NAWCWPNS TM 8126

TWA Flight 800 Missile Impact Analysis

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DECEMBER 1997

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FOREWORD

This report documents the results of a study conducted between October 1996 and October 1997 of the wreckage of TWA Flight 800. The work was performed for the Department of Defense's Office of Special Technology.

The report was reviewed for technical accuracy by C. Frankenberger and T. Dougherty. The findings of this study are preliminary in nature, and the report is released at the working level.

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2 December 1997

NAWCWPNS TM 8126, published by Code 474500D, 25 copies.

TECHNICAL MEMORANDUM (TM)

BIBLIOGRAPHIC INFORMATION

REPORT NUMBER	REPORT DATE	DISTRIBUTION STATEMENT
NAWCWPNS TM 8126	November 1997	A Statement; public release; unlimited distribution.

REPORT TITLE

TWA Flight 800 Missile Impact Analysis

AUTHOR(S) (Name, code, and telephone number)	NUMBER OF COPIES	NUMBER OF PAGES
Richard Bott. Code 418300D (760) 927-1248	25	22

ABSTRACT (Maximum 200 words)

The military services routinely conduct destructive testing of aircraft by subjecting them to missile and projectile damage under conditions likely to be encountered in combat. This live-fire testing has built considerable expertise in identifying warhead damage on aircraft structure and systems. The Federal Bureau of Investigation and the National Transportation Safety Board requested assistance from the military community in identifying possible missile impact damage on the wreckage of TWA Flight 800.

Visits to Calverton. N.Y.. were made to examine the wreckage from TWA Flight 800. These inspections were documented and combined with other data to analyze the possibility that a shoulder-launched missile was responsible for the destruction of the aircraft.

This report presents the results of the TWA Flight 800 analysis. This report is intended as a quick-look engineering summary, not a detailed scientific analyses.

SECURITY CLASSIFICATION OF REPORT:	SECURITY CLASSIFICATION OF ABSTRACT:	SECURITY CLASSIFICATION OF THIS PAGE:
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED

NAVWPNCEN 3900/1 (11-92)

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EXECUTIVE SUMMARY

Numerous incidents of shoulder-launched missiles impacting commercial airliners have been confirmed. All these incidents have occurred outside the United States, leaving civilian investigators with limited experience in identifying the damage characteristics of these weapons.

The military services routinely conduct live-fire testing during the design of combat aircraft to assess performance under realistic conditions. Warheads are often used in this testing. Civilian investigators requested the assistance of military live-fire test engineers to help identify possible missile damage on the recovered wreckage of TWA Flight 800.

The wreckage was examined on several occasions as TWA Flight 800 was reconstructed. The results of this examination are combined with other data to investigate the possibility that a shoulder-launched missile was responsible for destruction of the aircraft.

The following conclusions are based on the TWA Flight 800 analysis:

- No conclusive evidence of missile impacts exists on the recovered wreckage of TWA Flight 800.

- The possibility that a shoulder-launched missile was launched at TWA Flight 800, failed to impact, self-destructed in close proximity, and initiated the breakup of the aircraft is highly improbable. This theory would be nearly impossible to prove or disprove even with extensive analysis and testing. However, this effort would be useful in identifying methods to counter future terrorist attacks.

- Reaction of the inboard wing fuel tanks on a 747 aircraft to a missile impact is unknown because no previous test data are available for comparison.

- A database of test and mishap data on potential terrorist weapons versus commercial transport aircraft may be valuable for future mishap investigations.

The following recommendations are based on the TWA Flight 800 analysis:

- Conduct static warhead detonations in a large fluid-filled vessel and dynamic impacts of shoulder-launched missiles with and without live warheads on 747-100 aircraft.

- Conduct static warhead detonations in loaded cargo containers and dynamic impacts of shoulder-launched missiles with and without live warheads on cargo containers and fuselages of commercial transport aircraft.

- Perform analysis and testing to quantify the nature of the terrorist missile versus commercial transport problem so that countermeasures can be identified.

- Establish a formal relationship between the military aircraft survivability community and the commercial aviation industry to enhance aircraft survivability and safety.

BACKGROUND

Since the late 1970s, at least 26 civil aircraft have been shot down by man-portable air defense systems (MANPADS), also known as shoulder-launched missiles (Reference 1). None of these aircraft were U.S. carriers, and none of the incidents were subject to investigation by the National Transportation Safety Board (NTSB) or the Federal Bureau of Investigation (FBI). Therefore, these agencies have not accumulated significant experience with evidence characteristic of these weapons.

Many witnesses reported seeing an object they described as a 'flare' or 'rocket' ascend from the sea to the aircraft immediately before the crash of TWA Flight 800. Most of the aircraft wreckage has been recovered and many experts have performed detailed examinations, but as yet there are no conclusive signs of missile or warhead damage on the debris. Nonetheless, the 'missile theory' persists in various forms.

Past testing has shown the effects of MANPADS on military aircraft in static warhead detonations (the warhead sitting motionless next to the aircraft) and in dynamic tests (the missile traveling at intercept velocity). Extensive arena tests have been conducted to characterize the number, type, and velocity of fragments from specific warheads. The military services routinely conduct this testing as part of live-fire studies on their own combat systems or the investigation of foreign weapon system performance. Recognizing this experience, TWA Flight 800 investigators requested assistance in identifying signs of missile damage on the recovered wreckage.

TYPICAL WARHEAD DAMAGE

Past testing on both commercial and military aircraft has revealed effective methods of identifying missile damage on aircraft. The damage can be separated into four regions as distance increases from the point of warhead detonation. The first region, which is in the immediate vicinity of the detonation, is characterized by complete removal of the structure or subsystem components due to weakening by fragment penetrations and dislocation by the blast pressure wave. The second region contains numerous high-velocity fragment penetrations, soot residue from the explosive, and may exhibit distortion, but not wide-spread removal, of structure and components due to the pressure wave. The third region will contain more widely spaced high-velocity fragment penetrations, usually with little evidence of sooting or pressure wave damage. The fourth region will contain only occasional high- and low-velocity fragment penetrations. These regions do not have distinct boundaries between each other, and overlapping of characteristic damage between them is common.

This damage is typical of nearly all missile warheads. The dimensions of each region will vary widely, depending on the type of missile involved, and all regions may not be represented on a target. For example, a large surface-to-air missile with a proximity fuse could detonate 100 feet from an aircraft, leaving only high- and low-velocity fragment damage characteristic of region 4 on the target. Because of its small size, a shoulder-launched missile is typically a contact-fuzed weapon that must hit its target to be effective. For this reason, all regions would normally be represented in a shoulder-launched missile encounter. These shoulder-launched weapons were the primary target of the TWA Flight 800 investigation for the following reasons:

1. Shoulder-launched missiles are widely available and are an effective terrorist weapon.

2. Launch of the missile from the water would provide additional complexities in determining the origin of the launch.

3. Larger surface-to-air and air-to-air missile systems are expensive, require training and equipment not easily available, and leave clearly identifiable evidence over larger areas of the target than shoulder-launched systems.

Some types of damage inflicted by warheads can be caused by other events. For example, sooting may be caused by a fuel fire, and low-velocity penetrations are common in post-mishap ground or water impacts. However, high-velocity fragment penetrations are unique to explosive events and give investigators a conclusive method of identifying these encounters when they occur.

Previous testing on both commercial and military aircraft has shown that even with small shoulder-launched weapons, high-velocity fragmentation damage to the aircraft will exist over large areas of the target. These high-velocity penetrations are easily identifiable by melting/resolidification of the hole wall, material splashback surrounding the hole, and lack of deformation of the surrounding material. These characteristics occur at penetration velocities greater than approximately 4000 feet per second (depending on the materials involved), making them unique to explosive events. Gun-fired projectiles such as bullets usually travel at much lower velocities, around 3000 feet per second at the muzzle of the gun.

TWA FLIGHT 800 MISSILE IMPACT ANALYSIS

The TWA Flight 800 wreckage was analyzed on several occasions during the reconstruction to determine if a shoulder-launched missile could have been responsible for destruction of the aircraft.

For the purposes of this investigation, missile encounters in the TWA Flight 800 incident were separated into the following possibilities:

1. A fully operational missile impacted the aircraft and the warhead exploded.

2. A missile impacted the aircraft but the warhead did not explode.

3. A missile was launched at the aircraft but failed to intercept. The self-destruct feature of the missile detonated the warhead in the proximity of the aircraft.

Each of these possibilities is discussed in detail in the following paragraphs.

MISSILE IMPACT WITH WARHEAD DETONATION

Previous tests typically showed dense high-velocity fragment damage to aircraft structures over an area of roughly 20 square feet in the vicinity of the detonation, with less dense high-velocity penetrations well beyond this area. With approximately 95% of TWA Flight 800 recovered, fragment-damaged pieces of the aircraft should be present in the debris if a shoulder-launched missile warhead had detonated within or just outside the aircraft. There are no areas of missing material on the wreckage large enough to contain this amount of damage.

No conclusive identification has been made of high-velocity impact damage on any of the TWA Flight 800 wreckage. On the recovered aircraft debris, literally thousands of holes were closely examined to determine evidence of high-velocity impacts. The NTSB Structures Committee identified 196 holes for more detailed evaluation (Reference 2). After this examination, all but 25 of these holes were determined to have no characteristics indicative of high-velocity impacts. The 25 remaining holes received an even more in-depth examination. After this examination, all holes in the center wing section were classified as low-velocity impacts. Similar examinations of the holes outside the center wing section also revealed characteristics consistent with low-velocity impacts.

Two holes in the horizontal pressure deck above the left wing landing gear bay (pieces LF137 and RF60) possessed features of low- and high-velocity penetrations. The hole in LF137 was located at STA1457 and LBL110. Laboratory analysis of this hole indicates the penetrating object was moving downward and slightly aft. The hole in RF60 was located at STA1452 and LBL62, indicating the penetrating object was moving downward and slightly inboard. Both holes lacked deformation of the surrounding material, indicative of high-velocity penetration. However, the two holes did not possess material splashback or melting/resolidification of the hole wall, which suggests low-velocity penetrations.

Assuming the direction of the penetrations based on the examinations is correct, the flight paths of the penetrating objects diverge toward their origination points. In other words, the penetrating objects came from two different locations, which indicates they did not originate from a detonating warhead. Conceivably, this area of the aircraft would be highly loaded during water impact because of the presence of the landing gear and heavy wing carry-through structure. This high loading could create a more energetic release of material, possibly to the extent that penetrations exhibit some characteristics of high-velocity projectiles.

There are two areas on the 747 aircraft in which some uncertainty exists as to what evidence would be present if a shoulder-launched missile impacted, specifically in a baggage container or a large fuel tank. Military testing has not addressed these areas and without this previous test data, it is unknown if a missile would leave conclusive and obvious fragmentation damage. The infrared seekers on these missiles typically aim for hot spots, such as engine exhausts or inlets, and these cooler areas are not likely to be tracked by the approaching missile. However, because no comprehensive missile fly-out and endgame analysis or reliable test data exist, an examination of missile impacts in these areas was made.

Four baggage containers were located in the forward cargo compartment of TWA Flight 800. A diagram of all container locations is shown in Figure 1. The two containers on the left side of the aircraft, AKN7415 and AKN9737, were recovered in the red debris field and were not severely damaged. Both containers have virtually all sides intact, and the damage is consistent with water impact.

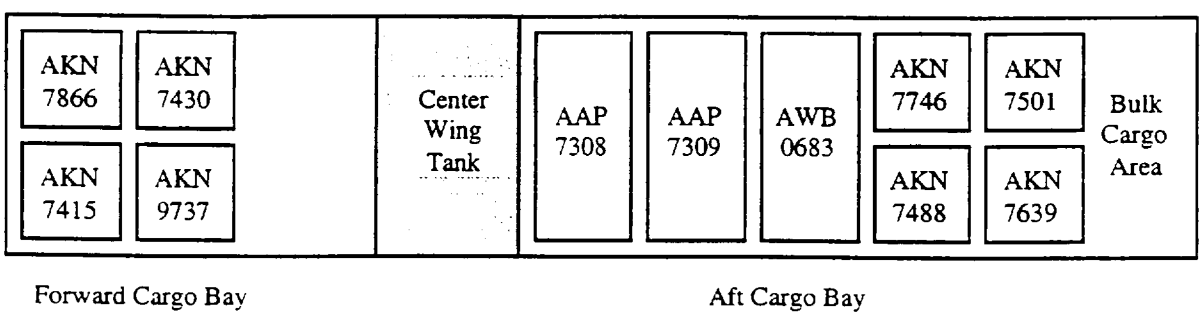


FIGURE 1. Cargo Container Locations on TWA Flight 800.

The two containers on the right side of the forward cargo hold, AKN7866 and AKN7430, were recovered in the yellow debris field. These containers are more severely damaged, but the majority have been recovered and reconstructed. The damage also appears to be attributable to water impact.

Seven baggage containers were in the aft cargo hold of TWA Flight 800. All containers were severely damaged and similar in appearance to each other. The nature and similarity of the damage to all aft containers are consistent with water impact. The only exception is a single baggage container, AWB0683, constructed of fiberglass reinforced plastic rather than aluminum, that shattered. This failure mode is typical of its more brittle construction and still consistent with water impact.

Because previous test data are unavailable, the appearance of a baggage container impacted by a missile is not specifically known, but some intuitive predictions can be made. An entry hole in the container probably would be circular or oblong, but may not be obvious if the surrounding material was broken apart. The exit side of the container would be more severely damaged as the kinetic energy of the missile imparted movement to the contents. If the missile functioned properly, the warhead would create extensive fragmentation damage to the container's contents and perhaps to the container itself. The detonation almost certainly would ignite a fire in the midst of such combustibles as clothes and other personal belongings. No fire damage exists on the recovered portions of the cargo containers. Some fire damage exists on contents, but this damage must have occurred during the fire on the water surface after impact because the containers themselves are not fire damaged.

Additionally, missile impact on a baggage container in the aft hold is unlikely the initiating event because failure of the aircraft began in or near the center wing fuel tank. Similarly, the baggage containers in the forward hold were located well forward of the center wing tank with the intervening space vacant. This physical separation between the center wing fuel tank and the baggage containers in the aft and forward cargo holds implies that an impact in these containers is unlikely the initiating event.

The inboard wing fuel tanks on the 747 are large, holding 12,240 gallons of fuel each. Although the inboard tanks on TWA Flight 800 were not filled to capacity at the time of the mishap, the dihedral of the wings in level flight would leave the ullage space located at the outboard ends and the inboard ends filled all the way to the upper wing skin. The military has not performed dynamic missile impacts on large fluid-filled structures such as these, and no known combat mishap data exist. Therefore, the damage on a 747 wing due to a shoulder-launched missile impact is unknown. Predictions can be made, but this uncertainty will continue to exist without validating test data.

The thickest part of the wing fuel tanks are at the fuselage where the number 2 and number 3 main tanks butt up against the center wing tank. A schematic of the 747 wing fuel tanks is shown in Figure 2. The kinetic energy of the missile body and the explosive energy of the detonating warhead would create a significant hydrodynamic ram event that could cause severe damage to one or more of the following structures even though the possibility exists that warhead fragmentation damage would not occur:

1. Upper/lower wing skins
2. Wing spar webs
3. Side-of-body ribs separating the center wing tank from the adjacent main wing tanks
4. Wing leading-edge fairing

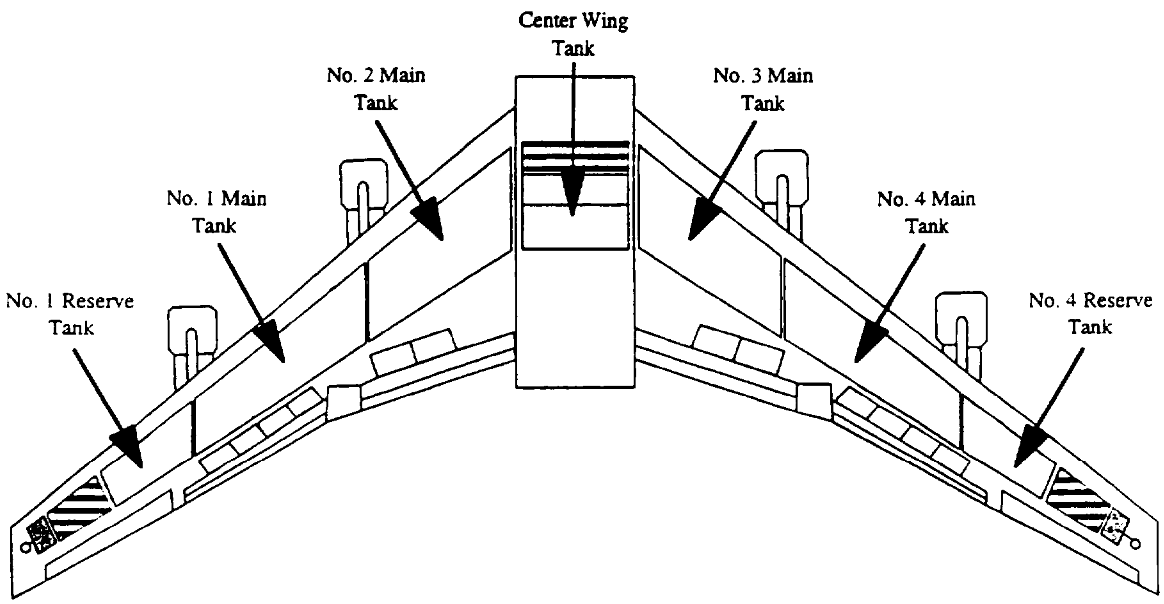


FIGURE 2. Boeing 747-100 Fuel Tank Arrangement.

Detailed examinations of the TWA Flight 800 wing fuel tanks were conducted. The left upper wing skin, the left side-of-body rib, and the left leading-edge spar exhibit different and more severe damage from their right wing counterparts. Figures 3, 4, and 5 show comparisons of the damage to the upper wing skins, side-of-body ribs, and inboard leading-edge spars, respectively. Close inspections of the wreckage in these areas revealed no evidence of penetrations by foreign objects and no high-velocity fragment damage consistent with a missile impact. NTSB and FBI documentation support these findings (References 3 and 4).

Nearly all wing wreckage was recovered downrange in the green zone, but several sections of the wing root leading-edge fairing, pieces A449 and A551, were recovered in

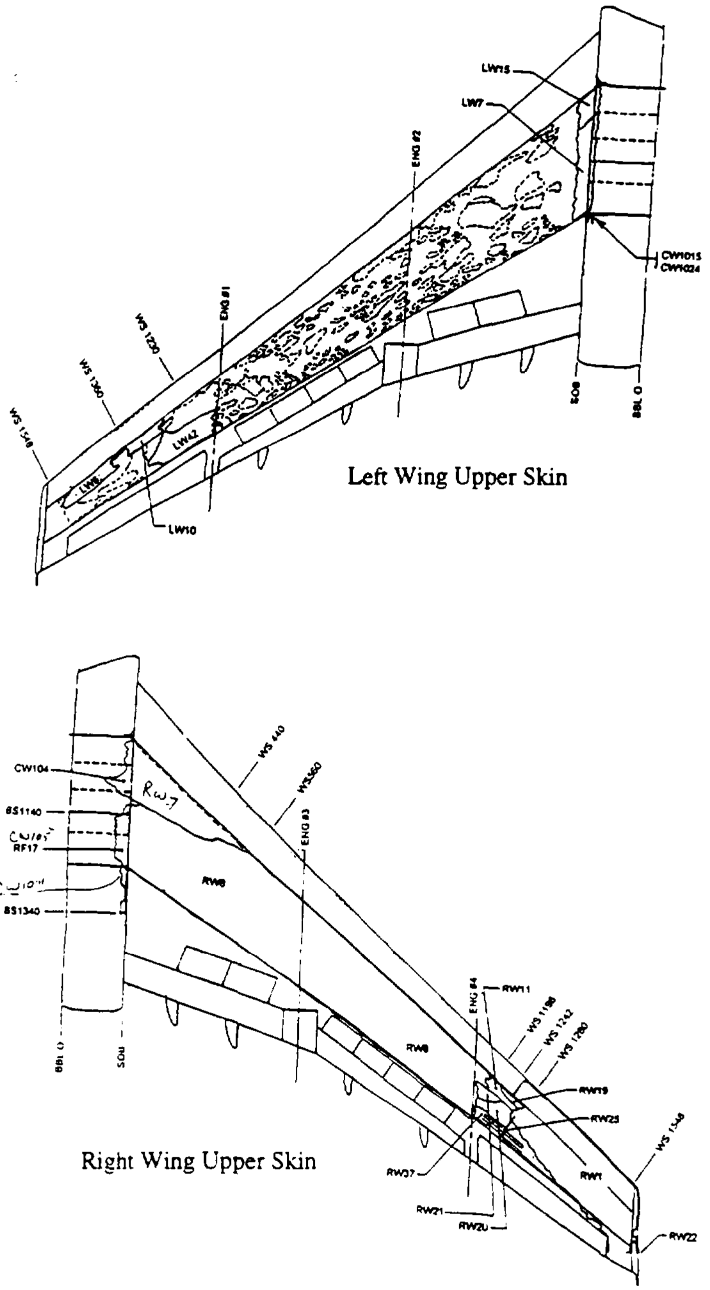
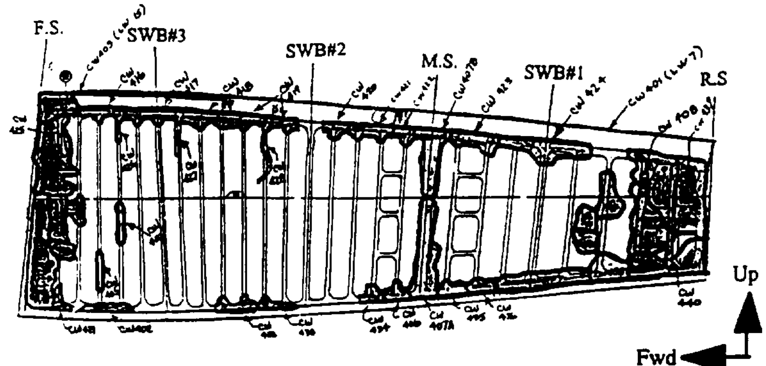
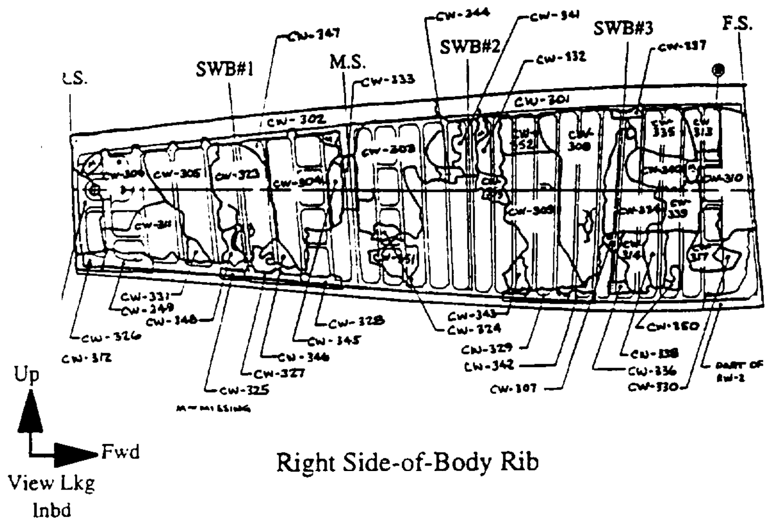


FIGURE 3. TWA Flight 800 Upper Wing Skin Damage.



Left Side-of-Body Rib

Note: Numerous small pieces cannot be placed.



Right Side-of-Body Rib

FIGURE 4. TWA Flight 800 Side-of-Body Rib Damage.

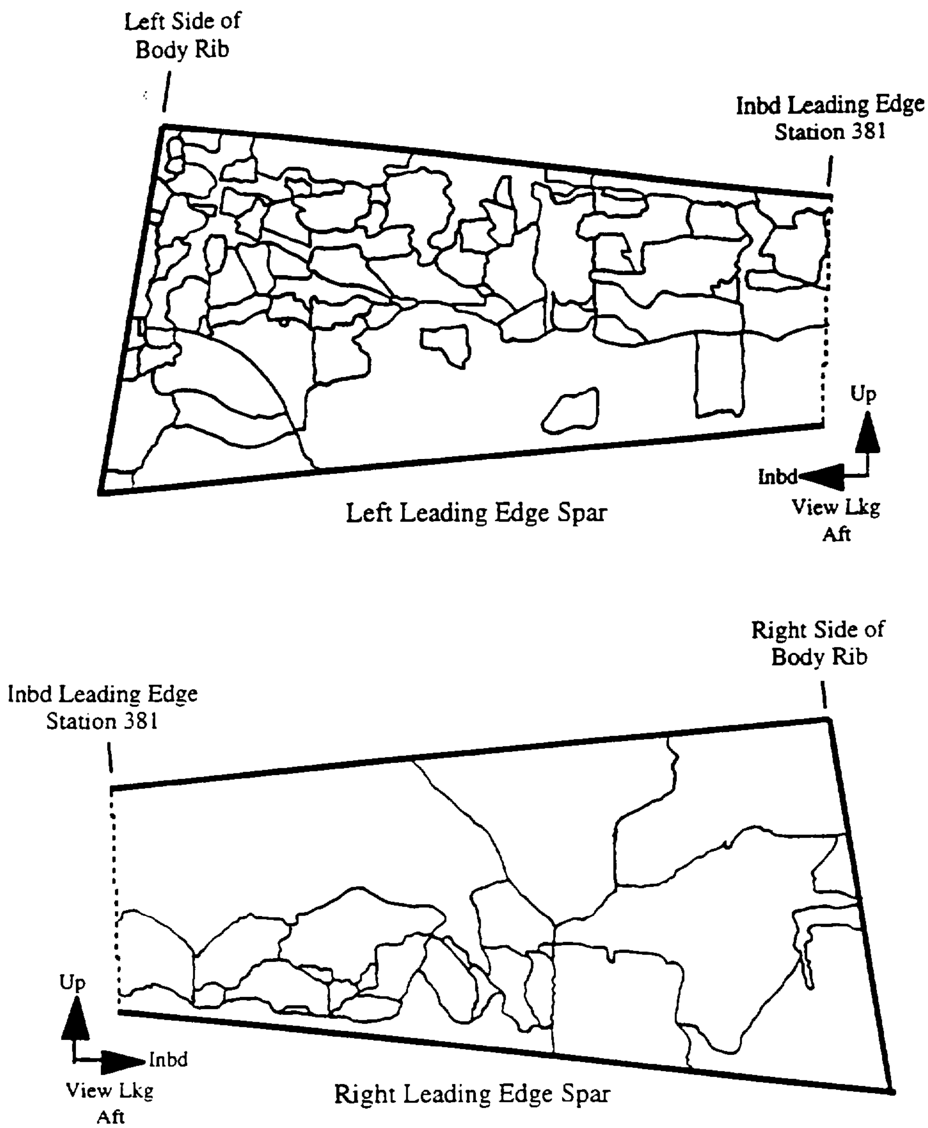


FIGURE 5. TWA Flight 800 Leading-Edge Spar Damage.

the red zone, indicating very early release from the aircraft. Attaching too much importance to these findings should be avoided for the following reasons:

1. Both pieces of leading-edge fairing were from a location immediately adjacent to the fuselage skin, indicating the missile flight path would have to be *exactly* parallel to the fuselage and on a reciprocal flight path. Based on missile simulations, this engagement is not likely.

2. Although both pieces were conclusively recovered in the red zone, each had intact sections of Nomex honeycomb structure attached, which could have provided some degree

of buoyancy. This buoyancy may have led to the components drifting on the surface before sinking or shifting on the ocean bottom before recovery.

3. No visible signs of foreign object impact, other than those associated with water impact, are on either these components or the adjacent components that have been identified. (Not all adjacent components have been identified.)

4. The two components were from the same area of the wing fairing but opposite sides of the aircraft. A449 is from the right wing fairing and A451 is from the left wing fairing. Examination of the reconstruction clearly reveals fractures and curling of the adjacent fuselage skin in these areas. Based on analysis conducted by the NTSB, fractures in the area of these components occurred very early (Reference 5). This determination implies the fairings were torn off as the fuselage broke up immediately after the center wing tank explosion.

Conceivably, a missile impact in the wing-root fuel tank area could create enough damage to cause the side-of-body rib to collapse into the center wing tank. This collapse could occur without significant release of material from the wing structure, but the preponderance of evidence suggests this did not occur on TWA Flight 800. Most compelling is the fact that both wings remained with the aft fuselage section until they were well downrange. If the severe left wing damage had been caused by a missile impact, the expected result would be an early release of that wing, or at least numerous pieces of it, well uprange in the red recovery zone.

Some unexplained damage characteristics on these structures have puzzled investigators, for example, the severe shattering of the left wing upper skin. While the damage mechanisms involved may not be completely understood, the recovery and reconstruction of TWA Flight 800 is the most comprehensive undertaking of its type ever made. This wing damage may be typical for severe water impacts but has gone unnoticed in previous mishaps due to the lack of recovery and reconstruction of debris. Further, the left and right wings of TWA Flight 800 impacted the water in different attitudes, as evidenced by the damage to the engines, which may explain the disparity in damage between the two structures. These damage characteristics are not deemed characteristic of a missile impact, but without validating test data this conclusion cannot be made with 100% certainty.

This lack of previous data, combined with the disparity in damage between the left and right wings of TWA Flight 800, indicates that impact of shoulder-launched missiles could be an area for further investigation via testing and analysis. Again, very compelling evidence exists that the wings on TWA Flight 800 were damaged downrange during in-flight breakup and water impact. The results of this testing will help eliminate conclusively the theory that missile impact was the initiating event for the loss of the aircraft and may assist investigators in future mishaps.

Finally, nearly all the TWA Flight 800 fuselage skin has been recovered. In the reconstructed portion of the aircraft between STA520 and STA1630, the missing skin is only on the order of 2.0% of the total area (Reference 6). Based on previous testing performed by the military and the Federal Aviation Administration (FAA), it is inconceivable that a warhead could have detonated in or near the fuselage without leaving evidence of high-velocity fragmentation damage somewhere on the recovered wreckage.

MISSILE IMPACT WITH NO WARHEAD DETONATION

If a shoulder-launched missile impacted TWA Flight 800 and the warhead failed to detonate, the lack of high-velocity fragmentation damage makes conclusive identification of the encounter slightly different than the analysis for a live warhead.

If the missile impacted a cargo container, damage to the container and contents would be similar, whether or not the warhead detonated, because kinetic energy of the missile body would be a primary contributor to the overall damage. The differences would be no high-velocity fragmentation damage and no ignition of the contents. Again, no data are known to exist for missiles impacting baggage containers; but this scenario is highly unlikely, because all the TWA Flight 800 containers exhibit damage characteristics consistent with water impact. The mechanism for initiation of an ullage explosion in the center wing tank as a result of a cargo container impact is difficult to envision because of the physical separation of all containers from the fuel tank.

Damage to the wing fuel tanks probably would be similar for both a functional warhead and a dud. The kinetic energy of a missile traveling at intercept velocity would be a significant contributor to the hydrodynamic ram damage inflicted to the wing structures. Previous testing using missiles with live and inert warheads fired at motionless aircraft has shown that the warhead contributes little to the overall damage on dry structures. With a fully operational missile impacting the leading-edge fairing of the wing, the warhead would be expected to fuse, with the detonation occurring somewhere just inside. However, no fragmentation damage is present on the recovered leading-edge structure. Other evidence previously noted also strongly suggests the wings were not involved in the initial event.

If the possibility of a missile with a nonfunctioning warhead impacting the aircraft is considered, the fuselage, in addition to the cargo container and fuel tanks, becomes an area of potential interest. The fuselage was previously discounted as a possible impact point due to the lack of high-velocity fragment damage on the recovered debris; however, a dud warhead encounter would lack this high-velocity fragmentation damage.

An entry hole could be quite small, although the missile would be expected to impact the aircraft with some amount of yaw angle and create a hole larger and more oblong than just its diameter. Additionally, the entry hole could be masked by the damage resulting from the in-flight breakup of the aircraft and water impact, making identification very difficult.

A missile penetrating the fuselage probably would break apart as it entered or impacted internal components. These broken pieces would spread apart some unknown distance in open areas, such as the cargo bay and passenger cabin. If these pieces impacted other components, for example, luggage, cabin liners, or galleys, they would impart some of their energy and accelerate the debris in a direction roughly in line with the missile flight path. For these reasons, exit points would be more visible than entry points.

The detailed reconstruction of TWA Flight 800 proved absolutely vital in identifying possible entry and exit points for a missile. Predicting the missile configuration and orientation at exit is difficult because of the variables involved, but a conservative exit-area diameter of 3 feet was assumed based on dry-structure impacts of tactical aircraft in previous testing. As previously stated, with approximately 98% of the fuselage skin accounted for, the inspection of the mock-up revealed no large holes. However, to ensure a complete presentation for this investigation, the following areas were evaluated in detail.

Left Side Hole From STA800-880, Stringer 34L-38L. This area is bounded by LF5 above, LF24B below, LF96 forward, and LF94 aft. Although the skin section in this area is missing, the underlying frames and stringers are completely intact. Neither the frames nor stringers exhibit significant penetrations or distortion, and all the frames are perpendicular to the skin. It is highly improbable that any object could have penetrated this area without damaging this substructure.

Left Side Hole From STA1040-1241, Stringer 26L to 29L. This area is just above the wing and bounded by LF38 on top, LF67B&C aft, and the upper wing skin below and forward. Both skin and substructure in this area are missing. However, this hole has an extremely high-aspect ratio, making it unlikely to be an exit hole. With nearly all the center wing tank upper skin recovered and no significant penetrations or smearing, this hole is equally unlikely to be an entry hole. Additionally, the fractured edge on the upper boundary of the hole is relatively straight with virtually no curling or waviness. This straight edge indicates the fracture resulted from in-plane stresses (tension or shear) not out-of-plane stresses, as would be exhibited in a missile penetration. It is physically possible that the aft end of this hole could be an entry hole because of the missing substructure; but entry angles are extremely limited because of the surrounding structure, such as wing, trailing-edge flap, and landing gear bay upper skin, none of which show any significant signs of smearing or penetrations. The most likely entry angle would range from an azimuth of 100 to 135 degrees from the nose of the aircraft and an elevation of -5 to -60 degrees from the horizontal plane of the aircraft. These negative elevation angles mean the missile would have been higher than TWA Flight 800 and diving down at impact—an unlikely event based on fly-out simulations. Interestingly, only one armrest from the adjacent row of seats (row 28L) has been positively identified. Row 27L seats have been recovered, and the two inboard seats are relatively intact. The flight attendant's seats just aft of row 28L are burn-damaged, but don't exhibit significant signs of distortion or penetration.

Right Side Hole From STA720-741, Stringer 16R to 19R. This area is bounded by RF4 forward and above, RF6A below, and RF5 aft. The area is located on the boundary of the debris recovered in the yellow and red zones. Both skin and substructure are missing, with pronounced aftward curling of the STA680, 720, and 740 bulkhead fractures at the top of the hole. No other evidence implicates this area as an entry or exit hole.

For all three of the areas described, no identifiable holes are on the opposite side of the aircraft. The recovered fuselage skins in the areas opposite these holes generally are large sections with few penetrations or damage except along fastener lines, indicating this damage occurred during the later breakup of the aircraft. Note that in the first area, all debris was recovered in the yellow zone; in the second, all debris was recovered in the green zone, implying these areas were not involved with the initial damage.

Additionally, it is important to note that previous civil aviation mishaps have occurred in which holes significantly larger than 3 feet in diameter were created in pressurized aircraft during flight without catastrophic failure of the fuselage, for example, United Airlines Flight 811 in February 1989 (Reference 7). The 747-122 involved in this incident lost the forward cargo bay door at an altitude of between 22,000 and 23,000 feet. The resulting explosive decompression ripped off nearly 200 square feet of the adjacent fuselage skin, yet the aircraft managed to return to Honolulu and land safely. This would imply that a live or dud missile would be unlikely to cause catastrophic structural breakup of a 747. Instead the missile would have to cause a critical system failure; in the case of TWA Flight 800, an explosion in the center wing tank.

Unfortunately, with no historical test data available for comparison, it is unknown exactly what to look for when shoulder-launched missiles impact open areas on large transport aircraft. Again the need for further testing and analysis is indicated, but these tests would be more applicable in building a database for future incidents rather than to the TWA mishap.

MISSILE SELF-DESTRUCT

The possibility of missile self-destruct has been discussed with experts from the Boeing Defense and Space Group who have published a report examining this scenario (Reference 8). This report should be consulted for a comprehensive review of the possibility that a missile was launched at TWA Flight 800, failed to engage, then self-destructed close enough to initiate the center wing tank ullage explosion.

The Naval Air Warfare Center Weapons Division has performed analysis that provides data pertinent to this theory. Cursory infrared signature measurements were made of 747 aircraft on approach to a commercial airport. These measurements clearly show the engines and air cycle machines under the center wing tank as hot spots on the aircraft and are, therefore, possible tracking points for a shoulder-launched missile (Reference 9). Additional signature testing was performed by the FBI in conjunction with fuel system flight tests off Long Island. Computer simulations of flyouts also were performed at China Lake for several shoulder-launched missiles against a spherical infrared source above the minimum detectable irradiance levels (Reference 10). These simulations varied the aspect angle of the missile launch from straight ahead of the approaching target, 45 degrees from the nose, and abeam. The slant range from the shooter to the target also was varied. These simulations show that under certain conditions several types of missiles could be close to the last known altitude of TWA Flight 800 at their self-destruct time-out.

Although the *possibility* of this scenario exists, the *probability* is extremely low. For a missile shooter to launch the weapon, the weapon to fly at the target, the target to be just beyond the kinematic envelope of the weapon, the warhead to be properly positioned at self-destruct, and one of the very few heavy fragments to impact in an area to penetrate the thick wing skin with enough residual energy to initiate an explosion is stretching credulity to the point that this scenario must be considered a low-priority area of concern.

Additional analysis incorporating infrared signature studies, missile performance and fly-out modeling, and endgame simulations backed by testing could provide insight, but is unlikely to ultimately prove or disprove this theory. On the other hand, the results of this analysis and testing could be extremely valuable in quantifying the terrorist missile versus commercial aircraft problem and developing a counter strategy.

COMMENTS ON THE TWA FLIGHT 800 INVESTIGATION

Considerable public interest in this investigation has been generated since the loss of TWA Flight 800. Conspiracy theories, friendly fire accusations, and numerous other rumors have surfaced regularly throughout the investigation. These events often required substantial devotion of manpower and other resources to ensure that a comprehensive review of the facts was performed.

During this author's impartial involvement in the investigation, there was never a doubt that every agency involved was focused on one specific goal—identifying the cause of the accident. The public should feel confident and take pride in the fact that all available resources were devoted to this goal without regard to political implications or cost. The criminal investigation by the FBI was tenacious in tracking down every single possible lead; the NTSB examined every aspect of the incident, often in microscopic detail, searching for clues; all other agencies involved performed similarly, bringing professionals together from around the world.

The open flow of information between these agencies was effective in allowing the investigators to analyze every aspect of the mishap. The author was granted complete access to data compiled by the FBI and NTSB, which greatly facilitated the analysis detailed in this report. Strong emphasis was placed on giving the public and press access to essential information whenever possible. Any rumors of conspiracy or cover-up are, in this author's experience, completely and absolutely unfounded.

Avenues are available to further enhance future mishap investigations. For example, all three military services institute combat survivability programs to improve the ability of U.S. weapon systems to avoid engagement by enemy shooters and withstand hits when they occur. The tools and expertise developed by the military could be extremely valuable for improving commercial aircraft survivability.

Numerous technologies exist to achieve survivability. Some of these technologies are expensive and carry large weight penalties, especially when retrofitted to older aircraft. The services recognize these constraints and institute formal programs at the inception of a new design, resulting in survivability enhancements with minimal impact on weight and cost over the baseline design. In fact there are numerous examples of survivability enhancements that result in weight and cost savings and offer improved safety during normal flight operations as well. Program managers are under intense pressures to keep costs low, and each improvement undergoes extensive cost-benefit analysis to buy its way onto the aircraft.

Establishing a formal program that brings military and civilian designers, regulators, and law enforcement agencies together could be very effective in preventing or reducing the loss of life in future mishaps. Improvements in airline safety can only succeed with active participation and buy-in by each organization at every step. These measures must be integrated across the board, from aircraft initial design to passenger screening and fleet operations. Although some cooperation currently exists between the FAA and the military, the establishment of a formal program among these agencies could be far more effective in bringing these resources to bear in a proactive stance. Officials from the FAA, NTSB, and International Federation of Airline Pilots' Associations have publicly endorsed increased cooperation with the military survivability community (References 11 through 13).

CONCLUSIONS

No conclusive evidence of missile impacts exists on any of the recovered wreckage of TWA Flight 800. No evidence of high-velocity fragment impacts exists, which indicates a live warhead did not detonate within or near the exterior of the aircraft. Additionally, a detailed inspection and analysis of all areas that a missile with a dud warhead could have impacted revealed no evidence of foreign object impacts consistent with this scenario.

With no previous test data available for comparison, it is unknown how the inboard wing fuel tanks on a 747 aircraft would react to a missile impact. Possibly, fuel could stop warhead fragments from reaching the structure of the aircraft, or a missile with a dud warhead could hit the structure without leaving clearly identifiable evidence of its impact. Strong evidence exists that this area was not involved in the initial event leading to loss of TWA Flight 800. However, conducting dynamic impacts of shoulder-launched missiles on the wing fuel tanks may provide the conclusive data needed to determine if a missile is responsible for the difference in damage between the left and right wings on TWA Flight 800.

A database of test and mishap data on potential terrorist weapons versus commercial transport aircraft could be valuable in future mishap investigations. Military aircraft live-fire testing can be of some value, but data on components unique to transport aircraft, such as large fuselages and cargo containers, are not available. This deficiency makes analysis of these components difficult for civilian investigators.

The possibility that a shoulder-launched missile was launched at TWA Flight 800, failed to intercept it, self-destructed in close proximity, and initiated the breakup of the aircraft is highly improbable. This theory would be nearly impossible to prove or disprove, even with extensive analysis and testing. However, this effort could be useful in identifying methods to counter future terrorist attacks.

The military services have invested heavily in the tools and technical expertise to design and build survivable combat platforms. The technologies developed for these weapon systems could be extremely beneficial to the commercial aircraft industry as well. Conversely, law enforcement agencies and civil aviation designers, regulators, and accident investigators are unequaled in their respective areas of expertise. A formal program must be established among these organizations to provide a tiered defense against terrorist attacks on U.S. commercial aircraft by reducing the susceptibility of the aircraft to exposure and the vulnerability of the aircraft to the damage inflicted.

RECOMMENDATIONS

The following recommendations are based on analysis of tests conducted on the wreckage of TWA Flight 800.

1. Conduct shoulder-launched missile static warhead detonations in a large fluid-filled vessel to characterize the ability of the fluid to slow or stop fragments.

2. Conduct dynamic impacts of shoulder-launched missiles with live and inert warheads on the inboard fuel tanks of 747-100 aircraft. The test aircraft should have water substituted for fuel in the wing tank, the fuselage should be pressurized, and the aircraft should be supported to approximate a 1-g load in the area of impact. The results of this testing may help to rule out finally and conclusively the possibility that a missile impact was the initiating event for the breakup of TWA Flight 800.

3. Conduct shoulder-launched missile static warhead detonations in a loaded cargo container to characterize the ability of the contents to slow or stop fragments.

4. Conduct dynamic impacts of shoulder-launched missiles with live and inert warheads into cargo containers located in the hold of a commercial transport aircraft. Any large transport aircraft would be a suitable test specimen, but the fuselage should be pressurized and supported to simulate a 1-g load in the area of impact.

5. Conduct dynamic impacts of shoulder-launched missiles with live and inert warheads into the fuselage of commercial transport aircraft. The fuselage should be pressurized and supported to simulate a 1-g load in the area of impact.

6 Conduct analysis and testing to quantify the terrorist missile versus commercial transport problem and identify countermeasures.

7. Institute a formal relationship between the military aircraft survivability community and the civilian aviation industry to enhance the survivability and safety of aircraft.

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