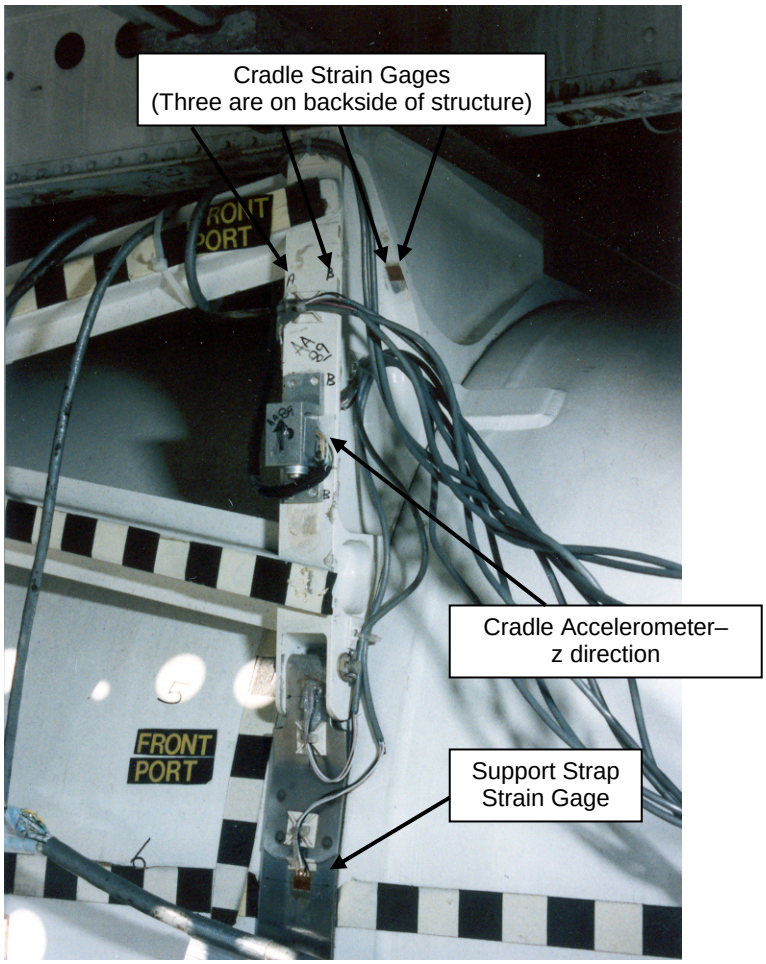


Figure 18. Fuel Tank Mounting System and Instrumentation Locations

3.2.2 Conformable Fuel Tank.

Since no damage was sustained to the test article during the simulated longitudinal impact test, the same conformable auxiliary fuel tank and the 10-foot section cut from FS 400 to FS 500A from the B-737-200 transport airplane were used in this drop test. Figure 22 shows the overall test article and fuel tank configuration. The test section included a below-floor cargo compartment with an access door located on the right (copilot) side (figure 19). The floor beams at each of end of the test section were reinforced (figure 19) to minimize the open-end effects. Nonstructural interior liners and insulation were removed from the airframe test section. The section was equipped with typical cabin seats that contained either a mannequin or an ATD. The total weight of the test article was 8780 pounds.

Figure 19. Test Section Showing Cargo Door and Reinforcing Beam

The installation consisted of a 500-gallon conformable tank, two longitudinal mounting rails, and two longitudinal aluminum straps. The rails were located on the right and left sides and were mounted to the underside of the cabin floor beams at FS 440 through FS 500. The fuel tank hung from the rails (figure 20) and was suspended between FS 446 and FS 489. The bearing blocks (figures 20 and 21) mounted on the rails at FS 445 and FS 490 and the two aluminum straps prevented the tank from moving. One end of each strap was attached to the bottom of the tank; the other end was mounted to the cargo compartment floor. The tank contained 404 gallons of water to simulate the weight of a full tank of fuel and was pressurized to 1.0 psi. All fuel ports on the tank were capped, and no fuel lines were used in the test. The fuel tank weighed 370 pounds, and the simulated fuel (water) weighed 3370 pounds.

The fuel tank and rails were instrumented with 12 accelerometers; two were mounted on each of the four sides of the tank (figure 22) and two were mounted on each of the two rails (figure 23). Each rail accelerometer was adjacent to a bearing block that secured the tank in place.

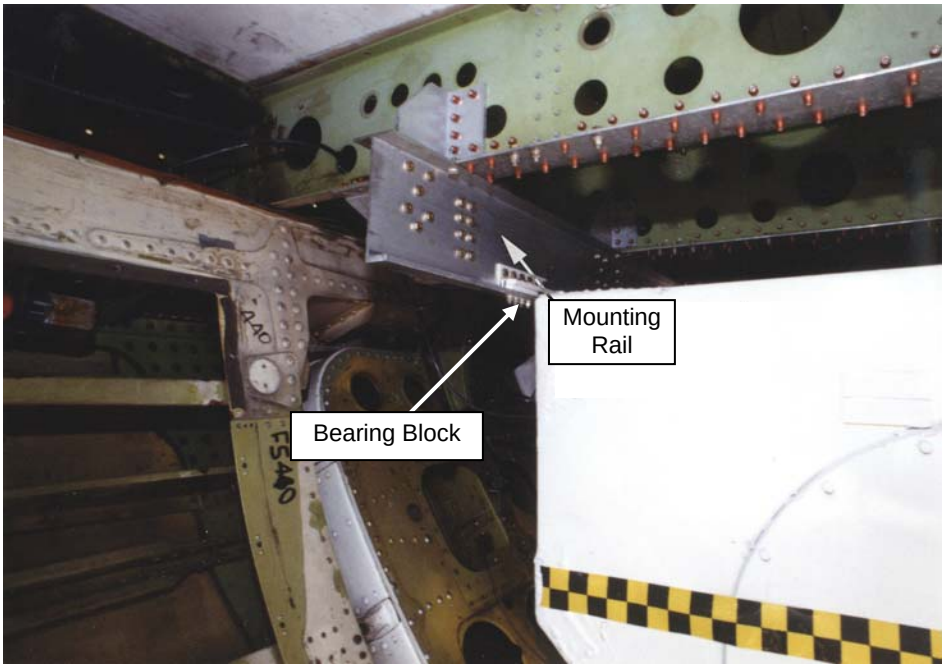


Figure 20. Fuel Tank Mounting Rail

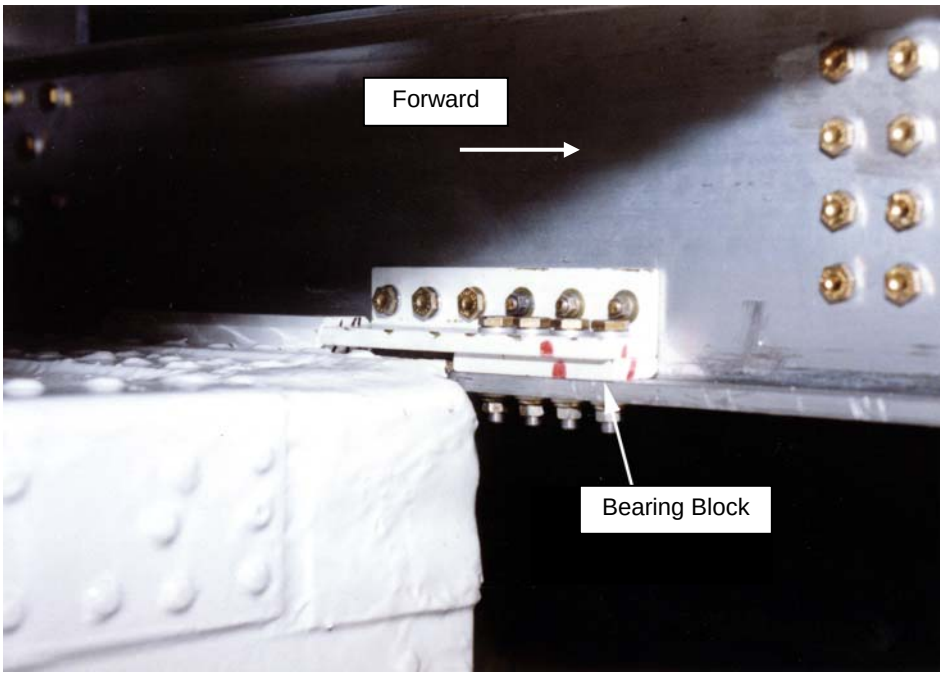


Figure 21. Fuel Tank Mounting Rail Bearing Block

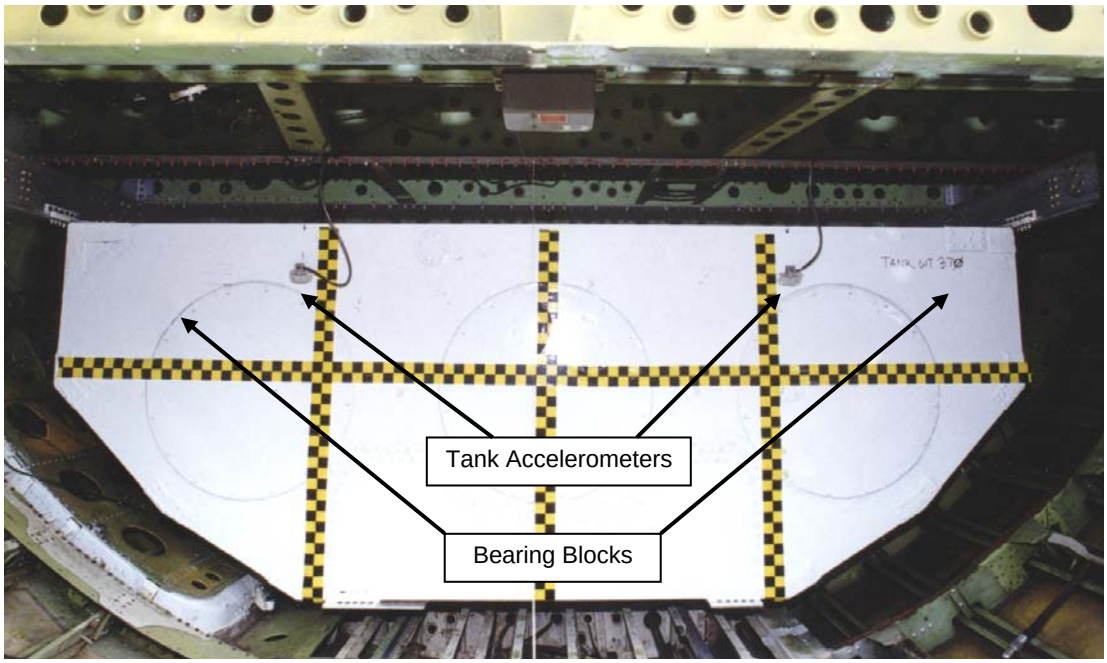


Figure 22. Overview of Conformable Auxiliary Fuel Tank Installation

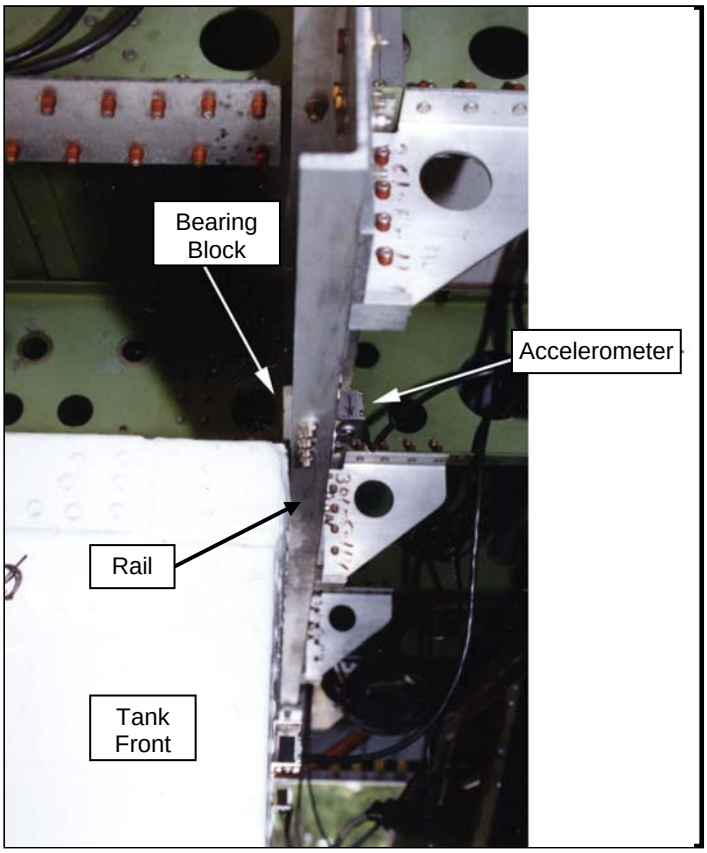


Figure 23. Fuel Tank Mounting Rail Accelerometer (looking up)

4. DATA ANALYSIS.

4.1 LONGITUDINAL TESTS.

4.1.1 Cylindrical Auxiliary Tank.

Three longitudinal tests were conducted, the tank remained attached to its mounting system, and no damage was sustained in any of the tests. The tests were conducted at 6.4, 10.9, and 13.0 g's with corresponding velocities 26.4, 35.2, and 38.6 ft/sec. The longitudinal tank accelerations are shown in table 1.

Table 1. Longitudinal Cylindrical Tank Accelerations

Location	6.4-g Test	10.9-g Test	13.0-g Test
Tank Right Side - G_{peak} (g) @ Time (ms)	*6.8 @ 132.4	*11.9 @ 122.4	*13.7 @ 114.5
Tank Right Side - Velocity (ft/s) @ Time (ms)	27.7 @ 249.9	35.3 @ 236.1	39.5 @ 162.5
Tank Left Side - G_{peak} (g) @ Time (ms)	7.0 @ 126.9	11.7 @ 120.4	14.0 @ 115.3
Tank Left Side - Velocity (ft/s) @ Time (ms)	26.9 @ 251.1	35.4 @ 237.8	39.8 @ 158.8
Tank Mount Right - G_{peak} (g) @ Time (ms)	13.2 @ 118.6	21.1 @ 85.6	26.5 @ 83.4
Tank Mount Right - Velocity (ft/s) @ Time (ms)	*56.2 @ 240.0	*73.4 @ 212.3	*81.2 @ 169.1
Tank Mount Left - G_{peak} (g) @ Time (ms)	6.4 @ 118.8	9.9 @ 95.6	12.4 @ 82.5
Tank Mount Left - Velocity (ft/s) @ Time (ms)	26.6 @ 236.8	34.6 @ 207.8	38.1 @ 187.6

*Suspected calibration error

4.1.2 Conformable Auxiliary Tank.

Simulated longitudinal impact tests were planned with peak accelerations of 6 and 9 g's and corresponding velocity changes of 23.2, 32.2, and 41.7 ft/sec. The 6-g test was conducted with an actual peak acceleration of 6.1 g's.

The auxiliary fuel tank completely separated from its mounting during the 6-g test. Separation began at approximately 64 ms at 5.5 g's, and was complete at approximately 76 ms at 5.2 g's. Due to the tank's mounting system failure in the 6-g test, the 9-g test was not performed until the mounting system was modified.

4.2 VERTICAL TESTS.

4.2.1 Cylindrical Auxiliary Tank.

For the vertical impact test, the cylindrical auxiliary fuel tank was dropped from a height of 14 feet and the impact velocity was approximately 30 ft/sec. The data was filtered with an Society of Automotive Engineers (SAE) J211 channel frequency class (CFC) 60 digital filter.

The test data showed two distinct pulses during the impact: the initial fuselage impact (fuselage impacting the platform) and the primary auxiliary fuel tank impact (the fuselage bottom hitting

the auxiliary fuel tank). Therefore, the vertical acceleration data was presented in two ways (table 2): as G_{peak} values, which were read directly from the filtered data, and G_{max} values, which were computed based on an idealized triangular pulse.

The average G_{max} tank system acceleration was about 31 g's. The force applied on the tank was distributed to the tank supports; i.e., the cradles and the straps. Strain gages were mounted on the cradles and straps to determine the load distribution. The maximum tension and compression strains for each location on the tank supports are identified in table 3.

Table 2. Vertical Cylindrical Tank Accelerations

	Left Side				Right Side			
	Measured	Idealized Triangular Pulse			Measured	Idealized Triangular Pulse		
Location	G_{peak} (g)	G_{max} (g)	Velocity Change (ft/s)	Duration (ms)	G_{peak} (g)	G_{max} (g)	Velocity Change (ft/s)	Duration (ms)
BS 1198 tank	36.6	32.3	36.88	71	39.3	32.8	38.54	73
BS 1200 cradle	36.1	31.5	34.99	69	34.9	27.2	31.51	72
BS 1160 tank	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
BS 1150 cradle	37.5	29.1	34.12	73	Invalid	Invalid	Invalid	Invalid

Table 3. Maximum Strains on the Cylindrical Tank Supports

Location	Tension Microstrain (initial impact)	Time (ms)	Compression Microstrain (primary impact)	Time (ms)
Aft port strap	117.28	34	-9.13	75
Aft starboard strap	76.61	34	-29.05	62
Forward port strap	392.03	46	-277.78	77
Forward starboard strap	124.27	31	-41.76	48
Aft port cradle	156.75	34	-1885.7*	71
Aft starboard cradle	172.77	34	-1890.4*	70
Forward port cradle	525.36	41	-1894.5*	66
Forward starboard cradle	452.54	31	-1896.5*	66
Aft port rib	No data	-	No data	-
Aft starboard rib	252.01	73	-30.06	23
Forward port rib	307.20	67	-451.29	94
Forward starboard rib	1875.2*	75	No data	-

*Indicates exceeded the full-scale value

All strains on the cradles exceeded the full-scale range programmed into data acquisition system. These high values of strains were the result of the fuselage bottom hitting the auxiliary fuel tank.

4.2.2 Conformable Auxiliary Tank.

For the vertical impact test, the conformable fuel tank was dropped from a height of 14 feet and the impact velocity was approximately 30 ft/sec. The data was filtered with an SAE J211 CFC 60 digital filter.

The accelerometer readings on the fuel tank right side appear to occur earlier than those on the left and are of slightly lower magnitude (table 4). This may be attributed to the protruding reinforced lip on the lower edge of the doorframe (figure 24), which would have contacted the right side of the fuel tank prior to the left side. The lip was partially crushed but caused the fuel tank and its contents to roll to the left, which resulted in a nonsymmetrical impact. Visual inspection of the auxiliary fuel tank rails confirmed that the right rail sustained little damage, while the left side was bent and twisted. Thus, the data from the left rail was unusable. The rail data on the right side at FS 447 was comparable to that shown by the cargo area ceiling accelerometers.

Table 4. Cargo Area Conformable Fuel Tank and Rail Accelerations

Location	Left Side			Right Side		
	G_{peak} (g)	Pulse Duration (ms)	Peak Time (ms)	G_{peak} (g)	Pulse Duration (ms)	Peak Time (ms)
FS 446 tank front	52	51	42	47	51	39
FS 457 tank side	51	46	37	48	38	35
FS 478 tank side	77	45	38	55	44	35
FS 489 tank rear	77	44	42	75	38	40
FS 447 rail	-	-	-	38	9	55
FS 487 rail	-	-	-	-	-	-

Note: The instrumentation cable at FS 487 on the right side was severed 35 ms into the test.

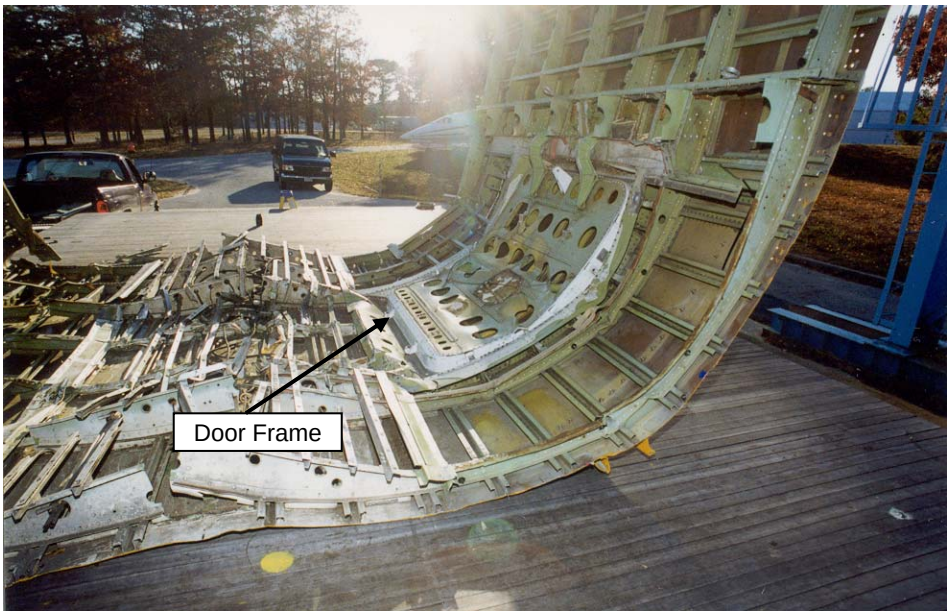


Figure 24. Test Section—Posttest—Door Frame

5. RESULTS AND DISCUSSION.

5.1 LONGITUDINAL TESTS.

5.1.1 Cylindrical Fuel Tank.

Figure 25 shows that the auxiliary cylindrical fuel tank remained attached to its mounting system and experienced no significant damage from the 6.4-, 10.9-, and 13.0-g simulated longitudinal impact tests. The cylindrical fuel tank installation was able to react to dynamic longitudinal inertial load factors in excess of the static longitudinal inertial factor found in Title 14 Code of Federal Regulations (CFR) Part 25.561.

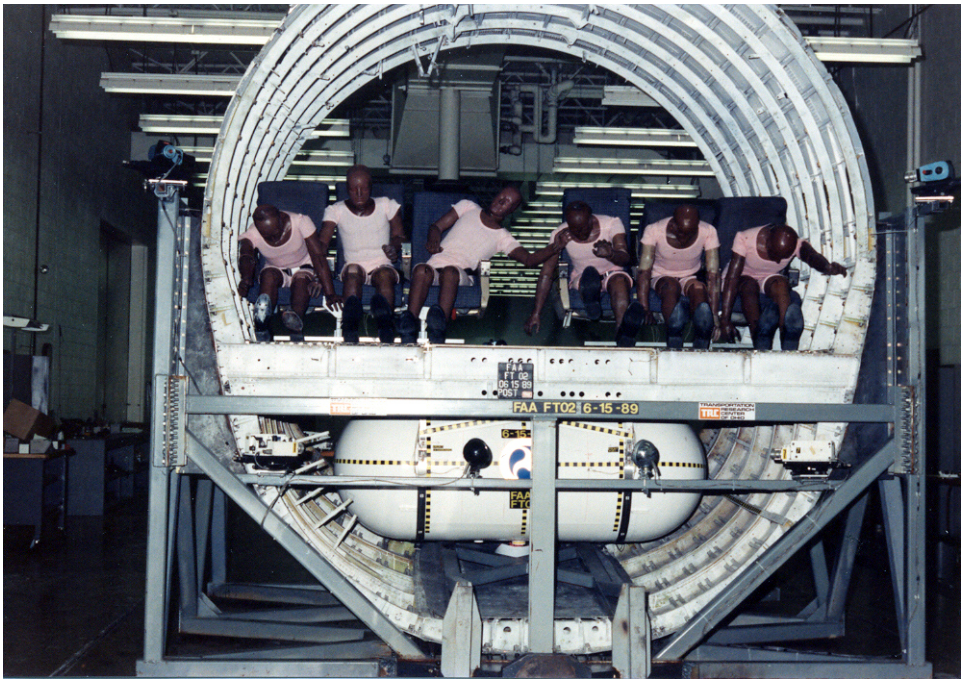


Figure 25. Posttest Cylindrical Fuel Tank 13.0 g's Longitudinal Test

5.1.2 Conformable Fuel Tank.

The auxiliary conformable fuel tank separated from its mounting as a result of the 6-g longitudinal impact load. The fuel tank then moved forward in the fuselage until it contacted the test facility's front brace of the steel fixture. The initial failure to the tank occurred at the forward end of both hanging flanges on the tank. The failure mode, which is shown in figure 26, was a shearing failure of the flanges on the tank when the tank's hanging flange was forced against the bearing blocks that resisted all the longitudinal impact loads. The mounting structure hanging rails, bearing blocks, and the bottom retention straps were also damaged in the test. Both mounting structure hanging rails experienced bending and tearing at the forward end (figure 27). In addition, the bottom retention straps were pulled from the fuselage floor at the attachment point as a result of the tank's forward motion. The bottom retention strap damage is shown in figure 28.

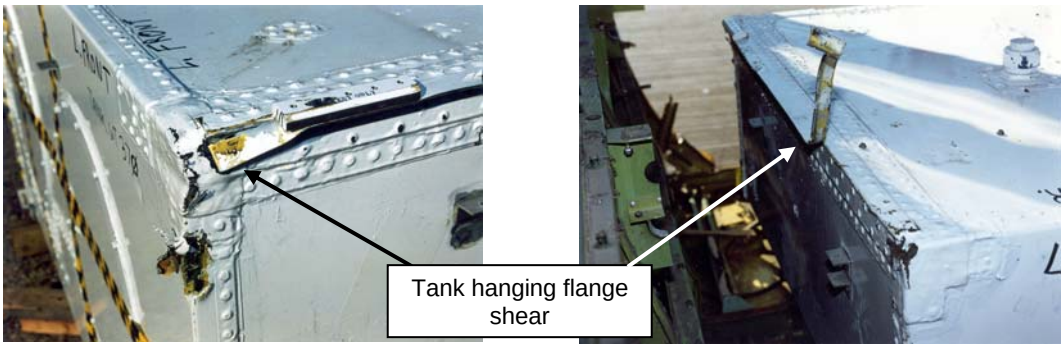


Figure 26. Initial Failure Modes—Shearing of the Tank Hanger Rails

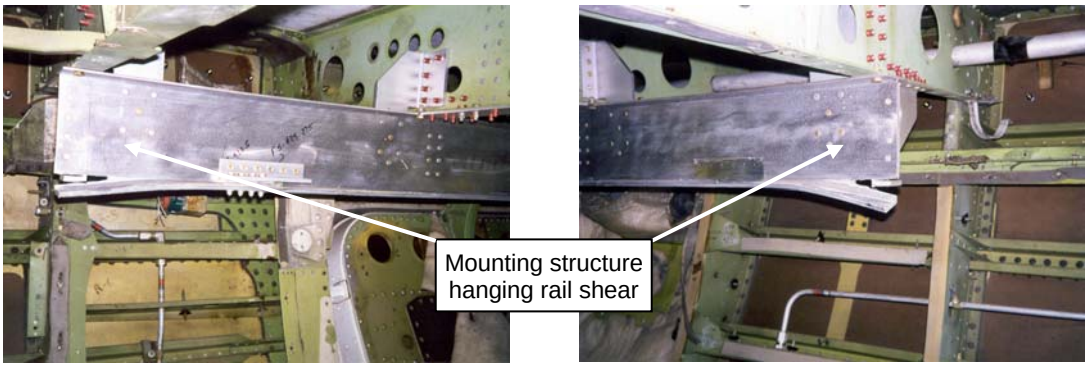


Figure 27. Conformable Auxiliary Fuel Tank Mounting System Damage

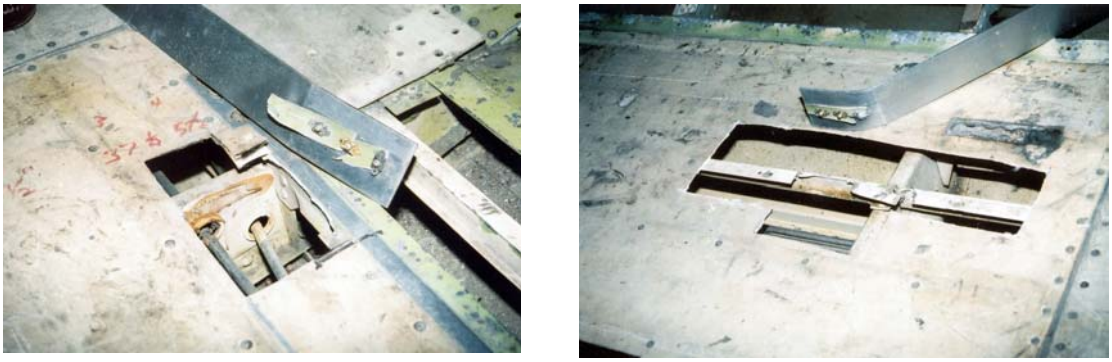


Figure 28. Conformable Auxiliary Fuel Tank Retention Straps

5.1.3 Potential Dynamic Amplification Effects.

Dynamic amplification effects were evaluated by comparing input acceleration values to measured auxiliary fuel tank acceleration values. The sled's maximum peak acceleration values were used as the input acceleration values, and an average of the auxiliary fuel tank's maximum peak accelerations were used as the measured acceleration values.

The cylindrical auxiliary fuel tank had acceleration values of 6.9 g's (6.4-g test), 11.8 g's (10.9-g test), and 13.9 g's (13-g test). This data shows small amplification effects, but it is not significant.

The conformable auxiliary fuel tank showed a maximum of 5.5 g's (6.1-g test) before separating from its mounting system. No acceleration amplification effects can be determined.

5.1.4 Certification Requirements.

The conformable auxiliary fuel tank is required, under 14 CFR Part 25.963, to resist rupture and to retain fuel under the inertial forces prescribed for the emergency landing conditions in 14 CFR Part 25.561. The conformable auxiliary fuel tank that was certified by analysis should have been capable of withstanding a 9-g static forward inertial load. The fuel tank failed a simulated longitudinal impact test at less than a 6-g dynamic inertial load. A review of the tank design disclosed a deficiency in the mounting system design. As a result, the mounting system was modified and the tank was certified by analysis to static load requirements specified in 14 CFR Part 25.561. The conformable auxiliary fuel tank and the new mounting system passed a 9-g simulated longitudinal impact test.

5.2 VERTICAL TESTS.

5.2.1 Cylindrical Fuel Tank.

The tank remained attached to its mounting system (figures 29, 30, and 31). The loads were spread out over the floor beams, which kept the fuel tank system from penetrating the cabin floor even though a few floor beams fractured.

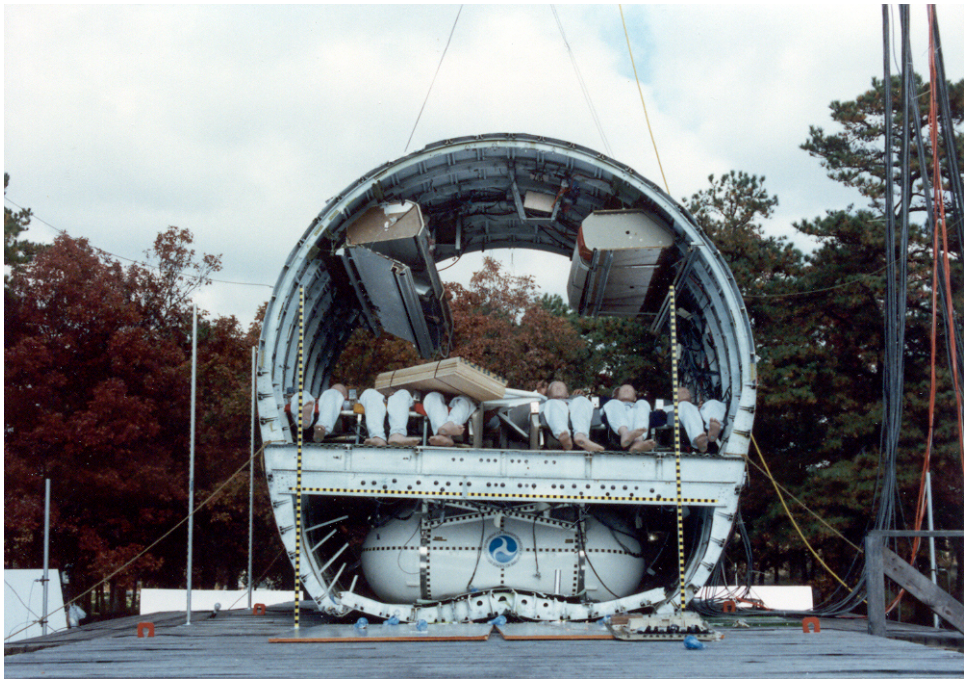


Figure 29. Posttest—Cylindrical Auxiliary Fuel Tank and Test Article

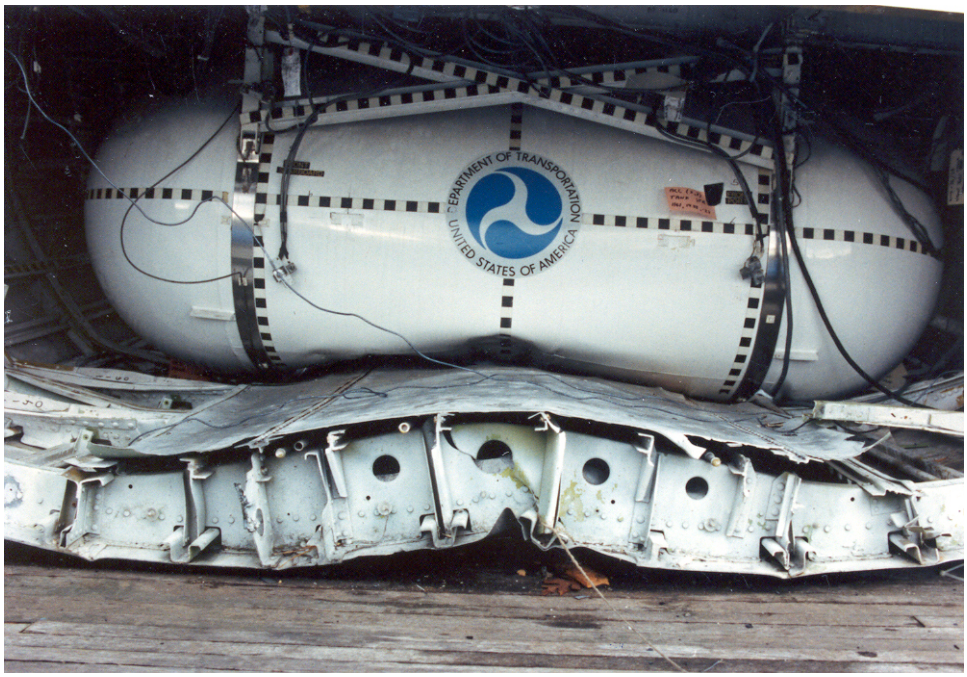


Figure 30. Posttest—Cylindrical Fuel Tank—Front

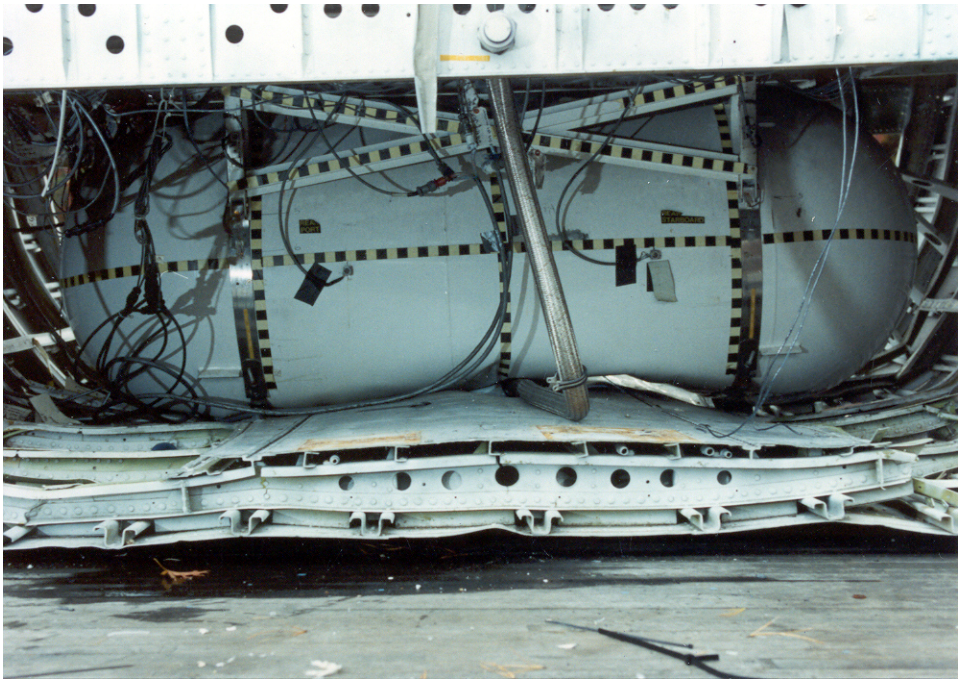


Figure 31. Posttest—Cylindrical Fuel Tank—Rear

The tank sustained approximately 4 inches of crush in the center lower surface due to the protrusion of the discharge fuel line hardware (figures 32 and 33). The ribs inside the tank fractured as seen in figures 34 and 35.

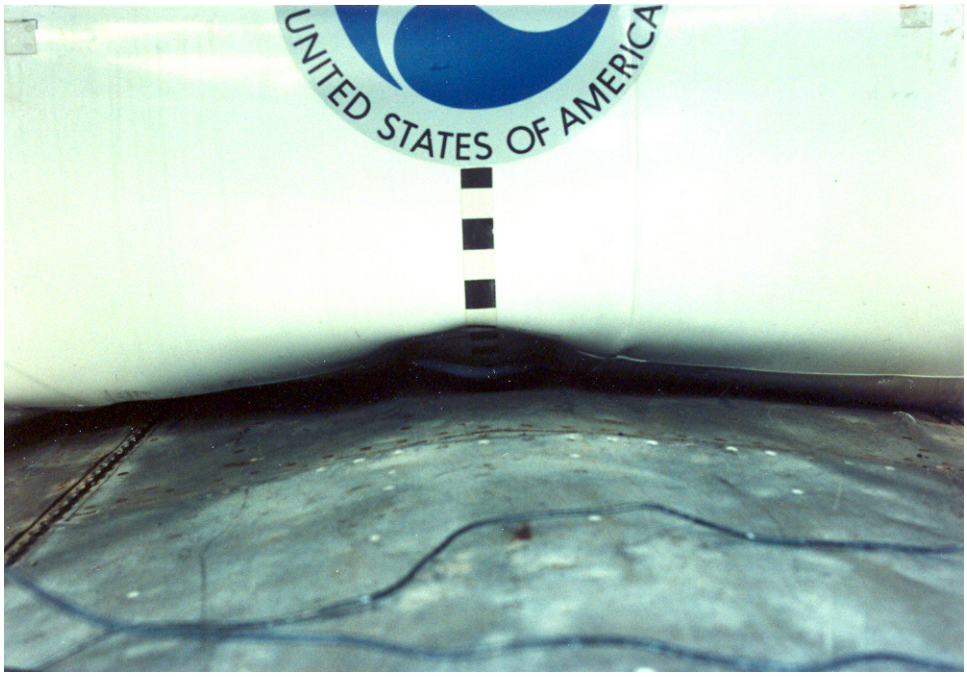


Figure 32. Close-Up Cylindrical Fuel Tank Crush—Front

Figure 33. Close-Up Cylindrical Fuel Tank Crush—Rear

Figure 34. Cylindrical Fuel Tank Fractured Ribs

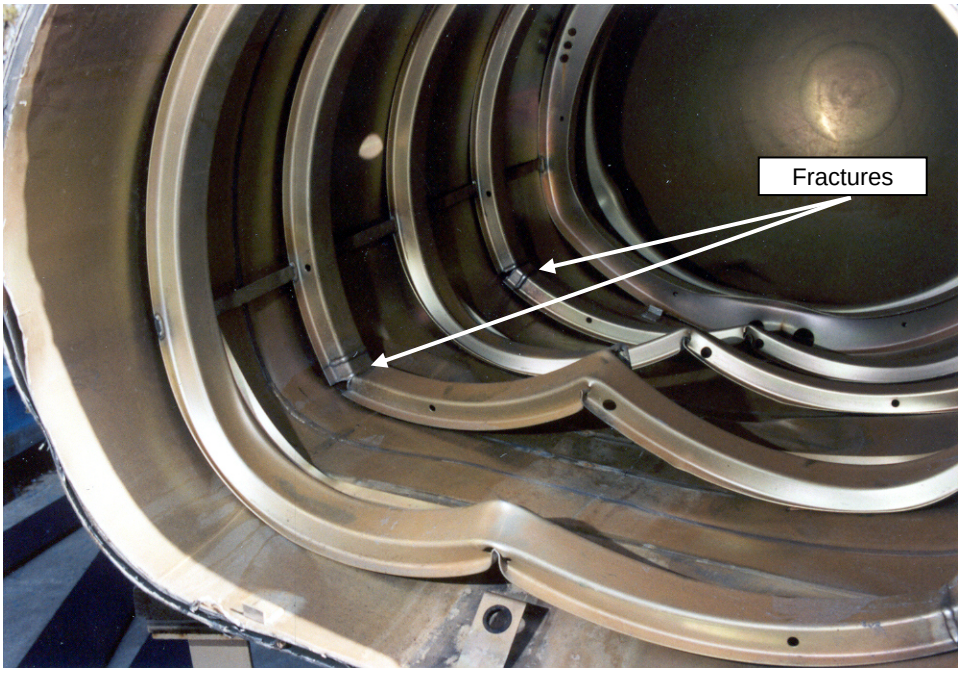


Figure 35. Close-Up Cylindrical Fuel Tank Fractured Ribs

The cylindrical tank leaked at the cracks around the welding of the discharge fuel line hardware at the bottom of the tank. This was a small, slow leak as shown in figure 36. The cracks around the drainage hole and the drainage hole connectors are shown in figures 37 and 38.

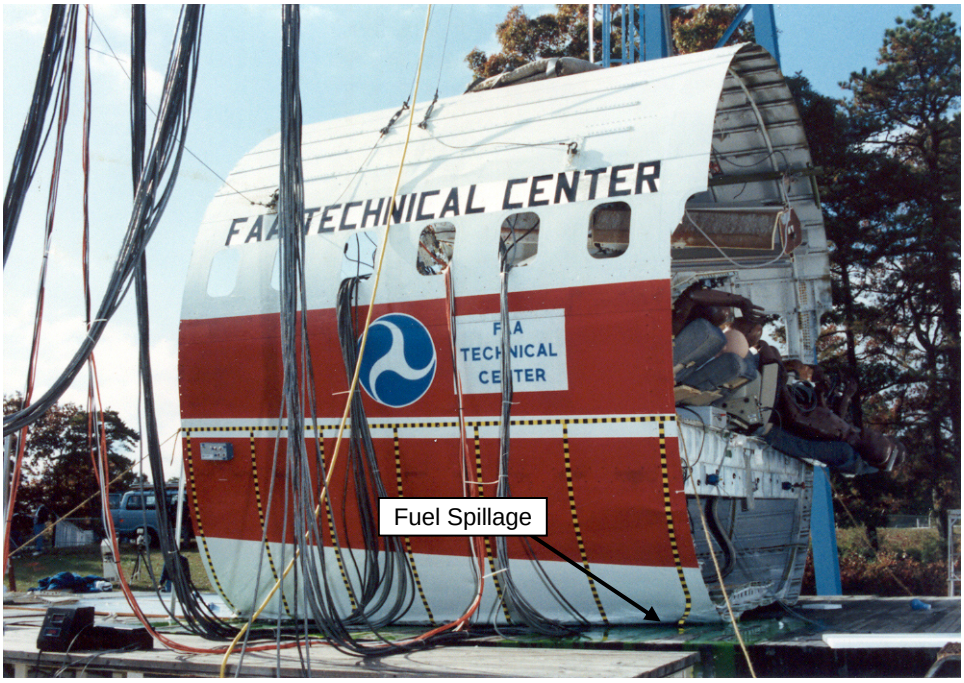


Figure 36. Posttest Cylindrical Fuel Tank—Leak at Discharge Fuel Line Area

Figure 37. Posttest Cylindrical Fuel Tank—Bottom of Tank

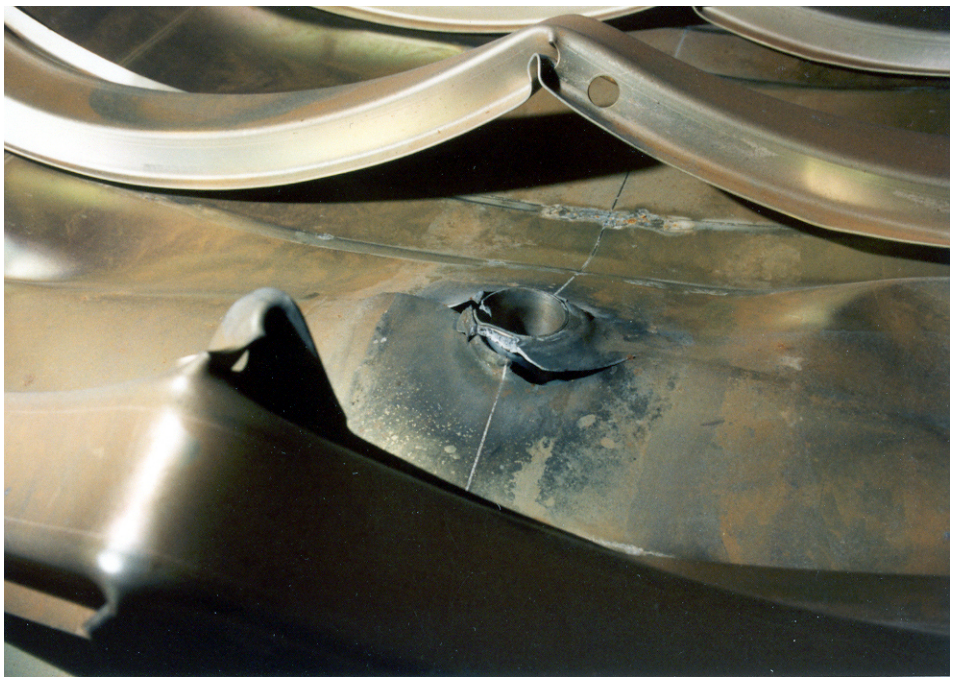


Figure 38. Posttest Cylindrical Fuel Tank—Leak at Discharge Fuel Line Area

5.2.2 Conformable Fuel Tank.

The conformable auxiliary fuel tank was very rigid and did not crush (figures 39 and 40). The result was that the cabin floor (figure 41), seat tracks (figure 42), and fuel tank mounting rails (figure 43) experienced significant deformation. The interaction of the fuselage structure with the fuel tank and its mounting system caused floor beams to fracture, which led to the failure of the adjacent seat tracks. The inner and outer seat tracks at FS 420 and FS 438 on the left side were fractured and separated from the floor. This resulted in the rear legs of the left-hand side/first row seat displacing into the cargo area (figure 42(a) and (b)). The seat track fractures were due to the interactive loading from the seat legs of the left-hand side/first row seat and the loading imposed by the tank below.

The left fuel tank mounting rail was bent in a U-shape (figure 43(b)). The mounting brackets that secured the rails to the floor beams remained attached to the rail. Only the mounting brackets at FS 500 remained attached to the floor beam. In the other locations where the mounting brackets were attached, they separated from and fractured the floor beam (figure 44). The floor beams located at FS 460 and FS 480 fractured. The floor beams at FS 440 and FS 500 remained intact.

The most noticeable deformation in the cabin area of the fuselage structure was the upward intrusion of the floor into the passenger cabin (figure 41(a)). The damage was localized in the floor area above and surrounding the fuel tank. However, a survivable volume was maintained, and the passengers would have been able to exit the airplane.

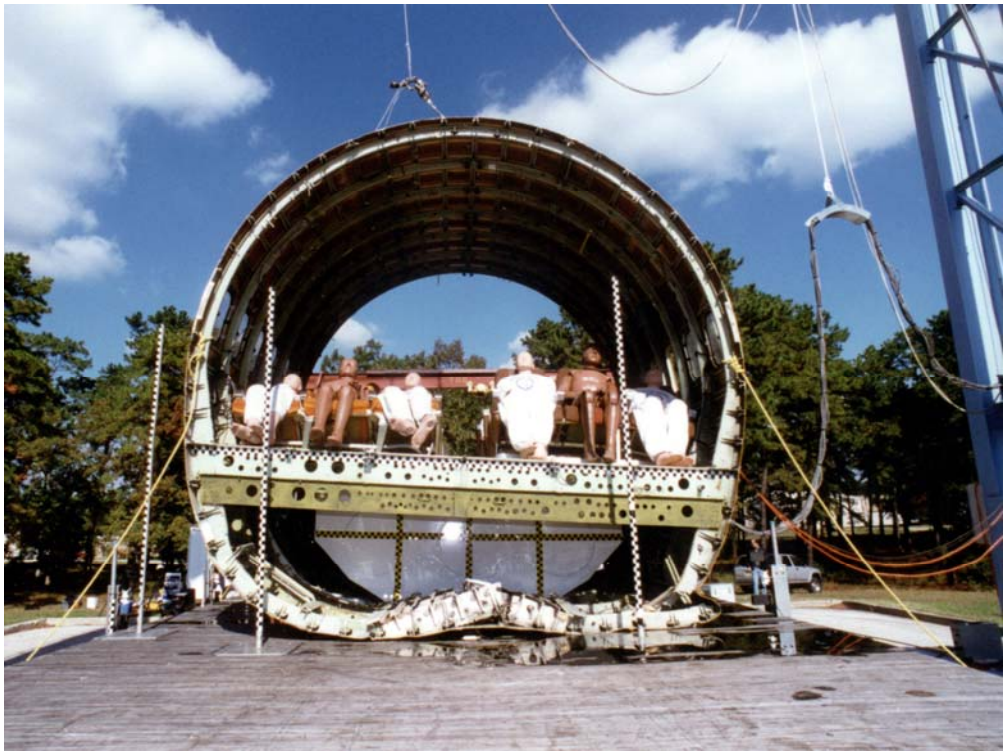


Figure 39. Posttest—Conformable Fuel Tank and Test Article

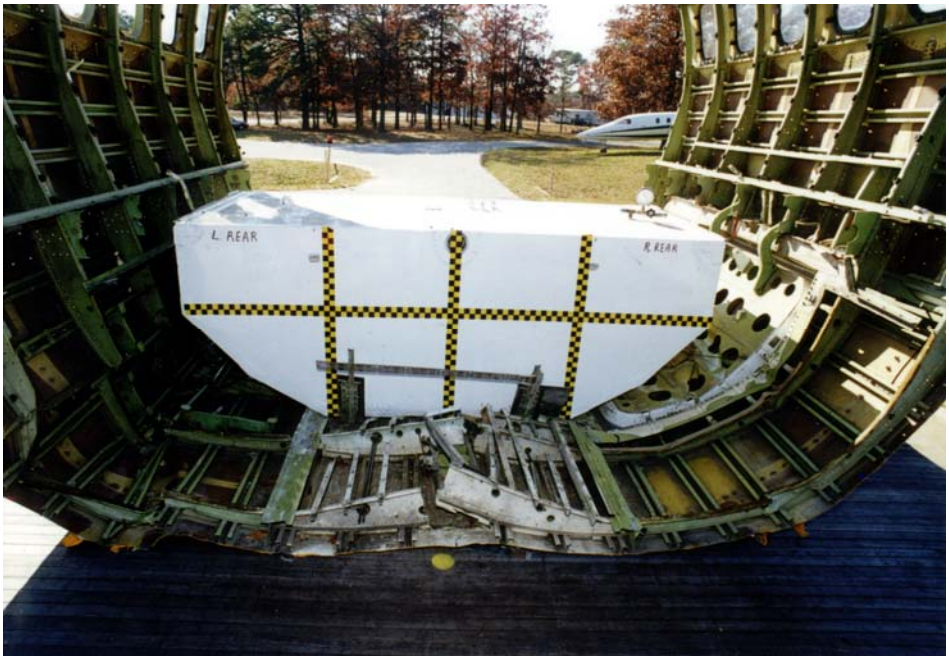
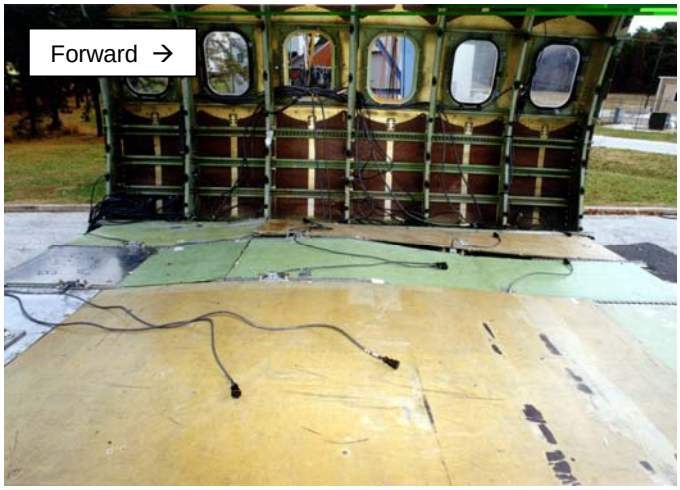
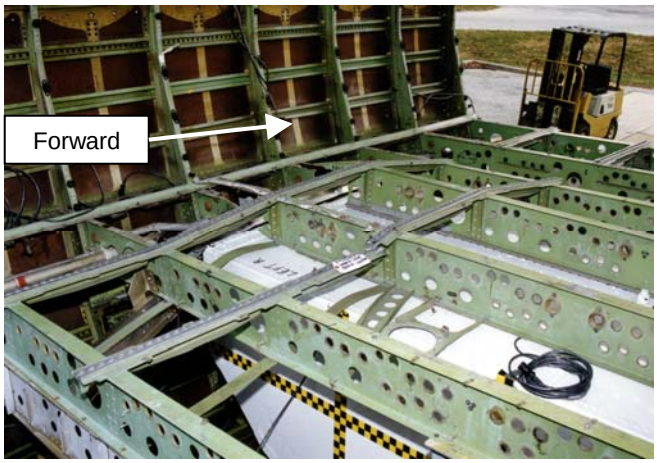


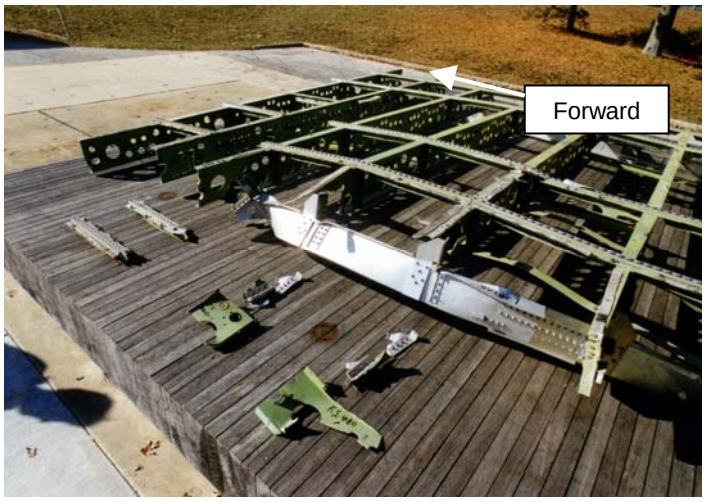
Figure 40. Posttest—Conformable Fuel Tank—Cabin Floor Structure Removed



a. Cabin Floor Buckle

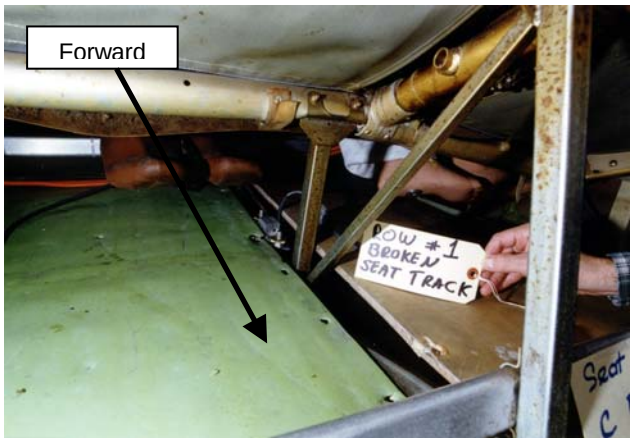


b. Floor Beams

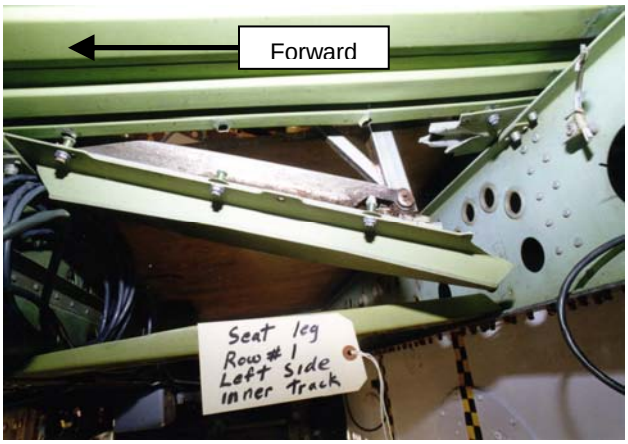


c. Floor Beams—Removed

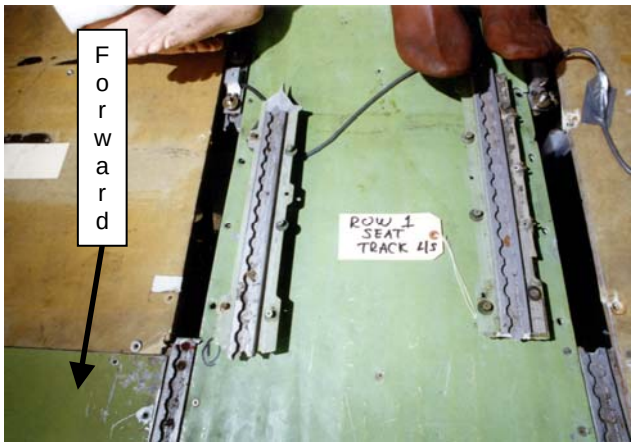
Figure 41. Cabin Floor Structure



a. Fractured Seat Track



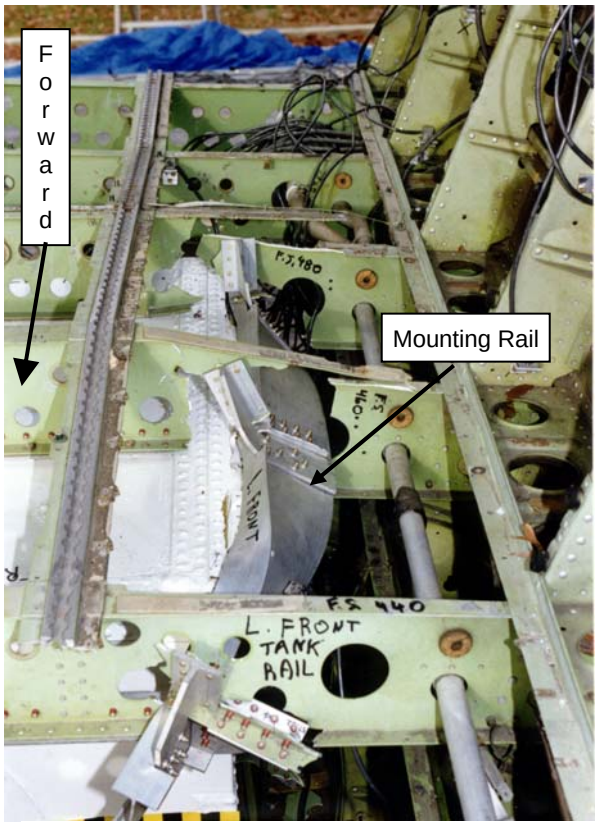
b. Seat Track Displaced Into Cargo Area



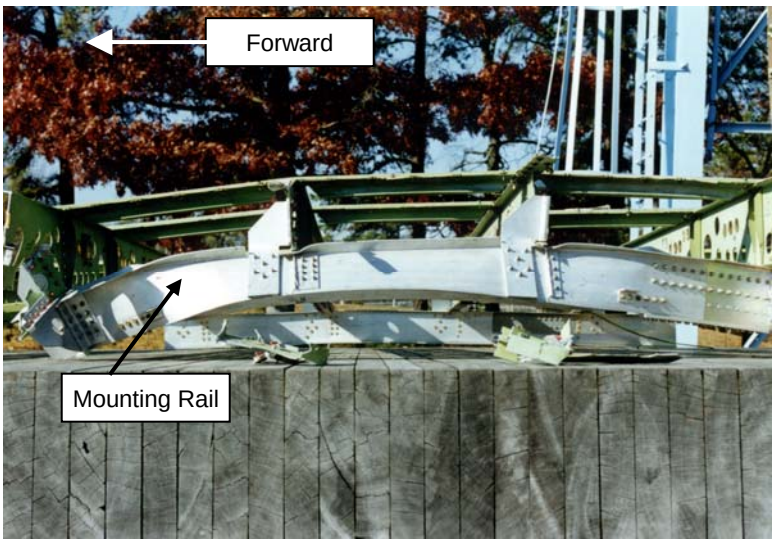
c. Inner and Outer Fractured Seat Tracks

d. Fractured Seat Tracks—Close-Up

Figure 42. Fractured Seat Tracks



a. Bent Mounting Rail



b. Mounting Rail—Removed

Figure 43. Posttest Fuel Tank Mounting Rail

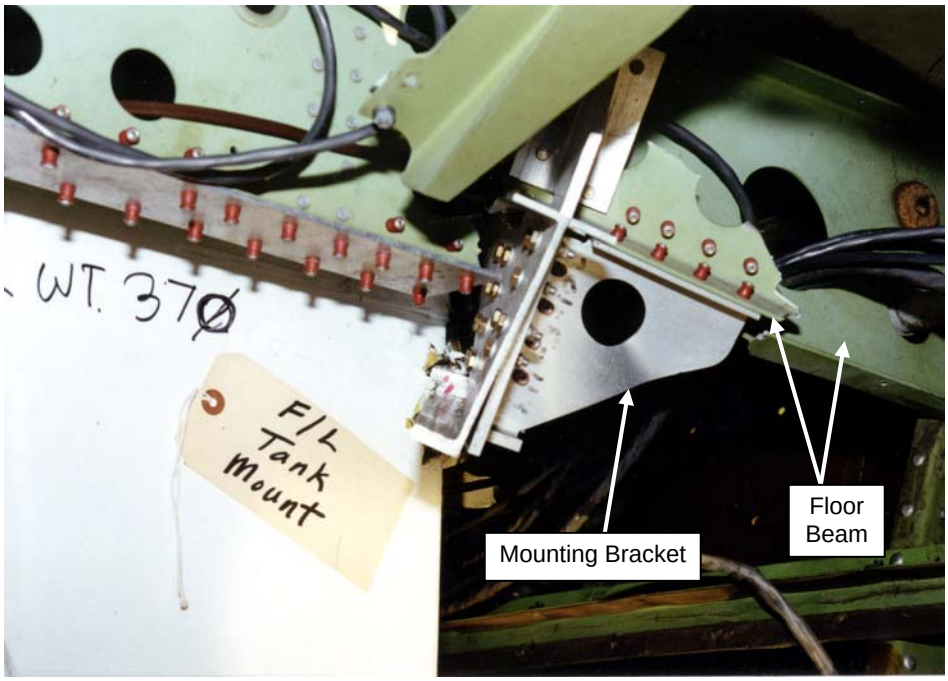


Figure 44. Fuel Tank Mounting Bracket—Fractured Floor Beam

The conformable auxiliary tank sustained substantial damage by the impact with fuselage cargo floor frames, metal members, and the cargo floor tracks that penetrated the bottom of the tank (figure 45). This damage resulted in significant fuel leakage as shown in figure 46.

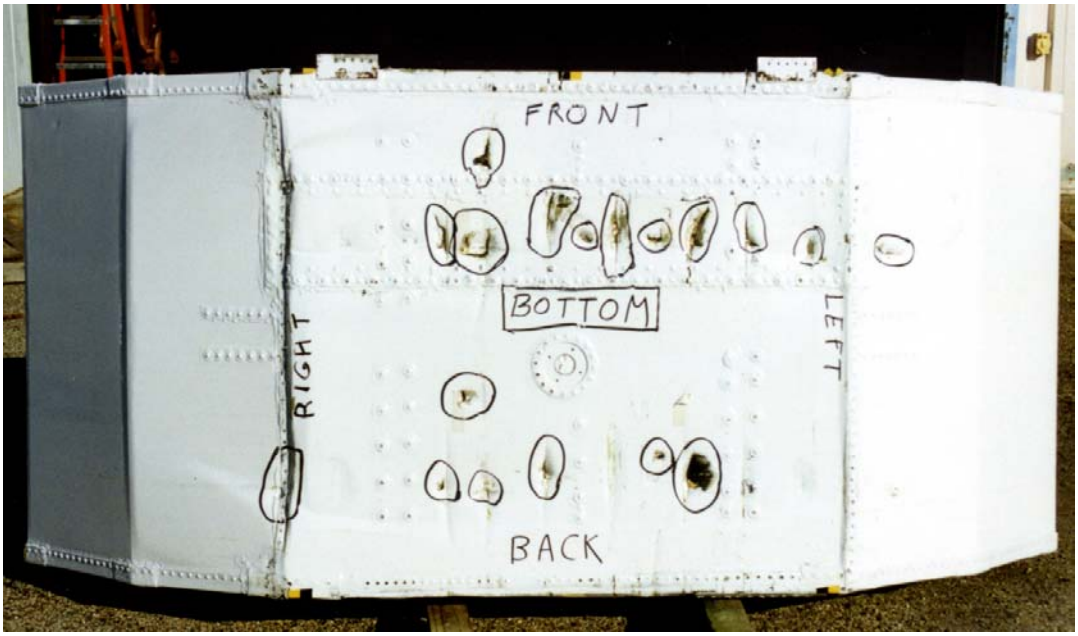


Figure 45. Posttest Conformable Fuel Tank Damage

Figure 46. Posttest Conformable Fuel Tank Leakage

5.2.3 Potential Dynamic Amplification Effects.

The dynamic amplification effects were evaluated by comparing input acceleration values to measured auxiliary fuel tank acceleration values. The average of the maximum peak fuselage acceleration values were used as the input acceleration values, and an average of the auxiliary fuel tank's maximum peak accelerations were used as the measured acceleration values.

Averaging the seven accelerations from the primary impact (fuselage sidewalls, floor, and ceiling), the B-707 fuselage experienced an acceleration of 38.3 g's. The average acceleration from the two cylindrical auxiliary tank accelerometers is 37.8 g's. This data shows no amplification effects.

The average acceleration of the 12 accelerometers from the cabin upper and lower sidewall of the B-737 fuselage was 32.8 g's. The conformable auxiliary fuel tank showed an acceleration of 60.3 g's. This data shows high amplification effects from the airplane's conformable auxiliary fuel tank.

5.2.4 Current Certification Requirements.

14 CFR Part 25.561(b)(3) [7] requires that the airplane must be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing when the occupant experiences the following ultimate static inertia forces acting separately relative to the surrounding structure:

- Upward, 3.0 g's

- Sideward, 3.0 g's on the airframe and 4.0 g's on the seat and other attachments
- Forward, 9.0 g's
- Downward, 6.0 g's (was 4.5 g's prior to Amendment 25-64, effective date July 16, 1988)
- Rearward, 1.5 g's

FAA Advisory Circular 25-8 [8] in part states that it should be shown by a crashworthiness analysis that the airplane lower fuselage and auxiliary fuel tank supporting structure are to be capable of withstanding the crash loads found in 14 CFR Part 25.561, as listed above.

The average vertical inertial loads experienced on the auxiliary fuel tank systems during the severe, but survivable impact tests were significantly higher than currently cited 6.0-g downward requirement. The cylindrical and the conformable auxiliary fuel tank systems had an average G_{peak} of 37 and 60 g's, respectively.

14 CFR Part 25.963(d) also states that fuel tank within the fuselage contour must be able to resist rupture and be able to retain fuel under the inertia forces prescribed for the emergency landing conditions in 14 CFR Part 25.561. Again, since the severe, but survivable vertical impact tests resulted in much higher impact loads than those found in the requirements, these results do not necessarily indicate a compliance issue.

6. CONCLUSIONS.

Postcrash fuel-fed fires are a major contributor to the fatal accident rate. The Federal Aviation Administration has been conducting research to better understand and minimize these fires. The objective of these tests was to determine the interaction between a typical transport airplane fuselage section, particularly its floor structure, and an auxiliary fuel tank under severe, but survivable, impact conditions.

Both the conformable and the cylindrical auxiliary fuel tanks used in these tests are representative of tanks being installed in narrow-body transport airplanes. The conformable fuel tank is being used more frequently than the cylindrical.

In both tests, longitudinal and vertical, the cylindrical tank did not damage the cabin floor and remained attached to its mounting system, but the conformable tank heavily damaged the cabin floor and broke free from its mounting system.

Both tanks leaked after the vertical impacts. The cylindrical auxiliary fuel tank sustained a small leak and the conformable auxiliary fuel tank leaked a significant amount of fuel.

Potential amplification effects are seen only in the vertical drop test of the conformable auxiliary fuel tank. The fuselage experienced an impact of 32.8 g's and the tank 60.3 g's.

A redesign or relocation of the cylindrical auxiliary fuel tank discharge plumbing might have prevented the rupture at the bottom of the tank and thereby prevented the fuel leakage.

In the vertical impact test, the rigid conformable auxiliary fuel tank caused damage to the cabin floor and floor tracks; whereas, the cylindrical auxiliary fuel tank resulted in no damage.

A habitable environment in the passenger cabin was maintained in all tests. However, the floor tracks failed in the conformable fuel tank vertical test. This could result in emergency evacuation issues, including inhibiting passengers from getting out of their seats and blocking emergency exits.

The vertical impact tests resulted in higher dynamic inertial load levels and a different type of loading condition as compared to the static load levels that they were designed to withstand.

The conformable auxiliary fuel tank, which was certified by analysis, should have been capable of withstanding a 9-g static forward inertial load. The fuel tank failed a simulated longitudinal impact test at less than a 6-g dynamic inertial load. A review of the tank design disclosed a deficiency in the mounting system design. As a result, the mounting system was modified and the tank was certified by analysis to static load requirements specified in 14 CFR Part 25.561. The conformable auxiliary fuel tank and the new mounting system passed a 9-g simulated longitudinal impact test.

The cylindrical auxiliary fuel tank remained attached to its mounting system, and no significant damage resulted from three separate simulated longitudinal tests of increasing severity.

7. REFERENCES.

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2. Wittlin, Gill, "Longitudinal Pulse Test Results for a Transport Airplane Section With an Auxiliary Floor-Mounted Fuel Tank," FAA report DOT/FAA/CT-91/3, November 1990.

3. Logue, T., McGuire, R., Reinhardt, J., and Vu, T., "Vertical Drop Test of a Narrow-Body Fuselage Section With Overhead Stowage Bins and Auxiliary Fuel Tank on Board," FAA report DOT/FAA/CT-94/116, April 1995.

4. McGuire, R. and Macy, T., "Longitudinal Acceleration Tests of Overhead Luggage Bins and Auxiliary Fuel Tank in a Transport Airplane Airframe Section," FAA report DOT/FAA/AR-99/4, June 1999.

5. McGuire, R., "Longitudinal Acceleration Tests of Overhead Luggage Bins and Auxiliary Fuel Tank in a Transport Airplane Airframe Section, Part II," FAA report DOT/FAA/AR-99/4, II, October 2000.

6. Abramowitz, A., Smith, T.G., and Vu, T., "Vertical Drop Test of a Narrow-Body Transport Fuselage Section With a Conformable Auxiliary Fuel Tank Onboard," FAA report DOT/FAA/AR-00/56, September 2000.

7. Federal Aviation Regulations, Title 14 Code of Federal Regulations Part 25.561.

8. FAA AC 25-8, “Auxiliary Fuel Systems Installation,” May 1986.