NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF AVIATION SAFETY
WASHINGTON, D.C. 20594

January 25, 2012

AIRWORTHINESS SPECIALIST'S REPORT OF INVESTIGATION

DCA11MA076

A. ACCIDENT

Operator:	Gulfstream Aerospace Corporation
Aircraft:	GVI (G650), Serial Number 6002
Location:	Roswell, NM
Date:	April 2, 2011
Time:	0934 MDT

B. SUMMARY

On April 2, 2011, about 0934 mountain daylight time, an experimental Gulfstream Aerospace Corporation (GAC) GVI (G650)[1], registration N652GD, serial number 6002, crashed during takeoff from runway 21 at Roswell International Air Center Airport (ROW), Roswell, New Mexico. The flight was being operated by the manufacturer as part of its G650 developmental field performance flight test program. The two pilots and the two flight test engineers were fatally injured, and the airplane was substantially damaged. The flight was being conducted under 14 *Code of Federal Regulations* Part 91, and visual meteorological conditions prevailed at the time of the accident.

On April 3, 2012, the NTSB airworthiness specialist launched to the accident site and was assisted by representatives of GAC, Parker Hannifin, Rolls-Royce and the FAA. The on-scene investigation was completed on April 7. On August 23, 2011 the NTSB and GAC representatives convened at the accident airplane wreckage stored at Air Salvage of Dallas, Lancaster, Texas. The purpose was to document the number and location of the ballast weights and the position of the horizontal stabilizer on the accident airplane. The following report summarizes the findings of these activities.

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[1] Gulfstream uses the Roman numeral designation "GVI" for aircraft certification purposes and the designation "G650" for marketing purposes. These designations mean the same aircraft model for purposes of this report and are used interchangeably.

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C. DETAILS OF THE INVESTIGATION

1. Airplane Information

The Gulfstream G650 is powered by two Rolls-Royce Deutschland Ltd & Co KG BR700-725A1-12 high bypass ratio turbofan engines. The engines are mounted within nacelles attached by pylons to the aft upper fuselage. The engine nacelles feature thrust reversers at the exhaust section to aid in slowing the aircraft during landing. The aircraft landing gear incorporates a steerable nose wheel and main wheel anti-skid braking. The fuselage is of semi-monocoque metal construction. The main fuselage is pressurized to support a cabin altitude of four thousand eight hundred fifty feet (4,850 ft) at a maximum operating altitude of fifty-one thousand feet (51,000 ft). Non-pressurized areas of the fuselage are the nose radome and aft equipment compartment in the aircraft tail section. The aft equipment compartment houses the Auxiliary Power Unit (APU), engine and APU fire extinguisher bottles, hydraulic system reservoirs, a fluid (engine/ APU oil and hydraulic system) replenishment station and additional mechanical and electrical installations. The fuselage is divided lengthwise into an above-floor section and a below-floor section. The below-floor section houses air-conditioning ducting, electrical distribution wiring and components and hydraulic lines. The above-floor passenger compartment may be configured in any of a variety of optional layouts, with a maximum possible seating capacity of eighteen (18) plus three (3) crew members. The main aircraft entrance door is located at the front of the passenger compartment, with the entrance area forming the separation between the cockpit and passenger compartment. Immediately aft of the cockpit and adjacent to the entrance area are the two main Electronic Equipment Racks, one on either side of the cockpit entrance, designated Left (LEER) and Right (REER). The racks contain the majority of the aircraft avionics components as well as wiring for electrical power distribution. A baggage compartment is provided at the rear of the passenger compartment, separated by an internal secondary pressure bulkhead with an integrated access door that may be used to enter the compartment during flight. The baggage compartment has an external door for ground loading/unloading. An Auxiliary Electronic Equipment Rack (AEER) is also installed in the baggage compartment. The aircraft wings are swept back thirty-three point two eight degrees (33.28°) with a leading edge sweep of thirty-six point eight nine (36.89°). They are cantilevered with a 2.85° dihedral (from WRP to WL). Each wing contains a fuel tank integrated into the wing structure. Wing anti-icing ducts are heated in the leading edge of the wing and the landing lights are located in the wing / body fairing.

Primary and secondary flight controls are installed on the wing trailing edge. The primary flight controls are the ailerons, augmented by two pairs of spoilers (the middle and outboard spoilers) which provide roll control. An additional pair of spoilers (the inboard spoilers) provide secondary ground and flight spoilers. Fowler flaps are mounted one per side. Winglets installed at the outboard end of each wing aid in drag reduction and improve fuel economy. At the wing roots on either side of the fuselage keel are the wheel wells and the main landing gear support structure.

The airplane tail section consists of a fixed vertical stabilizer and an adjustable horizontal stabilizer equipped with primary flight controls. Tail mounted primary flight controls are the left and right elevators attached to the trailing edge of the horizontal stabilizer, and a rudder attached to the trailing edge of the vertical stabilizer. Elevator trim is accomplished by displacement of the entire surface and movement of the horizontal stabilizer. Rudder trim is accomplished by displacement of the entire surface.

The G650 Primary Flight Control System (PFCS) includes the ailerons, multi-function spoilers[2], elevator and rudder; these surfaces are hydraulically powered for all axes, and controlled with fly-by-wire technology. See Figure 2 for control surface locations.

The pilot and copilot primary controls include control wheels, columns, and rudder pedals. Each primary control (wheel, column, pedals) is connected to position sensors. The position sensors provide the position of the respective control device to the Flight Control Computers (FCCs). The FCC's determine the appropriate amount of control surface motion and send the electrical command to a Remote Electronics Unit (REU) installed at the control surface (Figure 3). The REU sends a command signal to an electrically controlled hydraulic manifold. The manifold ports hydraulic fluid to an actuator, which moves the control surface. The REU also receives position information from a sensor connected to the piston of the hydraulic actuator and monitors the actuator performance. Each control surface, except the spoilers, is operated by two independent REU/actuator pairs. Each spoiler is controlled by one REU/actuator pair.

[2] Only the middle and outboard spoiler panels are used for roll control.

G650 General Weight Data:

A. Maximum Ramp Weight: 100,000 lb (45,359 kg)
B. Maximum Takeoff Weight: 99,600 lb (45,178 kg)
C. Maximum Zero Fuel Weight: 60,500 lb (27,442 kg)
D. Basic Operating Weight (Empty): 54,000 lb (24,494 kg)
E. Maximum Payload: 6500 lb (2948 kg) at BOW of 54,000 lb (24,494 kg)
F. Maximum Landing Weight: 83,500 lb (37,875 kg)
G. Maximum Fuel Capacity: 44,200 lb (20,049 kg)
H. Maximum Usable Fuel Capacity: 43,800 lb (19,867 kg)

G650 General Powerplant Data:

A. Manufacturer: Rolls-Royce Deutschland Ltd & Co KG
B. Model: BR700-725A1-12
C. Number Installed: 2
D. Takeoff Thrust (Sea Level): 16,100 lb/fr
E. Fan Area / Radius: 1963 in_2 / 50 in
F. Takeoff Thrust-To-Weight Ratio: 0.323

Airplane Dimensions (See Figure 1)

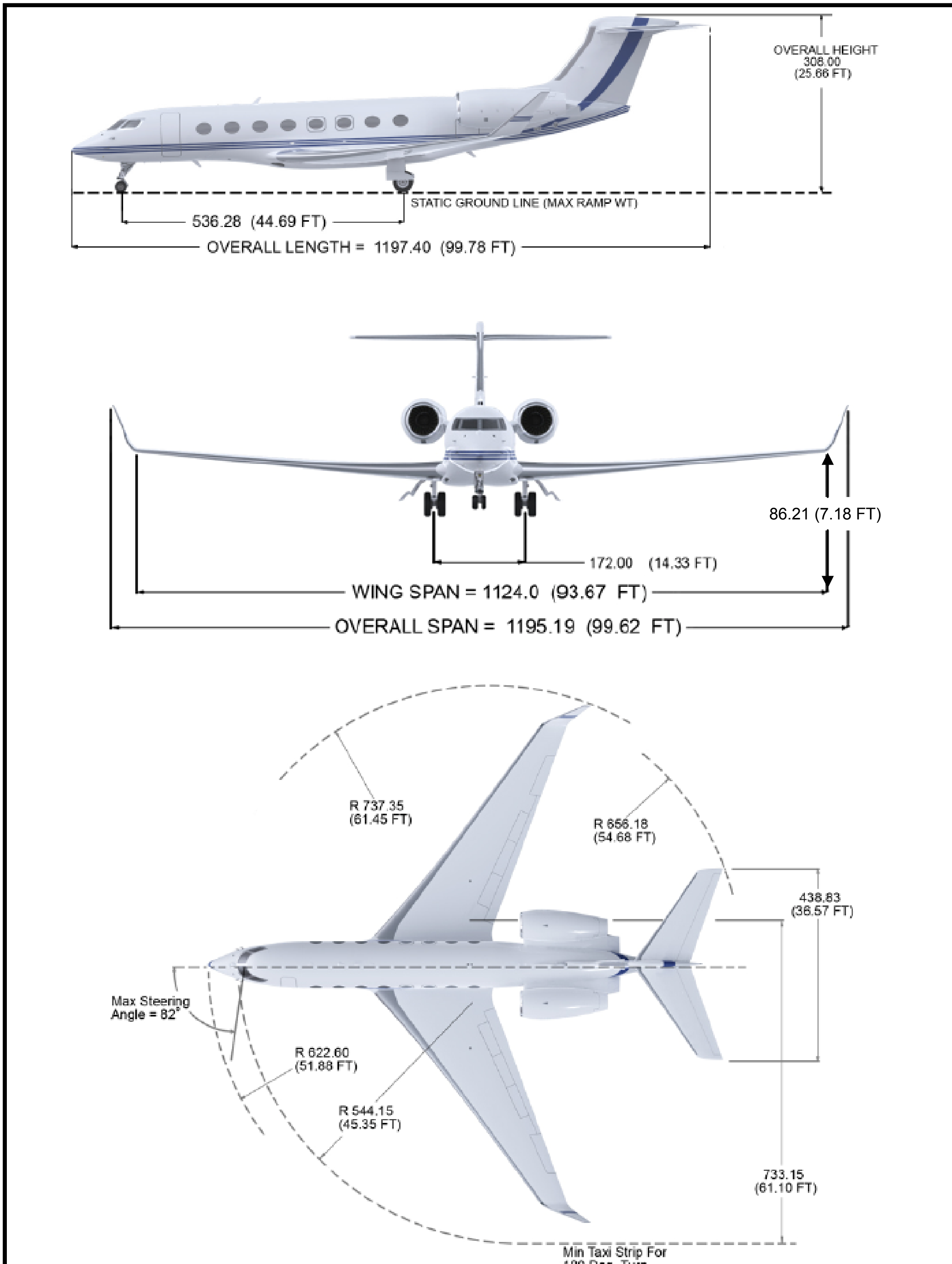


Figure 1 Airplane Dimensions

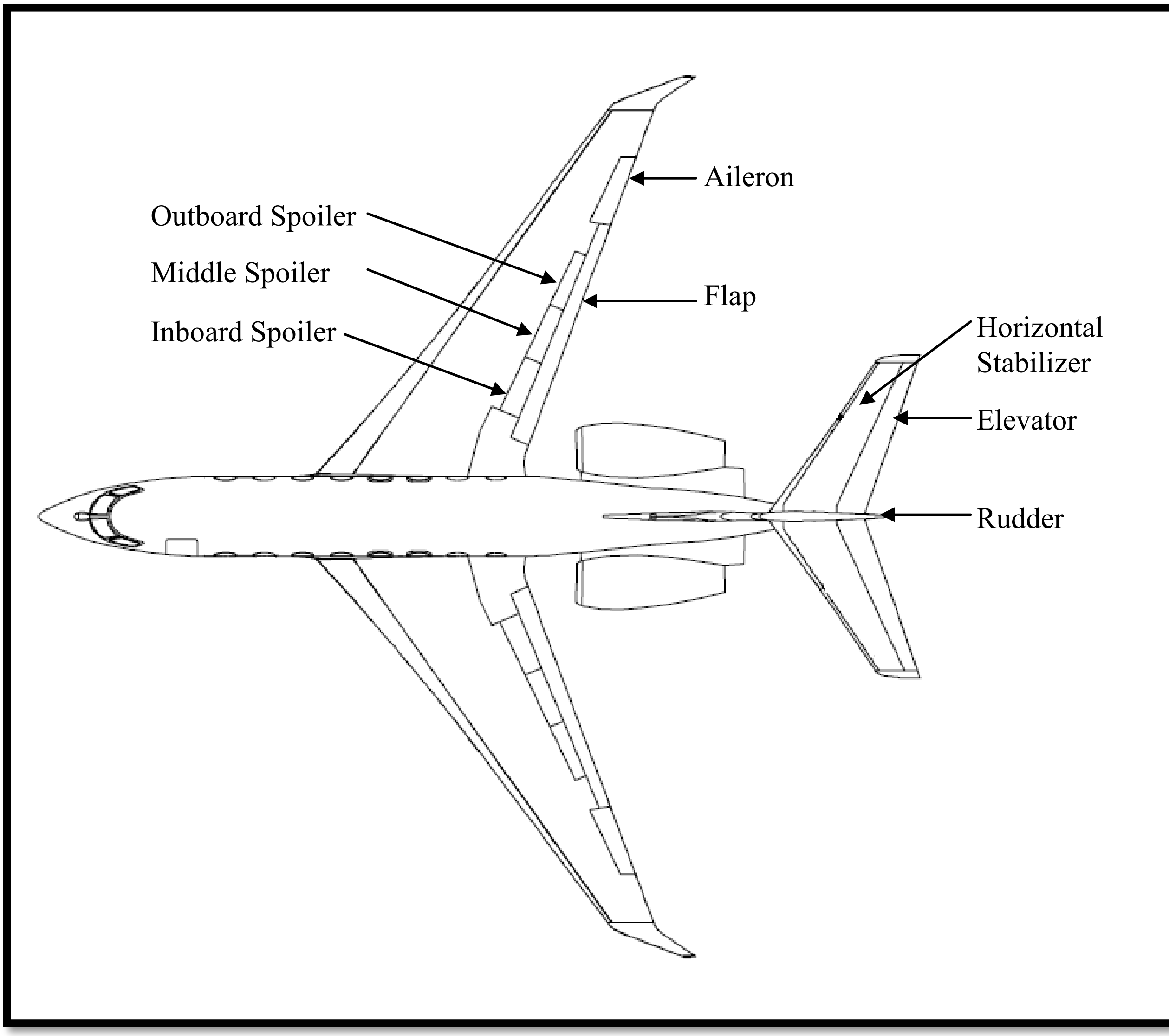


Figure 2 Flight Control Locations

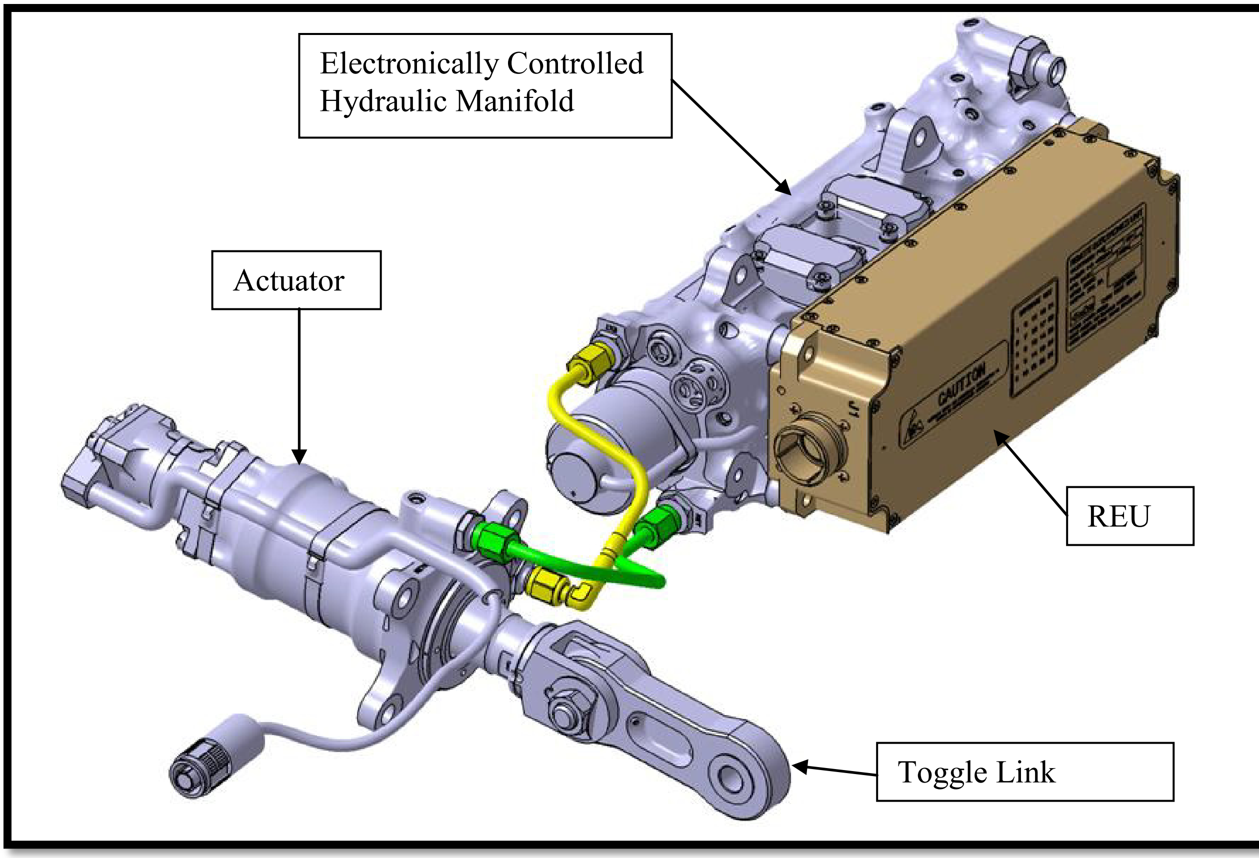


Figure 3 Typical Flight Control Actuator Installation

2. Wreckage Diagrams

Figure 4 provides an aerial view looking back over the wreckage path. There was evidence that the right wing tip first made contact with runway 21, starting about 5160 feet from the runway threshold. The right wing tip continued to touch the runway as the airplane departed the runway off the right side into the grassy area between runway 21 and taxiway B. There was evidence of a fire in the grass adjacent to the runway where the wing tip scrape marks departed the runway (Figure 5, 6). The right main gear tires contacted the ground, then the left main gear tires, then the right main gear tires (again), then the nose gear (Figure 7). The main gear separated from their attachments at the fuse separation points. The nose gear collapsed and the airplane then skid on its belly across the intersection of taxiways E and B (Figure 8). There were marks on the ground consistent with the approximate width and location of the forward and aft skegs[3]. There were also tire marks across the intersection consistent with the right and left main landing gear. The airplane continued through the intersection and into the grass area where it impacted a runway information sign (Figure 9) and an exposed concrete culvert (used for underground electrical access)(Figures 8-10). The concrete culvert is located approximately 165 feet from the centerline of the Taxiway B, and

[3] Two “skegs” are attached to the lower wing cover at centerline. These skegs are fabricated from titanium material to provide high abrasion resistance. The skegs are intended to protect the aluminum lower wing covers from abrasion in the event of a wheels-up landing.

approximately 1002 feet from the centerline of Runway 21. Impact with the culvert occurred just to the right of centerline of airplane and caused extensive structural damage to the center wing box including rupture of the fuel tank. The forward skeg was found about 15 feet from the culvert to the left of the line of travel of the airplane (Figures 8, 11). The aft skeg was located approximately 245 feet to the left and past the culvert in the area of the left main gear parts (Figures 8,12). The airplane continued to slide and impacted a weather station (Figure 13), which compromised the leading edge and fuel compartments of the left wing and damaged the vertical and horizontal stabilizer. The weather station consisted of an approximately 30 ft pole next to a steel beam support for other instruments (Figure 14). One of the steel beam supports was found embedded in the left engine housing, and another steel beam support was found in the debris field beyond the aircraft. The airplane continued to slide and rotate until it came to rest approximately 300 ft from the control tower, oriented approximately 90 degrees to its path. The aircraft was extensively damaged by post impact fire damage and impact with objects on the ground.

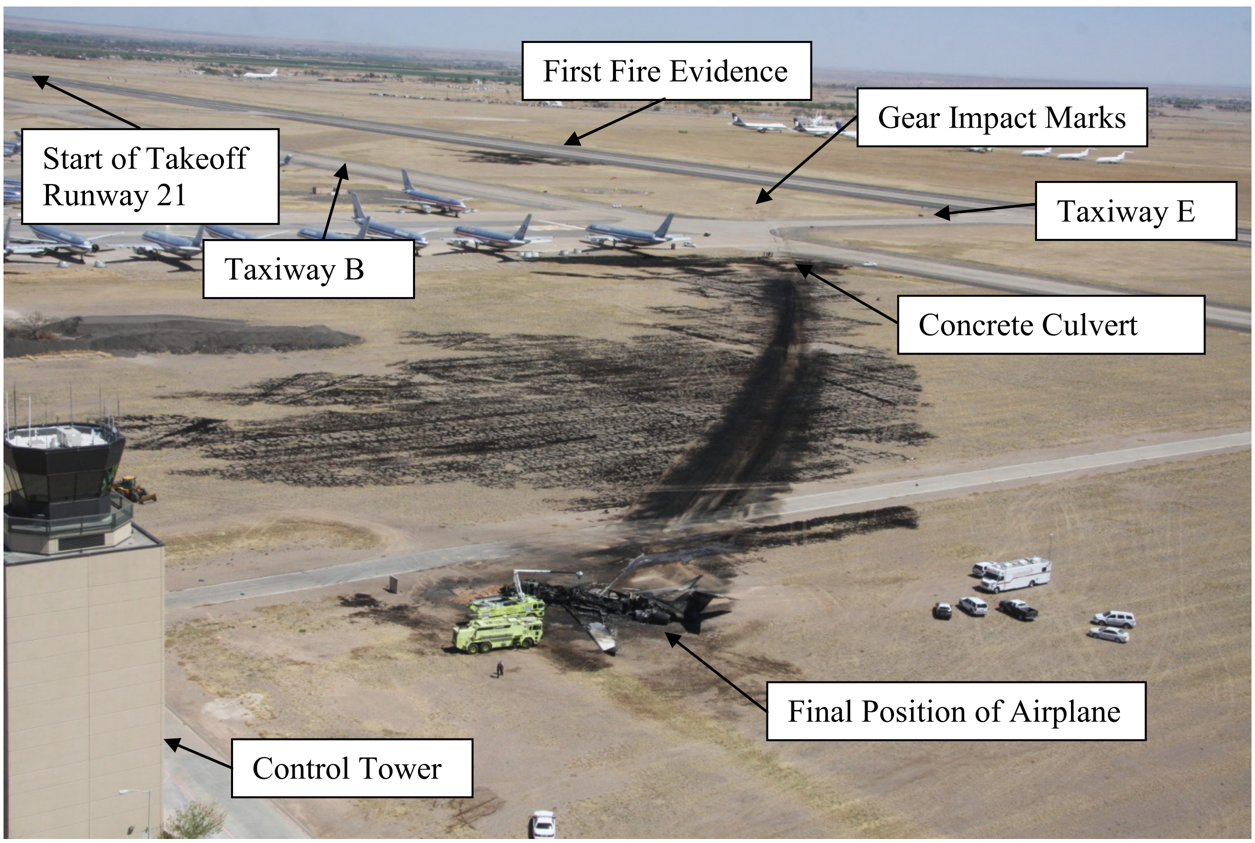


Figure 4 Overview of Wreckage Path from Final Position

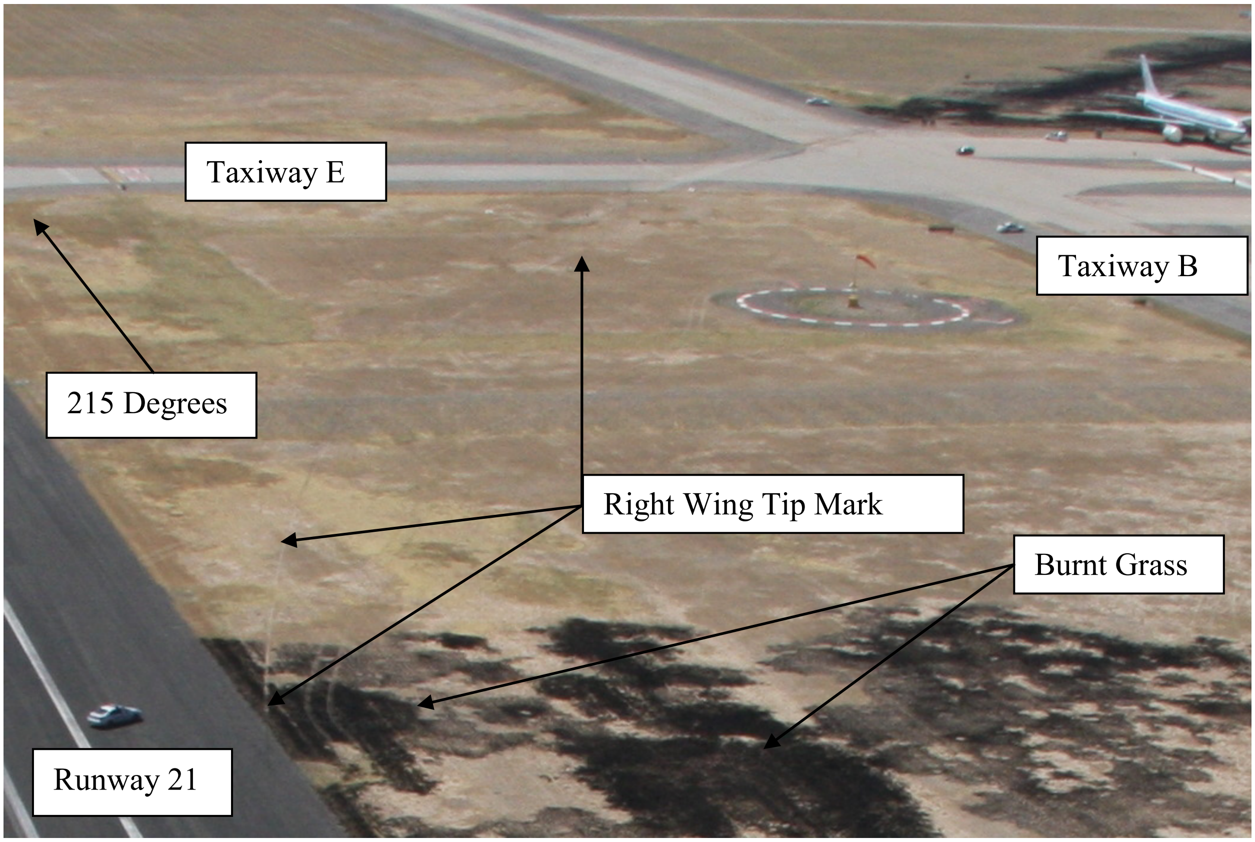


Figure 5 Wreckage Path From Takeoff Runway

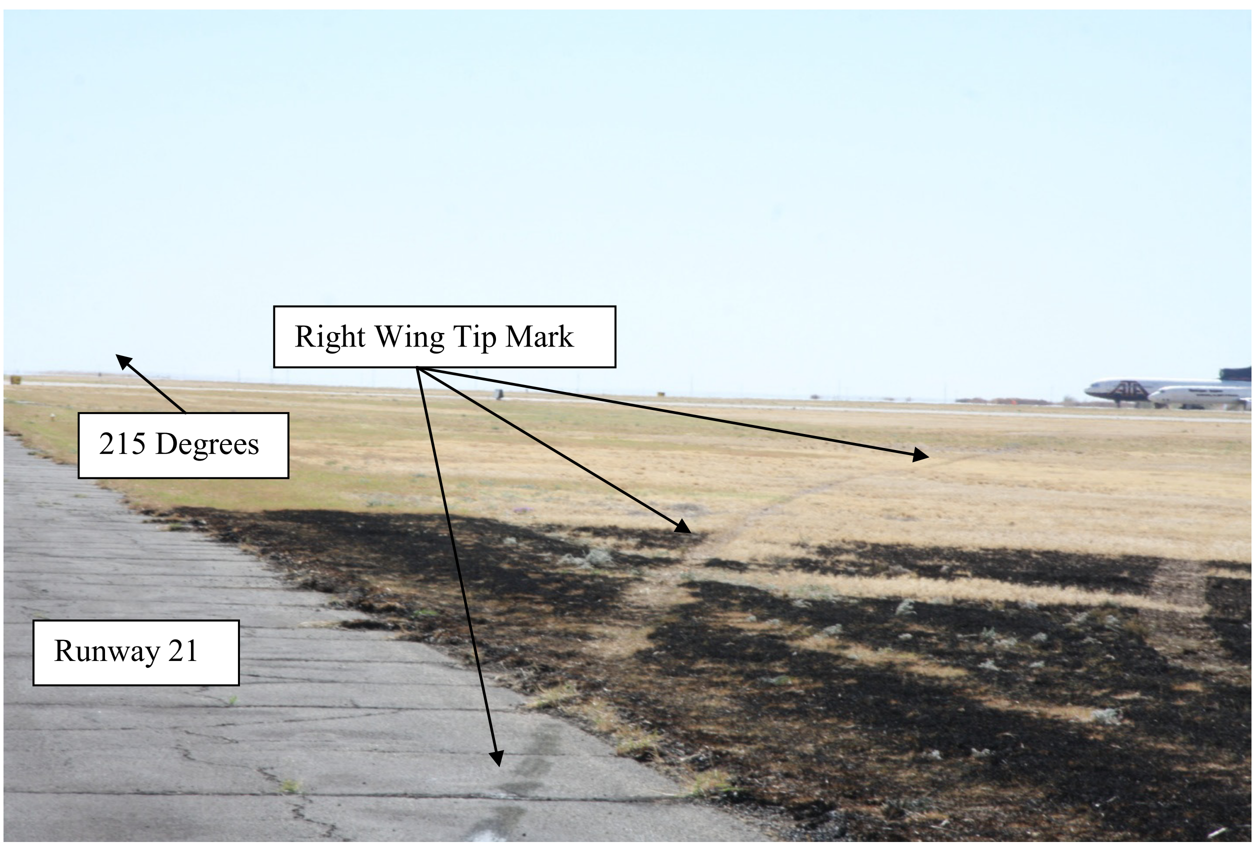


Figure 6 Wingtip Marks

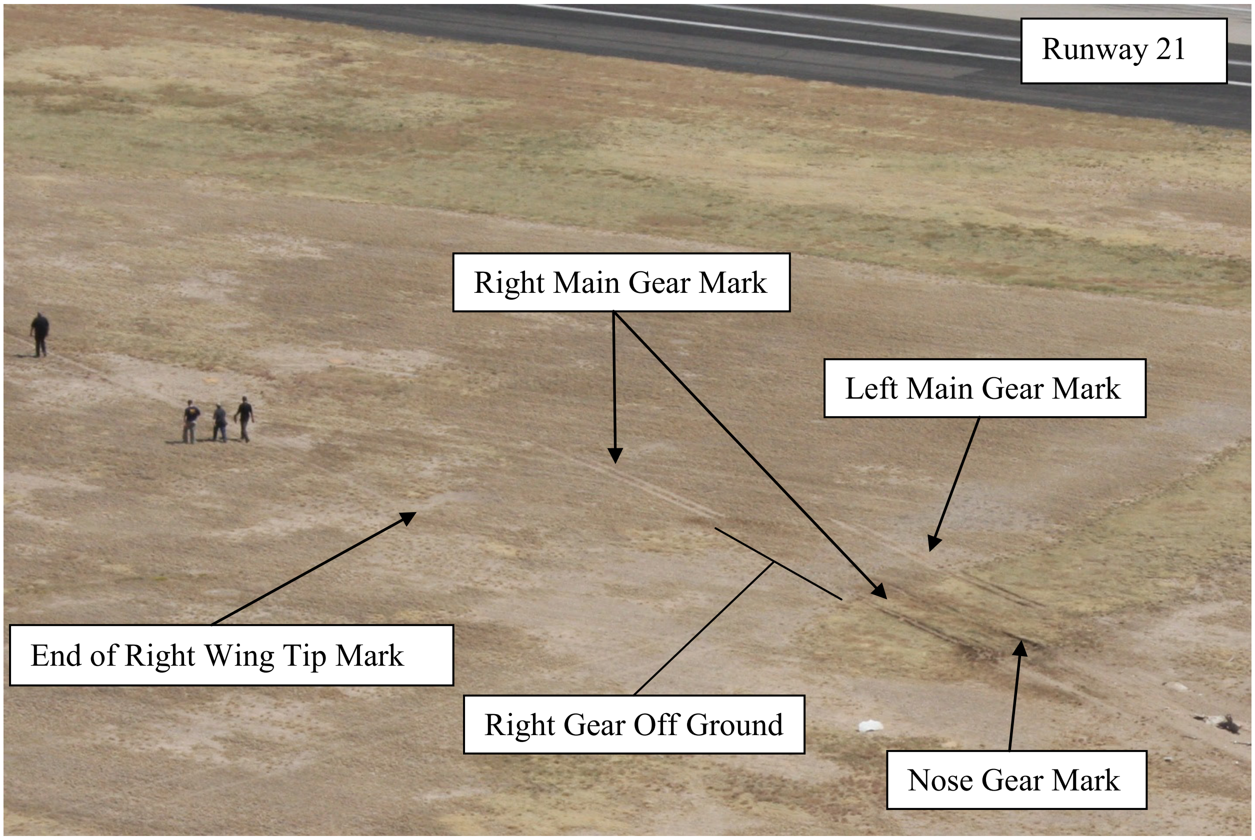


Figure 7 Landing Gear Marks

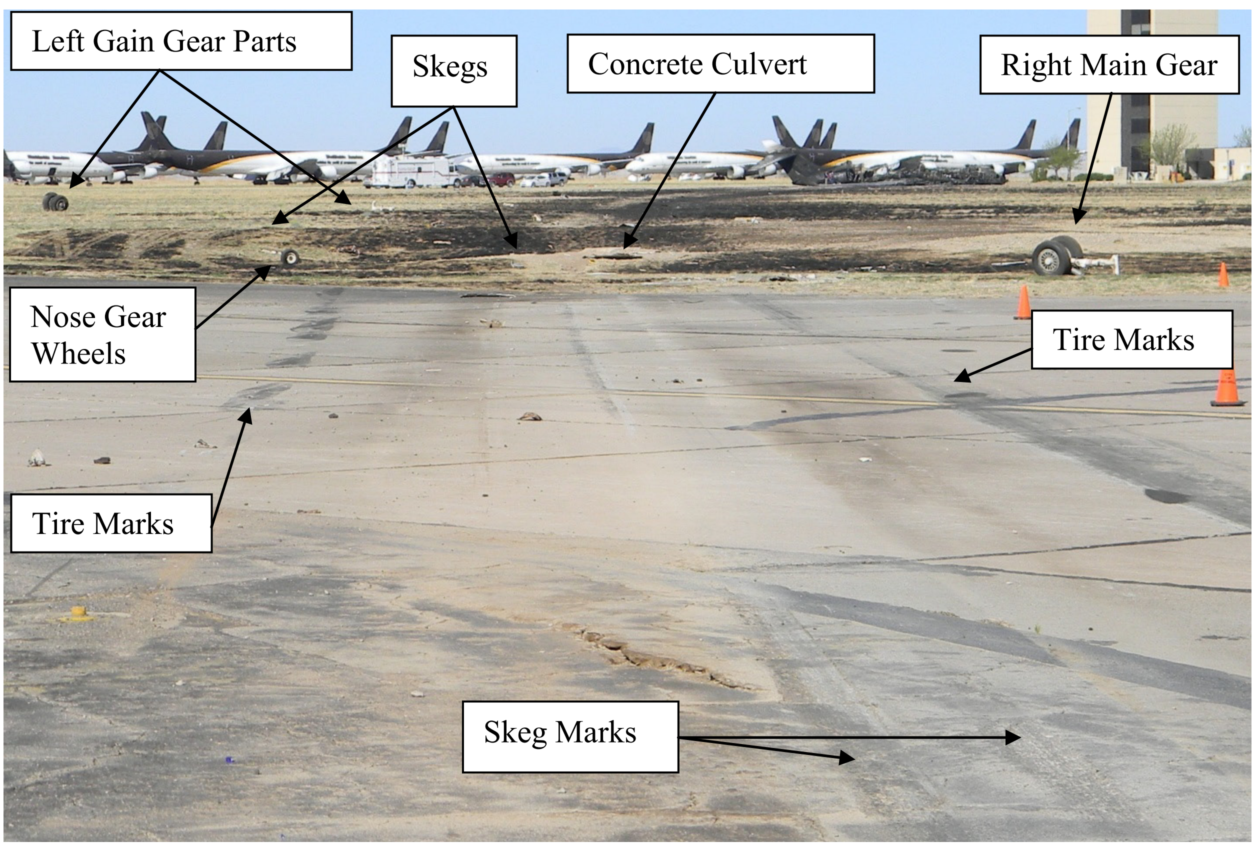


Figure 8 Marks on Intersection

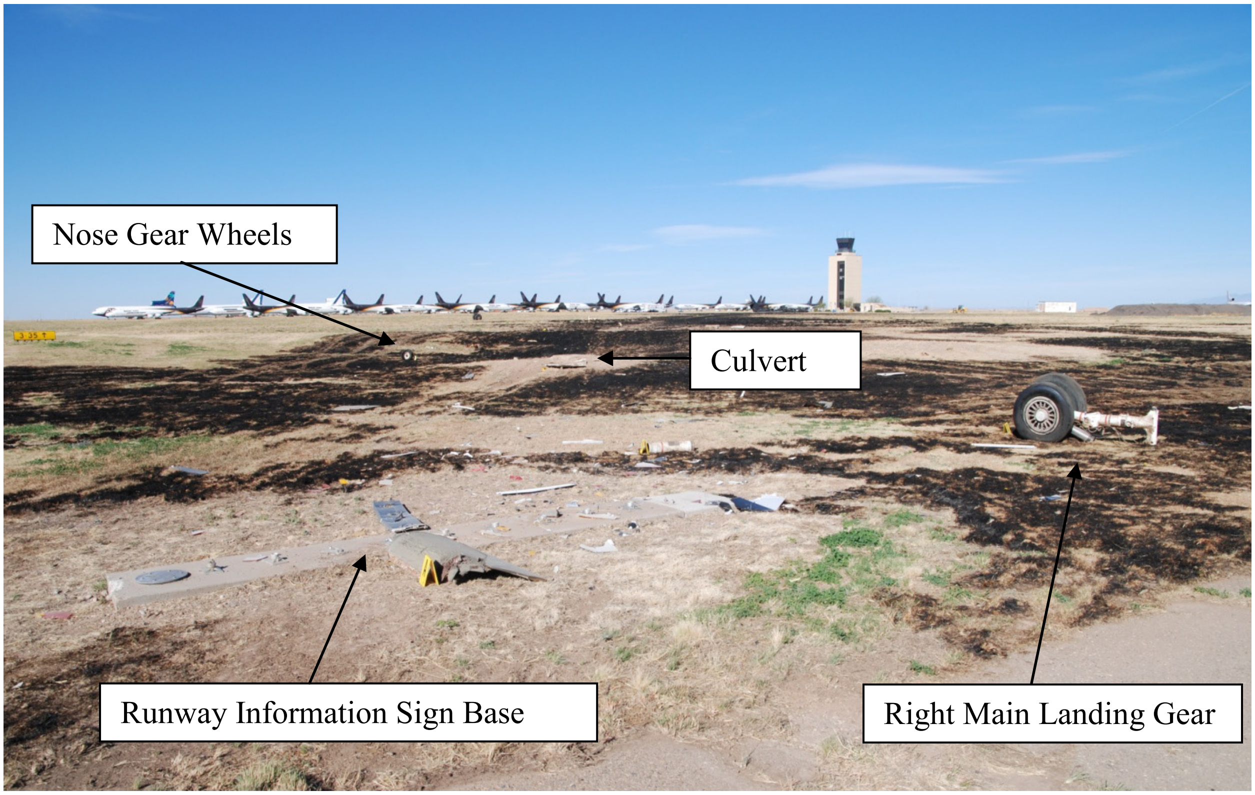


Figure 9 Impact with Runway Information Sign

Figure 10 Concrete Culvert for Electrical Access

Figure 11 Forward Skeg

Figure 12 Aft Skeg

Figure 13 Location of Weather Station

Figure 14 Weather Station Before Accident (View from SE end of Runway 30, direction about 250 degrees)

3. Left Wing Condition

The left wing experienced structural damage from impact with the weather station and substantial fire damage from the post impact fire (Figure 15). Figure 16 shows the wing station locations. The upper skin and ribs were melted from butt line (BL) 62.0 to approximately rib baffle station (RBS) 250 (Figure 17). At the leading edge (LE) there was a 24” X 46” hole centered at RBS 242 and a 10” x 12” hole centered at RBS 322. The LE had no further damage outboard to the wing tip. At the trailing edge (TE), from the wing tip in through the aileron had no damage. The aileron surface, four hinge fittings and two actuator attach fittings were all intact.

There are four flap tracks to which the flaps are attached. They are identified here from inboard to outboard A – D. There are jackscrews at tracks B and C which move the flaps.

The flap surface was intact from the most outboard portion to approximately 2 feet inboard of the outboard track (Track D) (Figure 21). Inboard of that point the surface and attach points were mostly melted. Flap track A was intact with flap rollers detached, but in close proximity on the ground. Flap track B was intact with the carriage still attached to the jackscrew (Figure 22). The jackscrew position was measured from the up stop to top of ballscrew – 16 5/8 inches, and the downstop to bottom of ballscrew - 12 3/4 inches. Flap track C was intact with the carriage still attached to the jackscrew (Figure 23). The jackscrew position was measured from up stop to top of ballscrew - 13 ¾ inches, and the downstop to bottom of ballscrew – 10 3/8 inches. According to Gulfstream these measurements of the jackscrew position are consistent with flaps in the 10 degree position. Flap track D structure and attach fittings all intact and connected to unmelted flap surface.

The composite spoilers had extensive heat damage. The outboard spoiler was delaminated and all four hinge fittings were detached and melted (Figure 24). The actuator and connecting link (toggle link) were intact, including attachment bolts (Figure 25). The middle spoiler was delaminated (Figure 26). The two hinges nearest the actuator were present with attach fittings, but heat damaged and fractured. The most inboard hinge was melted. The actuator and connecting link (toggle link) were intact, including attachment bolts (Figure 27). The inboard spoiler was delaminated and consumed (Figure 28), with all attach fittings melted.

Figure 15 Left Wing Overview

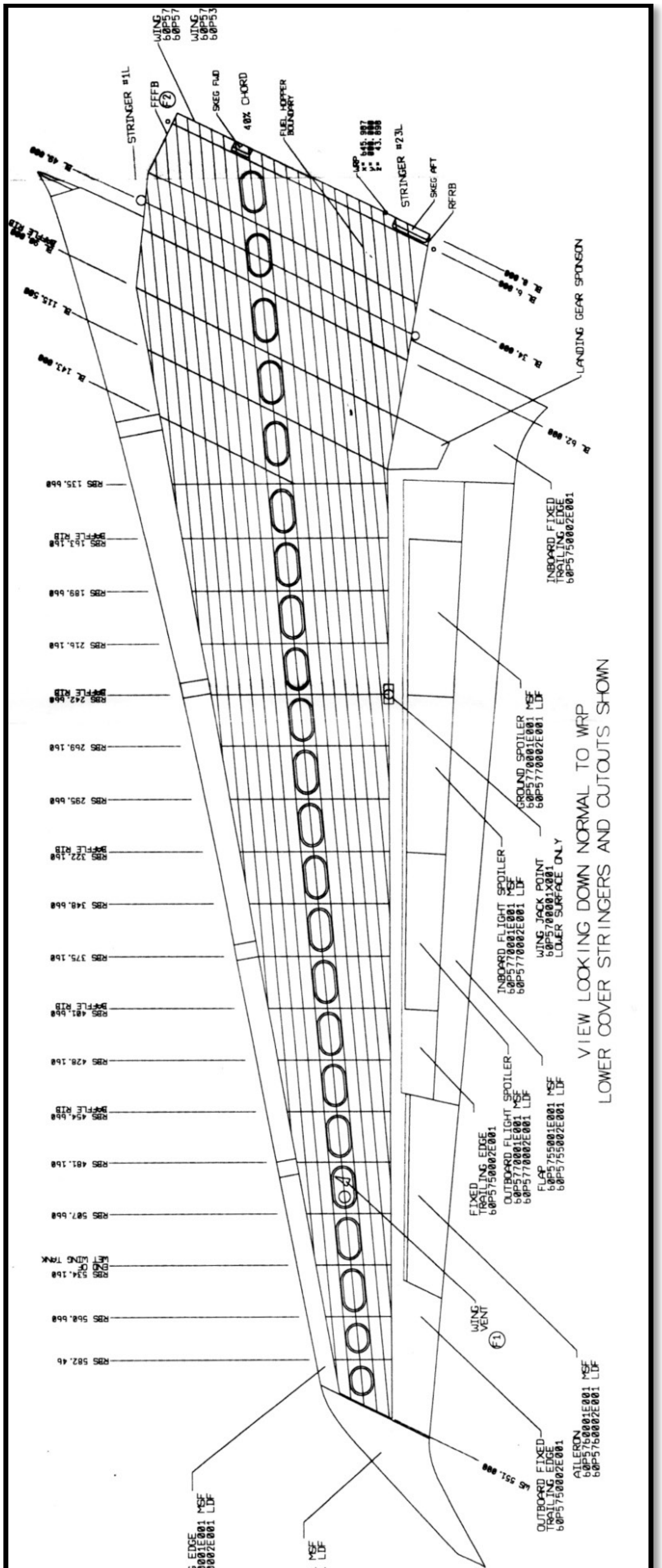


Figure 16 Wing Station Diagram

Figure 17 Left Wing Inboard Leading Edge

Figure 18 Left Wing Leading Edge

Figure 19 Left Wing Impact damage

Figure 20 Left Wing Impact Damage

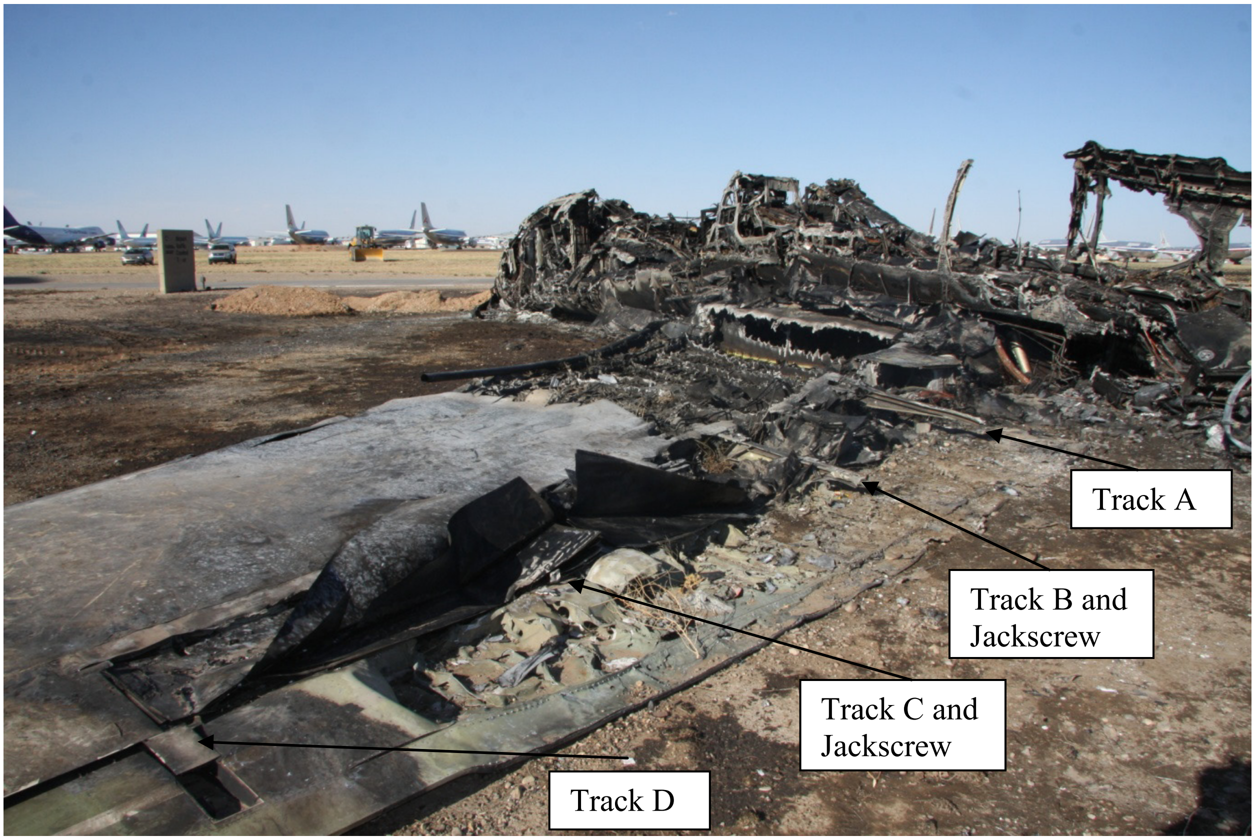


Figure 21 Left Wing Trailing Edge

Figure 22 Flap Track B and Jackscrew

Figure 23 Flap Track C and Jackscrew

Figure 24 Left Outboard Spoiler Turned Over

Figure 25 Left Outboard Spoiler Actuator Fittings

Figure 26 Left Middle Spoiler

Figure 27 Left Middle Spoiler Attachment Fitting

Figure 28 Left Inboard Spoiler

4. Right Wing Condition

The inboard portion of the right wing experienced substantial fire damage from the post impact fire (Figures 29 - 31). The leading edge had melted out to approximately RBS180. The upper skin was melted from BL 62.0 to approximately BL143. On the trailing edge, the flap surface was melted inboard of RBS 300.

Along the LE there were small dents at approximately RBS 260, RBS 325, and 585. At the bottom of the winglet there is a scrape from the LE to the TE (Figure 32).

The aileron surface was intact except the upper skin surface was bulged and detached near the outboard end (Figure 33). There was a small hole near the inboard end which had upward petalling. All attachment points were confirmed to be intact.

The outboard spoiler was intact with all hinges and actuator attached (Figure 34). The middle spoiler had some surface delaminated, with hinges present but detached from surface, the attach points for the actuator intact, and attached to the surface (Figure 35). The inboard spoiler had extensive heat damage and delamination of the surface (Figure 36). All hinge points were detached and the actuator attach fitting fractured.

The flap surface inboard of track A was located in the debris field (Figures 37, 38). The flap surface was consumed from track A to approximately 1 foot inboard of track C. The flap was intact from track C to the most outboard point. The track B jackscrew was still attached to the carriage and to the track (Figure 39). The jackscrew position was measured from the upstop to the top of the ballscrew – 16.75 inches, and from the downstop to bottom of ballscrew - 12 5/8 inches. Flap track C was intact with the carriage still attached to the jackscrew (Figure 40). The Track C jackscrew position was measured from the downstop to bottom of ballscrew – 10.25 inches, the upper portion could not be accessed for measurement. According to Gulfstream these measurements of the jackscrew position are consistent with flaps in the 10 degree position.

Figure 29 Right Wing Overview

Figure 30 Right Wing Trailing Edge

Figure 31 Right Wing Inboard Trailing Edge

Figure 32 Right Wing Tip Scrape

Figure 33 Right Wing Aileron

Figure 34 Right Outboard Spoiler

Figure 35 Right Middle Spoiler

Figure 36 Right Inboard Spoiler

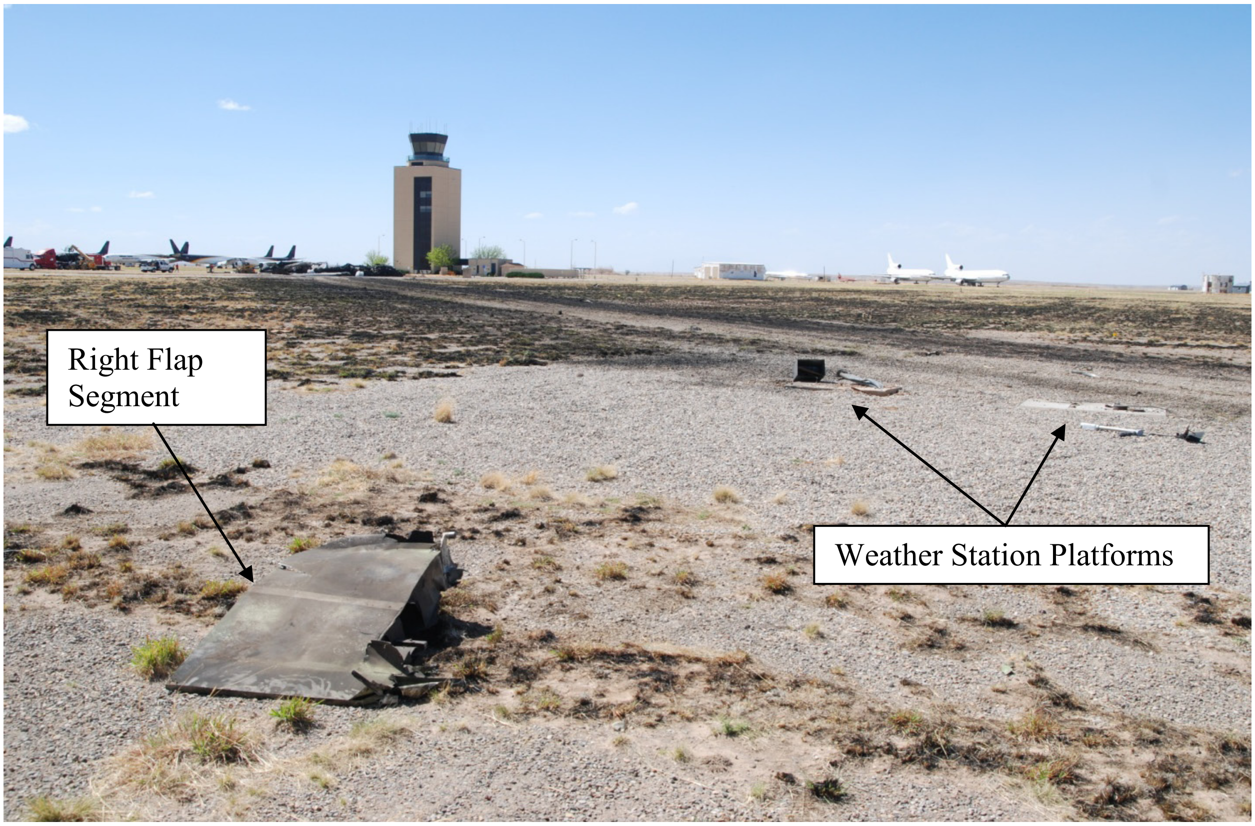


Figure 37 Right Flap Segment

Figure 38 Right Flap Segment Bottom

Figure 39 Right Flap Track B

Figure 40 Right Flap Track C

5. Center Wing Box Condition

Extensive damage to the center wing box floor, ribs and trusses could be observed through the melted area of the right wing (Figure 41). This area is a portion of the fuel tank. There was an accumulation of dirt inside the wing box. During recovery the fuselage was lifted off the wing, providing access to the damage. The forward spar had a large hole to the right of centerline (Figure 42). The lower skin was bent up in the area and a crack spanned from the hole to the upper skin. The upper skin was bent and separated from the spar. Inside the wing box it was observed that the truss at right BL 6 was damaged, the rib at right BL 34 had a large hole, and there was an accumulation of dirt inside the wing box (Figure 43). The rear spar of the wing box had a large hole outboard of the rib at right BL 34, which extended from the top skin to the lower skin. The lower skin was also fractured and missing.

Figure 41 Center Wing Box Damage

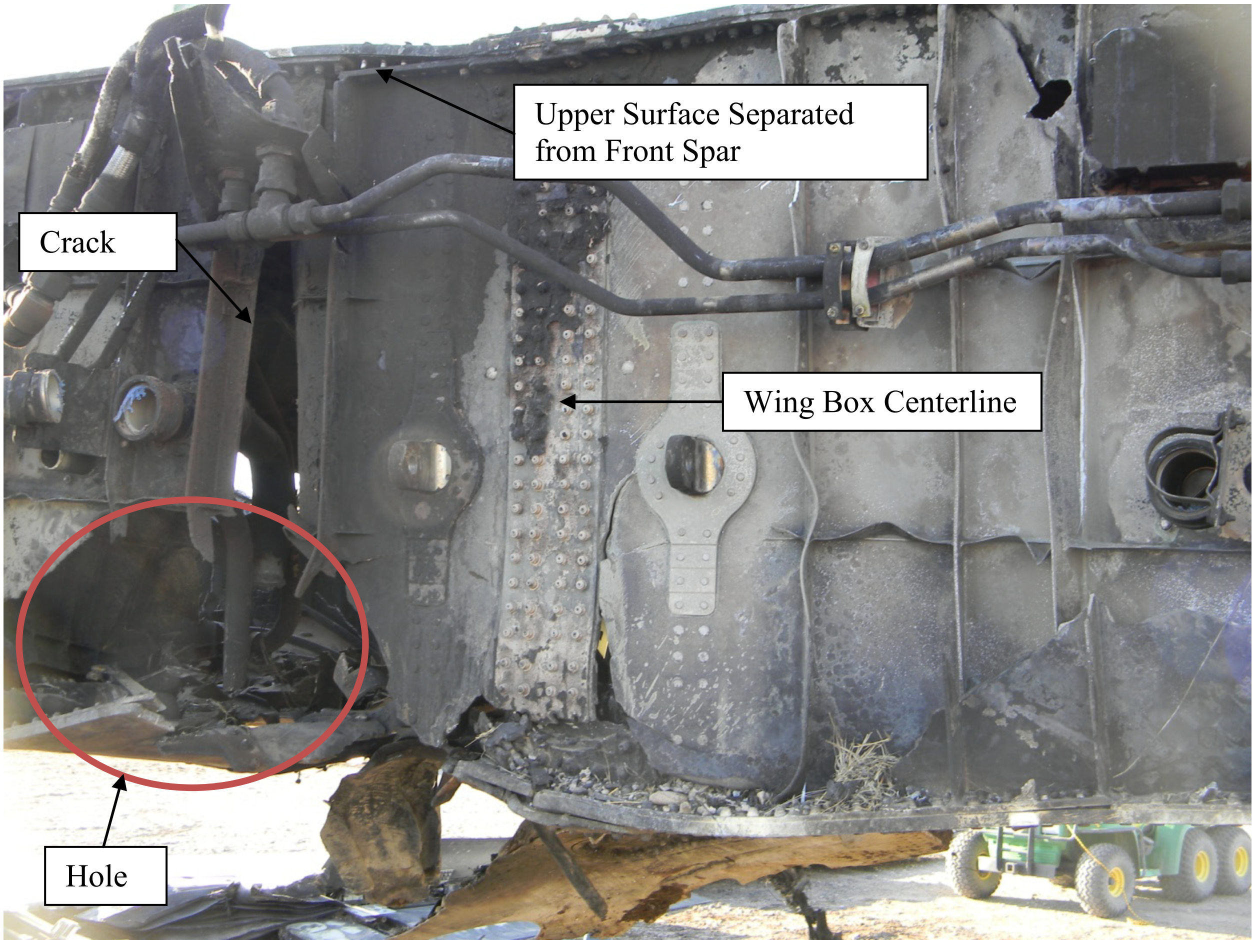


Figure 42 Center Wing Box Front Spar

Figure 43 Center Wing Box Internal View looking Aft

Figure 44 Center Wing Box Aft Spar Damage

7. Horizontal Stabilizer

The horizontal stabilizer had minor impact damage at the left inboard LE, some sooting and minor heat damage on the left and heavy sooting and more heat damage to the skin on the right (Figure 45). The position of the stabilizer was not measured until it was examined at the storage facility in Dallas, Texas on August 23, 2011. The right side lower skirt and the access panel were removed, and a portion of the top of the vertical stabilizer were cut away to gain access to the horizontal stabilizer trim actuator. There was no apparent damage to the actuator or attachment fittings. To determine the position of the stabilizer it was necessary to measure the distance between the two surfaces identified in Figures 46 and 47, then linear interpolate the position using the table provided by GAC (Figure 48). The distance was determined to be 4 1/8th inches, which corresponded to a surface position of approximately 7.9 degrees. This position was consistent with the requirement of the accident flight test card, and also the position of the horizontal stabilizer last reported by the accident airplane's flight test instrumentation system.

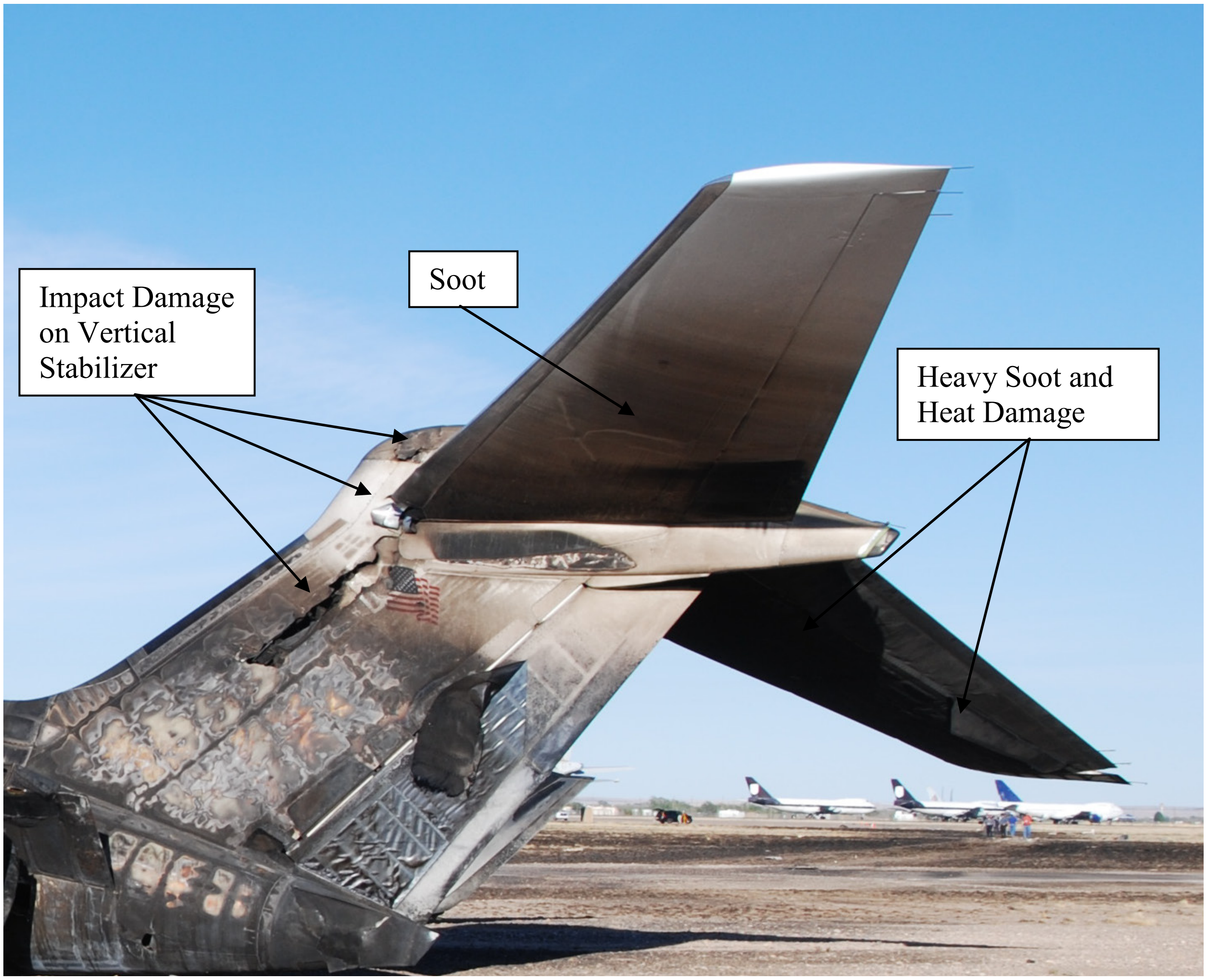


Figure 45 Horizontal Stabilizer Overview

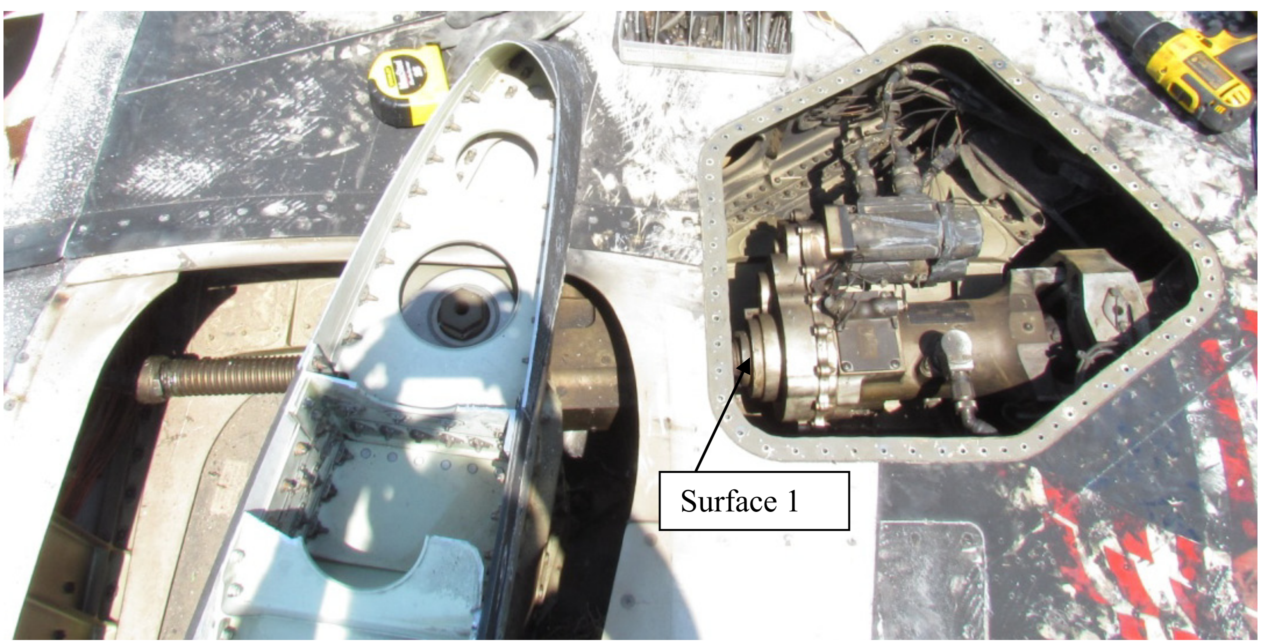


Figure 46 Horizontal Stabilizer Trim Actuator

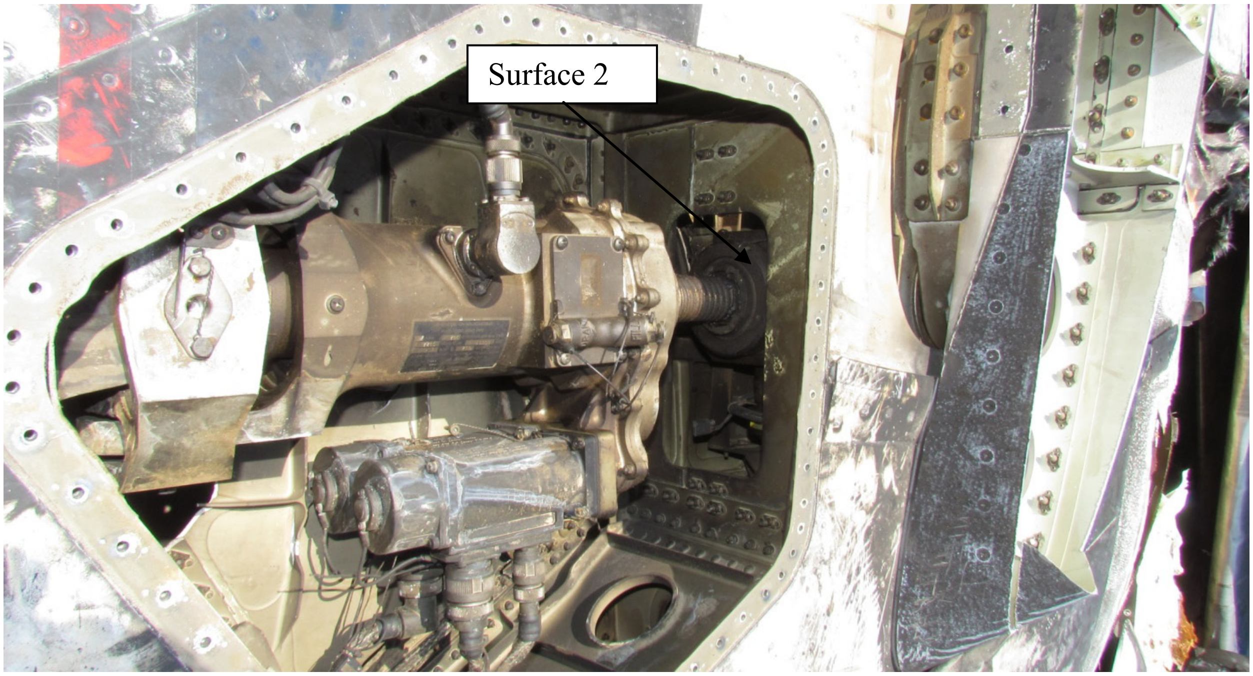
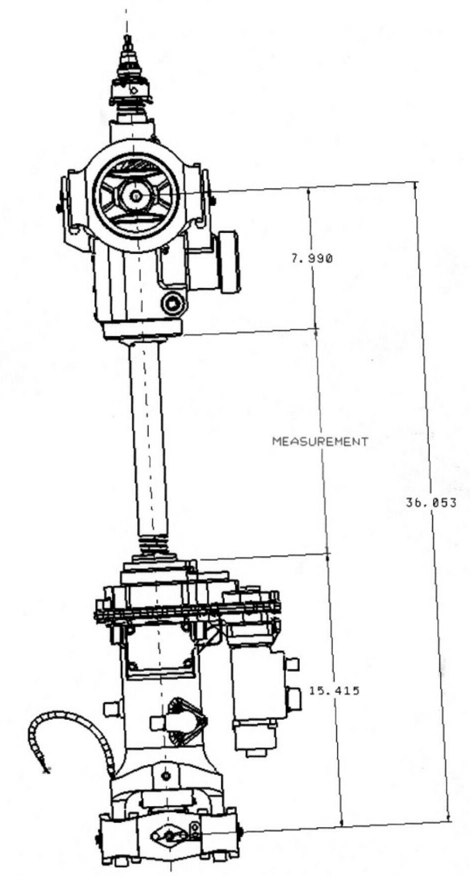


Figure 47 Horizontal Stabilizer Trim Actuator



Actuator shown in neutral position

Area 1-to-Area 2 Length, in.	Actuator Pin-to-Pin Length, in.	Surface Position, deg. (TED = +)
13.724	37.132	1.0
13.186	36.594	0.5
12.648	36.056	0.0
12.109	35.517	-0.5
11.570	34.978	-1.0
11.031	34.439	-1.5
10.493	33.901	-2.0
9.954	33.362	-2.5
9.415	32.823	-3.0
8.876	32.284	-3.5
8.338	31.746	-4.0
7.799	31.207	-4.5
7.261	30.669	-5.0
6.723	30.131	-5.5
6.186	29.594	-6.0
5.649	29.057	-6.5
5.112	28.520	-7.0
4.576	27.984	-7.5
4.041	27.449	-8.0
3.506	26.914	-8.5
2.972	26.380	-9.0
2.439	25.847	-9.5
1.907	25.315	-10.0
1.375	24.783	-10.5
0.846	24.254	-11.0

Figure 48 HSTA Position Measurement

8. Left Elevator

The left elevator surface was intact with minor sooting on innermost trailing edge (Figure 49). The actuator access panels were removed. All actuator attach fittings were intact (Figure 50). No heat damage or sooting was evident.

Figure 49 Left Elevator Lower Surface

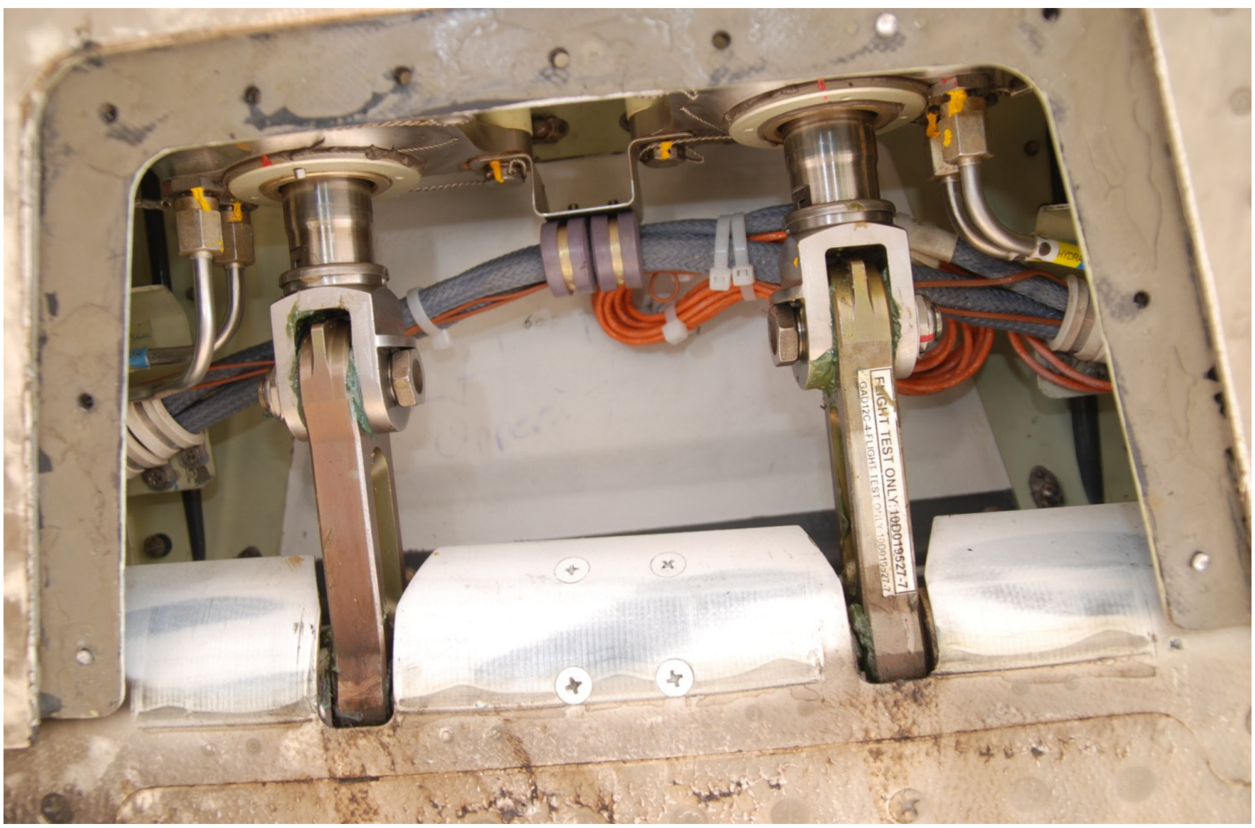


Figure 50 Left Elevator Actuators

9. Right Elevator

The right elevator surface was intact with heavy sooting and significant heat damage to the outboard portion skin (Figure 51). The actuator access panels were removed. All actuator attach fittings were intact (Figure 52). No heat damage, but minor sooting was evident.

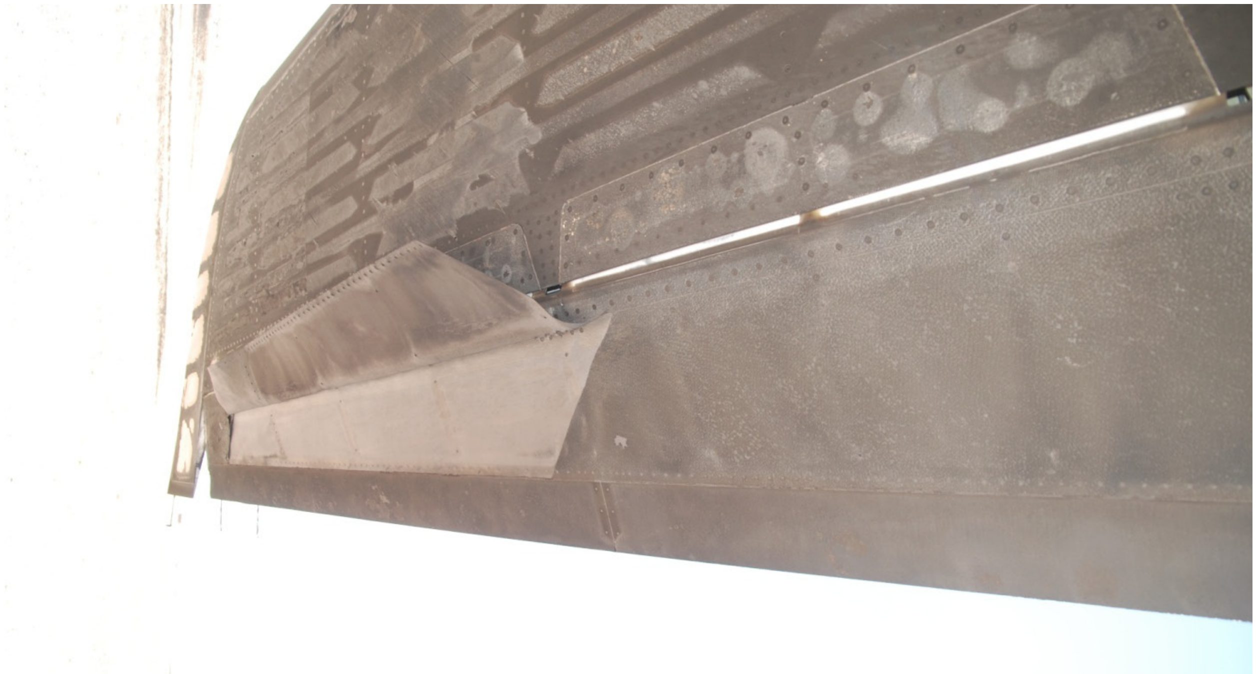


Figure 51 Right Elevator Lower Surface

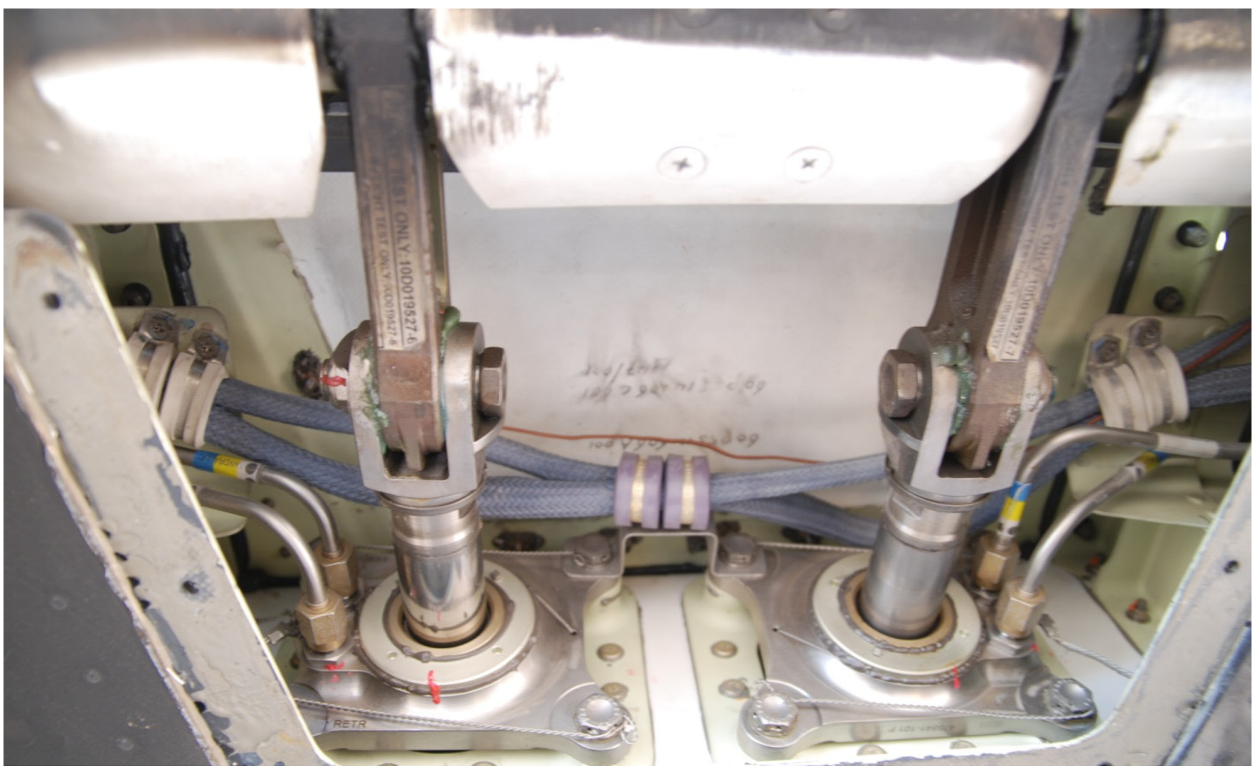


Figure 52 Right Elevator Actuators

10. Vertical Stabilizer

The vertical stabilizer had heavy sooting and heat damage to the skin on both sides (Figures 45, 53). There was an impact mark on the left side which extended to the top.

Figure 53 Vertical Stabilizer Right Side

11. Rudder

The rudder had heavy sooting and significant heat damage to the skin. The access panels were removed and the actuator attach fittings were intact (Figure 54).

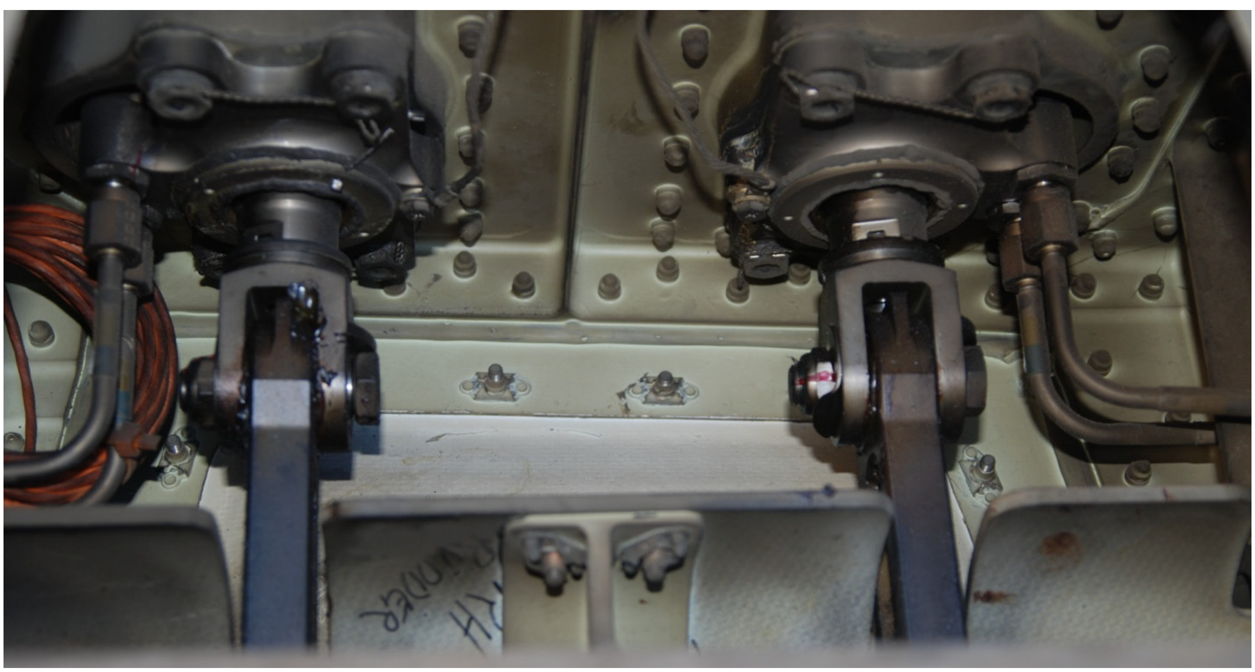


Figure 54 Rudder Actuators

12. Fuselage

The fuselage was severely damaged by the post crash fire (Figure 55). The crown of the airplane was mostly consumed from the flight deck to the aft pressure bulkhead. Figures 56 – 58 show the forward, mid, and aft fuselage segments respectively from the right side. The fuselage was fractured at approximately fuselage station 580 (Figure 57). Figures 59-60 show the right wing to fuselage linkages. Figure 61 shows the overview of the fuselage from the left side. Figures 62 – 64 show the forward, mid, and aft fuselage segments respectively from the left side. Figure 65 shows the main entry door. Figures 66-67 show the left wing to fuselage linkages. Figure 68 shows the fuselage station diagram for the airplane.

Figure 55 Right Forward Fuselage

Figure 56 Right Forward Mid Fuselage

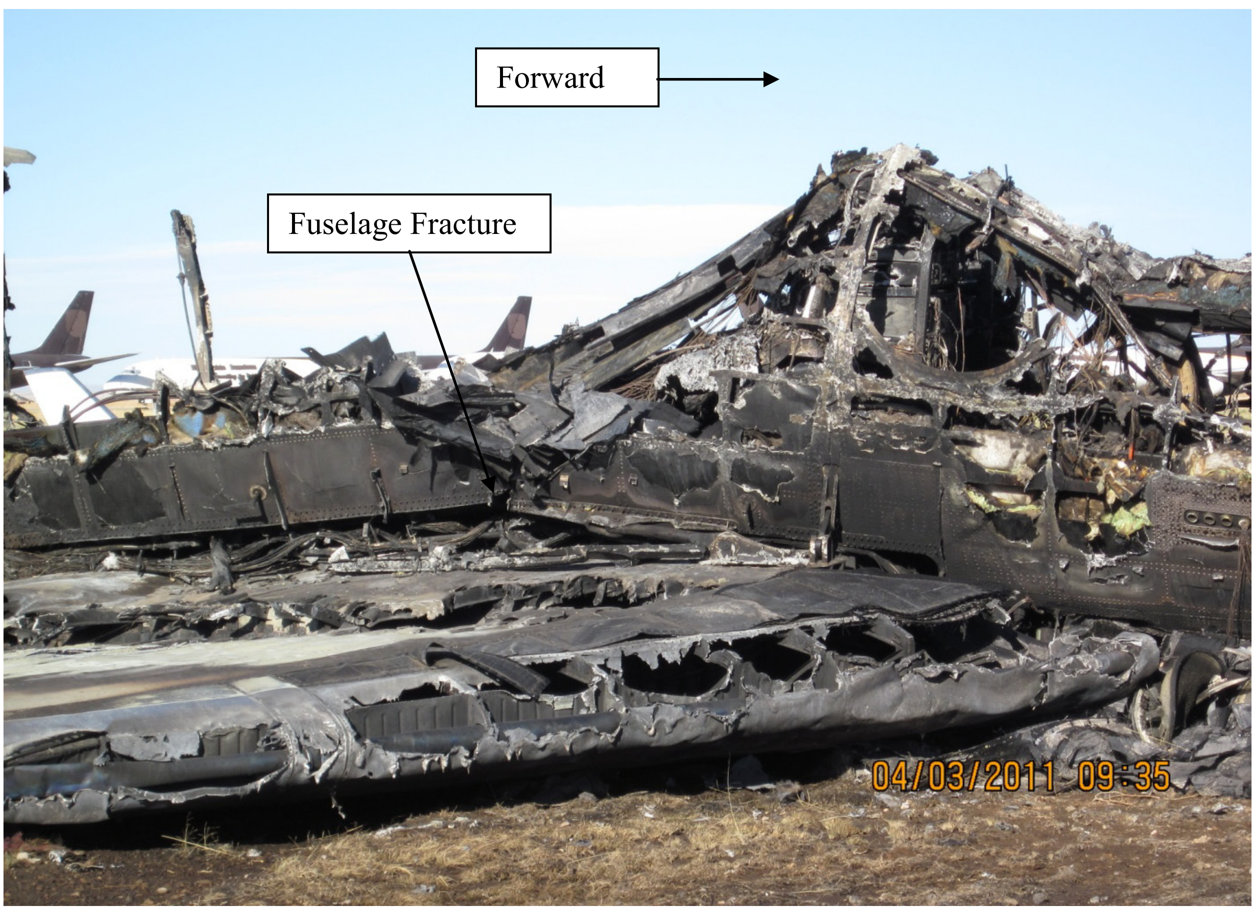


Figure 57 Right Center Mid Fuselage

Figure 58 Right Aft Mid Fuselage

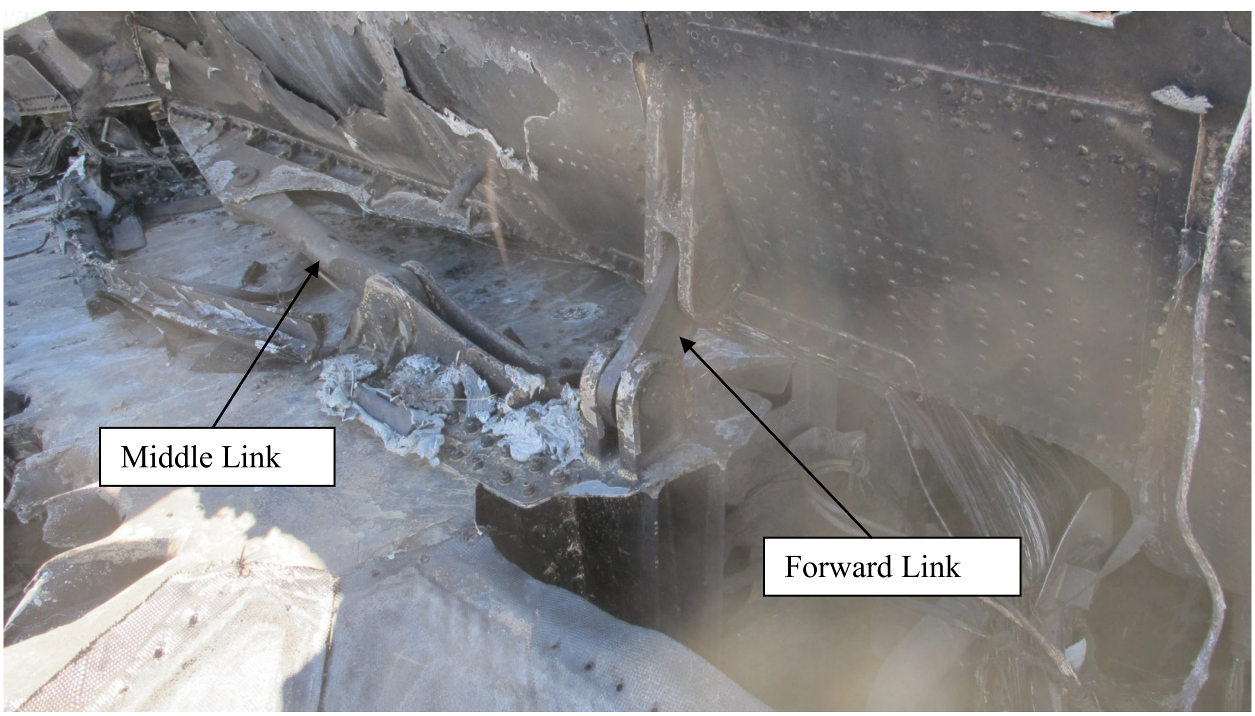


Figure 59 Right Wing to Fuselage Links

Figure 60 Right Aft Wing to Fuselage Link

Figure 61 Left Side Fuselage Overview

Figure 62 Left Fuselage Forward and Forward Mid Sections

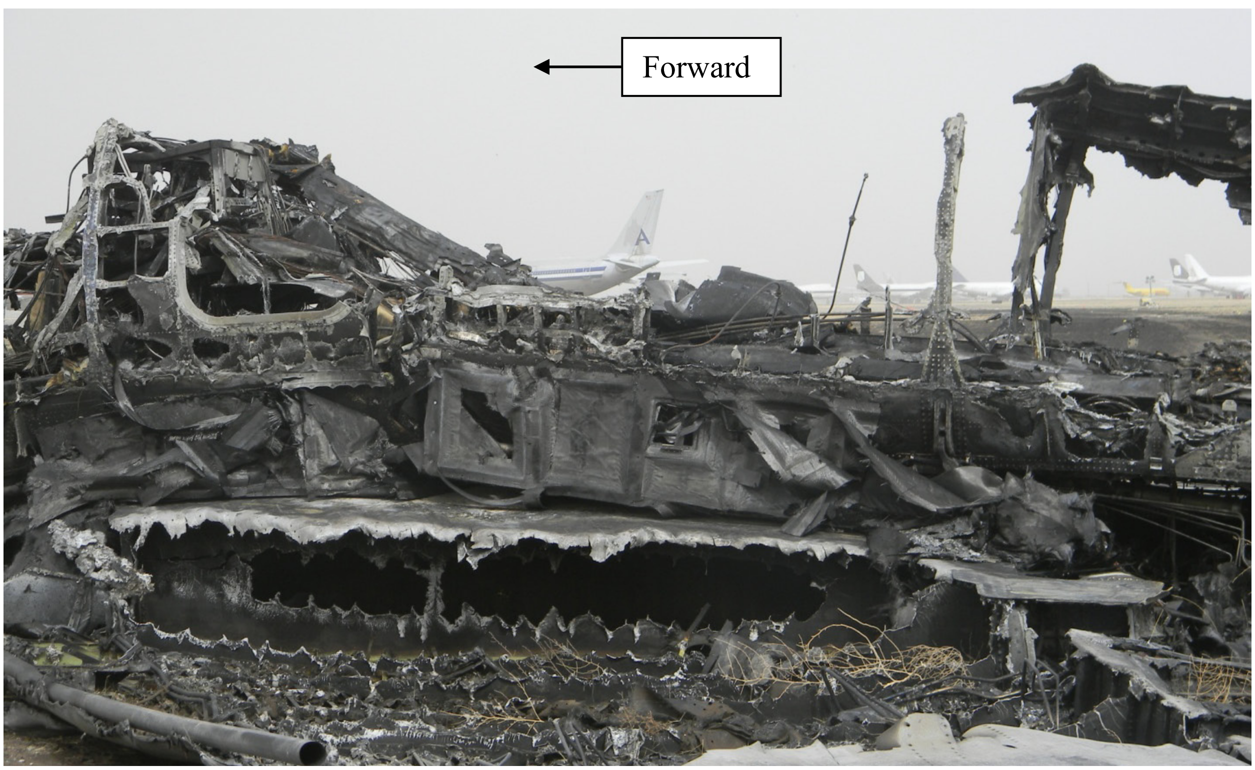


Figure 63 Left Fuselage Center Mid Section

Figure 64 Left Fuselage Aft Mid Section

Figure 65 Entry Door

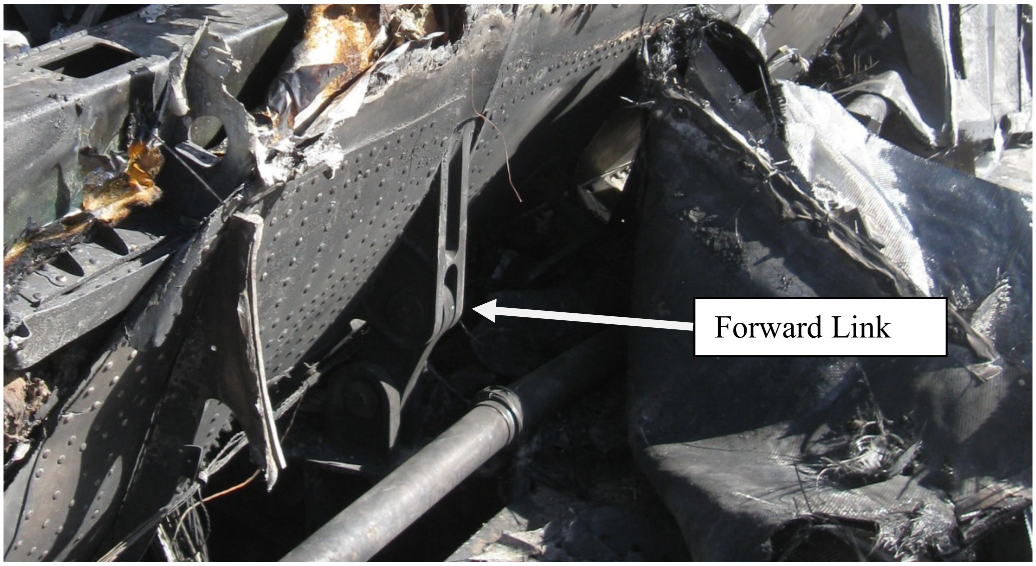


Figure 66 Left Forward Wing to Fuselage Link


Figure 67 Left Aft Wing to Fuselage Link

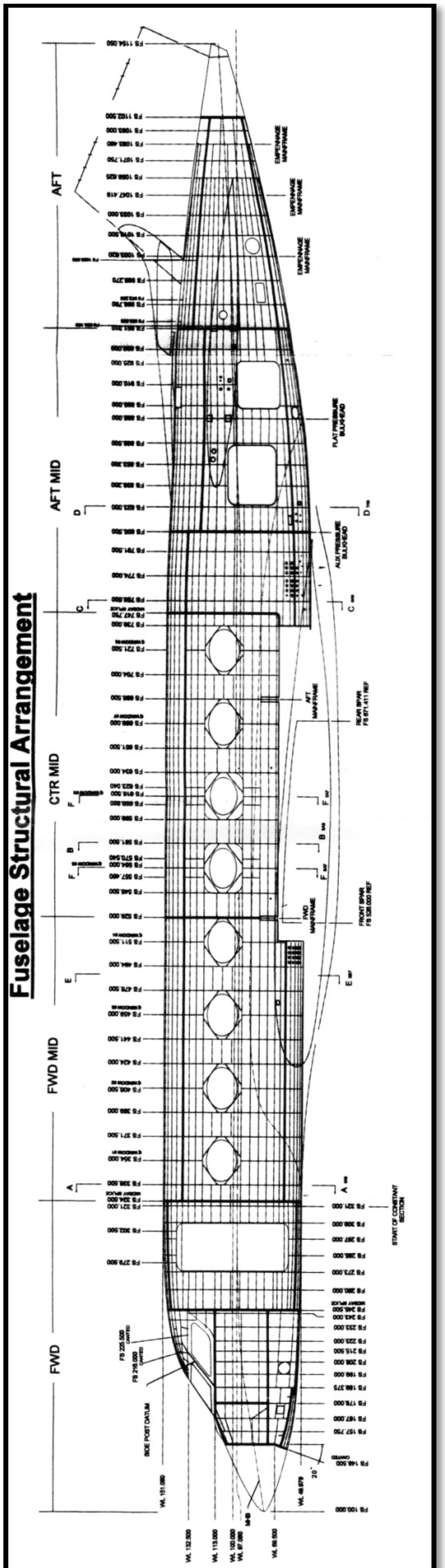


Figure 68 Fuselage Station Diagram

13. Weight Ballasts

Gulfstream used steel plates for ballast to load the airplane with the required weight distribution for each flight. According to Gulfstream documentation the ballast arrangement for the accident flight was as shown in Figure 69. The location of the ballast weights were confirmed when the wreckage was examined in Dallas, Texas. The ballasts were found to be in the positions shown in Figure 70 (indicated by red circles), which corresponded to the positions indicated in the Figure 69. Each stack had 12 approximately equal rectangular plates (20.25 x 13.25 inches) and a larger base plate (Figure 71). Two of the plates were removed, weighed and found to be 36.6 lbs each. One of the base plates was removed, weighed with the retaining bolts and fittings, and found to be 97.2 lbs. The estimated total weight at each location was 536.4 lbs. There were no other ballast weights located in the wreckage.

	Fwd Light, 2FTE		
	Wgt	Plates	F/S
Ballast RHS #1	541	Base + 12	297.0
Ballast RHS # 2	541	Base + 12	397.5
Ballast RHS # 3	541	Base + 12	501.5
Ballast RHS # 4	*0*		604.0
Ballast RHS # 5	*0*		628.0
Ballast RHS # 6	Emer rack		652.5
Ballast RHS # 7	0		676.0
Ballast RHS # 8			700.0
Ballast RHS # 9 *(Not Installed)*			
Ballast RHS #10	0		765.0
Ballast LHS # 1	541	Base + 12	348.0
Ballast LHS # 2	541	Base + 12	448.0
Ballast LHS # 3	0		476.0
Ballast LHS # 4	541	Base + 12	501.0
Ballast LHS # 5	0		604.0
Ballast LHS # 6	*0*		628.0
Ballast LHS # 7	0		652.0
Ballast LHS # 8	*0*		772.5
Baggage ballast #1	*0*		831.0
Baggage ballast #2	*0*		846.0
Baggage ballast #3	*0*		860.0
Baggage ballast #4	*0*		876.0

Figure 69 Ballast Configuration

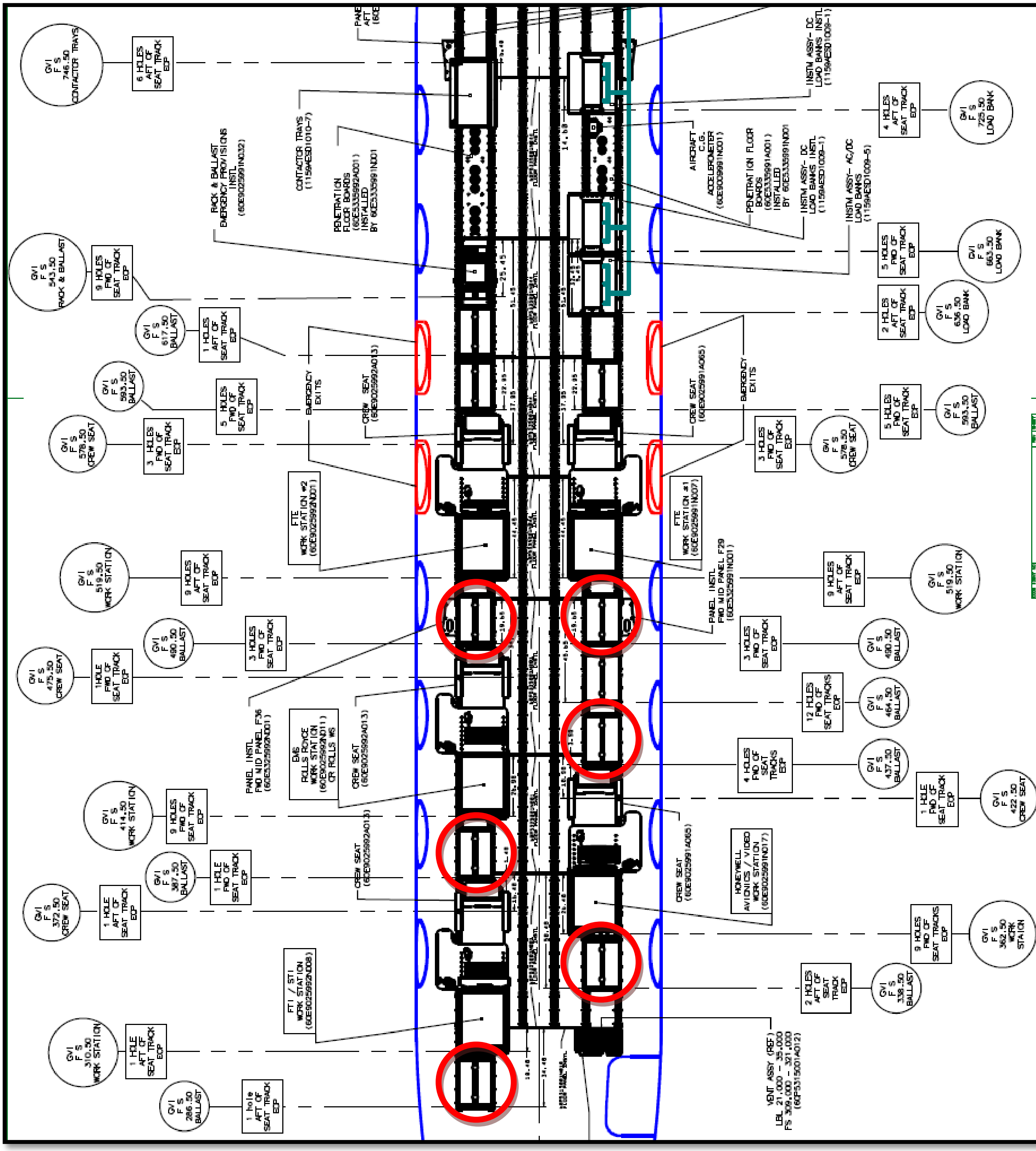


Figure 70 Ballast Locations

Figure 71 Example of Ballast Weight Installation (at Dallas, Texas)

14. Flight Control System Review

The accident airplane was equipped with high data rate flight data recorders, which recorded all control inputs (wheel, column, pedal) and surface positions as measured by the sensors in the actuators. The recovery and documentation of the data was provided in the Data Group Factual Report. This data was used by Gulfstream to examine the performance of the primary flight controls during the accident sequence. They used a desktop computer to emulate the FCC response given the accident flight conditions and control inputs from telemetry data. These results were then plotted along with the actual flight control positions recorded for the accident airplane. The results are plotted In Figures 72 – 77 (time 0 corresponds to 9:33:41.384 AM Local Time in the recorded accident data). For all plots the blue lines are accident airplane surface position data and the red is surface command output of the simulation. Gulfstream used telemetry data for this evaluation. During certain conditions, telemetry data can "drop-out". A drop-out is indicated by a momentary, large change in the recorded value, typically to an out of range value. This drop out can be observed in many of the plots around the 16 second point in the data. For all flight controls there was a close match between the simulation results and the recorded data for the accident flight.

With regard to the fidelity of this simulation tool, Gulfstream provided the following: The desktop tool included the control laws from Gulfstream's Configuration Management Database that corresponds to the control law version loaded on the accident airplane at the time of the accident (with changes applied to correspond to the MAID[4] settings that were in effect). This control law source is the basis for the FCC implementation, and is verified by use of test vectors to compare the module-level responses to the vendor's implementation. It is also the basis for integrated testing in the Integrated Test Facility and Iron Bird, where the responses from the FCC are compared to the commands computed by the off-line model as part of the evaluation of the FCC software prior to clearing it for installation on a test aircraft.

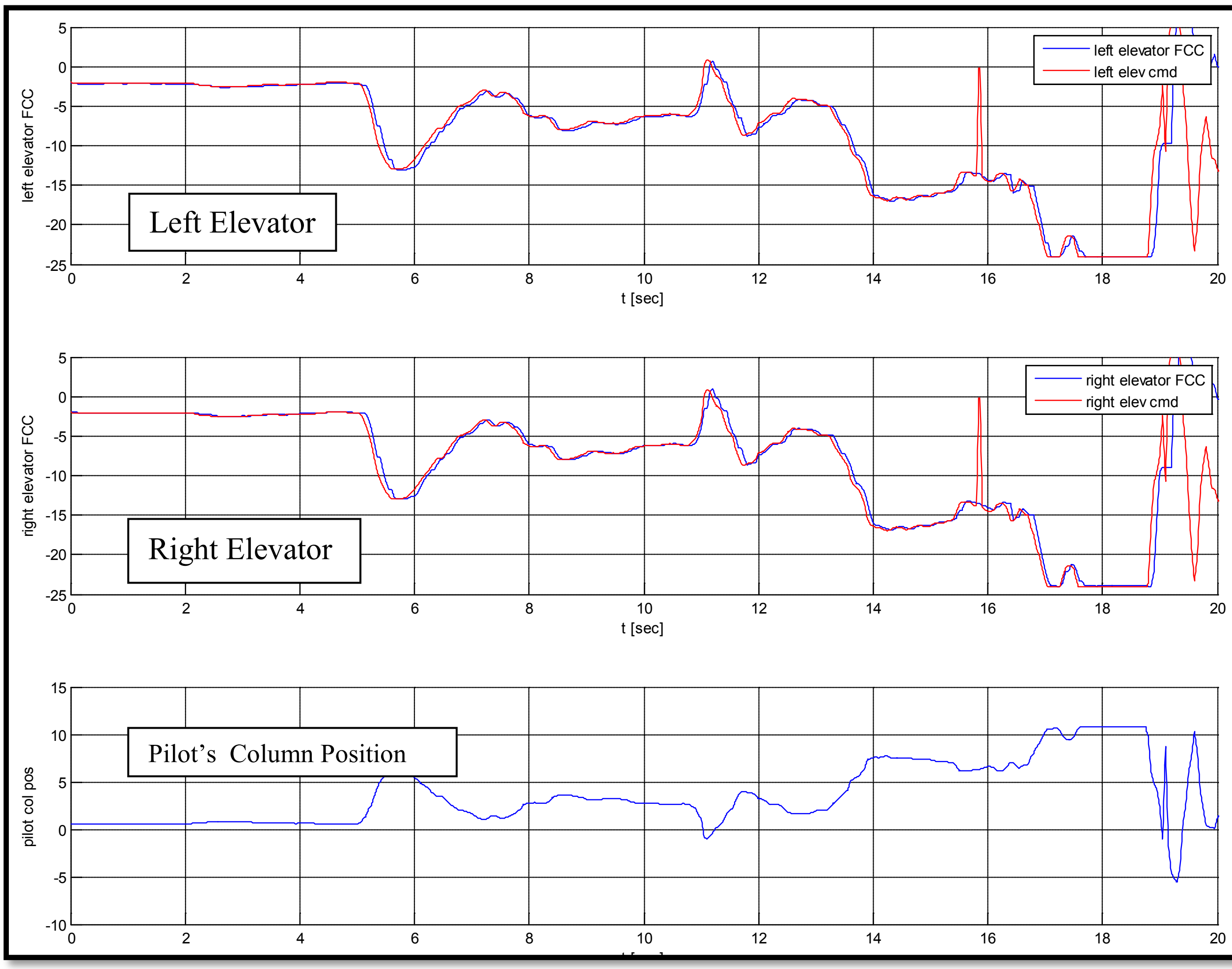


Figure 72 Comparison of Pitch Controls

[4] MAID (Modification Access of Internal Data) is a computer system which allows flight test engineers to modify FCC control laws during flight tests.

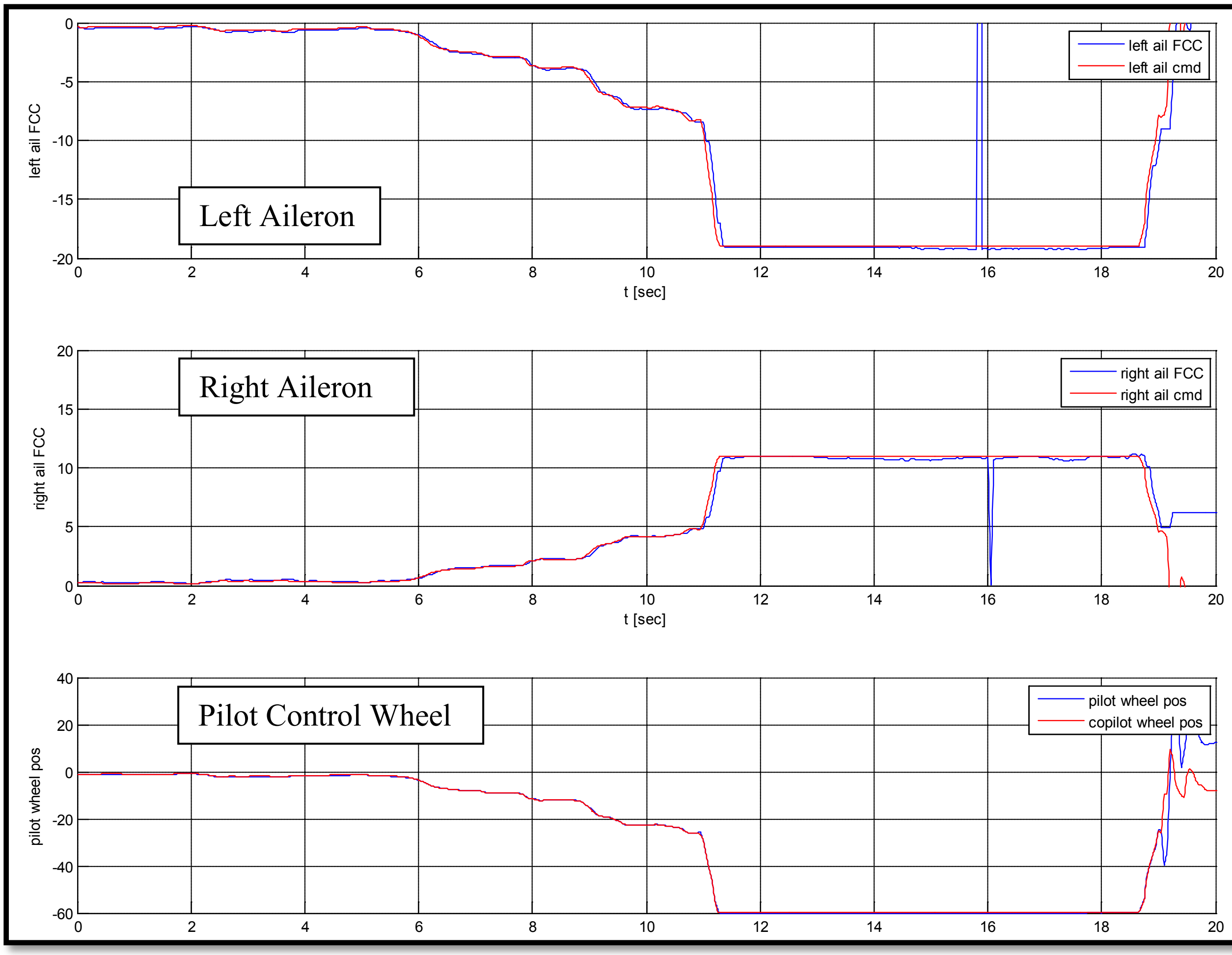


Figure 73 Comparison of Aileron Roll Controls

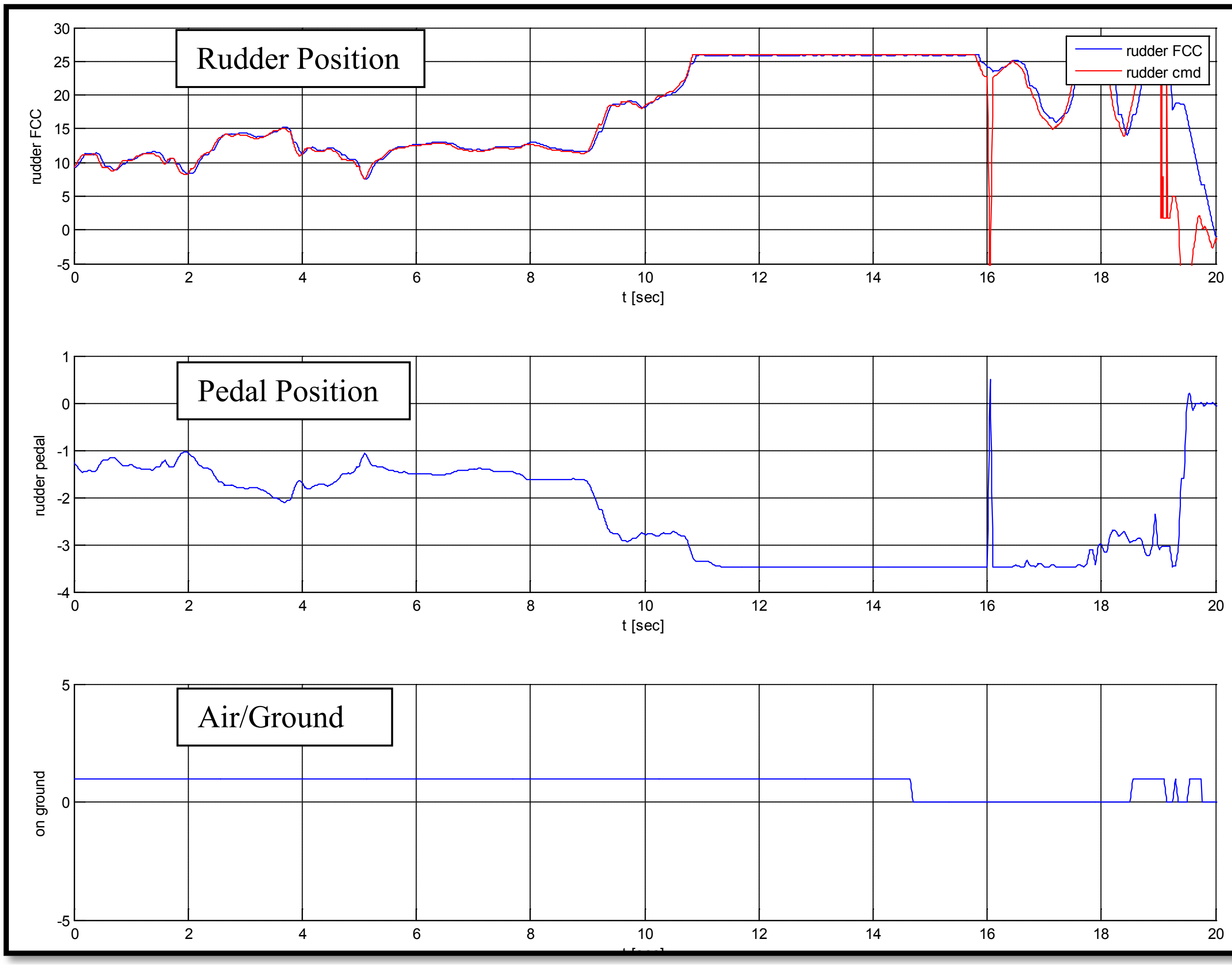


Figure 74 Comparison of Directional Flight Controls

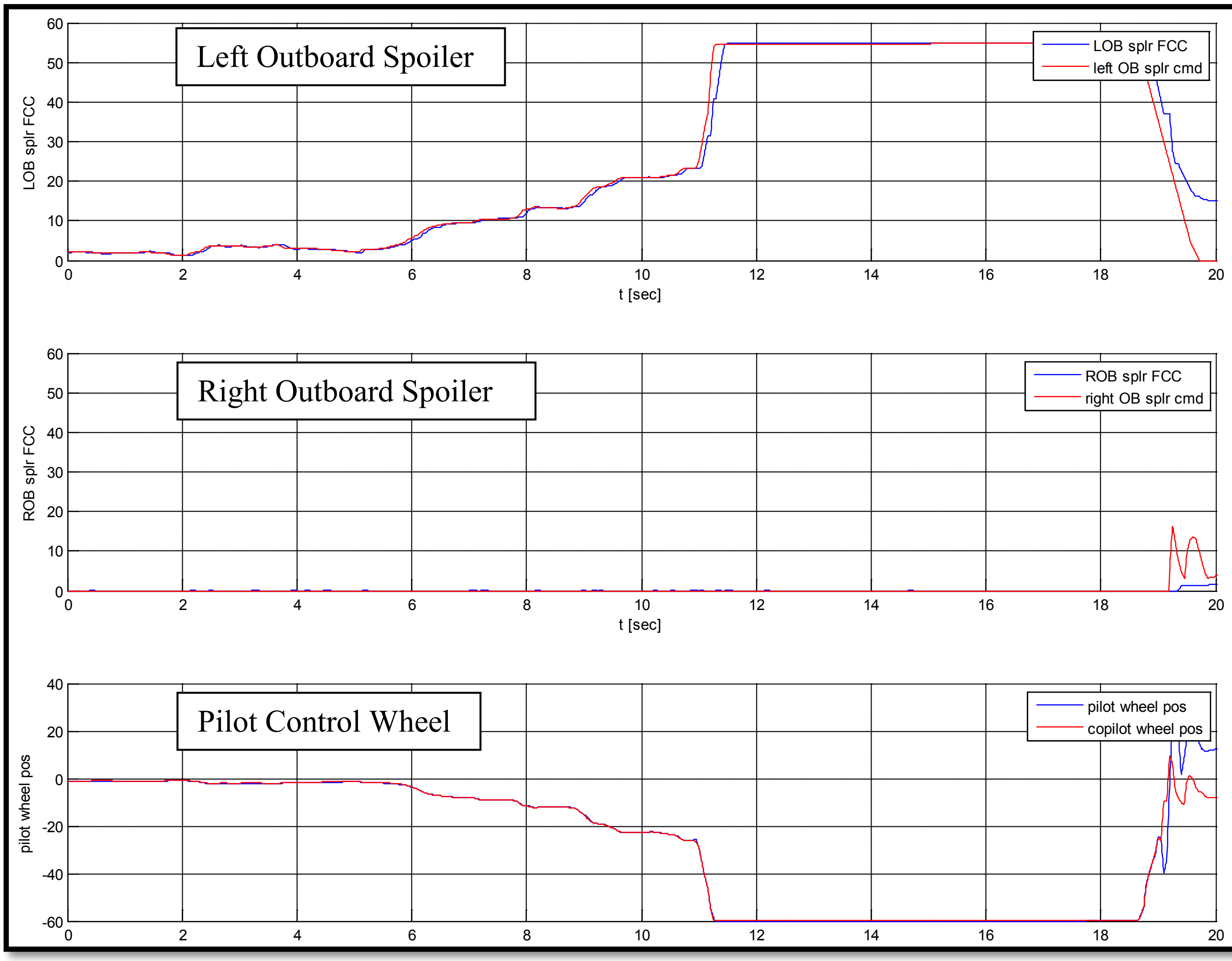


Figure 75 Comparison of Outboard Spoiler Roll Controls

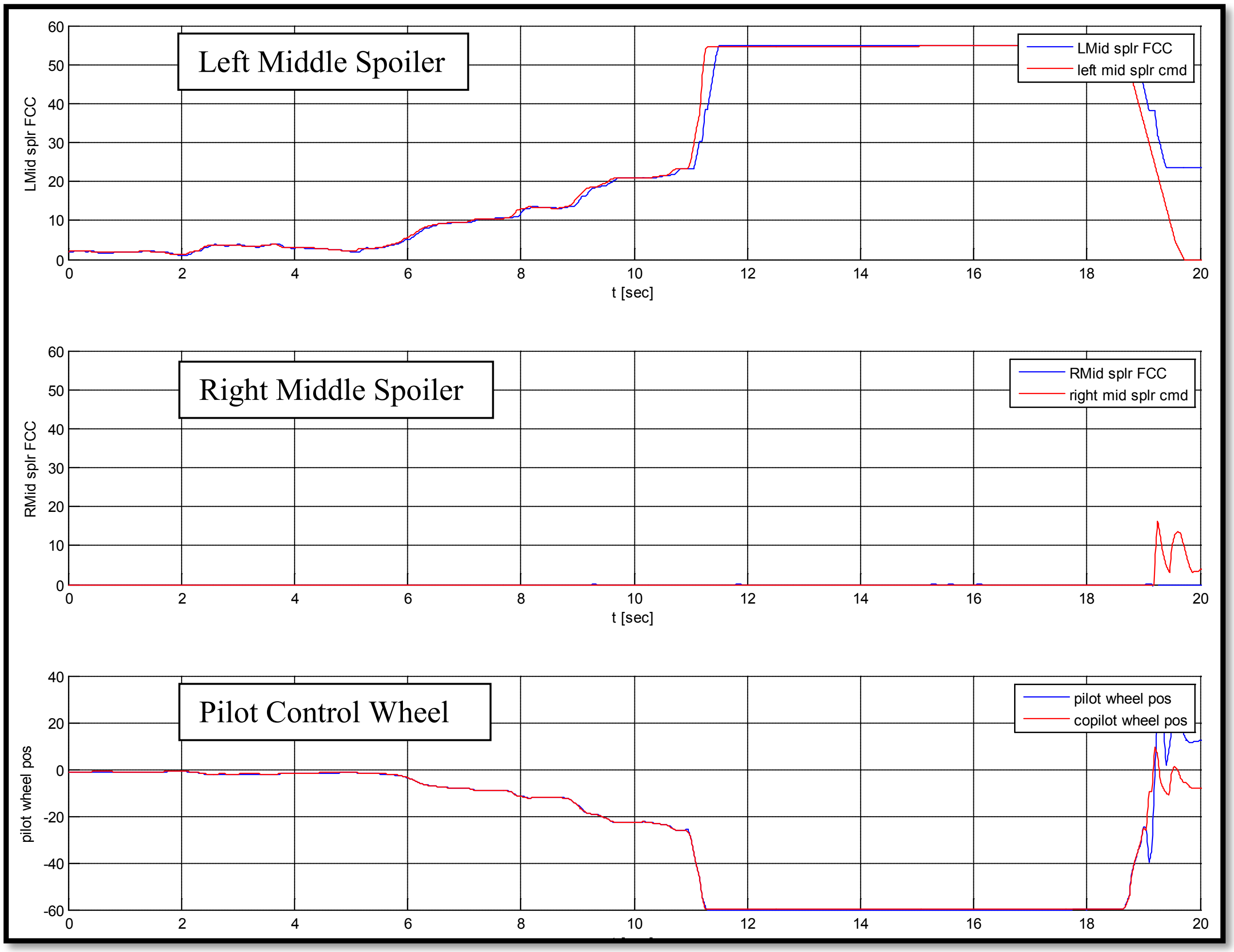


Figure 76 Comparison of Middle Spoiler Roll Controls

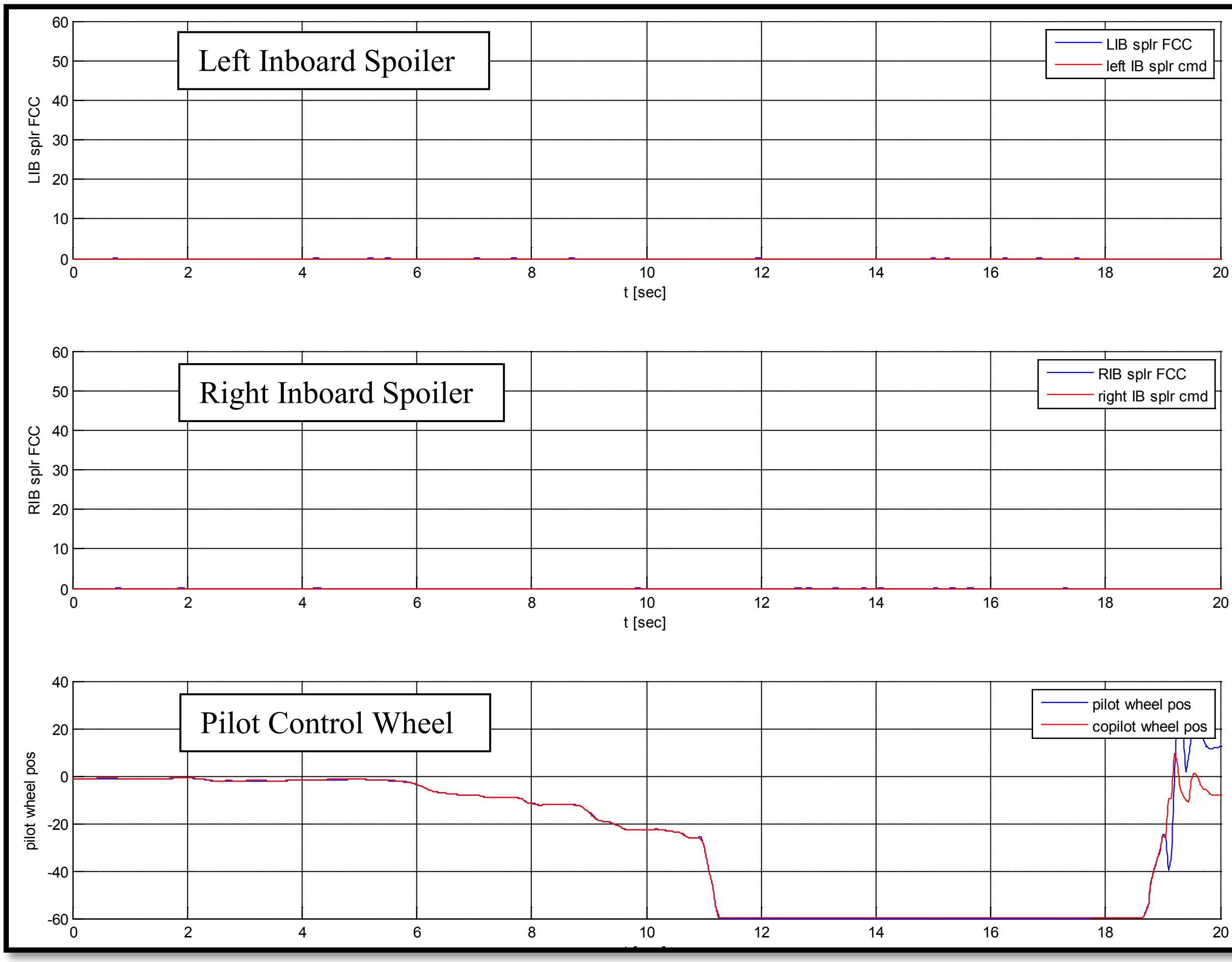


Figure 77 Comparison of Inboard Spoiler Roll Control

15. Stall Barrier/Warning System Description

The FCCs contain control laws that provide Angle of Attack (AOA) limiting. During Normal Mode operation, the embedded control laws limit the allowable AOA from exceeding the maximum AOA. Gulfstream advised that during initial development and company takeoff testing, flights were performed in First Flight Mode[5]. In this mode AOA limiting was disabled. However, even in the Normal Mode, all AOA limiting was disabled until 10ft AGL. The G650 also displays the normalized AOA, uses stick shakers (control column vibrators), and displays pitch limit indicators (PLIs) to warn pilots of an approaching stall (Figure 78). The FCCs compute normalized AOA (NAOA) for display, for positioning the PLI relative to the airplane symbol (the difference in degrees between the airplane symbol and the PLI is referred to as Delta PLI), and for activating the stick shaker. The initial value for stick shaker activation and delta PLI calculation was set to 0.85 NAOA, which is the shaker setting for GIV-X and GV-SP airplanes[6]. After initial takeoff testing of this model, Gulfstream evaluated the setting and

[5] First Flight Mode is a simplified operation mode of the FCS with no augmentation of the pitch or roll axes. It was used for the first flight of the G650, and periodically afterward as needed for specific test activities.
[6] 1.0 NAOA is based on the stall reference angle, and the margin between the stall reference angle and the aerodynamic stall angle is different among the Gulfstream models mentioned here.

decided to set it at 0.90 NAOA. The change was implemented via MAID for takeoff testing on Flight 125 (March 7, 2011) and for subsequent takeoff testing. A final review and approval to continue with this setting occurred on March 24, 2011.

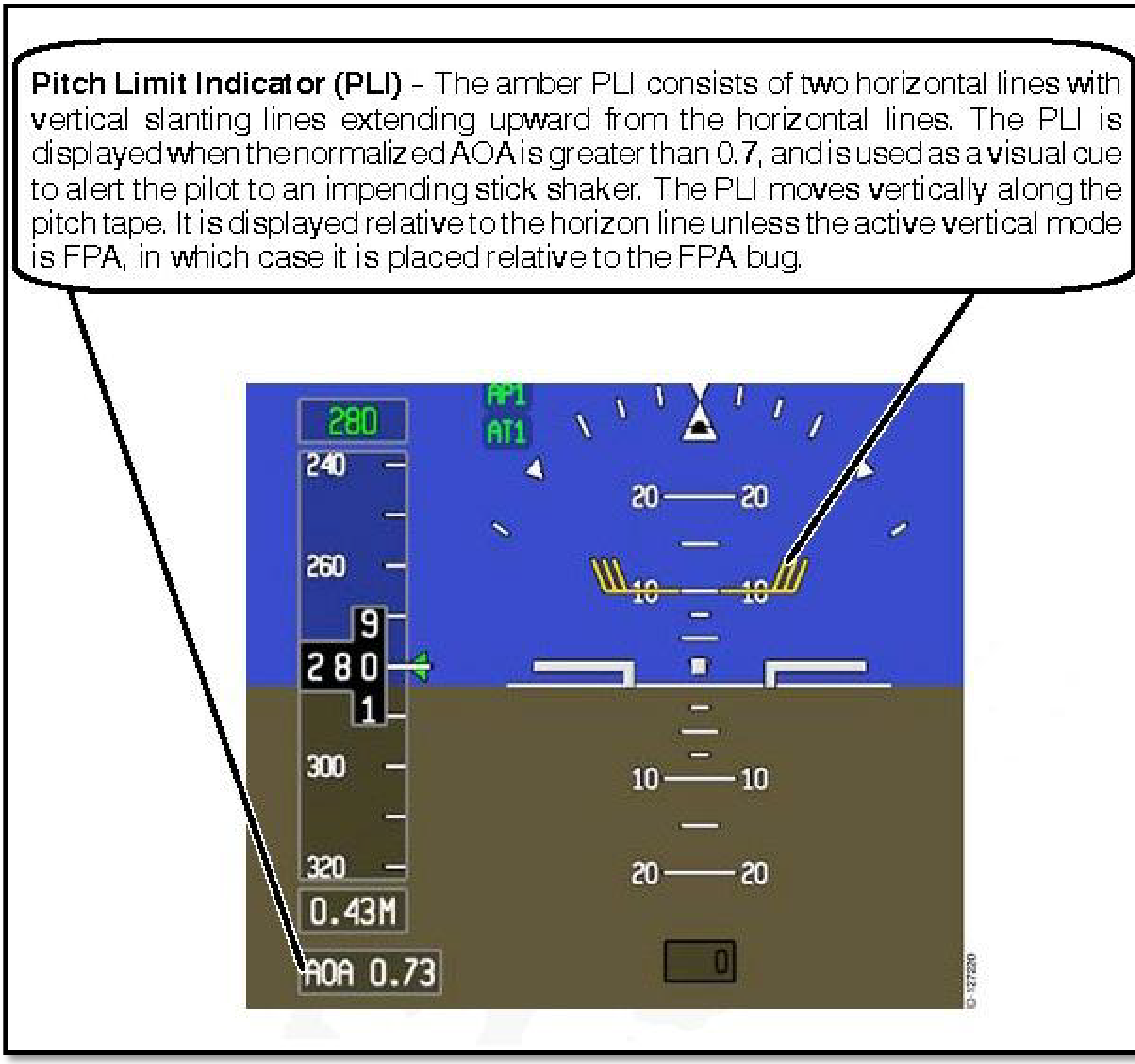


Figure 78 Pitch Limiter Indicator Description

16. Stall Warning System Review

The stall warning system was evaluated using the same desktop simulation tool described for flight control performance evaluation. Gulfstream plotted the simulated performance of the stick shaker activation and the delta PLI (Figure 79). Also included are the Normalized AOA values.

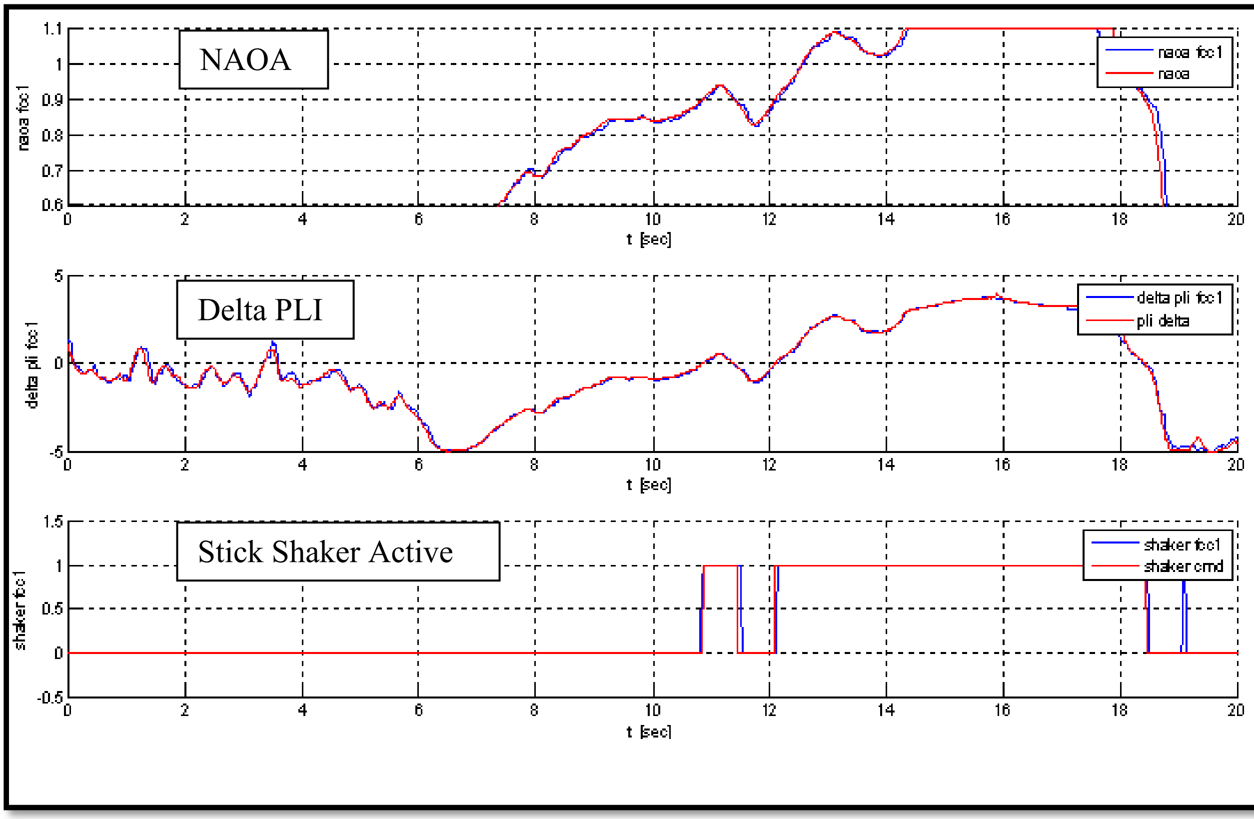


Figure 79 Stall Warning System Comparison

17. Main Landing Gear Description (Figure 80)

The main landing gear structural post and trunnion are attached with two (2) trunnion pins to the airframe at the wing trunnion mount. The trunnion pins have a fuse section to aid in landing gear breakaway in the event of an overload during landing. The structural post and trunnion provide mounting for the mooring ring, trailing arm pivot, main landing gear fairing door, main landing gear shock strut, wire harness and hydraulic lines. The main landing gear sidebrace actuator provides structural support when the gear is down, as well as hydraulic extension and retraction of the main landing gear. The main landing gear trailing arm provides pivot and attachment to the structural post, main landing gear axle, brake single pin torque takeout mount point and lower attachment for the main landing gear shock strut.

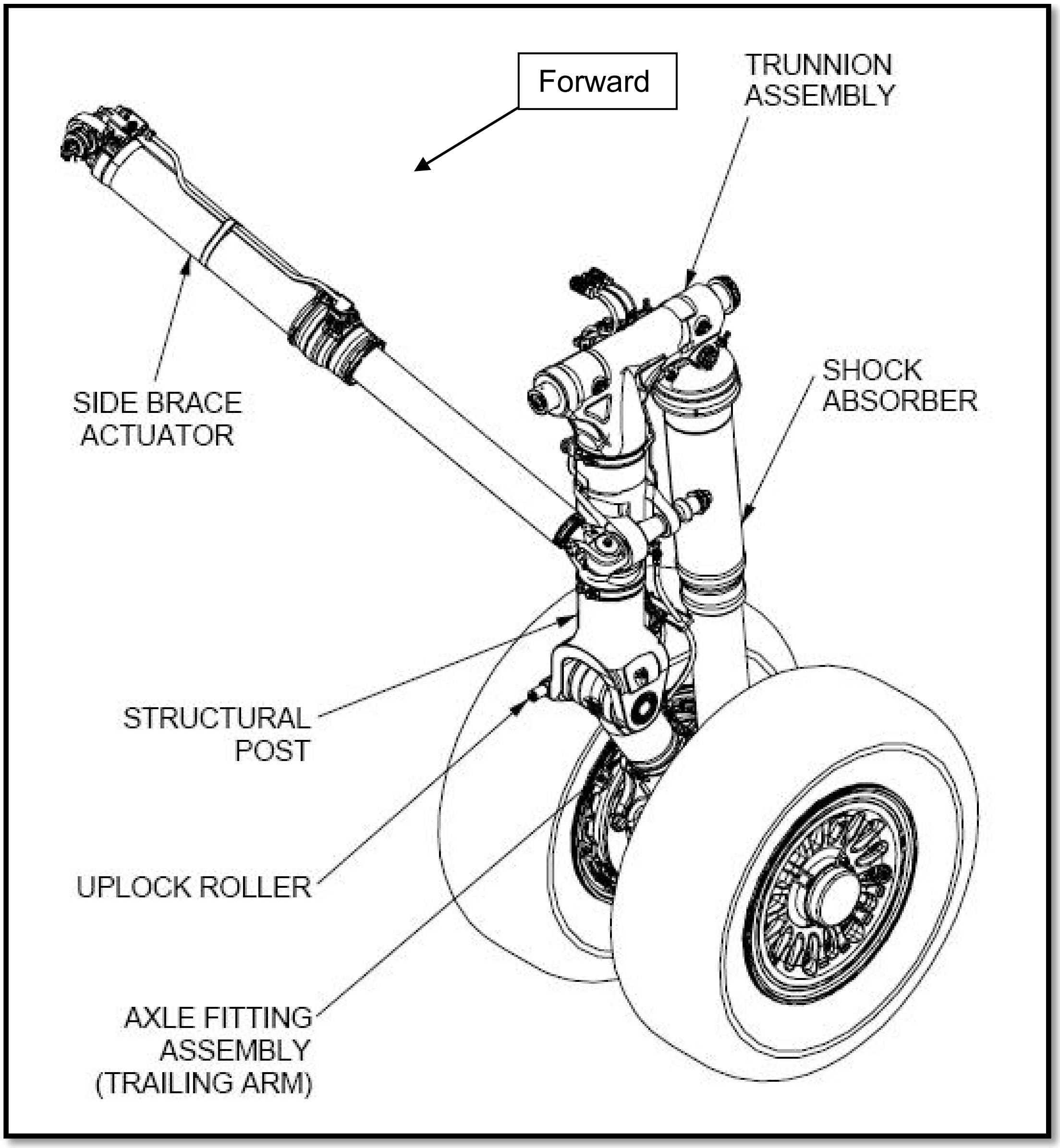


Figure 80 Main Landing Gear Description (left shown)

18. Right Main Gear Condition

The right main gear came to rest near the damaged runway information sign. It was still attached to the wheels and tires. The aft trunnion pin was fractured and the forward trunnion pin had damage on the upper edge (Figures 81, 82). The shock strut inner cylinder was still attached. The outer shock strut cylinder was separated and found approximately 10 yards from the gear. The inboard wheel was still inflated, but the outboard wheel had numerous punctures and was deflated. The side brace actuator was still attached to the side brace fitting on the rear spar (Figure 83). The Trunnion mount was intact (Figure 84).

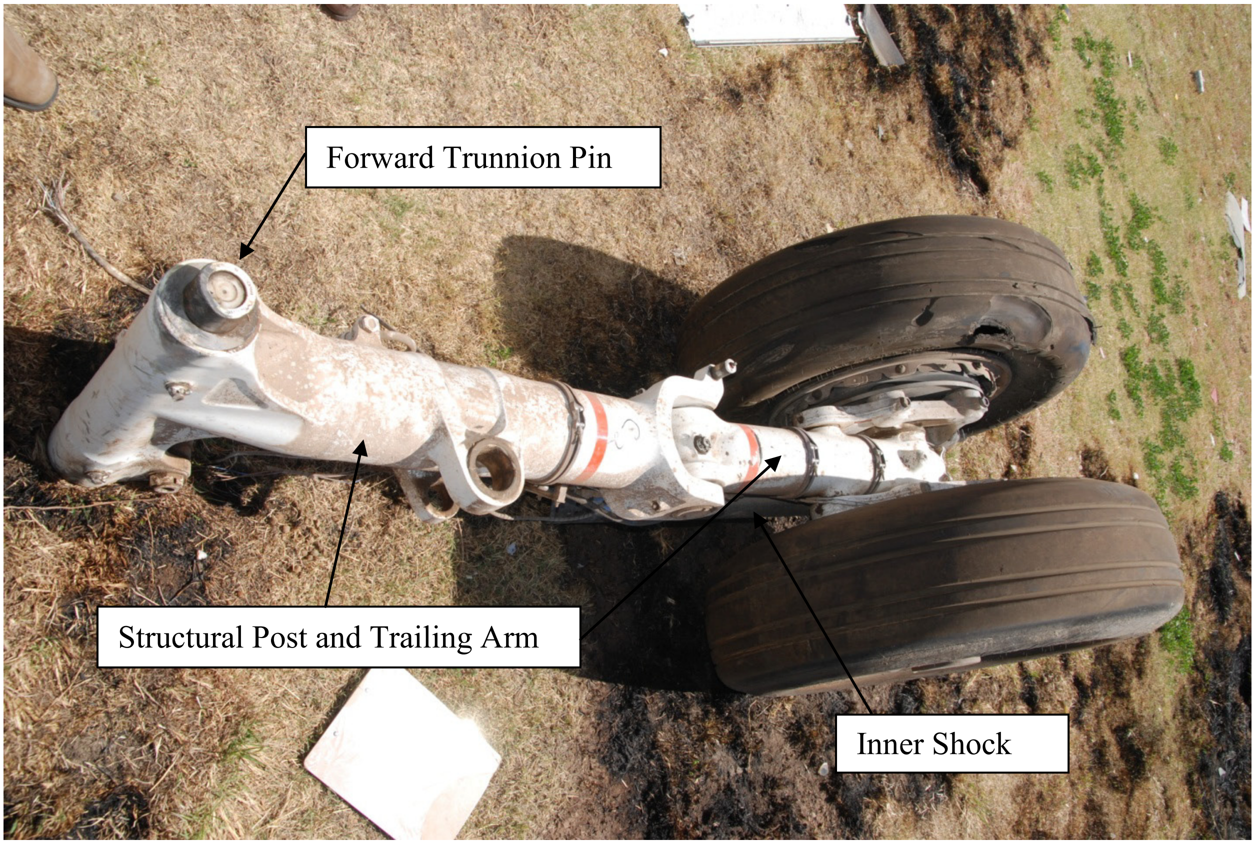


Figure 81 Right Main Gear

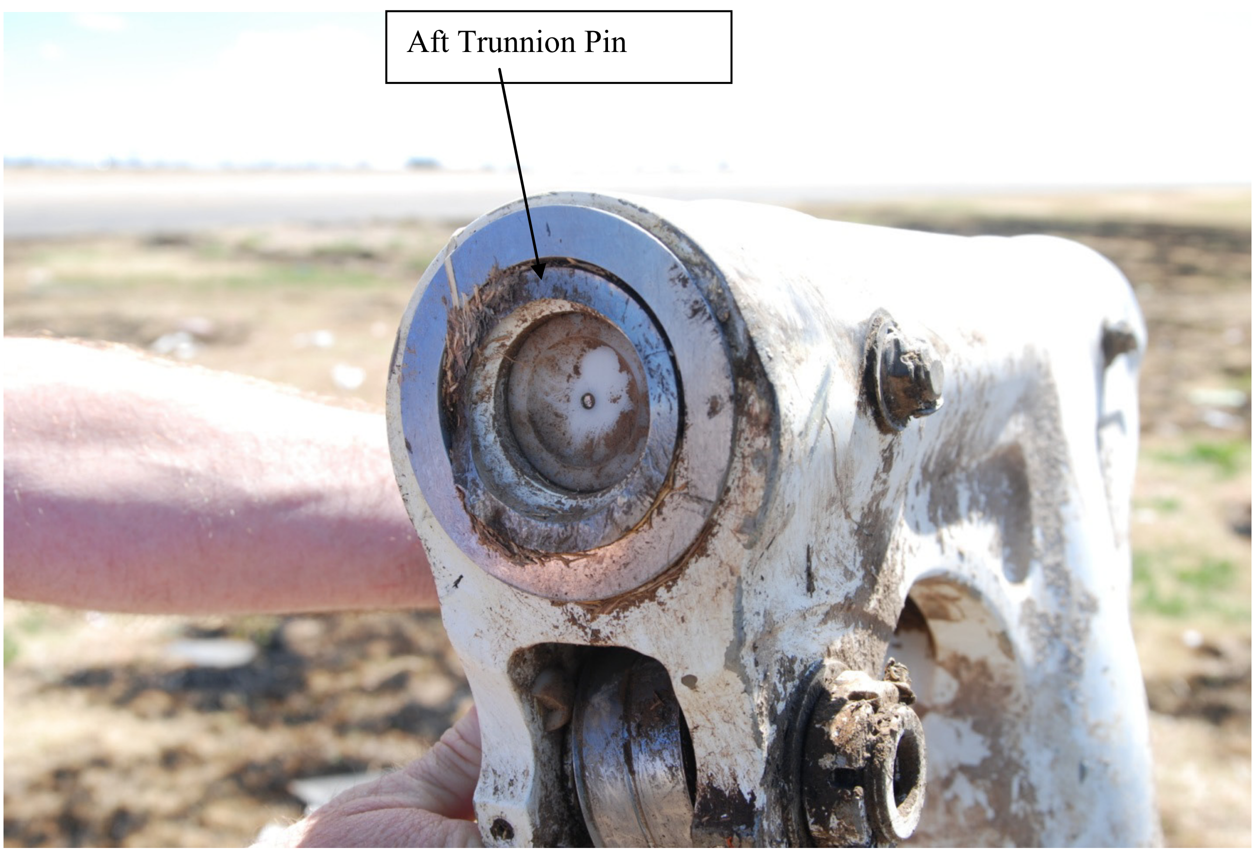


Figure 82 Right Main Gear Trunnion Pin

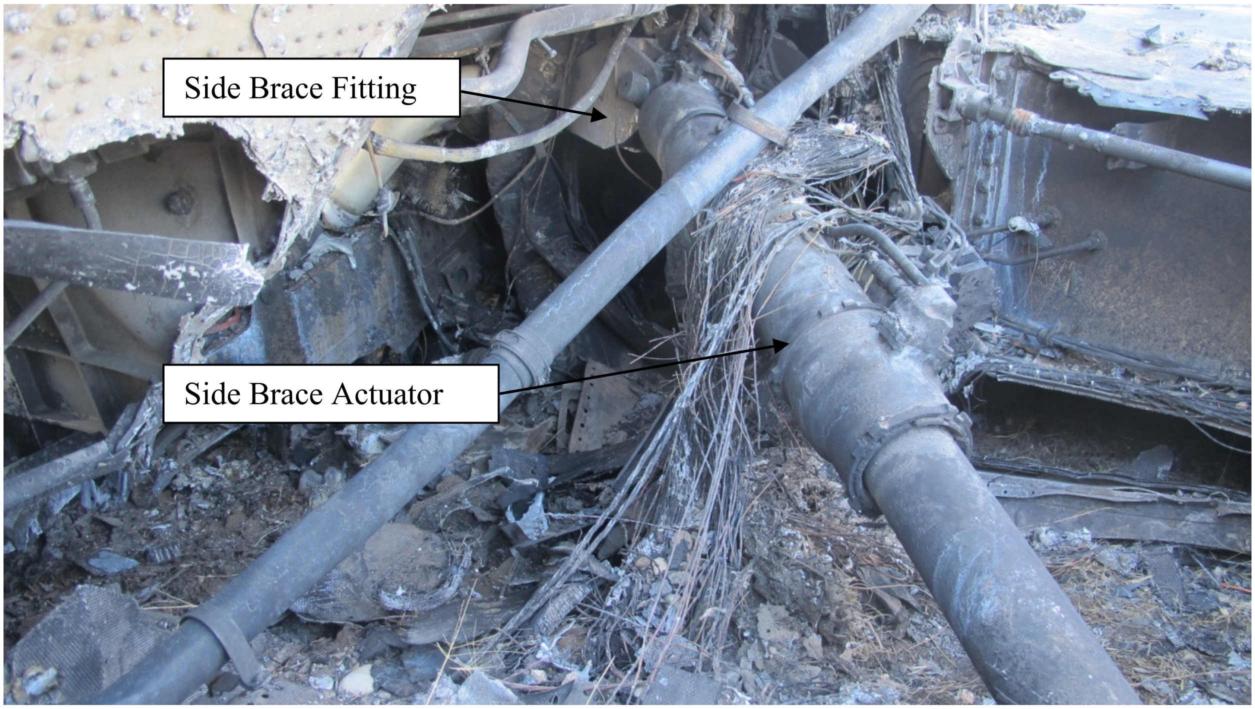


Figure 83 Right Main Gear Side Brace Actuator

Figure 84 Right Main Gear Trunnion Mount

19. Left Main Gear Condition

The left main gear came to rest approximately 100 yards past the concrete culvert to the left of the airplane path. The left main gear fractured approximately at the wheel height (Figure 85). The aft trunnion pin fractured (Figure 86). The side brace was still attached. The side brace fuse pin was fractured on one side (Figure 87). The outboard wheel was inflated and the inboard wheel was deflated. The inboard wheel had a large hole in the tire which was in line with a dent in the inner wheel hub. The shock strut was separated from the gear and fractured at the upper and lower attach fittings. The side brace aft attachment fitting was bent (Figure 88). The trunnion mount was intact (Figure 89).

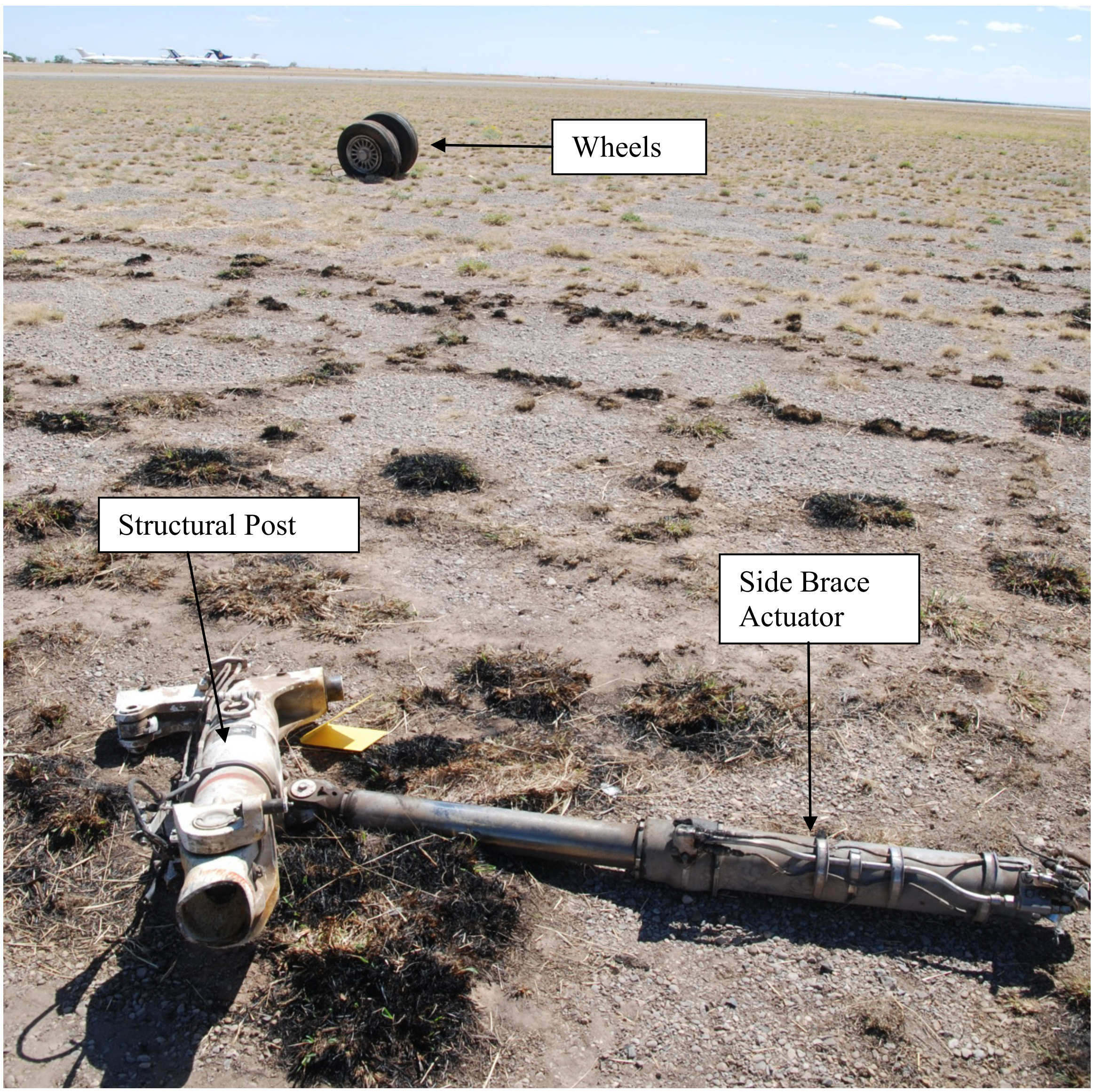


Figure 85 Left Main Landing Gear

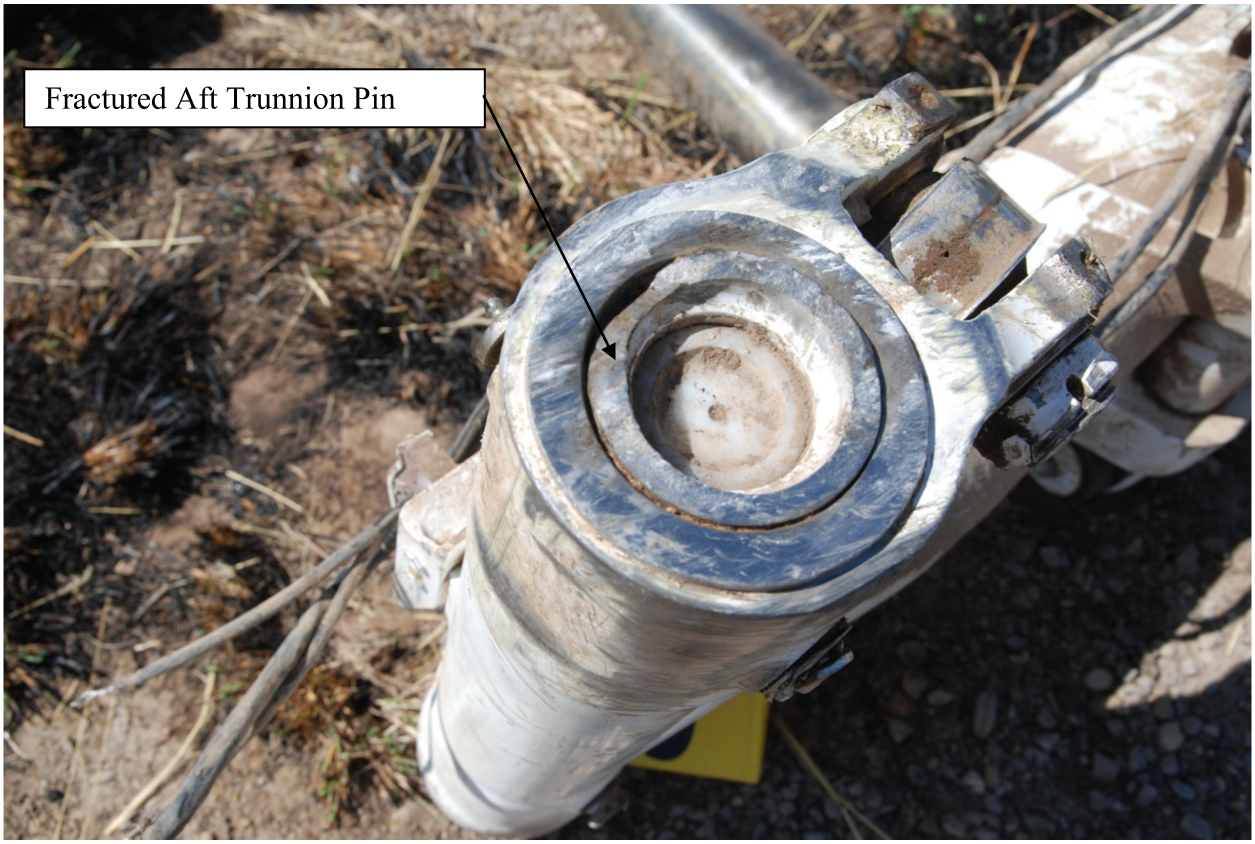


Figure 86 Left Main Gear Trunnion Pin

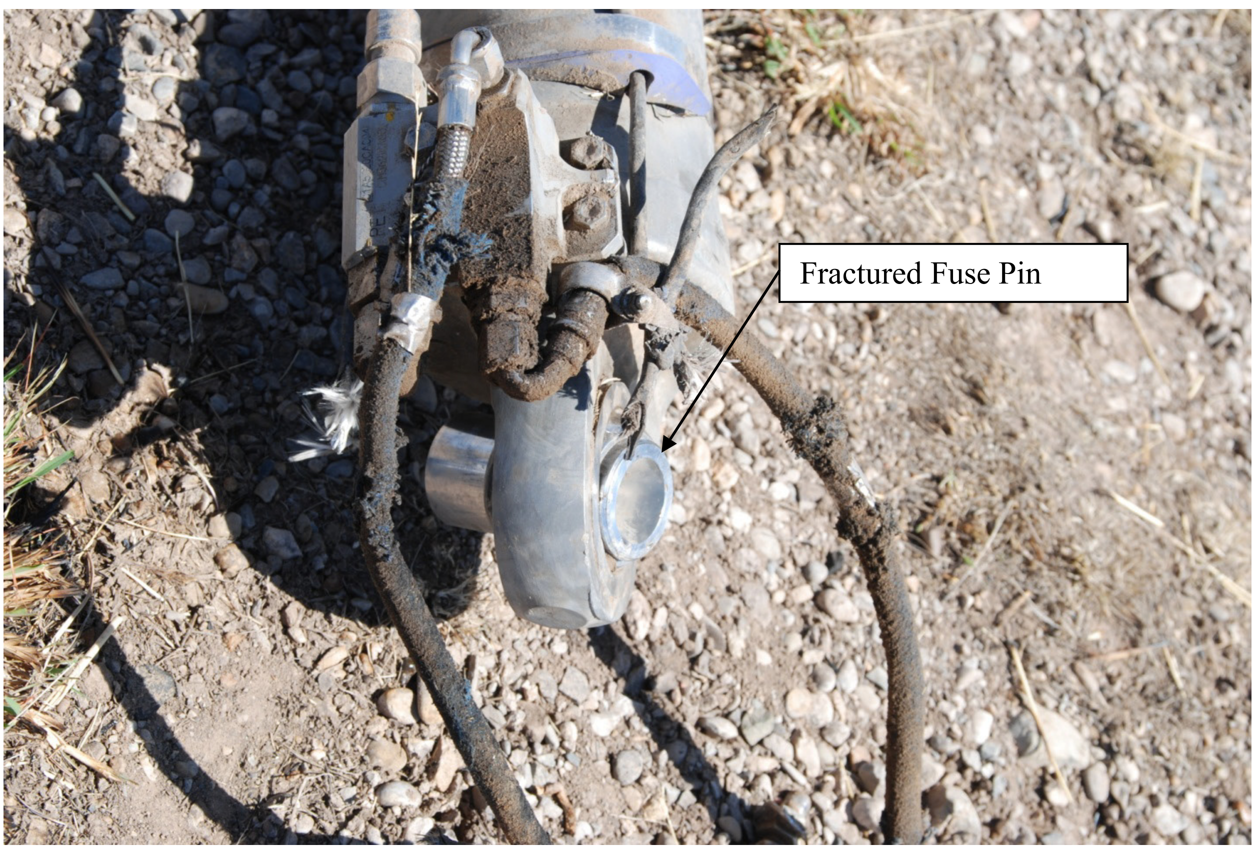


Figure 87 Left Main Gear Side Brace Actuator

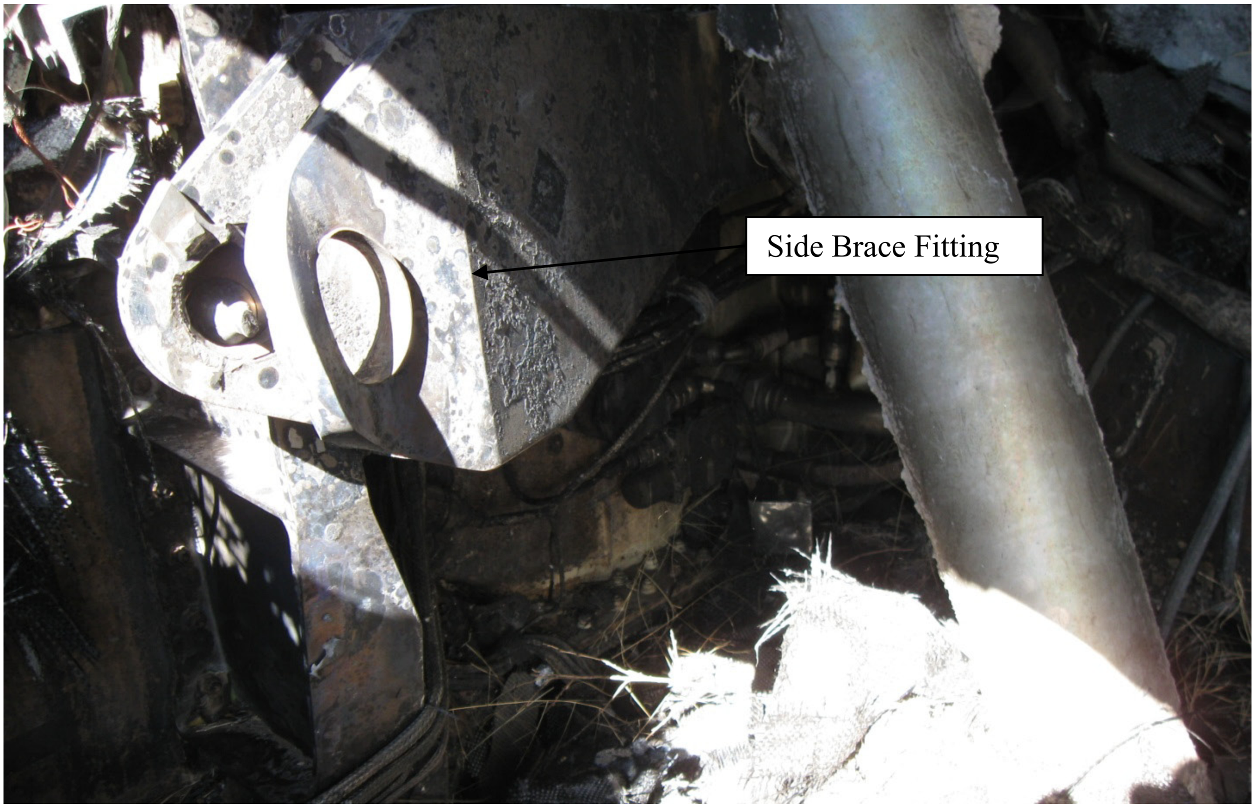


Figure 88 Left Main Gear Side Brace Fitting

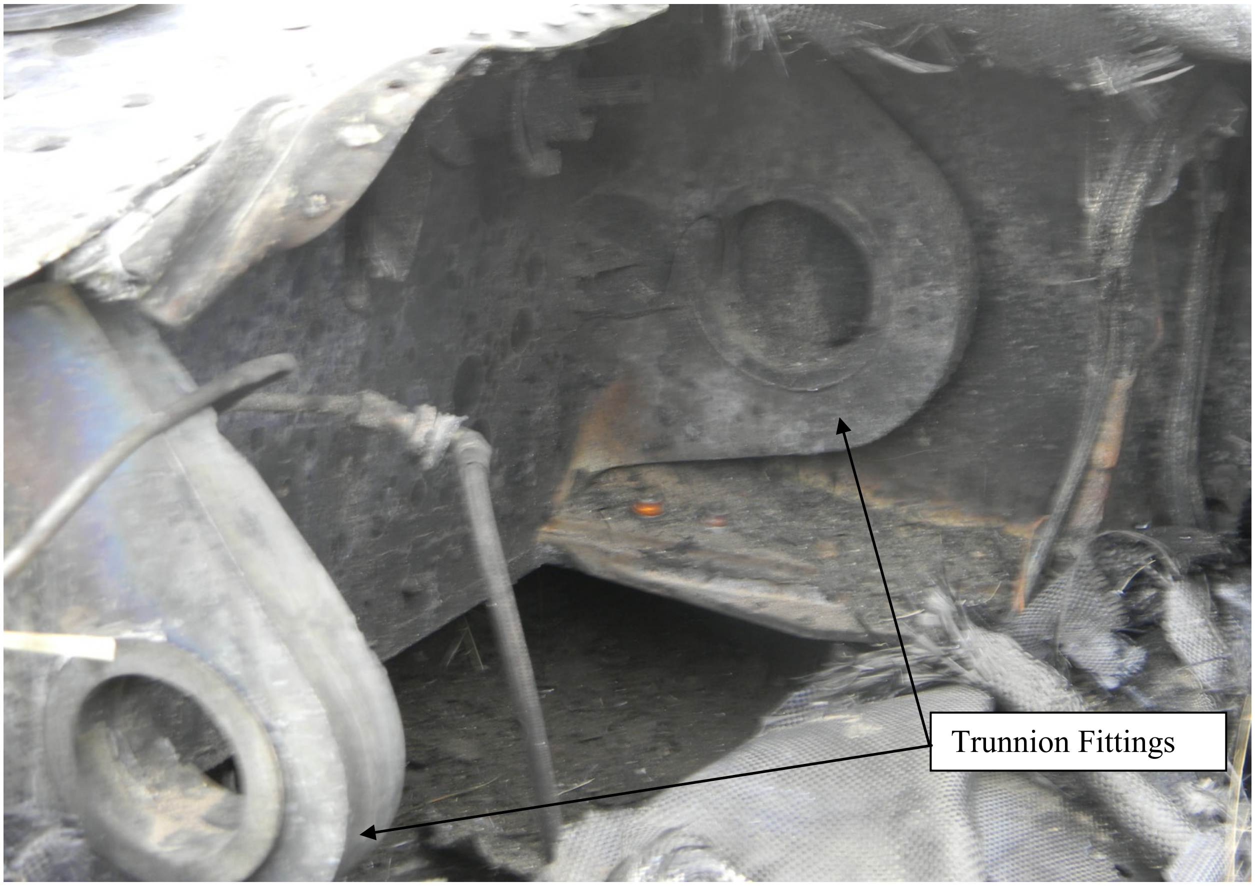


Figure 89 Left Main Gear Trunnion Mount

20. Nose Gear Condition

The nose gear wheel assembly came to rest approximately 10 yards from the concrete culvert to the left of the airplane path (Figure 90). The shock strut was fractured below the wheel height. Both wheels were deflated. There was a large dent in inner hub of the right wheel.

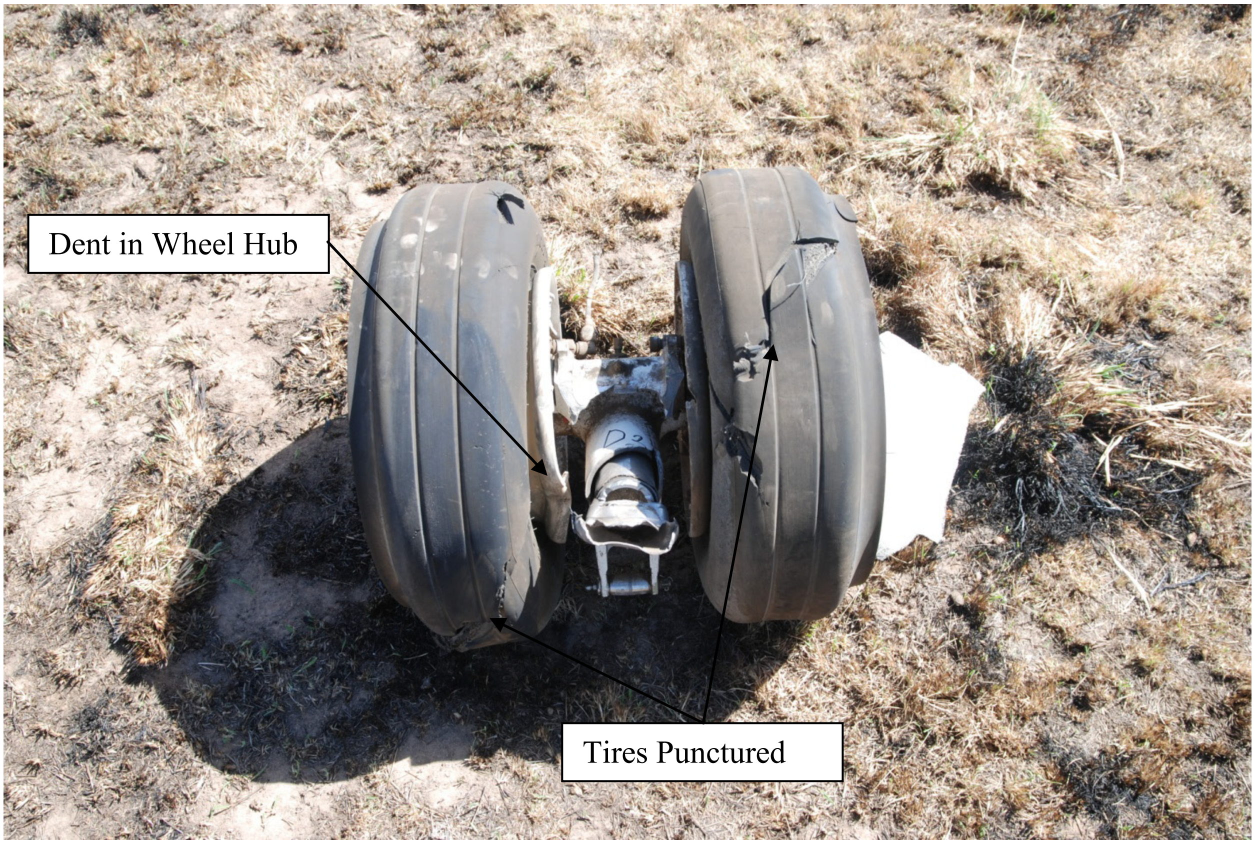


Figure 90 Nose Gear Wheel Assembly

21. Engine Monitoring System Data Review

Rolls-Royce Deutschland Ltd & Co KG performed and examination of the data from an engine monitoring system installed on the accident airplane. The findings are included in Attachment 1 to this report.

22. Wreckage Distribution

The NTSB requested assistance from the Federal Bureau of Investigation (FBI) with surveying the ground scars and markings left by the airplane, as well as the location of prominent wreckage items and airport property features. The FBI, in turn, requested the assistance of the New Mexico State Police (NMSP) and the Roswell Police Department (RPD) with this effort. Investigators from Gulfstream also surveyed the accident scene with a Differential GPS unit. Selected points from these surveys are highlighted in Figures 91 – 93 and the itemized description of these points are provided in Figure 94. The entire results of the NMSP survey is provided in Figure 96 and the DGPS data is provided in Figure 97.

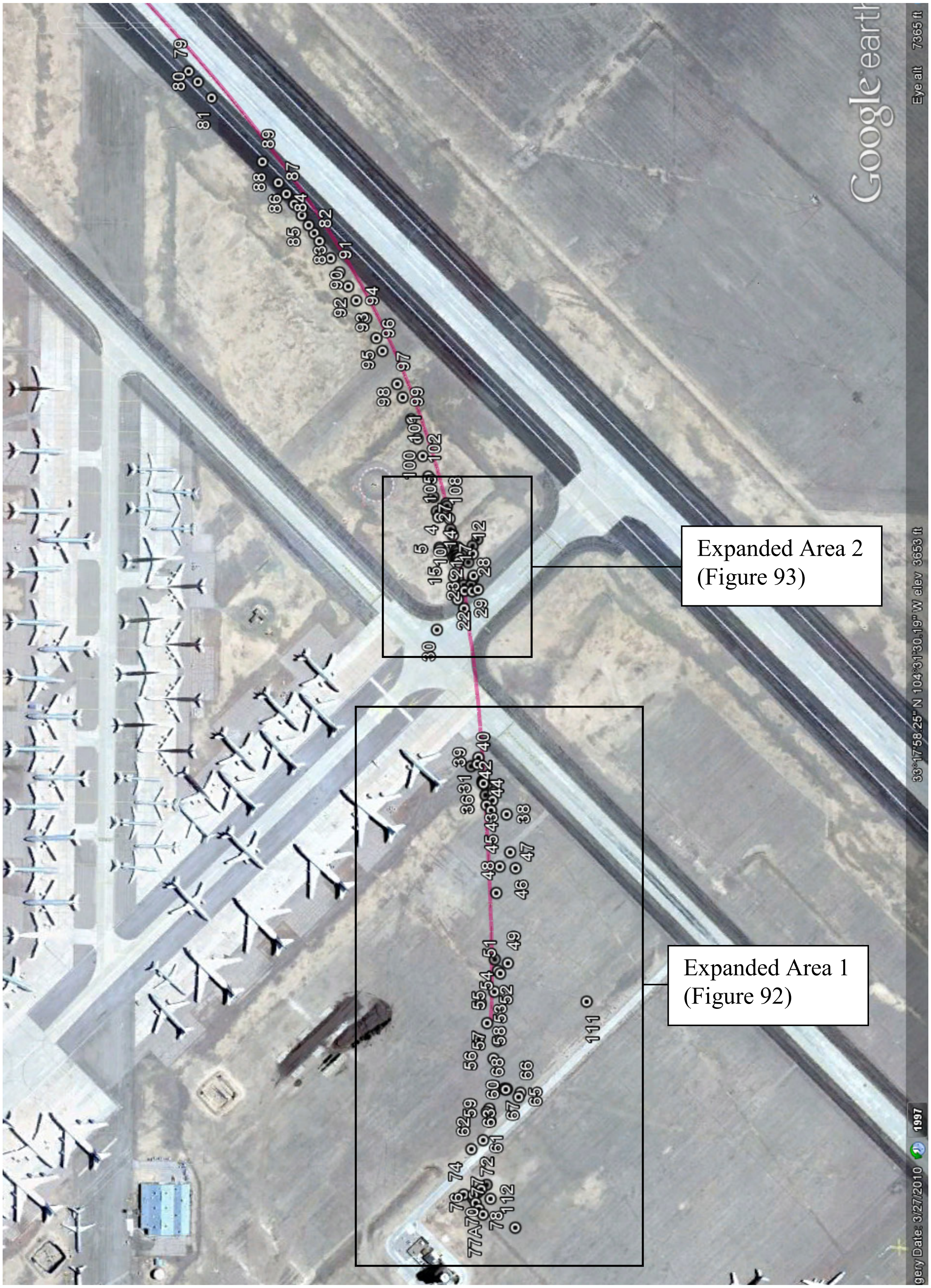


Figure 91 Wreckage Distribution

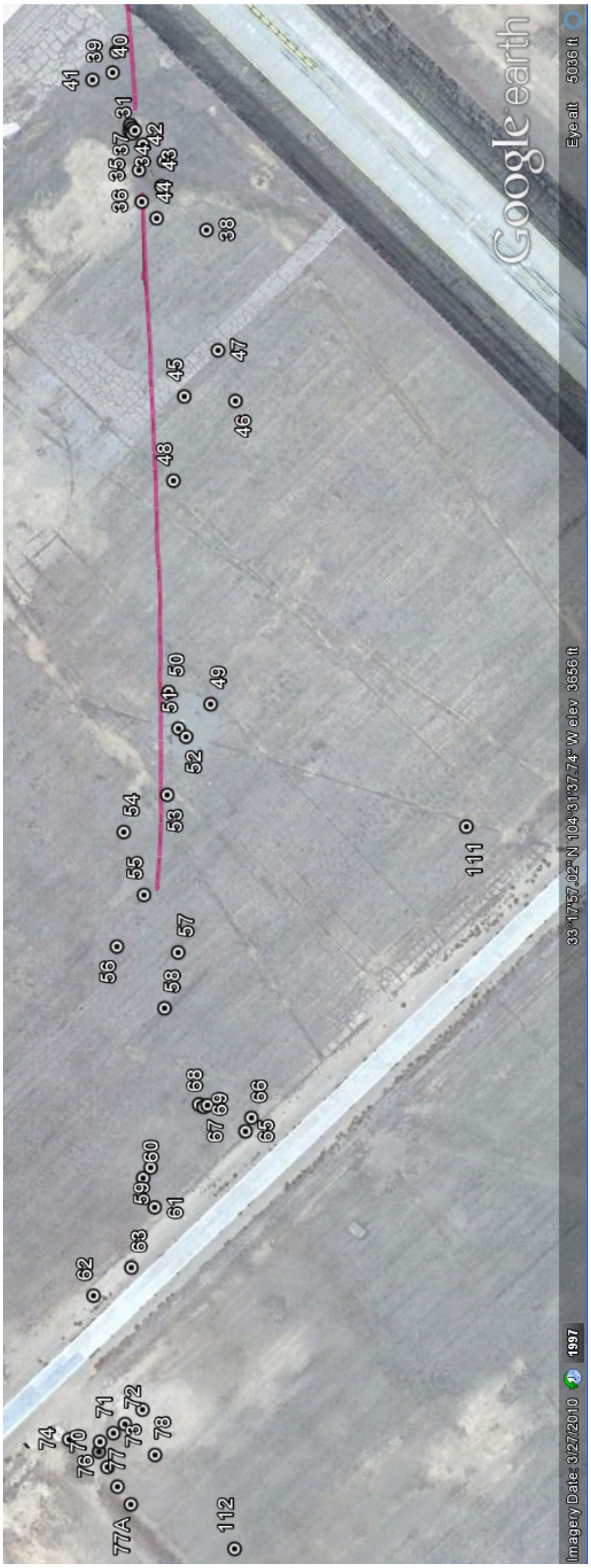


Figure 92 Wreckage Distribution (Expanded Area 1)

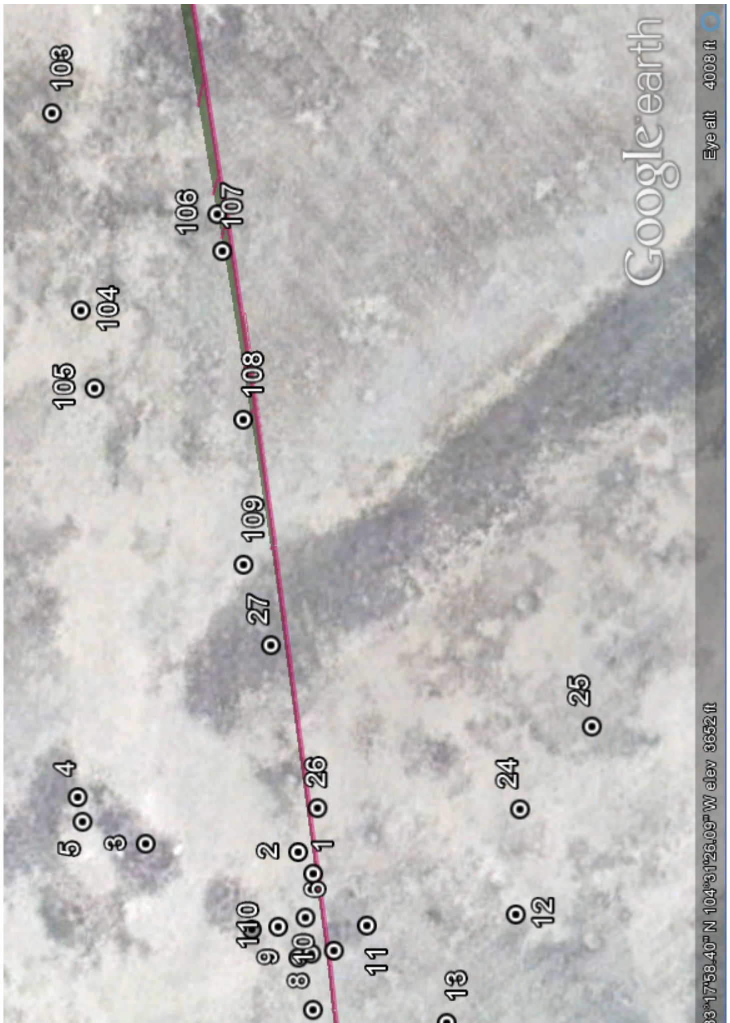


Figure 93 Wreckage Distribution (Expanded Area 2)

Table 1 Wreckage Distribution Itemized Parts List

Point	Longitude	Latitude	Part Description
1	-104.524036	33.2989687	MLG Inboard Door
2	-104.52402	33.2989798	Wing to Body Fairing element
3	-104.524024	33.2990805	Wing to Body Fairing element
4	-104.523992	33.2991279	Wing to Body Fairing element
5	-104.524011	33.2991233	Composite Material
6	-104.524071	33.2989713	Wing to Body Fairing Sub Structure
7	-104.524084	33.2990058	Wing To Body Fairing Link / Composite Fairing
8	-104.524099	33.2989654	Composite Fairing
9	-104.524103	33.2989736	Cannot identify
10	-104.524095	33.2989507	Composite Fairing
11	-104.524073	33.2989305	Composite Fairing
12	-104.524054	33.2988333	Composite Fairing
13	-104.524144	33.2988726	Pneumatic Duct
14	-104.524143	33.2989611	Pneumatic Duct
15	-104.524299	33.298999	Main Landing Gear Fairing Door Crank Arm
16	-104.524327	33.2989618	Composite Fairing
17	-104.524286	33.2988254	Portion of Torque Box
18	-104.524316	33.2988302	Main Landing Gear Fairing Door Crank Arm
19	-104.524387	33.2988467	Hydraulic Accumulators
20	-104.524387	33.2989104	Composite Fairing
21	-104.524446	33.2989043	Electrical Component
22	-104.524538	33.2989636	Composite Under Wing Body Fairing
23	-104.52445	33.2988354	Composite & Structure for Under Wing Body Fairing
24	-104.523971	33.2988365	L/H MLG Fairing Door
25	-104.523901	33.2987939	Composite Fairing
26	-104.523984	33.2989696	MLG Inboard Door
27	-104.523859	33.2990095	MLG Sponson Bearing
28	-104.524432	33.2987859	Portion of Torque Box and MLG Inboard Door Hinges
29	-104.524634	33.2989068	Portion of Torque Box
30	-104.52486	33.2991454	Portion of Torque Box
31	-104.52648	33.2987255	Concrete Culvert
32	-104.526471	33.2987331	Concrete Culvert
33	-104.526462	33.298726	Concrete Culvert
34	-104.52647	33.2987187	Concrete Culvert
35	-104.526602	33.2987067	Low point of berm near concrete drain
36	-104.526707	33.2986981	High point of berm
37	-104.526517	33.2986964	Fwd skeg
38	-104.526804	33.2985198	Plate from center hole

Table 1 Wreckage Distribution Itemized Parts List (Continued)

Point	Longitude	Latitude	Part Description
39	-104.526207	33.2987718	Portion of the R/H Main Landing Gear Fairing
40	-104.526276	33.2987812	Right Main Landing Gear Shock
41	-104.526299	33.2988366	Right Main Landing Gear Shock
42	-104.526573	33.2986382	Nose Landing Gear Wheels
43	-104.526657	33.2986446	Pneumatic Duct
44	-104.526763	33.2986571	Pneumatic Duct
45	-104.527355	33.2985777	Left Main Landing Gear Stuctural post and Sidebrace Actuator
46	-104.527371	33.2984374	Left Main Landing Gear Wheels
47	-104.527203	33.298486	Aft Skeg
48	-104.527634	33.298606	Left Main Landing Gear Shock
49	-104.528374	33.2984999	Right Flap Segment
50	-104.528334	33.2986156	"Grasshopper Fitting" MLG Inboard Door Retract Mechanism / "Banana Link" MLG Inboard Door Retract Mechanism
51	-104.528455	33.2985875	Weather Station
52	-104.528482	33.2985667	Weather Station
53	-104.528675	33.2986174	Portion of Torque Box and MLG Inboard Door Hinges
54	-104.528799	33.2987363	Inboard MLG Door Retraction Mechanism
55	-104.529007	33.2986794	Unknown
56	-104.529179	33.2987531	Unknown
57	-104.529196	33.2985846	Composite Fairing
58	-104.529381	33.2986209	Wing To Body Fairing Sub Structure Link
59	-104.529909	33.2986561	Unknown
60	-104.529944	33.2986765	Portion Of Torque Box
61	-104.53004	33.2986444	Fuel Pump
62	-104.530337	33.2988109	Hydraulic Replenisher Tank
63	-104.530241	33.2987072	Emergency window
64	-104.526451	33.2987316	Composite Fairing
65	-104.529783	33.2983969	Weather Station Pole Segment
66	-104.529738	33.2983808	Weather Station Pole Segment
67	-104.529699	33.2985013	Weather Station Pole Segment
68	-104.529705	33.2985116	Weather Station Pole Segment
69	-104.529697	33.2985243	Weather Station Pole Segment
70	-104.53082	33.2987904	Right Wing
71	-104.53079	33.2987535	Right Wing
72	-104.530759	33.2987221	Right Wing
73	-104.53071	33.298674	Right Wing
74	-104.530815	33.2988759	Nose
75	-104.530853	33.298793	Left Wing

Table 1 Wreckage Distribution Itemized Parts List (Continued)

Point	Longitude	Latitude	Part Description
76	-104.530903	33.2987693	Left Wing
77	-104.530967	33.2987414	Left Wing
78	-104.530858	33.2986388	Tail
79	-104.518963	33.3013784	Right Wing Scrape starts
80	-104.519073	33.3012955	Right Wing Scrape
81	-104.519243	33.3011735	Right Wing Scrape ends
82	-104.520754	33.3002087	Right wing scraped crosses shoulder
83	-104.52067	33.3002562	Right wing scrape
84	-104.520586	33.3003049	Right wing scrape
85	-104.520481	33.3003663	Right wing scrape
86	-104.520365	33.3004352	Right wing scrape
87	-104.520256	33.3005033	Right wing scrape
88	-104.520137	33.3005759	Right wing scrape
89	-104.519916	33.3007195	Right wing scrape starts
90	-104.520934	33.3001085	Right Wing Furrow
91	-104.521083	33.3000299	Right Wing Furrow
92	-104.521232	33.2999512	Right Wing Furrow
93	-104.521381	33.2998786	Right Wing Furrow
94	-104.521569	33.2997896	Right Wing Furrow
95	-104.521778	33.2996992	Right Wing Furrow
96	-104.521914	33.2996444	Right Wing Furrow
97	-104.522263	33.299511	Right Wing Furrow
98	-104.522404	33.2994621	Right Wing Furrow
99	-104.522636	33.2993868	Right Wing Furrow
100	-104.522841	33.2993288	Right Wing Furrow
101	-104.523025	33.2992816	Right Wing Furrow
102	-104.52324	33.299231	Right Wing Furrow
103	-104.523454	33.2991844	Right Wing Furrow
104	-104.523608	33.2991539	Right Wing Furrow
105	-104.523669	33.2991404	Wing lifts from ground
106	-104.523523	33.2990695	Touchdown of Right Gear - center of gear
107	-104.523552	33.2990641	Inboard Right Main Wheel touches down
108	-104.523683	33.2990407	Right Main Gear tracks stop
109	-104.523797	33.2990321	Right Main Gear back on ground
110	-104.524080	33.2989886	Last visible marks from right main gear
111	-104.528772	33.297803	Emergency Window

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