Aviation Investigation Final Report

Location:	Appleton, Wisconsin	**Accident Number:**	CEN11FA193
Date & Time:	February 14, 2011, 13:15 Local	**Registration:**	N535GA
Aircraft:	Gulfstream Aerospace Corp. GV-SP	**Aircraft Damage:**	Substantial
Defining Event:	Sys/Comp malf/fail (non-power)	**Injuries:**	3 None
Flight Conducted Under:	Part 91: General aviation - Flight test		

Analysis

While the airplane was inside the final approach fix, an amber left side hydraulic quantity low crew alerting system (CAS) message illuminated. The pilot flying (PF) noticed the hydraulic fluid quantity decreasing. Subsequently, an amber left hydraulic system fail CAS message appeared. The pilot not flying (PNF) pulled out the checklist to accomplish the left hydraulic system failure procedures and then suggested a go-around because the landing runway was about 500 feet shorter than the recommended minimum runway length indicated in the checklist. The PF decided to land due to the hydraulic quantity indications, prior autopilot problems, and the airplane's landing configuration. The PNF turned on the auxiliary pump about 500 feet above ground level, and both the PF and PNF thought the auxiliary hydraulic system could support normal spoilers, brakes, and nosewheel steering. The PF selected right thrust reverser aft and began pressing the brakes, but he felt no braking action. He reached for the emergency brakes; however, he did not immediately apply them to slow the airplane because he decided that there was not enough distance remaining to stop the airplane on the runway. Therefore, he attempted to go around with insufficient runway remaining by advancing the throttles to the maximum continuous thrust setting. The PNF did not see the airspeed increase and believed that not enough runway remained to get airborne, so he pulled the throttles back to avoid a runway overrun. The airplane exited the runway and sustained substantial damage. A review of the cockpit voice recorder transcript indicated that, before the emergency, the flight crew did not maintain a disciplined cockpit environment that focused on operationally relevant discussion but instead repeatedly made reference to and discussed objects on the ground and other operationally irrelevant topics. The lack of a sterile cockpit did not promote crew coordination and communication and adherence to procedures, which would have helped mitigate this emergency.

A postaccident examination of the airplane revealed that the nose landing gear swivel assembly, which had passed an acceptance test procedure before its installation on the airplane, was seized and bound and had a fracture on its inboard connecting tube, which was the site of the hydraulic fluid leak. The swivel assembly had galling wear scars on the outside diameter of the spool and the inside diameter of the

housing; both the spool and housing were made from similar aluminum alloys that have a propensity to gall and adhere to each other when rubbed together. The connecting tube fracture was consistent with a single bending and torsional overload event associated with high opening forces or seizure in the center swivel due to galling wear. The center housing/spool seizure was consistent with a misalignment of the swivel, which led to the binding together of the similar aluminum alloys of the spool and housing. Further examination showed that the nose landing gear hydraulic system did not have a volumetric hydraulic fuse designed to minimize the loss of hydraulic fluid in the event of a line break downstream of such a device.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this accident to be: The pilot flying's (PF) decision to land on a shorter-than-recommended runway with a known left hydraulic system failure rather than go around as suggested by the pilot-not-flying, his failure to immediately apply emergency brakes following the detection of the lack of normal brakes, and his attempt to go around late in the landing roll with insufficient runway remaining. Contributing to the accident was the nose landing gear swivel assembly failure, the lack of a hydraulic fuse before this critical failure point, and the design of the swivel using two similar alloys with a propensity to adhere to each other when rubbed together. Also contributing to the accident was the lack of a disciplined cockpit environment.

Findings

Aircraft	Hydraulic fluid - Fluid level
Aircraft	(general) - Failure
Not determined	(general) - Unknown/Not determined
Personnel issues	Incorrect action selection - Pilot
Personnel issues	Lack of action - Pilot
Personnel issues	Delayed action - Pilot
Personnel issues	CRM/MRM techniques - Flight crew
Aircraft	(general) - Design

Factual Information

History of Flight

Approach-IFR final approach	Sys/Comp malf/fail (non-power) (Defining event)
Landing-landing roll	Runway excursion

On February 14, 2011, about 1315 central standard time, a Gulfstream Aerospace Corporation GV-SP airplane, N535GA, had a landing overrun on runway 30 (6,501 feet by 150 feet, dry grooved concrete) at the Outagamie County Regional Airport (ATW), near Appleton, Wisconsin, following a reported loss of a hydraulic system. The two airline transport pilots and one passenger were not injured. The airplane incurred substantial left wing damage when the left main landing gear collapsed during the overrun. The airplane was registered to and operated by Gulfstream Aerospace Corporation under the provisions of 14 Code of Federal Regulations Part 91 as a maintenance test flight. Day, visual flight rules conditions prevailed for the flight, which operated on an activated instrument flight rules flight plan. The local flight departed from ATW about 1010.

The purpose of the flight was a test flight following the installation of the airplane's interior prior to delivery of the airplane to its owner. According to the report submitted by the operator, a preflight brief started at 0815 and some "writeups" were noted. Taxi, engine "run-ups", and takeoff were reported as normal.

The flight to the Marquette, Michigan, area was normal. All inflight checks were found to be normal. However, writeups were noted with the number one flight management system, the elevator trim, and mach trim. The autopilot disengaged during two inflight maneuvers. Following a low approach at the Austin Straubel International Airport, near Green Bay, Wisconsin, the flight crew was cleared direct to SUDIE, an initial approach fix for the area navigation (RNAV)/global positioning system (GPS) runway 30 approach at ATW.

Flaps 10 degrees were selected prior to an intermediate fix named "APESE." Flaps 20 degrees were selected between APESE and the final approach fix (FAF) named "ZUMUG." A discussion about another approach and maintenance issues was conducted and a full stop landing was decided upon to follow the GPS approach. As the airplane approached the virtual glide slope, the pilot flying (PF) called for the landing gear to be selected down and called for the landing checklist to be conducted. The landing gear came down with an indication of three green lights and no red lights. The pilot not flying (PNF) completed the before landing checklist to "include arming ground spoilers, warning inhibit, pumping up Brakes/Hydraulics/Brake Accumulator to 3000 psi" except for "selecting full flaps." Full flaps were to be selected at the PF's call for full flaps. The PNF also selected the Landing Mode on the Cabin Pressure Controller. Subsequent to that, an amber left side hydraulic quantity low crew alerting system (CAS) message illuminated when the airplane was inside the FAF. The PF selected the hydraulic synoptic page and noticed the hydraulic quantity decreasing. The PF called for flaps full and PNF selected flaps full. No movement of the flaps occurred so the PNF re-selected flaps 20 degrees. Shortly after that an amber left hydraulic system fail CAS message appeared.

The PNF pulled out the checklist to accomplish the procedures related to the left hydraulic system fail CAS message and suggested a go-around. At the beginning of the checklist, there is a note that, in part, indicated, "Select a runway that is at least 7,000 feet (2133.6 m) long and 150 feet (45.7 m) wide." According to the operator's report, the PF decided to land due to the significant hydraulic leak and the airplane was in a landing configuration below 1,000 feet above ground level (AGL) with prior autopilot/trim problems. The PNF continued to comply with the left hydraulic fail checklist and turned on the auxiliary (AUX) pump at approximately 500 feet AGL. At the beginning of the checklist, there is a caution statement to verify the availability of the auxiliary system fluid by selecting the AUX pump on for a minimum of 30 seconds to assure that pressure can be maintained. Based on flight data recorder (FDR) data, the left and right contactor transitioning from "Open" to "Closed" 26 seconds prior to all wheels on-ground, consistent with the AUX pump selected on. According to the operator's report, both the PF and PNF indicated that they thought before landing that they had a good auxiliary hydraulic system with normal spoilers, brakes, and nose wheel steering.

The PF had throttles at idle as the airplane touched down on the runway. He indicated that it "felt it took a long time to get the nose down."

According to the operator's report, the PF selected right thrust reverser aft. He began pressing the brakes and felt no braking action. The PF reported that he reached for the emergency brakes, saw the 3,000 feet of runway remaining sign, and decided it would not be enough remaining distance to stop. He attempted to go-around by advancing throttles to the maximum continuous thrust setting.

The PNF felt there was not enough runway remaining to get airborne, saw the airspeed was stable at 100 knots indicated airspeed (KIAS), and did not feel acceleration or see the airspeed start to increase. The PNF pulled the throttles back. The PNF reported that he made this decision to avoid a worst-case scenario of a runway overrun at an even higher speed just as the engines were finally spooling up. The PNF estimated that approximately 1,000 feet of runway remained when the throttles were pulled back. At that time, the PF reached up, deployed right thrust reverser, and began steering airplane to the right to avoid obstacles. The aircraft exited the end of runway 30 at approximately 95 KIAS. The airplane veered right and came to a stop after left main landing gear collapsed.

Pilot Information

Certificate:	Airline transport; Commercial	**Age:**	46,Male
Airplane Rating(s):	Single-engine land; Multi-engine land	**Seat Occupied:**	Left
Other Aircraft Rating(s):	None	**Restraint Used:**	
Instrument Rating(s):	Airplane	**Second Pilot Present:**	Yes
Instructor Rating(s):	None	**Toxicology Performed:**	No
Medical Certification:	Class 1 Without waivers/limitations	**Last FAA Medical Exam:**	December 21, 2010
Occupational Pilot:	Yes	**Last Flight Review or Equivalent:**	January 7, 2011
Flight Time:	6181 hours (Total, all aircraft), 555 hours (Total, this make and model), 5115 hours (Pilot In Command, all aircraft), 82 hours (Last 90 days, all aircraft), 33 hours (Last 30 days, all aircraft), 3 hours (Last 24 hours, all aircraft)		

Co-pilot Information

Certificate:	Airline transport; Commercial	**Age:**	46,Male
Airplane Rating(s):	Single-engine land; Multi-engine land	**Seat Occupied:**	Right
Other Aircraft Rating(s):	None	**Restraint Used:**	
Instrument Rating(s):	Airplane	**Second Pilot Present:**	Yes
Instructor Rating(s):	None	**Toxicology Performed:**	No
Medical Certification:	Class 1 Without waivers/limitations	**Last FAA Medical Exam:**	November 9, 2010
Occupational Pilot:	Yes	**Last Flight Review or Equivalent:**	November 19, 2010
Flight Time:	4793 hours (Total, all aircraft), 1176 hours (Total, this make and model), 4105 hours (Pilot In Command, all aircraft), 90 hours (Last 90 days, all aircraft), 32 hours (Last 30 days, all aircraft), 4 hours (Last 24 hours, all aircraft)		

The Pilot Flying

The PF, age 46, seated in the left pilot seat, held an airline transport pilot certificate with a rating for multi-engine land airplanes and commercial pilot privileges for single engine land airplanes. The PF was type rated in Gulfstream Aerospace G-IV, G-V, and Cessna CE-500 airplanes. His most recent Federal Aviation Administration (FAA) first-class airman medical certificate was issued on December 21, 2010, and it listed no limitations. The operator indicated that the PF had accumulated about 6,181 hours of total flight time of which 5,115 hours were as pilot-in-command. The PF had accumulated 555 hours in G-V airplane of which 40 hours were flown in the G-V airplane in the 90 days preceding the accident. The PF had flown about 82, 33, and 3 hours in the last 90 days, 30 days, and 24 hours respectively. The PF's last flight review occurred on January 7, 2011. According to the operator, the PF had military fighter flight experience and had accumulated about 4,500 hours of flight time in the military.

The Pilot Not Flying

The PNF, age 46, seated in the right pilot seat, held an airline transport pilot certificate with a rating for multi-engine land airplanes and commercial pilot privileges for single engine land airplanes. The PNF was type rated in Gulfstream Aerospace G-IV and G-V airplanes. His most recent FAA first-class airman medical certificate was issued on November 9, 2010, and it listed no limitations. The operator indicated that the PNF had accumulated about 4,793 hours of total flight time of which 4,105 hours were as pilot-in-command. The PNF had accumulated 1,176 hours in G-V airplane. The PNF had flown about 90, 32, and 4 hours in the last 90 days, 30 days, and 24 hours respectively, which were all flown in a G-V airplane. The PNF's last flight review occurred on November 19, 2010. According to the operator, the PNF had military fighter flight experience and had accumulated about 3,200 hours of flight time in the military.

Aircraft and Owner/Operator Information

Aircraft Make:	Gulfstream Aerospace Corp.	**Registration:**	N535GA
Model/Series:	GV-SP	**Aircraft Category:**	Airplane
Year of Manufacture:		**Amateur Built:**	
Airworthiness Certificate:	Transport	**Serial Number:**	5305
Landing Gear Type:	Retractable - Tricycle	**Seats:**	20
Date/Type of Last Inspection:		**Certified Max Gross Wt.:**	91400 lbs
Time Since Last Inspection:		**Engines:**	2 Turbo fan
Airframe Total Time:	10 Hrs at time of accident	**Engine Manufacturer:**	Rolls-Royce
ELT:	C126 installed, not activated	**Engine Model/Series:**	BR700-710C411
Registered Owner:	Gulfstream Aerospace Corporation	**Rated Power:**	15385 Lbs thrust
Operator:	Gulfstream Aerospace Corporation	**Operating Certificate(s) Held:**	None

The N535GA was a Gulfstream Aerospace Corporation GV-SP airplane with serial number 5305. The FAA issued an amended standard airworthiness certificate for the airplane, on November 9, 2010. The operator reported that at the time of the accident, the airplane had accumulated about 10 hours of total flight time. The airplane had a maximum ramp weight of 91,400 pounds and it was powered by two nacelle mounted Rolls Royce BR700-710C4-11 high bypass ratio turbofan engines rated at 15,385 lbs of takeoff thrust at sea level on a standard day. According to the operator, it typically takes a minimum of eight seconds for the engines to reach full thrust from idle. The engine nacelles feature thrust reversers at the exhaust section to aid in slowing the aircraft during landing. The aircraft landing gear incorporated a steerable nose wheel and main wheel anti-skid braking. The fuselage was of semi-monocoque metal construction.

The main aircraft entrance door was located at the front of the passenger compartment. The cantilevered aircraft wings were swept back 27-degrees and had a 3-degree dihedral. Each wing contained a fuel tank integrated into the wing structure. Primary and secondary flight controls were installed on the wing

trailing edge. The primary flight controls were the ailerons, with the left aileron having an adjustable trim tab. Secondary flight controls include the Fowler-type flaps and spoilers. At the wing roots on either side of the fuselage keel were 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.

According to the airplane's operating manual, the airplane was equipped with two hydraulic systems, left and right, each powered by an engine driven pump installed on the respective left and right engine that pressurizes fluid contained in dedicated reservoirs. Both systems were independent, each with separate lines and no common point for fluid interchange to preserve the integrity of each system.

Hydraulically powered aircraft components, except the engine thrust reversers, were redundantly protected with an alternate hydraulic power source, dual (left and right) hydraulic actuators, hydraulic accumulator pressure, or compressed nitrogen bottle pressure. Control surfaces used throughout the flight regime were powered using actuators connected to both hydraulic systems, with either system capable of independently powering the controls.

Control surfaces and aircraft sub-systems used in the takeoff and landing phases were powered by a single system, the left hydraulic system. The left hydraulic system was unique in that left system fluid may be pressurized by two sources other than the engine driven pump. Either the electrically driven auxiliary (AUX) pump or a power transfer unit (PTU) driven by the right hydraulic system pressure, which can pressurize left system hydraulic fluid. These two hydraulic pressurization sources offer additional redundancy by using separate quantities of left system hydraulic fluid. The PTU pressurizes normal left system fluid, but the AUX pump uses a dedicated quantity of left system fluid preserved within the left system reservoir in the event of left system fluid loss. If all left and AUX hydraulic fluid was lost, the components essential to landing can be operated using pressure stored in accumulators or nitrogen bottles. The landing gear had pressurized nitrogen as an emergency activation source and the brakes had a hydraulic accumulator as an emergency activation source.

The left hydraulic system supplies fluid drawn from a reservoir and pressurized by an engine-driven pump to all aircraft components and subsystems that require the additional force of hydraulic pressure for normal operation. Since left hydraulic system pressurized some aircraft components and subsystems, two additional means of pressurizing the left system were incorporated to compensate for the loss of the left engine or pump: an electric AUX pump and a PTU driven by right system pressure. The AUX pump was provided with a dedicated volume of hydraulic fluid in the left system reservoir to ensure that AUX pump pressure was available if left system fluid was lost.

The engine-driven hydraulic pump was mounted on the engine accessory gearbox within the nacelle. Engine rotation spins the hydraulic pump so that the pump operates whenever the engine was running. A shutoff valve was installed in the supply line between the reservoir and the pump, powered by the left essential bus, and was controlled by the left engine fire handle. Pulling out the fire handle closes the shutoff valve, preventing hydraulic fluid from entering the engine nacelle.

The left system hydraulic reservoir was located on the left side of the aft equipment bay and the reservoir was divided internally into two compartments, one for left system fluid and the other for AUX pump fluid. The total capacity of the left hydraulic system, including the fluid in system lines was 20.6

gallons, with the reservoir containing five 5.7 gallons, of which 3.7 gallons were available to the left system and 2 gallons reserved for use by the AUX pump.

The left fluid quantity within the reservoir was displayed on a direct reading circular gage, mounted on the side of the reservoir and in the cockpit from data from an electrically powered linear variable differential transducer within the reservoir. The left hydraulic quantity displayed on cockpit synoptic / system windows was the most accurate reading of fluid in the reservoir.

According to the operator, the AUX system quantity display will indicate full when there is any residual fluid in the left hydraulic system and the system will display empty when the left hydraulic system shows empty. There are no intermediate displays for the AUX system.

The electrically powered AUX pump was plumbed into the left hydraulic system and was powered by the left essential DC bus, and can produce a flow of 2 gallons per minute at 3,000 psi. Since the AUX pump was located at some distance from the left system reservoir, a boost pump was installed in the supply line to the AUX pump. The AUX pump can provide hydraulic pressure to operate components essential to configuring the aircraft for approach and landing if no other means of pressurizing the left hydraulic system was available. The AUX pump was also used to pressurize the brake accumulator.

Performance of the hydraulic system components may be monitored on the hydraulics or summary synoptic 2/3 window displays. The hydraulics synoptic display offers the most comprehensive view of the left and right systems. On the summary synoptic window, hydraulic pressures and quantities were shown digitally in colors reflecting system operation - white for normal ranges and amber for abnormal conditions.

The right hydraulic system was operationally similar to the left system, but limited to providing redundant hydraulic power to the flight controls, and single source power to the right engine thrust reverser and the motor drive of the PTU impeller.

According to the operator, during the condition where there was no hydraulic fluid in either the left or AUX system, the ground spoilers would not auto deploy on landing because there would be no hydraulic pressure to initiate the ground spoilers "pop up" signal. Porting of the fluid in the AUX system through a discontinuity in the left hydraulic system can occur when the AUX pump was operated. The failure of both the left and auxiliary hydraulics results in the loss of nose wheel steering, main and AUX brakes, ground spoiler control, left thrust reverser, auxiliary rudder operation and flaps. Emergency brakes are however still available based on pressure remaining in the brake accumulator. Landing gear extension could be accomplished through a compressed gas charge.

Meteorological Information and Flight Plan

Conditions at Accident Site:	Visual (VMC)	**Condition of Light:**	Day
Observation Facility, Elevation:	ATW,918 ft msl	**Distance from Accident Site:**	0 Nautical Miles
Observation Time:	13:27 Local	**Direction from Accident Site:**	0°
Lowest Cloud Condition:	Few / 3500 ft AGL	**Visibility**	10 miles
Lowest Ceiling:	None	**Visibility (RVR):**	
Wind Speed/Gusts:	10 knots /	**Turbulence Type Forecast/Actual:**	/
Wind Direction:	340°	**Turbulence Severity Forecast/Actual:**	/
Altimeter Setting:	30.12 inches Hg	**Temperature/Dew Point:**	2°C / -7°C
Precipitation and Obscuration:	No Obscuration; No Precipitation		
Departure Point:	Appleton, WI (ATW)	**Type of Flight Plan Filed:**	IFR
Destination:	Appleton, WI (ATW)	**Type of Clearance:**	IFR
Departure Time:	10:10 Local	**Type of Airspace:**	

At 1327, the recorded weather at ATW was: Wind 340 degrees at 10 knots; visibility 10 statute miles; sky condition few clouds 3,500 feet; temperature 2 degrees C; dew point -7 degrees C; altimeter 30.13 inches of mercury.

Airport Information

Airport:	Outagamie County Regional Arpt ATW	**Runway Surface Type:**	Concrete
Airport Elevation:	918 ft msl	**Runway Surface Condition:**	Dry
Runway Used:	30	**IFR Approach:**	Global positioning system;RNAV
Runway Length/Width:	6501 ft / 150 ft	**VFR Approach/Landing:**	Full stop

ATW was located about three miles west of Appleton, Wisconsin, at a field elevation of 918 feet MSL. Runway 30 was equipped with a medium intensity approach lighting system with runway alignment indicator lights, high intensity runway edge lights, and a precision approach path indicator. Runway 30 was 6,501 feet by 150 feet, dry grooved concrete and had a published 0.9% up-slope. Runway 3 was 8,002 feet by 150 feet grooved concrete and had a 0.1% down-slope.

Wreckage and Impact Information

Crew Injuries:	2 None	**Aircraft Damage:**	Substantial
Passenger Injuries:	1 None	**Aircraft Fire:**	None
Ground Injuries:	N/A	**Aircraft Explosion:**	None
Total Injuries:	3 None	**Latitude, Longitude:**	44.25,-88.51667(est)

The airplane came to rest about 1,900 feet and 305 degrees magnetic from the departure end of runway 30. The left landing gear was found collapsed. According to the operator, the airplane was raised and relocated to a hangar at ATW. The airplane was inspected and substantial damage was found to the left hand forward lower wing plank, the left hand middle lower wing plank, the left hand front spar, the left hand flap, left hand winglet, the left hand inboard trailing edge box, and the left hand wing to fuselage fairing. An image of the brake accumulator revealed it still had a 3,000-psi charge.

The nose landing gear swivel assembly, part number 7438-4, serial number 0748, was found fractured at the inboard connecting tube between the center and the aft housing near the braze joint at the center housing end. The swivel was subsequently sent for detailed examination.

Communications

No significant communication took place between the flight crew and air traffic control during the final approach and landing.

Flight recorders

The accident airplane was equipped with a Universal Avionics, model 1606, cockpit voice recorder (CVR), serial number 191. The CVR was sent to the National Transportation Safety Board's laboratory. The CVR was in good condition. The CVR recorded 2 hours of aircraft operation.

The accident airplane was equipped with a Universal Avionics, model 1607, flight data recorder (FDR), serial number 152. The FDR used solid-state flash memory as the recording medium. The recorder was found to be in good condition. The FDR was sent to the National Transportation Safety Board's laboratory for readout and evaluation. About 73.5 hours of data were recorded on the FDR, including data from the event flight.

The airplane manufacturer provided to the FDR group the CAS messages recorded in the Fault History Database (FHDB) from the February 14, 2011 event aircraft. In general, the FHDB collects maintenance messages and CAS messages at a 1-hertz rate logged by the Central Maintenance Computer during the event flight.

Medical and Pathological Information

The operator reported that post-incident drug testing was conducted and the tests for both pilots were negative for the testing performed.

Tests and Research

The CVR Group produced a partial transcript of the flight's CVR readout. The readout revealed the crew did not use a professional communication procedure or discipline consistent with a sterile cockpit communication procedure while maneuvering for approaches at the Austin Straubel International Airport, near Green Bay, Wisconsin and at ATW. A significant portion of the cockpit communications prior to 1310 were not related to the purpose of the test flight. About 1310 the PF asked that the landing gear be extended and subsequently he verbalized that a low hydraulic quantity indication illuminated. The PNF stated that the airplane had a hydraulic fluid leak and he indicated that he would look at the checklist. The crew confirmed that the flaps would not extend further than 20 degrees. The PNF stated that the left hydraulic system fail indication illuminated and asked if the crew should go around. Referencing the hydraulic leak, the PF indicated no to the go around question. The PNF subsequently verbalized 3,800. The PF asked for the availability of the brakes in reference to the hydraulic leak. The PNF verbalized part of a checklist and no reply is heard in reference to the brake availability question. A warning for flaps too low is heard and the PF asked that the flap warning be silenced. A background sound consistent with the nose landing gear contacting the runway was heard and the PNF asked if the PF had brakes. Both crew members reported no brakes were available. The PF indicated that he wanted to go around. The PNF indicated that that they should not go around. The PNF indicated that the airplane had only accelerated to 100 knots. The CVR Group's report is appended to the docket material associated with this investigation.

According to the FDR Group's report appended to the docket material associated with this investigation, the FDR data revealed at 1310:46, during the final approach, the landing gear transitioned from "Up" to "Not Up" while descending through a pressure altitude of 2,721 ft. At 1310:48, the left and right battery contactors transitioned from "Not Closed" to "Closed" consistent with the AUX hydraulic pump being selected ON and four seconds later indicated "Not Closed". During this time, the auxiliary hydraulic system pressure increased from 120 psi to 1,300 psi and then decreased to 444 psi. At 1311:09, a left hydraulic quantity low FHDB CAS message was recorded. At this time, the pressure altitude had

decreased to about 2,433 ft. At 1311:28, the left hydraulic pressure transitioned from greater than or equal to 2,400 psi to "-" indicating that the left hydraulic system pressure was less than 2400 psi. At this time, the pressure altitude had decreased to 2,182 ft. At 1311:34, the left hydraulic system pressure decreased to 164 psi and remained below 200 psi for the rest of the landing. At 1311:38, a left hydraulic system fail FHDB CAS message was recorded. At 1311:57, while descending through the pressure altitude of 1,786 ft, the flap handle increased from 20 degrees to 39 degrees. The recorded left and right flap position remained at 20 degrees. About 6 seconds later, the flap handle decreased back to 20 degrees. At 1313:12, the left and right battery contactors transitioned from "Not Closed" to "Closed" consistent with the AUX hydraulic pump being selected on. Those contactors remained "Closed" for the remained of the landing. At 1313:18, the left and right engine throttle resolver angles decreased from about 5 degrees to 0 degrees, consistent with idle forward thrust. At 1313:26, an auxiliary hydraulic fail FHDB CAS message was recorded. At this time, the pressure altitude decreased to about 684 ft. At 1313:28, the recorded vertical acceleration data was consistent with the main wheels touchdown. At 1313:31, the throttle resolver angles decreased to about -5 degrees. At 1313:33, the right engine thrust reverser data transitioned from not deployed to "Deployed"; whereas the left engine thrust reverser remained not deployed and remained not deployed during the landing. The recorded aircraft pitch angle was 1.4 degrees. At 1313:34, the left and right brake pedal transitioned from not applied to "Applied". The recorded left and right inboard and outboard brake pressures did not increase and remained below 208 psi for the remainder of the landing. At this time, the ground speed was about 122 knots and the calibrated airspeed was about 124 knots. At 1313:36, the aircraft pitch angle decreases to -0.70 degrees. At 1313:38, a left thrust reverser fail FHDB CAS message was recorded. At this time, the weight on wheels data transitioned from an in-air indication to an on-ground indication consistent with all three landing gear indicating they were now on the ground. At this time, the ground speed was about 112 knots and the calibrated airspeed was about 117 knots. At 1313:39, the right engine throttle resolver angle decreased to -22 degrees, consistent with maximum reverse thrust, and the left engine's angle remained at -6 degrees. At 1313:44, both engine's throttle resolver angles increased to about 39 degrees, consistent with full forward thrust being requested, and the right engine thrust reverser data transitioned to not deployed. At this time, the ground speed was approximately 100 knots and the calibrated airspeed was 102 knots. At 1313:49, both engine throttle resolver angles decreased to 0 degrees, consistent with idle forward thrust. At this time, the ground speed was 98 knots and the calibrated airspeed was 101 knots. At 1313:51, the recorded data for both brake pedals transitioned from not applied to applied indications and both engine throttle resolver angles decreased to -5 degrees. At 1313:53, the right engine thrust reverser data transitions from "Not Deployed" to "Deployed." At 13:14:12, the weight on wheels data transitioned to an in-air indication. At this time, the ground speed was 26 knots. At 1314:16, the FDR's data dropped out.

Radiographic studies were conducted at Varian Medical Systems, Inc. on March 24 - 25, 2011 in Lincolnshire, Illinois, to examine and document the internal configuration of the hydraulic swivel assembly from the nose landing gear. The hydraulic swivel assembly was documented using a combination of computed tomography (CT) scans and digital radiography. The swivel assembly, serial number 0748, was imaged using 11 digital radiographs and 3,021 CT slices.

Review of the images indicated that there were areas within the center swivel that contained irregular gaps between the inner spool and outer housing. In some areas, the gaps were wider than adjacent areas, and in other areas, the gaps were smaller than adjacent areas. Some thin pieces of unknown debris were noted in one of the seal cavities. The Computed Tomography Specialist's Factual Report is appended to

the docket material associated with this investigation.

A swivel assembly examination was conducted on April 7, 2011, at PneuDraulics, Inc. in Rancho Cucamonga, California. A review of the swivel manufacturer's records revealed that three other swivel assemblies had been returned to the swivel manufacturer. According to PneuDraulics, swivel assembly, serial number 0414, was received at PneuDraulics in April of 2011 and it had reported broken tubes attributed to an installation error where the center swivel segment was installed downwards while being attached to the drag brace. Swivel assembly, serial number 0540, had been returned in June of 2010 with a report of "received on gear wrapped towards the right." Swivel assembly, serial number 0689, had been returned in May of 2010 with broken tubes attributed to an installation error of the landing gear assembly.

The accident swivel assembly was photographed and filter patch collection from a wash of the swivel's ports was conducted. The swivel was placed in an acceptance test procedure jig and there was a 0.03-inch misalignment exhibited in reference to that jig. According to the swivel manufacturer's records, the accident swivel had passed its acceptance test procedure alignment and force specifications before it was shipped for attachment on the nose landing gear at Goodrich, which was subsequently sent to Gulfstream for installation during initial phase manufacturing of the accident airplane.

The swivel assembly was disassembled. The center spool (or shaft) had to be forced from its housing. Galling wear scars were present on the inside diameter of the housing and the outside diameter of the spool. The dimensions of all critical to function features on the swivel center housing and spool were measured and compared with manufacturer's specifications. The housing spool grooves met specifications. The spool lands, which were the raised portions between the grooves, met specifications in areas that did not exhibit galling.

A metallurgical examination of the disassembled swivel pieces was conducted between April 26 and 28, 2011, at Applied Technical Services, Inc. in Marietta, Georgia. The swivel assembly dimensions were measured. The fracture surfaces on the fractured connecting tube were exposed by fracturing the balance of the tube in the laboratory by hand. The fracture surfaces were examined using a scanning electron microscope equipped with energy dispersive spectroscopy (EDS). In the region of the original fracture, the fracture features revealed a thin area of interdendritic fracture at its outer diameter, followed by a thin region of intergranular fracture, consistent with a brittle fracture of the braze filler and tube areas. The rest and majority of the fracture surface exhibited microvoid dimples consistent with ductile fracture. The lab-induced overload fracture surface exhibited the same zones and characteristics. No evidence of progressive cracking or preexisting damage was observed. The ductile area of the fracture surface was analyzed by EDS and was found to be compositionally consistent with its specified aluminum alloy 6061. The interdendritic areas near the outer diameter surface exhibited higher concentrations of silicon, which was consistent with the specified braze filler material. The failed tube fractured at the braze fillet exhibiting interdendritic/intergranular fracture features and the crack progressed as ductile overload into the original tube material. No microstructural abnormalities were observed. Hardness of the tube base materials and alloyed zones were measured and both tube samples met the requirements of aluminum alloy 6061-T6.

The swivel assembly housing and spools were sectioned to further examine areas exhibiting galling wear scars. The galled and unaffected surfaces of the housing and the spool samples were analyzed by EDS

and no evidence of foreign matter was detected on galled areas. All samples exhibited elements that were consistent with their reported aluminum alloys. The spool samples exhibited significant levels of oxygen and sulfur, consistent with the reported anodizing process. The housing samples did not exhibit any evidence of anodic coating on the undamaged surfaces adjacent to the galled areas. Only the galled areas exhibited some concentrations of oxygen and sulfur, consistent with transfer of the anodic coating from the spool samples at the contact points. Recessed areas of the housing samples exhibited anodizing. The housing and spool samples were metallographically prepared through the galled areas. The housing samples did not exhibit anodic coating layers on the lands (closest to spool contact) as specified by the assembly drawing requirements but did exhibit anodic coating in the recessed grooves. The spool samples exhibited anodic coating layers. No microstructural abnormalities were observed in the samples.

The hardness of the housings and spools were tested and their electrical conductivity was measured. The forward-center spools, and center-aft housings met aluminum alloy 6061–T6 requirements and the aft spool and forward housing exhibited slightly lower hardnesses than their requirements.

The anodic coating thicknesses on the spools and groove areas of the housings were measured and the samples had thicker coatings that did not meet the specified assembly drawing requirements.

Surface roughness of the housing and spool samples were measured at relatively undamaged areas near the damaged areas and the samples met the specified assembly drawing requirements.

Debris from a filter patch collection during swivel disassembly was analyzed by EDS and no evidence of foreign metallic materials was found. All particles were consistent with aluminum, paint, and polytetrafluoethylene (PTFE).

Materials of the T-seal and the backing ring samples from the center spool were verified using Fourier transform infrared spectroscopy techniques. The materials of the T-seals were consistent with known ethylene propylene rubber. The materials of backing rings were consistent with known PTFE. All T-seal samples met the minimum hardness specifications.

The Applied Technical Services, Inc. report is appended to the docket material associated with this investigation.

Additional Information

The parameters evaluated for the purpose of this report appeared to be in accordance with the federal FDR carriage requirements, except Relative Time and Pressure Altitude. There appears to be a discrepancy between the sampling rate requirements in 14 CFR Part 91 and the sampling requirements for 14 CFR Part 135 and 14 CFR Part 121. The accident aircraft recorded Relative Time once every 4 seconds and Pressure Altitude once every second, which meet the requirements for 14 CFR Part 135 and 14 CFR Part 121; whereas Appendix E to 14 CFR Part 91 specifies the sampling interval for Relative Time to be once per second and Pressure Altitude to be 11 per second.

Gulfstream's submission, in part, stated:

Gulfstream believes that the published 14 CFR Part 91 Appendix E is typographically incorrect as it does not harmonize with the [Minimum Operational Performance Specification For Crash Protected Airborne Recorder Systems ED-112] and Parts 121 and 135. The sampling requirement for "Time or Relative Time" should be once every 4 seconds for Parts 91, 121 and 135. The sampling requirement for "Pressure Altitude" should be once every second for Parts 91, 121 and 135. Gulfstream representatives, along with representative from GAMA (General Aviation Manufacturers Association) discussed this with an FAA Recorder Specialist during the June 14, 2012 US/Europe International Safety Conference. The FAA representative stated that this issue has been known for at least 12 months and it is indeed a typographical error that will be corrected on the next revision to 14 CFR Part 91 appendix E.

FDR data frame correlation documentation is required in 14 CFR Part 121.343(j), 14 CFR Part 121.343a(d) and 14 CFR Part 135.152(f)(2). In contrast, FDR data frame correlation documentation is not required for 14 CFR Part 91.609. However, FDR data frame documentation is essential for decoding FDR data. Upon request, Gulfstream provided the FDR documentation to the NTSB but the documentation was insufficient to decode the data and difficult to understand. Therefore, it was necessary to have Gulfstream's assistance in decoding and verifying the data.

Gulfstream's reference to FDR Documentation in their submission, in part, stated:

Subsequent to the FDR Group Meeting, Gulfstream revised GVSP-GER-6098 revision j (rev j) … and provided a copy to the NTSB. The NTSB has since commented on GVSP-GER-6098 (rev j), noting "editorial errors and inconsistencies".

Gulfstream has made improvements to GVSP-GER-6098 (rev k) to address the editorial errors and inconsistencies. … While rev k is improved, Gulfstream recognizes that this document will need a thorough reexamination and modification. Gulfstream has accepted this as a follow-on task and will execute appropriately.

Gulfstream's reference to Quick Reference Handbook (QRH) procedures in their submission, in part, stated:

The [QRH] procedure checklist for Left Hydraulic System Failure at the time of the accident had two separate procedures, one dealing with loss of Left system pressure and fluid, and the

other dealing with loss of Left and Aux Hydraulic system. Both of those procedures had the identical caution with the statement: "To verify the availability of Auxiliary system fluid, select the Aux pump on for a minimum of 30 seconds and check for Auxiliary system pressure. If pressure cannot be maintained, assume that the Auxiliary system is not available and proceed to the Left System and Auxiliary Hydraulics System Loss of Fluid."

The reason for the caution on both checklists is that the synoptic indication of fluid in the Aux system is predicated on the piston position for fluid in the Left system reservoir and not the actual fluid in the Aux system. The only quantity enumerated is for the fluid in the Left system and not the Aux. If the Left system reservoir piston is positioned to empty, the Aux system will indicate empty, even if fluid is present. The only reliable check of fluid being present in the Aux system is the ability to maintain system pressure. That is why it is imperative for the crew to note the caution and complete the directed action.

The change to the QRH in the case of experiencing a Left Hydraulic System failure now incorporates the assumption that upon the failure of the Left Hydraulic System, the Aux system is lost as well. The procedure plans for the worst case scenario of losing all Left and Aux fluid upon touchdown, directing the crew to prepare for landing without ground spoilers or normal braking. If the Aux System remains functional, landing and braking operations will be normal.

Gulfstream's reference to Crew Resource Management in their submission, in part, stated:

Gulfstream has refocused our efforts to promote proper Crew Resource Management among all of its crews. Gulfstream will encourage Flight Safety International, its principle flight training resource for customer aircrews, to incorporate lessons learned from this accident into its training regimen.

PneuDraulics reference to Proposed Safety Recommendations in their submission, in part, stated:

After a review of the Gulfstream GV-SP hydraulic system architecture, it seems that a fundamental improvement to the hydraulic system on the Nose Wheel section of the aircraft would be the addition of a velocity or volumetric hydraulic fuse. This component is designed to minimize the loss of hydraulic fluid in the event of a line break downstream of such

a device. In fact, the GV-SP does have hydraulic volumetric fuses as part of the main landing gear brake system to protect against hydraulic system pressure loss should a similar incident happen in the main landing gear area.

The NTSB IIC was advised by the FAA of an incident in San Juan, Puerto Rico, on December 20, 2001, involving a Gulfstream V. That airplane's hydraulic fluid leaked during the flight and the airplane's four main tires blew out when the flight crew used the airplane's emergency brakes to stop the airplane on the runway.

A service difficulty report of an incident on July 22, 2001, indicated that a Gulfstream V had a nose landing gear swivel assembly rupture. The report indicated that ruptured swivel had accumulated 520 hours and 273 cycles. According to Gulfstream, the hydraulic input to the nose wheel steering system was redesigned to include PneuDraulics modifications to the nose wheel swivel assembly.

The executive summary in NTSB Aircraft Accident Report NTSB/AAR-11/01, Crash During Attempted Go-Around After Landing, East Coast Jets Flight 81, Hawker Beechcraft Corporation 125-800A, N818MV, Owatonna, Minnesota, July 31, 2008, in part, stated:

On July 31, 2008, about 0945 central daylight time, East Coast Jets flight 81, a Hawker Beechcraft Corporation 125-800A airplane, N818MV, crashed while attempting to go around after landing on runway 30 at Owatonna Degner Regional Airport, Owatonna, Minnesota. The two pilots and six passengers were killed, and the airplane was destroyed by impact forces. The nonscheduled, domestic passenger flight was operating under the provisions of 14 Code of Federal Regulations Part 135. An instrument flight rules flight plan had been filed and activated; however, it was canceled before the landing. Visual meteorological conditions prevailed at the time of the accident.

The National Transportation Safety Board determines that the probable cause of this accident was the captain's decision to attempt a go-around late in the landing roll with insufficient runway remaining. Contributing to the accident were (1) the pilots' poor crew coordination and lack of cockpit discipline; (2) fatigue, which likely impaired both pilots' performance; and (3) the failure of the Federal Aviation Administration (FAA) to require crew resource management (CRM) training and standard operating procedures (SOPs) for 14 CFR Part 135 operators.

Administrative Information

Investigator In Charge (IIC):	Malinowski, Edward
Additional Participating Persons:	Rexford White; Federal Aviation Administration; Milwaukee, WI Randy Gaston; Gulfstream; Savanah, GA Greg Burns; Pneudraulics, Inc.; Rancho Cucamonga, CA Ben Evans; Goodrich; Oakville, ON, Canada
Original Publish Date:	January 30, 2014
Last Revision Date:	
Investigation Class:	Class
Note:	
Investigation Docket:	https://data.ntsb.gov/Docket?ProjectID=78368