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Sequence and Characteristics of the Structural Failure of the Mandarin Airlines (China Airlines) MD-11 Fuselage Number 518 – August 22,1999 Accident at Hong Kong International Airport

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REFERENCES

Reference 1 China Air Accident "Performance Group Report"

Reference 2 MDC-00K1008, "Materials and Process Engineering Report on Mandarin Airlines (China Airlines) MD-11 Fuselage Number 518 Accident at Hong Kong International Airport, Hong Kong, China"

1.0 DESCRIPTION OF STRUCTURAL ARRANGEMENT

A rendering of the MD-11 structural arrangement in the vicinity of the main landing gear is included as Figure 1. Note that the rendering is "artistic" in character and incorrectly shows some structure which should (from the view depicted) be hidden.

The MD-11 main landing gear is cantilevered off the rear spar of the wing. Two trunnion bolts attach the main landing gear strut (blue) to the wing fitting (green). The wing fitting attaches to the rear spar (yellow). Vertical, drag and side loads applied to the landing gear are reacted through the trunnion bolts into the wing fitting and from there into the main torque box of the wing.

The forward of the two main landing gear trunnion bolts is a designed "fuse". For very high drag loads (as might be encountered during an off-runway excursion, or if the landing gear struck an obstruction) the forward bolt is designed to shear as the forward main landing gear trunnion moves downward.

Loads about the main landing gear pivot axis (gear sideloads) are reacted via a trusslike structure made up of the folding side brace (magenta), the fixed brace (light blue), and the strut. This arrangement results in loads which are primarily up and down (vertical) at the joint where the truss attaches to the fuselage. The loads at this joint are primarily up when an inboard acting sideload is applied to the landing gear, and down when the sideload is outboard.

The fuselage attach point for the truss is on a machined beam referred to as the "trap panel" because of its trapezoidal shape. The trap panel is shown in red in Figure 1.

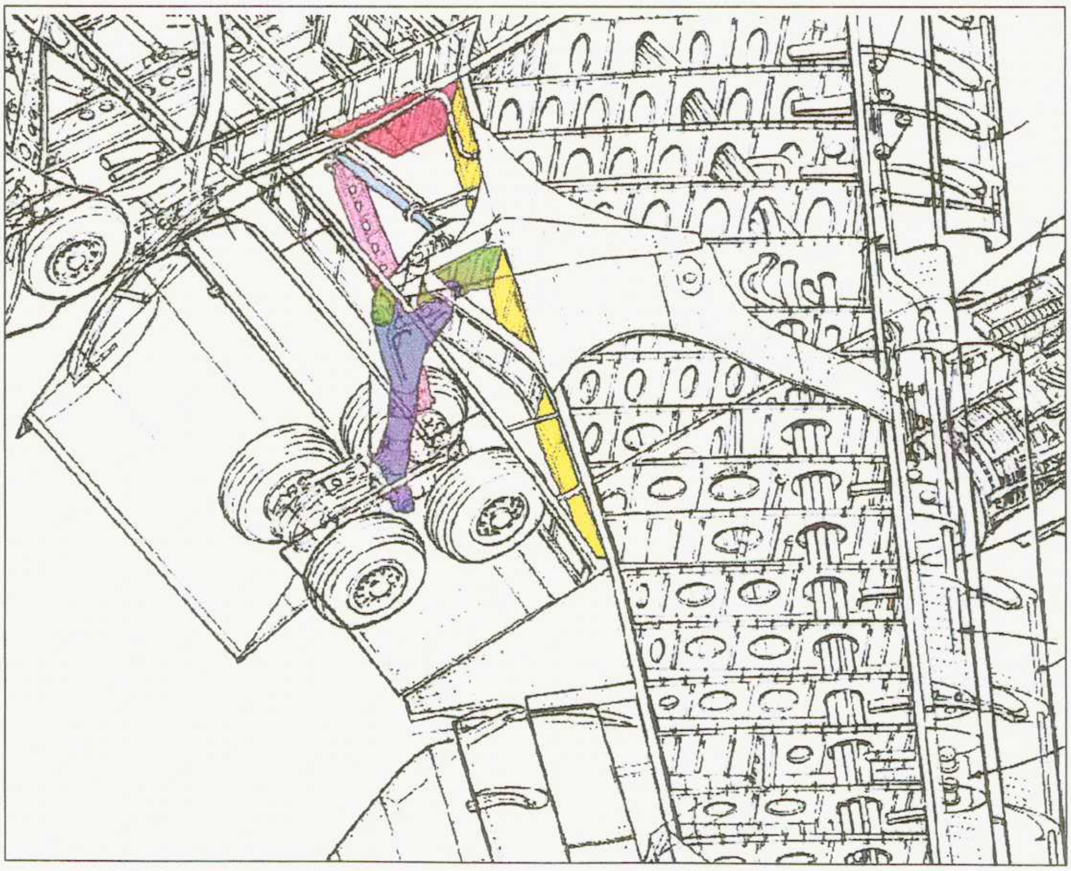

Figure 1. MD-11 Structural Arrangement in the vicinity of the MLG-to-Wing attachment

2.0 LANDING CONDITIONS

The attitude of the accident aircraft, along with the velocity and acceleration components were estimated from data obtained from the flight data recorder. More detail is available in the report published by the Performance Group of the accident investigation team (Reference 1). From a structural loads perspective the most significant of these parameters is the sink rate (velocity towards the ground) which has been estimated to be in the vicinity of 18-20 feet-per-second. The next most significant parameter is the roll attitude (approximately 3 degrees right-wing-down).

It should be noted that the design sink rate for a symmetric landing (zero degrees roll) is 10 feet-per-second. Recognizing that the kinetic energy which must be absorbed to decelerate an aircraft moving towards the ground is a function of the velocity *squared*, it is observed that the energy from a 20 foot-per-second sink rate is four times (not double) that from a 10 foot-per-second sink rate. And since the aircraft was rolled right at touchdown, most of the load was taken by the right-hand main landing gear.

3.0 LANDING SIMULATION

MD-11 crash landing simulation analyses were run using initial conditions consistent with the accident aircraft at touchdown. The aircraft was rolled right-wing-down 3 degrees, pitched nose-up 4.5 degrees, and was descending at nearly 20 feet-per-second. There was no perceptible roll rate and the lift on the airplane was roughly equal to its weight. The high sink rate combined with the rolled attitude caused

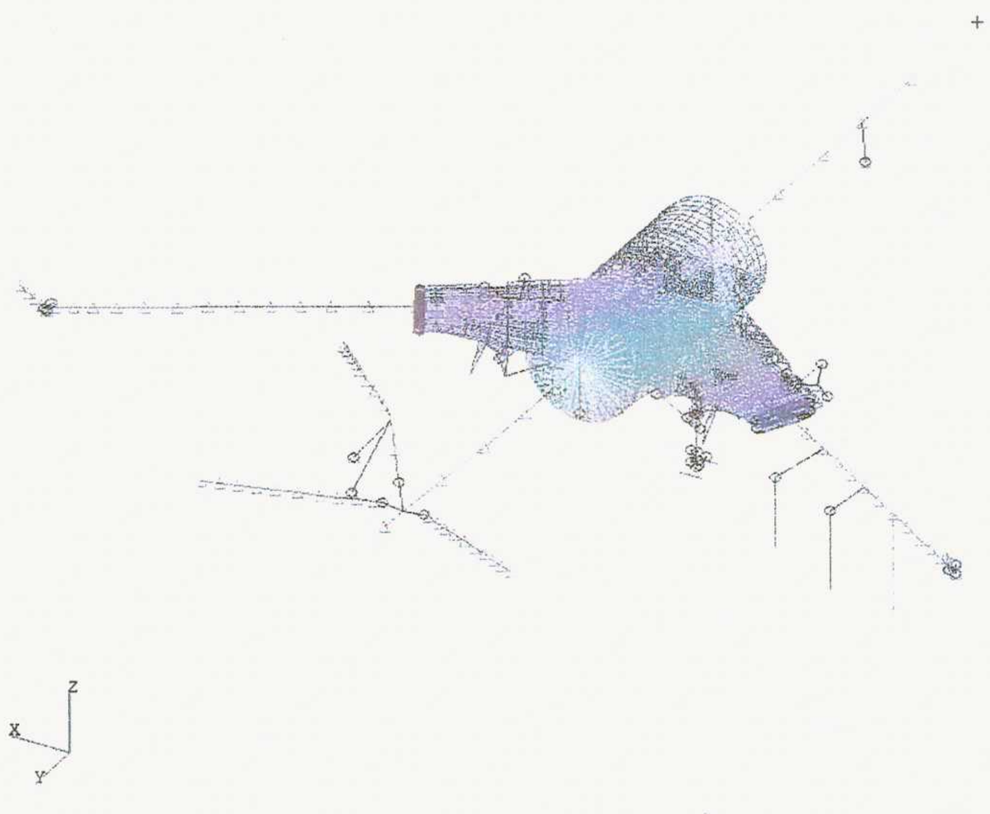

Figure 2. MD-11 Dynamic Landing FE Model

bottoming of the right main landing gear strut and generated a vertical load "spike" which failed structure in the area where the right main landing gear attaches to the right wing.

The structural failures (of the right wing rear spar in particular) which were observed in this accident bore notable similarities to those that were observed for a FedEx MD-11 that was involved in a crash landing at Newark, New Jersey on July 31st, 1997. A significant amount of analysis was conducted to simulate the FedEx accident and estimate structural loads on the right main landing gear, the right MLG-to-wing attach fitting, the right wing rear spar, and the right landing-gear-side-brace-fitting-to-trap-panel joint. These analyses were conducted using an in-house aircraft dynamic landing program (B7DC), a commercially available finite element program (MSC NASTRAN), and a commercially available nonlinear kinematics code (ADAMS).

Based on knowledge and experience gained in analyzing the FedEx accident a simplified analysis technique was developed for studying the effects of very high sink rate landings on aircraft structure. The crash landing analyses performed for this accident utilized MSC NASTRAN. A transient nonlinear solution was run using a detailed finite element model of the MD-11 inboard wing and center fuselage, combined with a coarser idealization of the remaining structure. (See Figure 2). The main landing gear was idealized using the BUSH1D element, which allowed the gear nonlinear spring and damping characteristics to be input in table form. The results from this model were compared and correlated with certification analyses (for cases within the design limits of the aircraft) and with the FedEx ADAMS analysis and were shown to be satisfactory.

The most significant differences in the structural loads applied to the aircraft during the FedEx and the China Airlines accidents lay in the drag loads applied to the right main landing gear. Landing gear drag loads were not significant for the FedEx accident. This is because the aircraft touched down, bounced, then landed a second time at a high sink rate and sink acceleration, and at a significantly rolled attitude. Since the high vertical loads occurred on the second touchdown, the wheels were already spinning and drag loads were minimal. The high vertical loads for the China Air accident occurred at the initial touchdown so "spin-up" and "spring-back" (plus and minus drag) loads were significant.

The existence of significant drag loads for the China Air accident required an adjustment to the simplified NASTRAN analysis technique. Spin-up and spring-back loads (essentially a time history of the main landing gear drag loads) were estimated using B7DC (the certification landing gear loads analysis program) and the time history was manually input into the NASTRAN solution. The peak load from the B7DC time history was phased to correspond with the peak right main landing gear vertical load.

Figure 3 displays the landing gear strut and tire loads for the China Airlines baseline case (Case 4.010). The structure responds linearly for this case and it is assumed that all of the lift on the right-hand wing is lost when the right main landing gear load reaches 600,000 lbs. (This assumption is consistent with analyses that were run for the FedEx crash simulations, which used ADAMS to dynamically calculate wing lift as a function of local angle of twist). For the China Airlines analysis, both the left main landing gear and the center landing gear pick up load well before the right main landing gear reaches its peak load.

The strut and total-tire load time histories should be equal for a given gear (note that the right main landing gear strut load oscillates near its peak and separates after the peak due to NASTRAN convergence problems). These convergence problems do not have a significant effect on the time history of the other gear loads or the peak value of the right main landing gear total-tire load.

Time histories of key loads from Case 4.010 are plotted in Figure 4. From the figure, the right main landing gear strut load peaks at 1.4 million pounds, the peak rear spar shear flow is 35,000 lbs/in, and the peak load on the right main landing gear forward trunnion bolt is 1.2 million pounds. The rear spar shear flow is well in excess of what is required to fail the rear spar shear web and the forward trunnion bolt load is roughly that which is required to fail it.

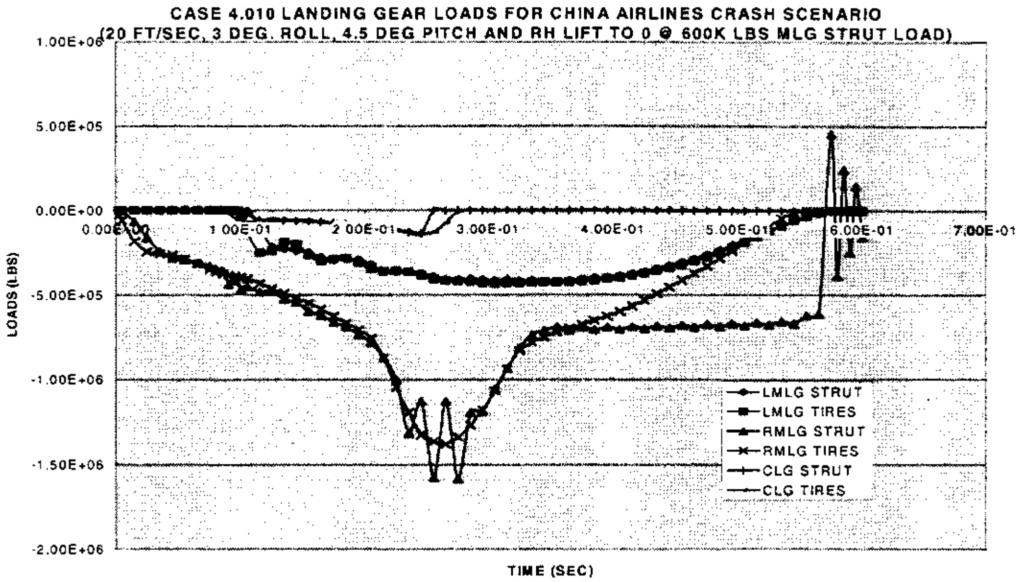

Figure 3. Case 4.010 Landing Gear Loads for China Airlines Crash Scenario

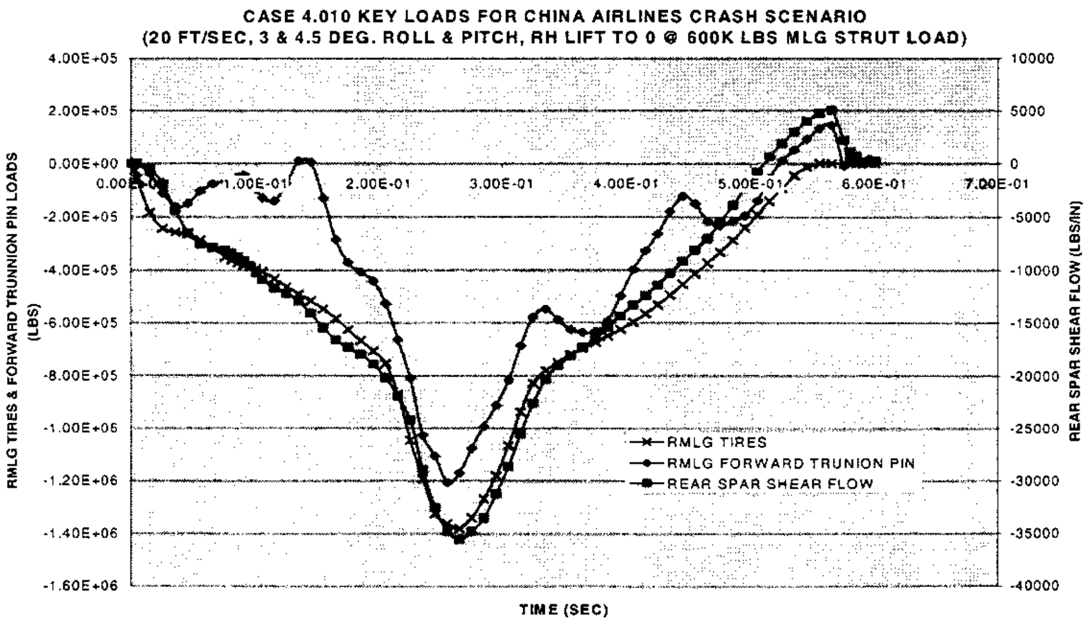

Figure 4. Case 4.010 Landing Gear Loads for China Airlines Crash Scenario

The results of this analysis, although not rigorous, confirm that loads high enough to fail the forward trunnion bolt and the rear spar shear web are feasible, and that the failure sequence described in the following sections is reasonable.

4.0 STRUCTURAL FAILURE SEQUENCE

The most likely sequence of structural failures is summarized below. Details and supporting evidence are included in the Sections 5.0 through 11.0.

- Due to the combination of a high sink rate and a right-wing-low rolled attitude, the right main landing gear shock strut bottomed and the vertical load on the right main gear "spiked".
- The forward trunnion bolt on the right main landing gear sheared upwards as a result of a very high vertical gear load combined with a large "springback" moment.
- The forward trunnion of the right main landing gear was driven upwards and contacted the MLG-to-wing attach fitting, damaging the fitting.
- The rear spar web and caps of the right wing fractured, inboard of the MLG-to-wing attach fitting.
- The inboard upper wing panel of the right wing began to collapse from back to front.
- The outboard (right) wing twisted significantly nose down which caused the MLG-to-wing attach fitting to move up, and the main landing gear tires to move aft and outboard.
- The track attached to the inboard flap on the right wing was pried off the rollers that support it at the fuselage side-of-body.
- The inboard flap on the right wing twisted off its outboard hinge support fitting and separated from the aircraft.
- Excessive movement of the right main landing gear and its wing attach fitting imparted large "prying" loads on the side-brace-fitting-to-trapezoidal-panel (S-B-F-T-T-P) joint.
- The right main landing gear fixed brace failed near the S-B-F-T-T-P joint.
- With the side brace failed, large sideloads were introduced to the S-B-F-T-T-P joint by the folding side brace.
- The S-B-F-T-T-P joint failed; first the inboard attach bolt fractured, then an outboard section of the outboard trapezoidal panel "split off" releasing the outboard attach bolt and its barrel nut.
- The right main landing gear strut, now released from the fuselage (trap panel), pivoted outboard; the trunnion arms contacted the MLG-to-wing attach fitting. The resulting "short couple" (prying) loads finished separating the landing gear from the attach fitting.
- The right nacelle contacted the runway (at about the same time as the inboard flap was separating the S-B-F-T-T-P joint was failing) and the right wing engine/pylon assembly was twisted off. (The pylon-wing separation appears to have been dominated by side loads applied to the nacelle rather than vertical loads).
- The aircraft began to roll clockwise having lost the integrity of the right wing, yet still carrying enough speed to generate meaningful lift on the left hand wing.
- Failures beyond this point were consequent, are not considered particularly relevant, and were not studied in detail.

5.0 FORWARD TRUNNION BOLT FAILURE

The first structural element thought to have failed in this accident is the forward trunnion bolt, also known as the "zero margin trunnion pin". This bolt is designed to reliably shear at a predetermined load (approximately 1.2 million lbs) and acts as a "fuse" when the main landing gear is subjected to excessive drag loads. Figure 5 shows the location of the zero margin trunnion pin.

When acting as a fuse against excessive drag load the zero margin trunnion pin fails by shearing downwards (i.e. the forward trunnion of the main landing gear moves downward relative to the wing attach fitting). In this accident this bolt failed in the *upwards* direction due to a combination of high landing gear vertical load, and a high "springback" moment. Both the high vertical load and the high "springback" moment were a result of the excessive (18-20 ft/sec) sink rate.

"Spin-up" and "springback" loads occur when an aircraft touches down and the tires are not yet spinning (a normal occurrence). First the runway exerts a drag force ("spin-up") on the tires which starts them spinning and bends the strut aft. As the tires spin up the drag force disappears and the strut "springs

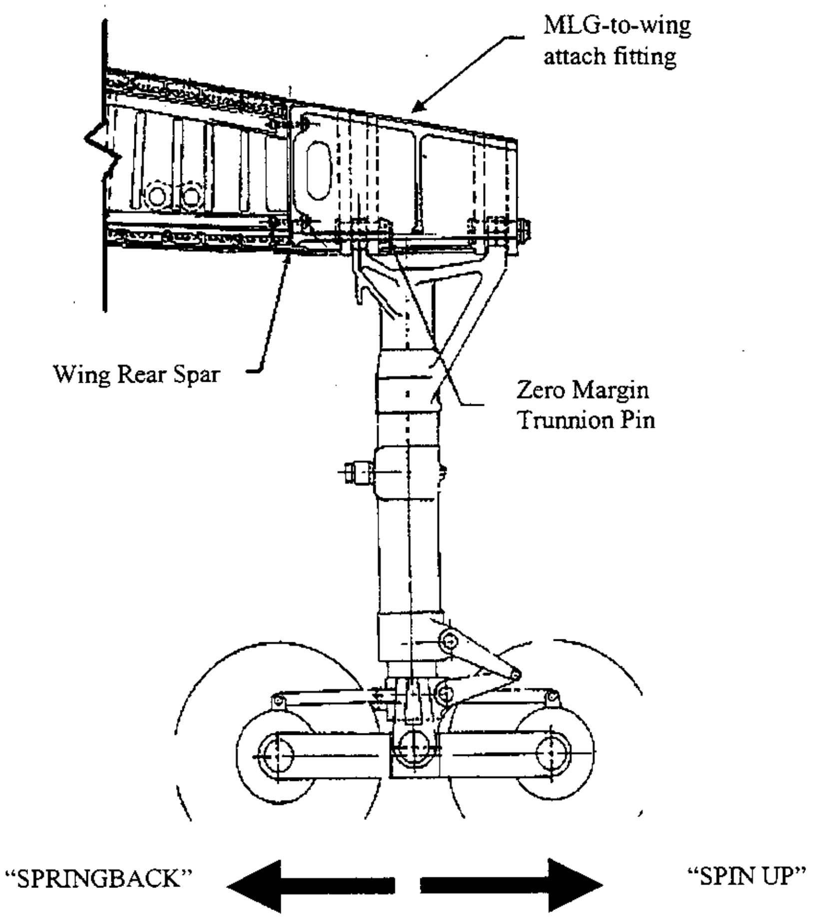

Figure 5. Main-Landing-Gear-to-Wing Attach Arrangement

back" (bending the strut forward). For conditions within the aircraft design range this phenomenon is well known and understood, and analytical tools are available to calculate the associated loads.

As described in Section 3 the spin-up and springback loads for this accident were estimated using B7DC (an in-house aircraft dynamic landing program). When the estimated springback loads were combined with the vertical loads predicted for a 20 ft/sec touchdown, it was shown that a 1.2 million lb load on the forward trunnion bolt was within the feasible range.

It should be noted that the structural loads presented in Section 3 are estimates and are based on analytical extrapolation in to a regime for which we have little or no data to establish correlation. In fact we believe the springback moment obtained from B7DC is probably underestimated.

The results of the metallurgical examination of the forward trunnion bolt are presented in the Boeing Materials and Process Engineering Report (Reference 2) in Section 4.5.2. The findings are consistent with the theory that the forward trunnion bolt failed as the forward trunnion of the main landing gear was moving upwards relative to the wing attach fitting. This relative motion is most evident in Figure 38 of Reference 2, which shows how the aft portion of the bolt is bent down.

Note that the bolt failed at the forward zero-margin groove. The bolt is loaded in double-shear; there are zero-margin grooves at both shear interfaces.

6.0 DAMAGE TO THE MAIN-LANDING-GEAR-TO-WING ATTACH FITTING

After shearing the forward trunnion bolt at the forward zero-margin groove, the forward trunnion of the right main landing gear was driven upwards and contacted the wing attach fitting, damaging the fitting. This is clearly evident in a photograph taken at the crash site (Figure 6) and in Figures 34 and 35 of the Materials and Process Engineering Report (Reference 2).

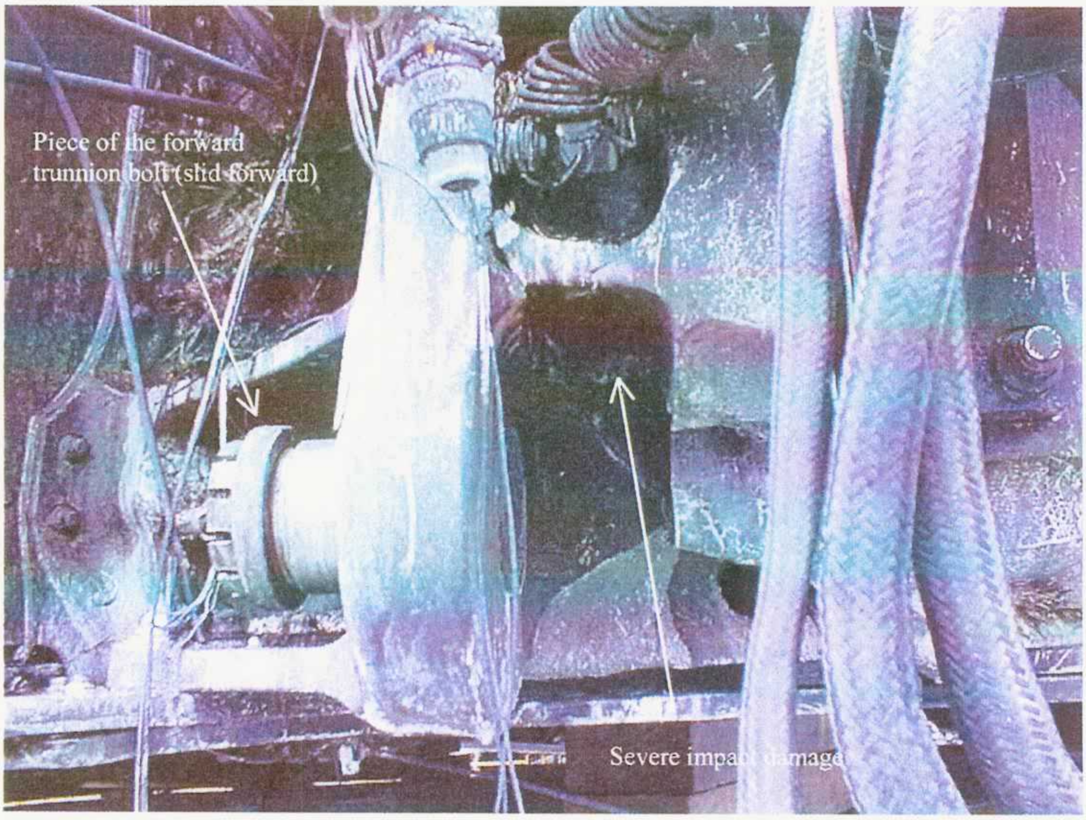

Figure 6. Damage to MLG-to-Wing Attach Fitting at the forward lugs

7.0 REAR SPAR FAILURE

With the forward trunnion bolt sheared, and the forward trunnion of the right main landing gear jammed upwards into the wing attach fitting, the vertical load on the gear was driven into the wing rear spar. Both rear spar webs fractured (in this area the web is doubled for failsafe reasons), along with the upper and lower rear spar caps. The rear spar web fractures were oriented roughly 45 degrees relative to the spar caps, as is typical of shear overload of a beam web.

The rear spar web was identified as the first structural element thought to have failed in the FedEx accident that occurred in Newark, New Jersey on August 31st, 1997. A significant amount of analysis was conducted to validate the FedEx failure sequence, so this failure mode was quickly recognized when the wreckage of the China Airlines aircraft was examined.

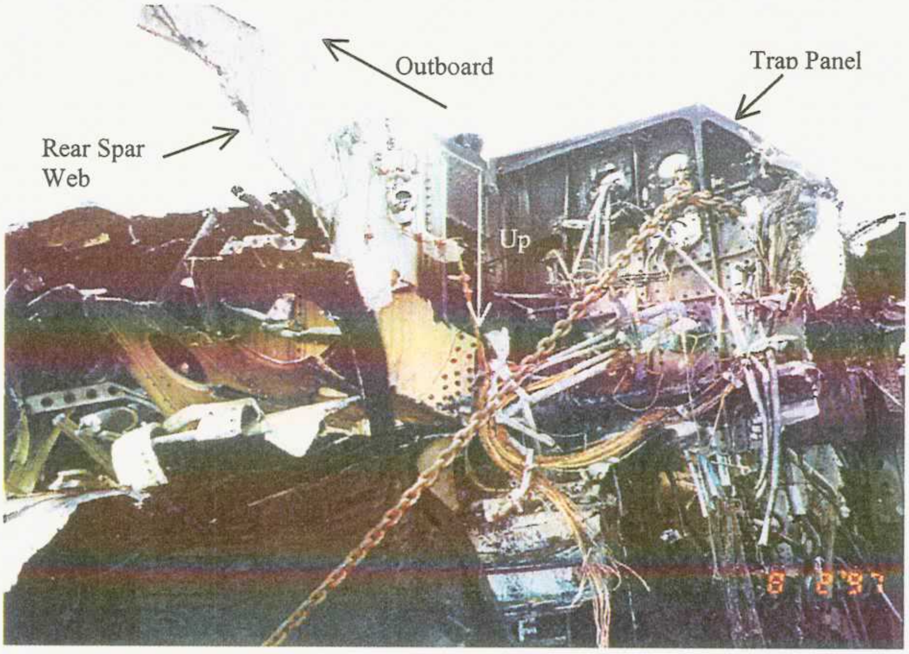

Figure 7. Right Wing Rear Spar Web Fracture from Ship 553 (FedEx - Newark)

A photograph of the FedEx aircraft showing the right wing rear spar web fracture is included as Figure 7. Note that the aircraft is inverted in this photograph.

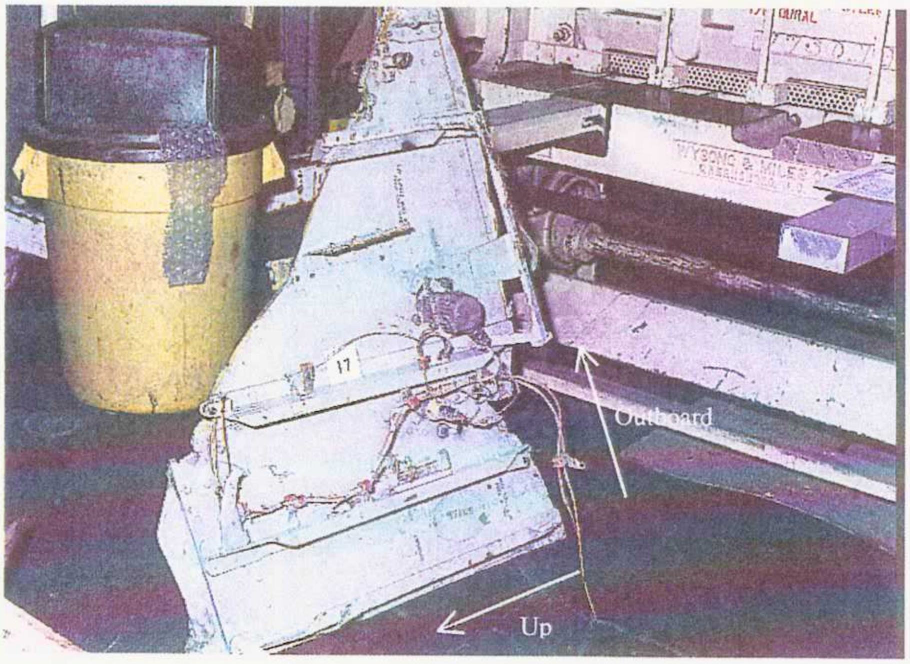

Figure 8. Right Wing Rear Spar Web Fracture from Ship 518 (China Airlines)

A lab photograph of the right wing rear spar web which was cut from the China Airlines aircraft is included as Figure 8. When examined closely it was observed that the rear spar web fractures from the two accidents occurred at almost identical locations.

8.0 INBOARD FLAP DEPARTURE

The inboard flap is located just aft of the main landing gear (Figure 9) and is supported at its inboard end by a track/roller arrangement (Figure 10) and at its outboard end by a simple hinge (Figure 11). The track is mounted on the flap and the rollers on the fuselage (Figures 12 and 13). The outboard hinge is supported off the wing rear spar.

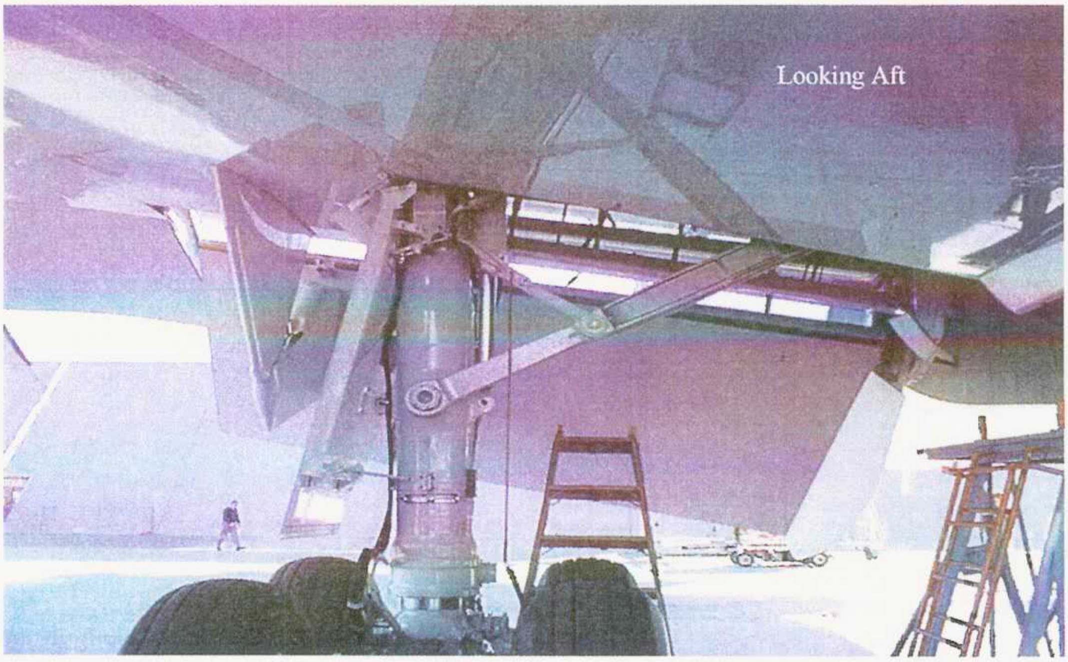

Figure 9. Inboard Flap (Location relative to MLG)

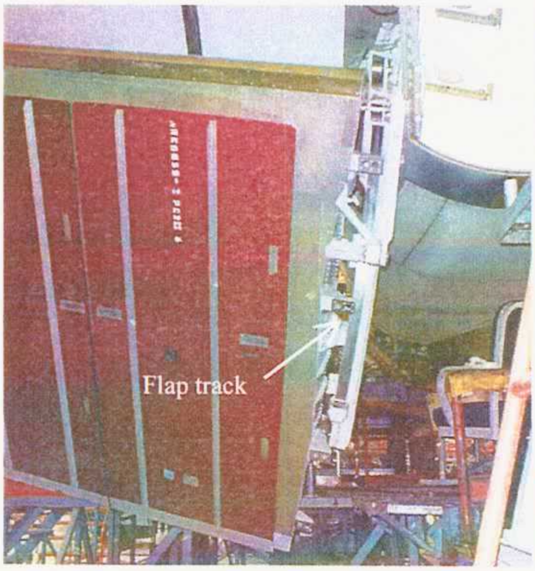

Figure 10. Inboard Flap inboard support

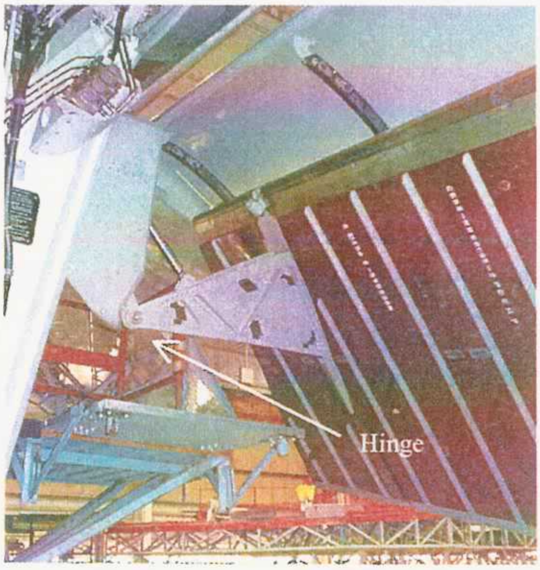

Figure 11. Inboard Flap outboard support

The flap track is an I-beam with return lips on the inboard legs of the two caps. The upper "lip" is captured by three side rollers which limit the outboard motion of the flap track (Figures 13 and 14).

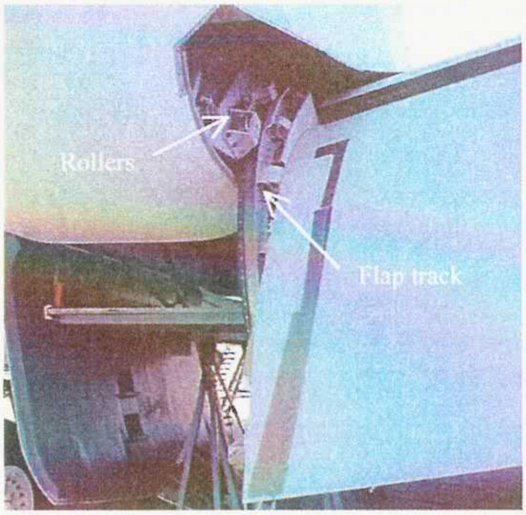

Figure 12. Inboard Flap track and rollers

Figure 13. Inboard Flap rollers (flap removed)

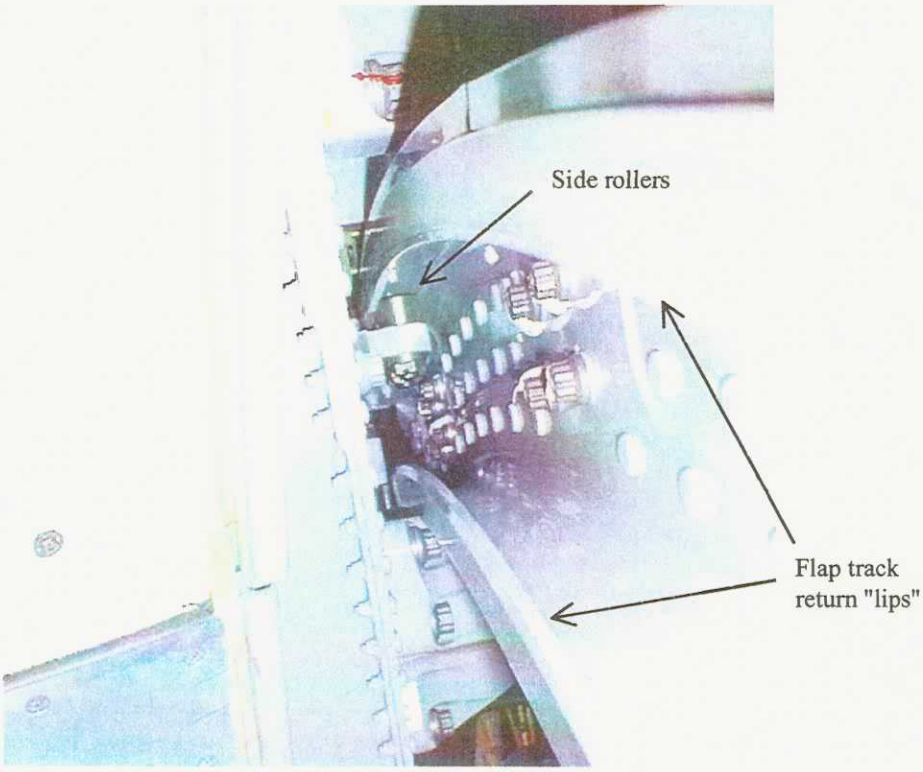

Figure 14. Inboard flap track and side rollers

With the aircraft structurally intact the nominal side loads (inboard-outboard) are small as is evident by the relative size of the side rollers.

Continuing the failure sequence of the China Airlines accident, fractures of the wing rear spar webs, and of the upper and lower spar caps destroyed the integrity of the right wing as a "box structure" resulting in very large relative displacements between the inboard flap's inboard support (mounted to the fuselage) and its outboard support (mounted to the wing, outboard of the landing gear). This relative movement effectively pried the flap track off its roller support system. Once the inboard end became unsupported, the flap easily twisted off its outboard hinge, separating at the tension bolts where the aft hinge attaches to the flap box.

As was the case for the wing rear spar failure mode, there are some observed similarities in the FedEx and China Airlines inboard flap failures. Both inboard flaps were found near the beginning of the debris field, were relatively intact (having almost no lower surface damage), and evidenced local shear-out failures of the flap track lips at the side roller locations.

The China Airlines inboard flap was found off to the left of the runway and is thought to have been carried there by the crosswind (which was blowing right-to-left) after it departed the aircraft. The flap, as it was found, is pictured in Figure 15. The FedEx inboard flap was found on a taxiway to the right of the runway (Figure 16); note there was little or no crosswind present when the FedEx accident occurred.

Figure 15. Right Inboard Flap from Ship 518 (China Airlines)

Figure 16. Right Inboard Flap from Ship 553 (FedEx - Newark)

It is viewed as significant that the lower surfaces of these flaps suffered no significant damage. The inboard flap would have been directly in the path of the main landing gear had the gear separated before the flap and would have been badly damaged. It is clear then, that the main landing gear did *not* "knock" the inboard flap off the aircraft.

The local shear-out failure of the flap track is evident in a photograph taken at the accident site (Figure 17). The location of this failure is consistent with the position of the side rollers for the reported flap setting of 35 degrees. The same type of failure is observed in the photograph of the inboard flap from the FedEx-Newark aircraft (Figure 18); in this case the failure location is consistent with the reported flap setting of 50 degrees.

Figure 17. Right Inboard Flap track from Ship 518 (China Airlines)

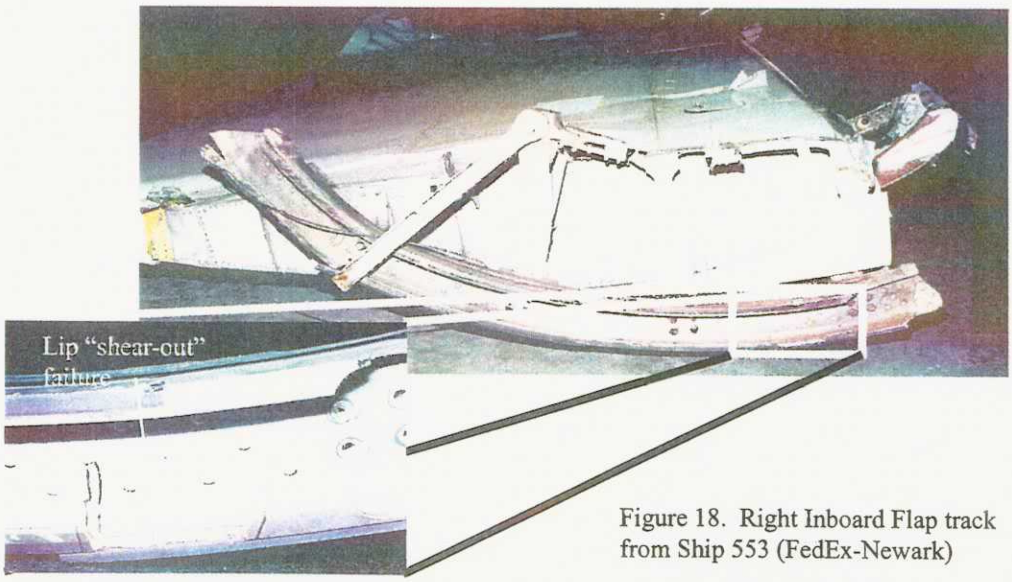

Figure 18. Right Inboard Flap track from Ship 553 (FedEx-Newark)

9.0 DAMAGE TO SIDE-BRACE-FITTING-TO-TRAP-PANEL JOINT AND TO THE FIXED AND FOLDING SIDE BRACES

The location of the side-brace-fitting-to-trap-panel (S-B-F-T-T-P) joint is highlighted in Figure 19. A photograph of a this area (taken from inside the landing gear wheel well) in included as Figure 20 along with a sketch of the joint (with the fixed and folding side braces removed).

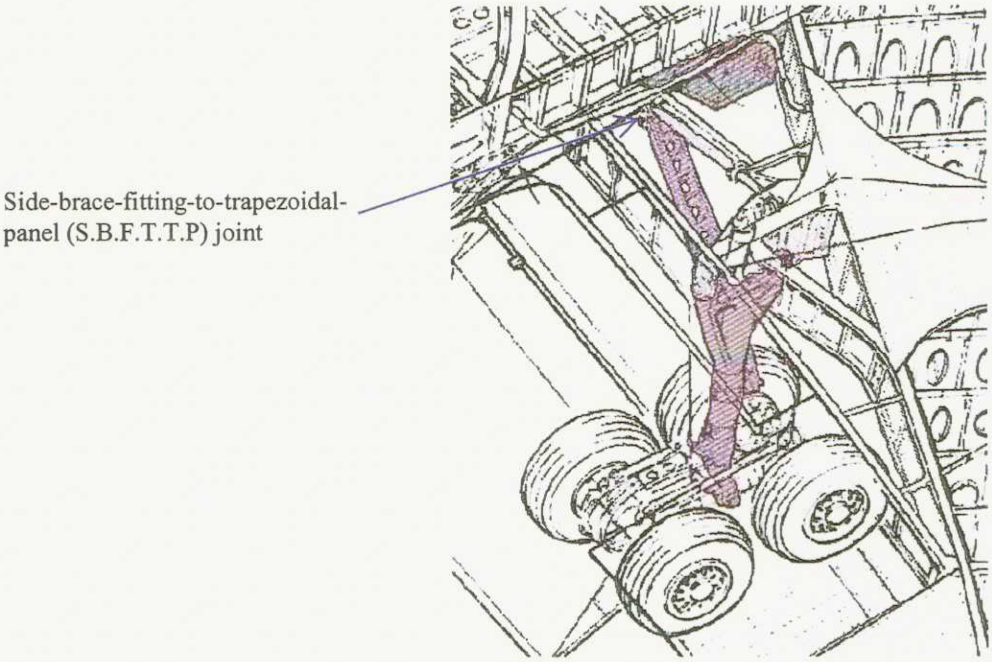

Figure 19. Location of the side-brace-fitting-to-trap-panel joint

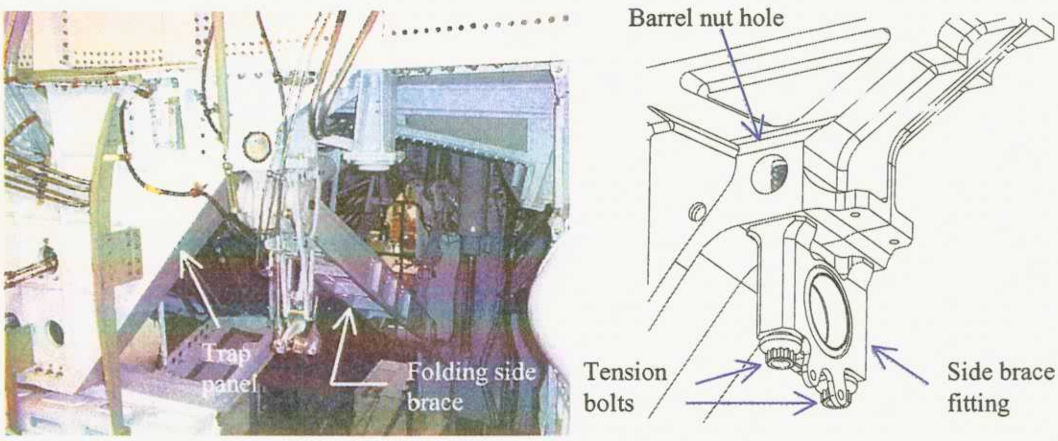

Figure 20. Side-brace-fitting-to-trap-panel joint (from inside the right wheel well)

The fixed brace and folding side brace are connected to one another and to the side brace fitting via a large pin. The side brace fitting is attached to the trap panel with two long tension bolts and mating barrel nuts. As discussed in Section 1.0 this joint is designed to take primarily vertical loads; the fore-and-aft and inboard/outboard loads are nominally small.

As was the case for the for inboard flap's departure, the damage to the S-B-F-T-T-P joint was the result of large relative displacements between attach points on the wing and on the fuselage. After the right wing rear spar failed, the MLG-to-wing attach fitting moved up (relative to the fuselage) and the outboard wing twisted severely nose-down. This motion effectively tilted the truss formed by the MLG strut, and the fixed and folding side braces, and applied a nose-down twist to the S-B-F-T-T-P joint. This applied twist rocked the side brace fitting (bottom-end-aft) and resulted in "impressions" on the lower surface of the trap panel (Figure 21). Similar impressions were observed on the underside of the trap panel from the FedEx-Newark accident aircraft.

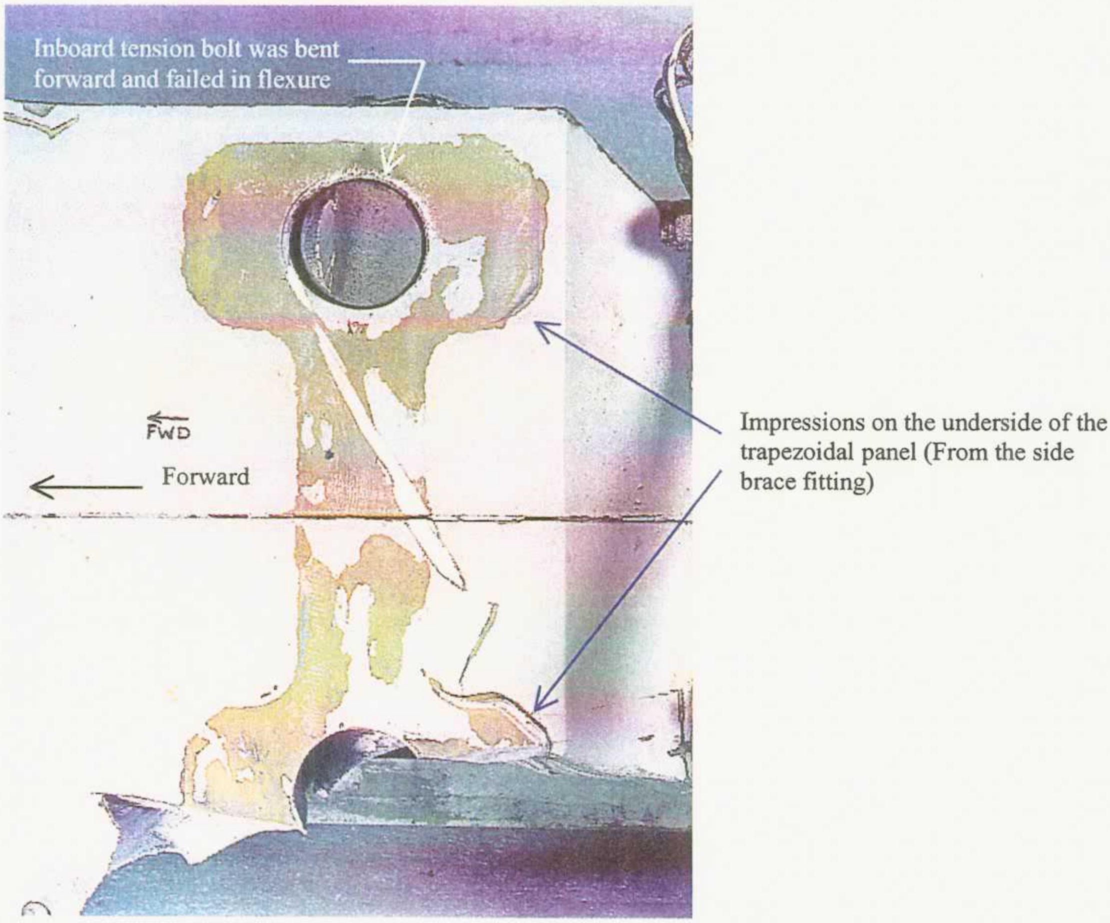

Figure 21. Underside of the right trapezoidal panel

Figure 22 is another photograph of the S-B-F-T-T-P joint area. The photograph is annotated to point out the limited clearance between the clevis end of the fixed brace and the side brace fitting. Excessive upward motion of the outboard end of the fixed brace (which is connected to the MLG-to-wing attach fitting) results in contact in the noted area, and creates a "short couple" prying load at the joint. Evidence of contact in this area for parts taken from the China Airlines accident aircraft is seen in Figure 23. Similar evidence was also noted for the FedEx-Newark accident aircraft.

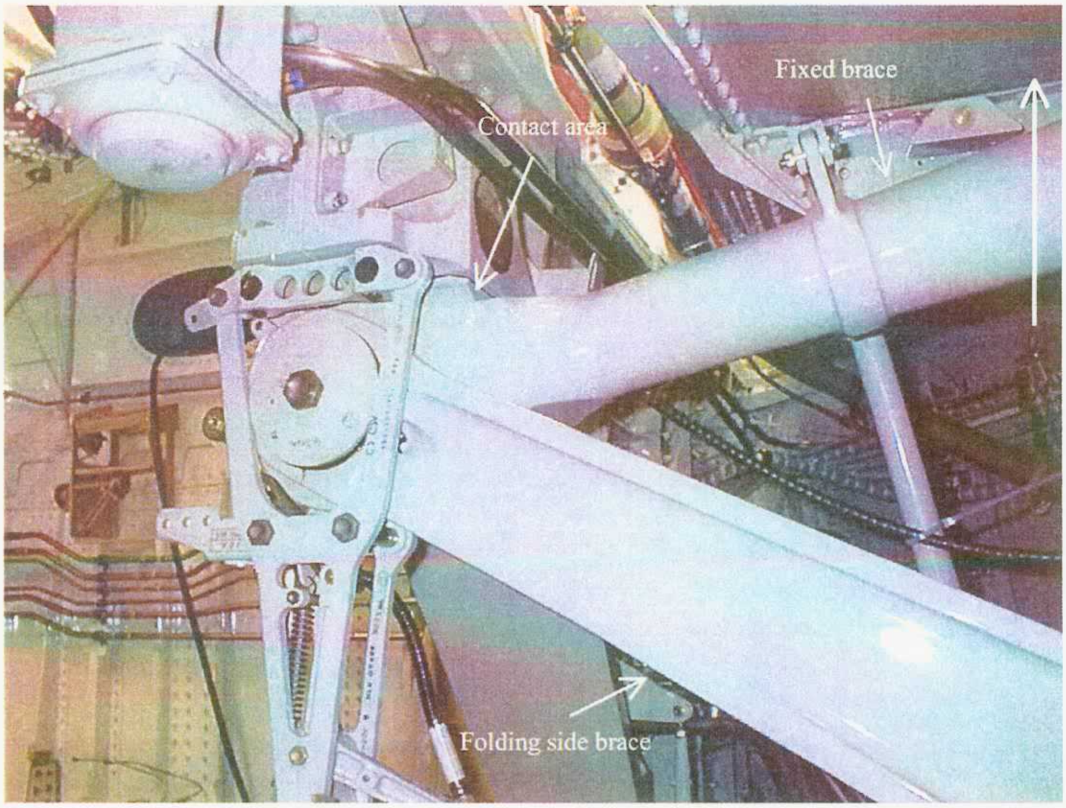

Figure 22. Side-brace-fitting-to-trap-panel joint (from aft and outside the right wheel well)

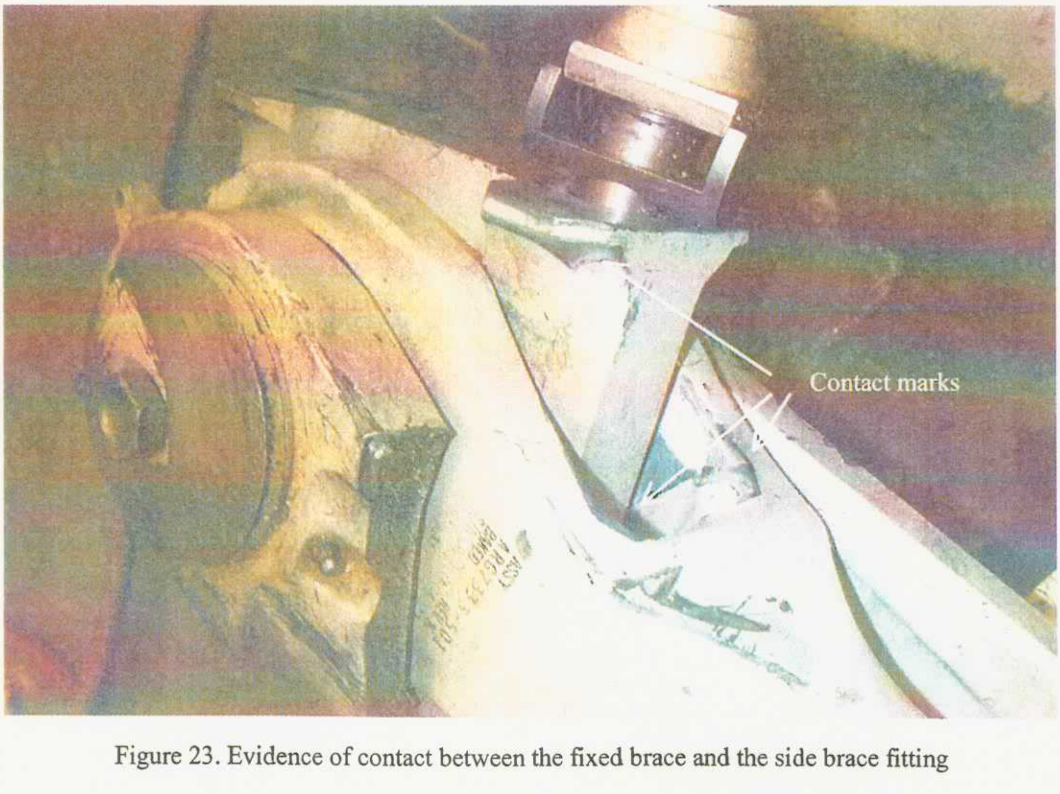

Figure 23. Evidence of contact between the fixed brace and the side brace fitting

The presence of a large prying load at the S-B-F-T-T-P joint results in severe distress to this joint. This manifests itself as localized high bending (flexure) at the outboard end of the fixed brace, and a large tension load on the inboard of the two tension bolts attaching the side brace fitting to the trap panel. Evidence of flexural distress of the fixed brace was observed in parts taken from both the China Airlines and FedEx-Newark accident aircraft. The fixed brace from the China Airlines aircraft failed completely (Figure 24). The fixed brace from the FedEx-Newark aircraft was bent and suffered a stress corrosion fracture (Figure 25). The stress corrosion fracture is attributed to residual stress resulting from a high flexural load. Note also in Figure 25 the evidence of local contact with the side brace fitting.

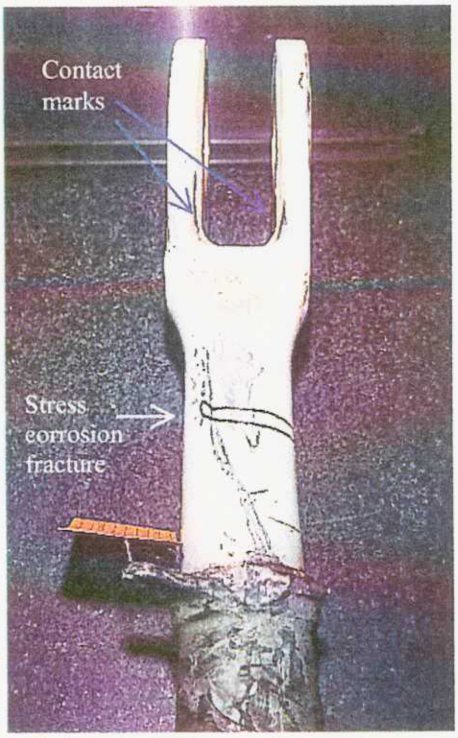

Figure 24. Outboard end of the fixed brace from Ship 518 (China Airlines) [left]
Figure 25. Outboard end of the fixed brace from Ship 553 (FedEx-Newark) [right]

Figure 24 also shows damage to the upper folding side brace. The upper folding side brace is an I-section "laid on its side" with lightening holes in the web (Figure 19). The fixed brace after it failed in flexure, appears to have dropped down into the upward facing "channel" of the I. Relative motion between the outboard wing and the fuselage then appears to have "punched" the inboard end of the fixed brace through the web and aft cap of the upper folding side brace.

The final two failures at the S-B-F-T-T-P joint involve the two tension bolts that attach the side brace fitting to the trap panel, and the trap panel itself. The inboard of the two tension bolts failed in flexure and was bent lower-end-forward (Figure 21 and also Figure 15 of Reference 2). This is thought to have been a consequence of the fixed brace having previously failed, coupled with the lower end of the main landing gear strut moving aft. The folding side brace, acting as a lever, would then apply a twist about the vertical axis of the S-B-F-T-T-P joint. Presuming the outboard tension bolt is acting as a pivot, this would tend to bend the inboard bolt forward.

The outboard tension bolt did not fail. Instead a portion of the outboard face of the trap panel appears to have "split off", releasing the outboard barrel nut and tension bolt (Figure 26). This is thought to have occurred *after* the inboard bolt had failed and appears to have been the result of a prying load applied by the outboard tension bolt, the prying load resulting from the folding side brace pulling outboard on the side brace fitting. (Note the photograph is upside-down relative to the normal position in the aircraft).

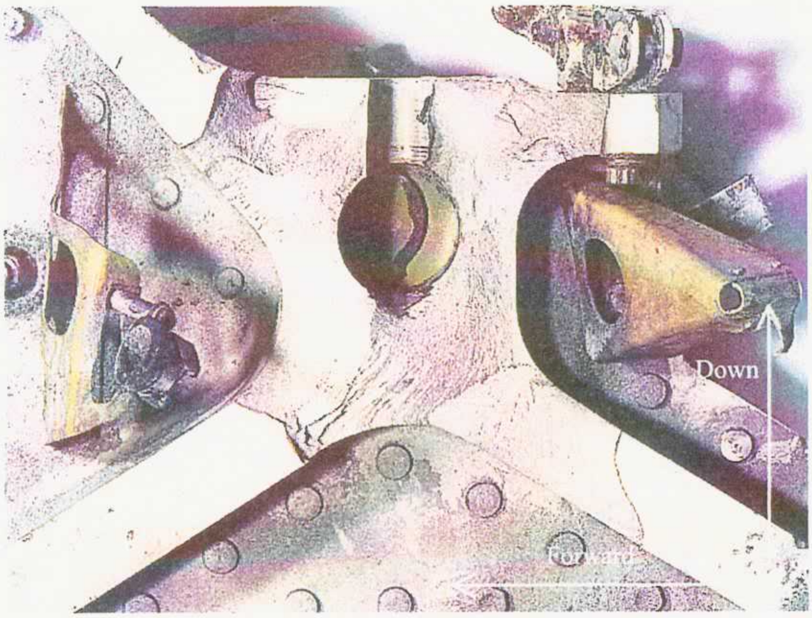

Figure 26. Outboard trap panel failure at the S-B-F-T-T-P joint

10.0 DAMAGE TO THE MAIN LANDING GEAR TRUNNION ARMS AND ADDITIONAL DAMAGE TO THE MLG-TO-WING ATTACH FITTING

There is clear evidence that the right main landing gear strut, once released at the S-B-F-T-T-P joint, rotated outboard and contacted its wing attach fitting. Similar observations were made for the parts from the FedEx-Newark accident aircraft (see Figures 27 and 28). This type of contact creates a "short couple" prying action that easily breaks the gear loose from the fitting.

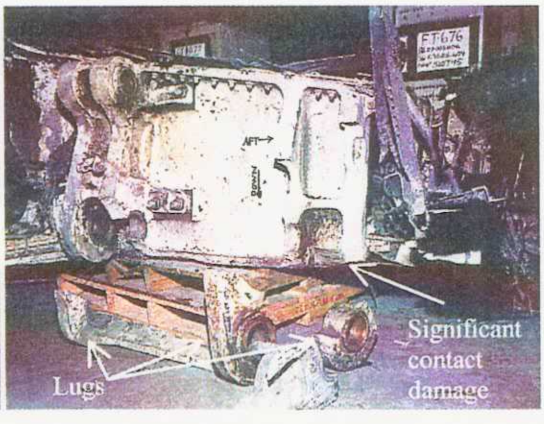

Figure 27. Right main landing gear strut from Ship 553 (FedEx-Newark) [left]
Figure 28. Right MLG-to-wing attach fitting from Ship 553 (FedEx-Newark) [right]

In the case of the China Airlines accident the markings indicating contact between the right main landing gear strut and the wing attach fitting are slightly different (and not quite as clear). This is primarily due to the fact that the forward trunnion connection was partially failed (See Section 5.0) before the strut rotated outboard. The contact area for the forward trunnion was therefore very localized, and quickly resulted in the fracture of the remaining connection (the aft lug). See Figures 29 and 30. The two lugs that support the *aft* trunnion, the fowardmost still connected to a large piece of the wing fitting, also

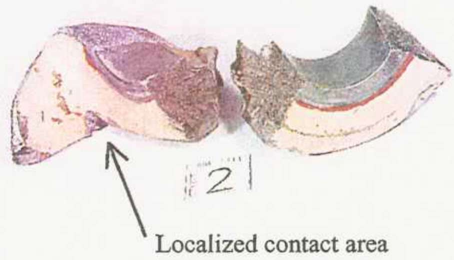

Figure 29. Wing fitting lugs that support the MLG forward trunnion [left]
Figure 30. Separated pieces of the aft wing fitting lugs that support the MLG forward trunnion [right]

cracked off as a result of the gear rotating outboard (Figure 31). This separated the right main landing gear from the aircraft. The contact area on the aft trunnion arm is shown in Figure 32. A photograph of the wing fitting, showing the mating area for the two aft trunnion support lugs, is included as Figure 33.

Figure 31. Right main landing gear assembly

Substantial sidewall abrasion was noted on the inboard sidewall of the aft inboard tire on the right main landing gear truck (Figure 34). This evidence further supports the theory that the gear rotated outboard putting the inboard sidewalls of the inboard tires in contact with the ground.

Figure 32. Aft trunnion arm of the right main landing gear strut [left]
Figure 33. Right MLG-to-wing attach fitting from Ship 518 (China Airlines) [right]

Figure 34. Inboard aft tire from the right main landing gear

11.0 RIGHT HAND WING PYLON FAILURE MODE

Figure 35 illustrates and describes the key elements of the attachment of the engine pylon to the wing. Figure 36 shows how the wing engine pylons are designed to "fuse" in the event of a wheels up landing to protect against rupture of the wing fuel tanks.

If the loads acting on the nacelle are primarily upwards, the engine pylon's aft attach bulkhead is designed to break at the top of the monoball housing, freeing the back end of the pylon and allowing the engine/nacelle to tilt up and act as a "ski". This failure mode has been verified by testing and validated in a number of in-service incidents. (As a point of reference, this *was* the observed failure mode for the right engine pylon from the FedEx-Newark accident).

Figure 37 shows that the right pylon failure mode was different for the China Airlines accident aircraft; the right engine pylon aft-attach bulkhead is still attached to the right wing. Figure 38 shows the right engine pylon. The observed failures suggest that the loads on the nacelle included a significant sideways component. This is thought to have occurred because the outboard wing, as the failure progressed, began to sweep further and further aft.

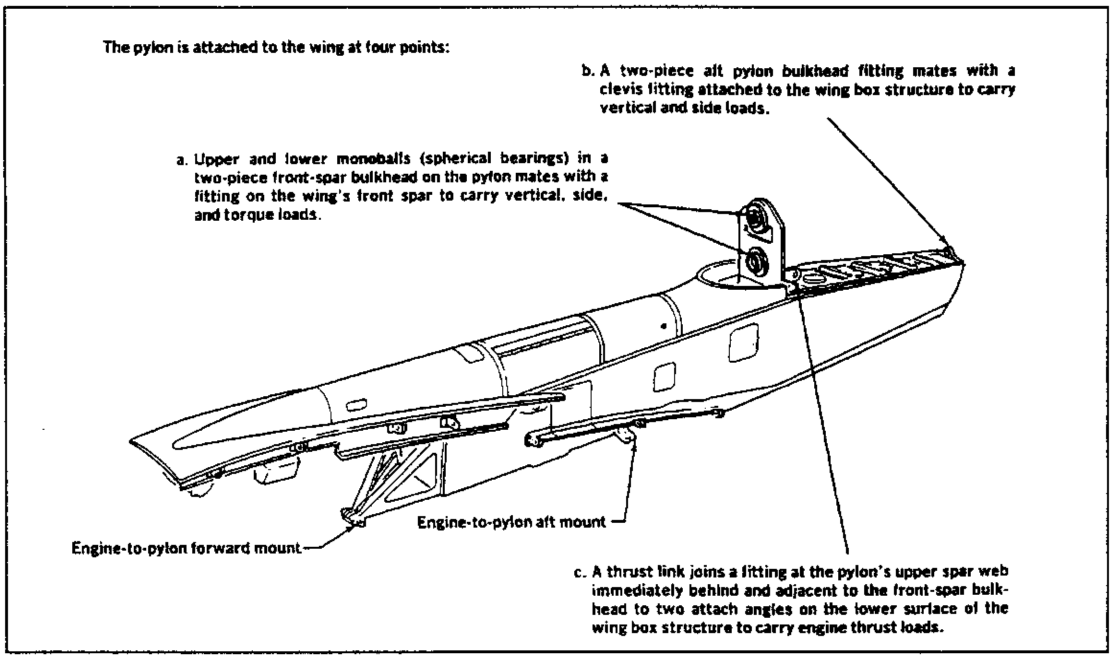

Figure 35. Pylon-to-wing attachment details

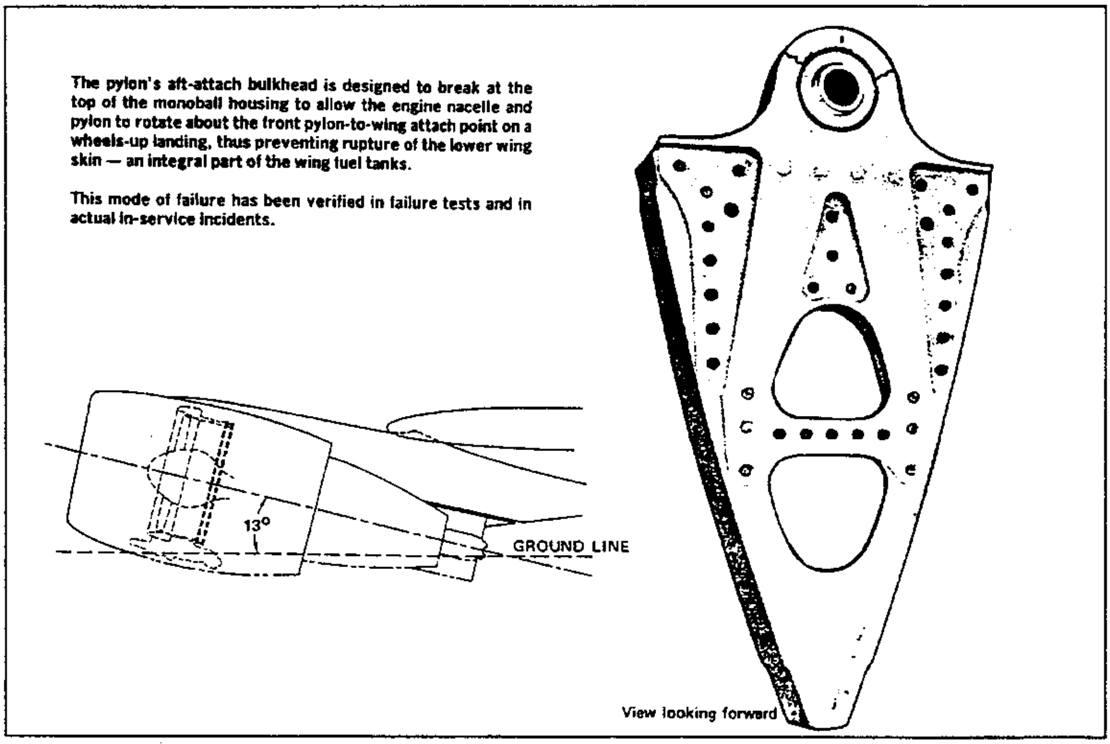

Figure 36. Wing pylon "fusing" mechanism

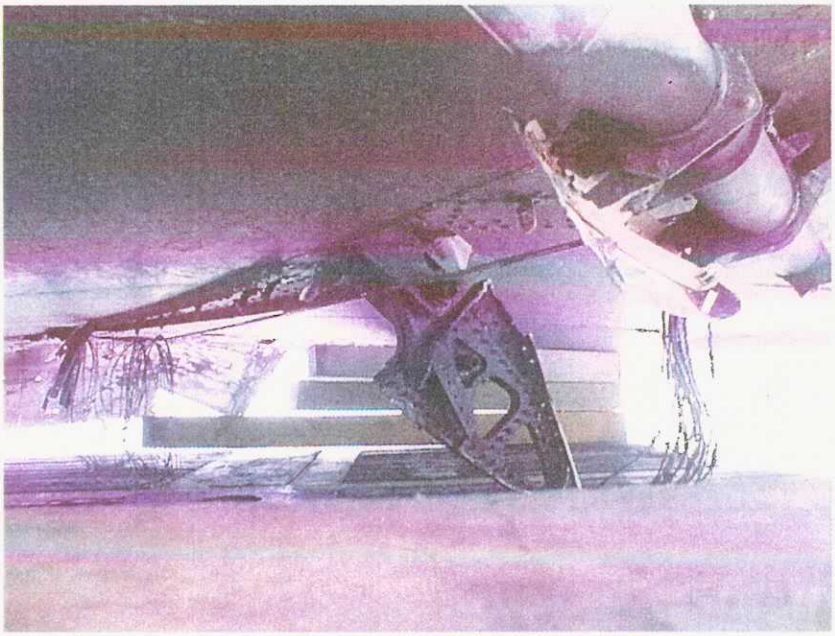

Figure 37. Right engine pylon aft-attach bulkhead still attached to the right wing

Figure 38. Right engine pylon

12.0 SUMMARY

Analysis was conducted to attempt to understand the structural failure sequence, failure modes, and failure characteristics of the accident aircraft. The analysis included primarily the review and examination of failed parts and photographs from the accident site, along with a limited amount of dynamic loads analysis using parameters taken from the Flight Data Recorder.

The analysis has produced a definition of a failure sequence that is reasonable and appears to have no significant inconsistencies with the accident observations.

The failure appears to have initiated with the forward trunnion bolt of the right hand landing gear (the trunnion shearing upwards) closely followed by failures of the inboard right wing rear spar webs and caps. These failures were the result of an extremely high vertical load and an associated "springback moment" applied to the right main landing gear. Both the high vertical load and the high "springback moment" were a result of the excessive (18-20 ft/sec) sink rate, and the slightly rolled (3 degrees right-wing-down) touchdown attitude.