G550 Outfitting Check Flight Accident
Gulfstream Party Submission

CEN11FA193

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1 INTRODUCTION

On February 14, 2011 the crew of G550, SN 5305 was flying an approach into Appleton Wisconsin (ATW) as part of accomplishing the checkout flight associated with the G550 Completion Flight Test Procedures document. On landing, the aircraft departed the end of the runway and traveled approximately 2000 ft before coming to a stop.[1] The aircraft's left main gear collapsed and the aircraft sustained damage to the left flap and the left wing. The sequence of events that resulted in the damage started with the failure of a Nose Landing Gear (NLG) swivel which caused loss of both the left system hydraulic fluid and the auxiliary hydraulic fluid resulting in loss of further flap actuation, normal brakes, nose wheel steering, auto ground spoiler deployment and left thrust reverser. After touchdown and deploying the right thrust reverser, the pilot flying (PF) discovering that no braking action was available. The PF decided to go-around because he did not think there was sufficient runway available to stop using the emergency brake. The pilot not flying (PNF) interceded and pulled the throttles to idle because he felt certain there was not sufficient runway available to get airborne prior to departing the paved surface. The PF then deployed the right thrust reverser as the airplane departed the runway surface.

1.1 Production/ Completion Test Flight

The flight was crewed by two experienced production/completion test pilots. A production/completion test pilot is responsible for conducting flight test evaluations of production aircraft, engines, avionics systems, and all other systems to assure that the airplane is in compliance with the type design (including supplemental type design) and performance specifications. A production/completion test pilot uses approved test card procedures to ensure that the flight is conducted safely and effectively. The purpose of the flight is to ensure that the aircraft performs all tests to demonstrate it meets the FAA approved Type Design and Supplemental Type Design. To that end, the checkout flight objective is to identify any malfunctions and expose components to the full flight envelope with the intent of inducing infant mortality or identifying manufacturing errors and assure overall aircraft performance and operation. The expectation is that the production/completion test pilot crews will be exposed to malfunctions more often than Gulfstream's customer pilots and that the production/completion test pilot is prepared for any failure possibility.

1.2 Event Description

Prior to the accident, the crew was cleared for an RNAV/GPS Runway 30 approach as part of the Completion Flight Test Procedures. Runway 30 is 6501ft by 150ft with a +0.9% slope. The winds were 340 degrees at 10kts. At approximately 11 miles from touchdown, the PNF selected flaps 10. Inbound to the final approach fix, the PNF selected flaps 20 and as the vertical glide path for the approach became active, he selected gear down. PNF completed before landing checklists up to just prior to full flaps which includes arming ground spoilers, selecting warning inhibit ON and momentarily actuating Aux Hydraulic

[1] Gulfstream uses both a formal model designation, "GV-SP" and a marketing designation "G550" to define the model of the accident aircraft. The two terms are synonymous for purposes of this Submission.

pump switch ON to charge the brake accumulator to 3000 psi. At this point the aircraft was configured to land except for the selection of full flaps.

The crew was then alerted by an amber **L Hydraulic Quantity Low** message. The PF selected the hydraulic synoptic page and noted the hydraulic quantity decreasing. The PNF would later recall that the Aux quantity indicated full as evidenced by the hydraulic system synoptic displaying green on the Aux part of the display giving him the impression that the Aux system was available. Twenty-nine seconds after **L Hydraulic Quantity Low** message was displayed, an amber **L Hydraulic System Fail** message was displayed. Next the PF called for full flaps. The PNF, already involved in accomplishing the emergency procedure section of the Quick Reference Handbook (QRH), selected full flaps but there was no movement, as fluid in the left system had been depleted. In order to display the correct VREF speeds, the PNF reselected to flaps 20. The PNF reports that he suggested a go-around. The PF decided to land. The PF noted in his written report that his decision to land was due to significant hydraulic leak, that the aircraft was already in the landing configuration, that the aircraft was below 1000 feet above ground level (AGL), and the PF's concerns with the prior autopilot/trim problems experienced earlier in the flight.[2]

The PNF devoted his attention to completing the Left Hydraulic System (SYS) Failure-Loss of Pressure and Fluid checklist prior to landing and per step 14 selected Aux pump-ON, 16 seconds prior to Main Landing Gear (MLG) touchdown. With the landing imminent, the PNF discontinued his review of the checklist at this point, failing to note step 18 requiring the manual deployment of the speed brakes.

The Digital Flight Data Recorder (DFDR) data did not indicate any system pressure rise in the Aux Hydraulic system and recorded that Aux System pressure remained below 200 PSI for the duration of the landing. The purpose for having the Aux pump selected ON was to provide continuous pressure to the brakes and steering after landing in the event of Left Hydraulic System failure.

Five seconds prior to MLG touchdown, the DFDR records that no Aux Hydraulic system pressure was available and the **Aux Hydraulic Fail** message was displayed on the CAS System. Because the warning inhibit was selected ON per the normal checklist, there was no aural warning tone to inform the crew of the amber message indicating the loss of the Aux system. Touchdown airspeed was 137 KCAS, which was 12 knots faster than the scheduled Vref speed of 125 KCAS. The airplane landed long, using 2048 feet of runway before main gear touchdown, leaving 4453 feet remaining to stop the airplane. With no hydraulic fluid in the Left or Aux Hydraulic system, the ground spoilers could not auto deploy on landing because there was also no hydraulic pressure to the Ground Spoilers Control "pop-up" signal. The PF had throttles at idle and following MLG touchdown felt that

[2] Gulfstream believes that the noted trim problem was not a valid reason for not going around since it did not affect the safe operation of the airplane. Similarly, the loss of hydraulic fluid was not a reason for immediate landing either since the right hydraulic system was operating normally and powered all the flight controls for continued safe flight, and written procedures were available for landing with left and aux hydraulic systems failed.

it took a long time to get the nose down, which was a result of the ground spoilers not deploying. The DFDR indicated that approximately 8 seconds transpired from Main Landing Gear (MLG) touchdown to NLG touchdown. The PNF did not manually deploy the speed brakes per the emergency Left Hydraulic Fail checklist, which is a backup precaution in the event that the Ground Spoilers do not deploy.

The PF commanded thrust reversers deployment, deploying only the right thrust reverser as the hydraulic failure prevented left thrust reverser deployment, and when pressing the brake pedals felt no braking action and reported initially reaching for the emergency brake. At this time, the Runway Awareness and Advisory System (RAAS) audio calls out "3000 remaining".[3] Six seconds later, RAAS calls out 2000 feet remaining and then 3 seconds after that call out the PF elected to initiate a balked landing, stowing the right thrust reverser and advancing the throttles to takeoff power, thinking that there was not enough distance remaining to stop. Three seconds later RAAS calls out 1000 remaining. With no engine acceleration and the airspeed stable at 101 KCAS, and approximately 1000 ft. remaining (the DFDR/CVR recorded approximately 800 ft. remaining), the PNF, on his own initiative, pulled the throttles to idle.

The PF seeing that they were going to depart the runway, commanded thrust reversers deployment, deploying only the right thrust reverser as the hydraulic failure continued to prevent left thrust reverser deployment, as the aircraft departed the end of the runway and directed his attention to avoiding an antennae array and two buildings. After clearing those obstacles, the aircraft traversed a shallow depression where the left main gear collapsed. The aircraft continued traveling approximately another 500 ft. before coming to a stop. The crew shut down the engines and exited the aircraft thorough the main entry door.

[3] At the time it prepares this Submission, Gulfstream does not have access to the CVR transcript, which may confirm several details assumed in this report. However, Gulfstream has been provided the CVR RAAS callouts.

1.3 Relevant DFDR Data for Accident Event

The foregoing event description and other analysis in this submission is based in part on the following relevant facts obtained from the DFDR data.

TABLE 1 DFDR DATA

Counter	Main TD (seconds)	Gear Down (seconds)	Function	Comments
11517	-309		Flap handle selected to 20	
11523	-303		Flaps have moved to 20	
11663	-163	0	Main Gear Down	Indicates that the Gear is Not UP
11666	-160	3	L/R Battery contactor closed for 4 seconds	Aux Hydraulic pump ON
11670	-156	7	L/R Battery contactor open	Aux Hydraulic pump OFF
11686	-140	23	L HYDRAULIC QUANTITY LOW CAS message	From the Fault history Data Base (FHDB) no debounce, Amber message
11703	-123	40	Left Hydraulic Pressure starts dropping	
11706	-120	43	Left Hydraulic Pressure below 2400 PSI	Discrete
11712	-114	49	Left Hydraulic Pressure below 200 PSI	
11715	-111	52	L HYDRAULIC SYSTEM FAIL CAS message	From the Fault history Data Base (FHDB) 5 sec debounce, Amber message
11735	-91	72	Flap handle selected to 39	Flaps do not move
11741	-85	78	Flap handle selected to 20	
11810	-16	147	L/R Battery contactor closed for remainder of flight	Aux Hydrulic pump ON - No pressure rise
11816	-10	153	L/R Throttle resolver angle goes to 0.0 degrees	0 = flight idle Thrust
11821	-5	158	AUX HYDRAULIC FAIL CAS message	From the Fault history Data Base (FHDB) 10 sec debounce, Amber message
11826	0	163	Main Gear Touchdown	Vertical and Long Accel data, Rad Alt = 0 feet
11829	3	166	L/R Throttle resolver angle goes to -5.0 degrees	-5.0 = TR idle Thrust
11831	5	168	R TR deployed	Discrete
11831	5	168	Pitch Attitude Angle 1.5	Approx -0.5 to -1.5 = normal pitch angle on ground
11832	6	169	L/R brake Pedals depressed	Discrete
11832	6	169	R Throttle resolver angle to -22	-22 = Max reverse Thrust
11832	6	169	RAAS CVR callout - 3000 Feet remaining	CVR
11833	7	170	L/R brake Pedals NOT depressed	Discrete
11833	7	170	Pitch Attitude Angle 0.0	
11834	8	171	L/R brake Pedals depressed	Discrete
11835	9	172	Pitch Attitude Angle -0.6	
11837	11	174	WOW, left, right , and nose WOW on gnd	Combined WOW
11838	12	175	RAAS CVR callout - 2000 Feet remaining	CVR
11841	15	178	L/R brake Pedals NOT depressed	
11841	15	178	L/R Throttle resolver angle to +39	+39 = Max forward thrust
11842	16	179	R TR NOT deployed	
11844	18	181	RAAS CVR callout - 1000 Feet remaining	CVR
11847	21	184	L/R Throttle resolver angle to 0	0 = flight idle Thrust
11849	23	186	L/R brake Pedals depressed	Discrete
11849	23	186	R Throttle resolver angle to -5.0	-5 = TR idle thrust
11850	24	187	L Throttle resolver angle to -5.0	-5 = TR idle thrust
11851	25	188	End of runway	Accel Data
11851	25	188	R TR deployed	
11871	45	208	WOW to air	One of the three WOW switches went to the air mode. Left gear failed
11876	50	213	Engine run switches selected to OFF	Gap in data prior to this event
General Comments: WOW = combined WOW. Gear = Up/ Not Up. Left TR does not unlock or deploy. Battery contactor close = Aux Hydraulic pump ON. Debounce = delay. RAAS callout distance = distance at end of callout.				

2 Hydraulic System Description

The G550 Hydraulic System provides for the storage and delivery of fluid under high pressure to actuate various hydraulically operated systems throughout the aircraft. The hydraulic system is comprised of a left and right system, an auxiliary system and a Power Transfer Unit (PTU) System. This design allows for a great deal of redundancy such that the failure of one system will not result in the inability to actuate any subsystem except for the respective engine's thrust reverser. If a single hydraulic system should fail, there will always be at least one other way to actuate the respective engines thrust reverser. Each of the primary flight controls are powered by "Dual Hydraulic Actuators" which mean that each actuator uses both left and right system hydraulic fluid through totally independent paths. This makes the loss on one hydraulic system all but completely transparent to the flight crew with regard to the primary flight controls.

The Main Hydraulic System consists of the Left and Right Hydraulic System. Two dedicated engine driven pumps supply the fluid under pressure, one to each main system. The Left Hydraulic System performs the majority of the hydraulic functions on the aircraft, thus it has the largest capacity reservoir. The Right Hydraulic System is a smaller and completely independent system that remains isolated for performing its few specific functions. Each main system has its own reservoir for storing fluid, a manifold that controls distribution of the fluid and an accumulator to absorb shocks.

The Left Hydraulic System provides pressurized fluid for:

Ailerons	Elevators
Rudder	Flight Spoilers
Ground Spoilers Control	Ground Spoilers
Yaw Damper	Stall Barrier
Landing Gear	Left Thrust Reverser
Flaps	Hydraulic Motor Generator
Nose Wheel Steering	Brakes
Left Accumulator	

The Right Hydraulic System provides pressurized fluid for:

Ailerons	Elevators
Rudder	Flight Spoilers
Ground Spoilers*	Yaw Damper
Stall Barrier	Right Thrust Reverser
Power Transfer Unit	Right Accumulator

* Ground Spoilers will not deploy on landing without Left System hydraulic pressure or Aux System pressure to the Ground Spoilers Control "pop-up" signal.

The Auxiliary Hydraulic System supplements the Left Hydraulic System and can be operated automatically or manually to power:

Flaps
Brakes
Ground Spoilers Control (hydraulic pressure for "pop-up" Signal)
Nose Wheel Steering
Rudder/Yaw Damper
Landing Gear Doors (on the ground)
Main Entrance Door (Aux is the only source of hydraulics)
Parking Brakes/Emergency Brakes (Aux is the only source for charging the brake accumulator)

Although the Aux System is independent of the Left System, the Aux System's reservoir is physically located within the Left System's reservoir.

2.1 Operation of Brakes Using Aux Hydraulic System

The Parking/Emergency Brake Accumulator is fully pressurized to 3000 psig when the Aux System Pump is in operation. Accumulator pressure may be read on the accumulator pressure gauge in the nose wheel well, on the copilot lower instrument panel indicator, or on the Brakes and Summary synoptic pages. A check valve is installed in the hydraulic line between the Aux Pump and the Accumulator to ensure the Accumulator remains charged when the Aux Pump is de-energized. When the Parking Brake Handle is engaged, the Accumulator Pressure is sent directly to the Inboard and Outboard Brake Shuttle Valves. The Brake Shuttle Valves transition from the Normal to the Emergency position. Pressurized hydraulic fluid is now transferred directly from the Emergency Brake Accumulator to the Brake System.

2.2 Operational Impact of Loss of Left and Aux Hydraulic System

The loss of both the Left and the Aux Hydraulic System will result in loss of:
1. Nose Wheel Steering
2. Main & Aux Brakes (Emergency Brakes are still available)
3. Flaps
4. Ground Spoiler Control
5. Left Thrust Reverser
6. Aux Rudder operation
7. Ability to recharge brake accumulator
8. Left System pressure to flight controls. (Flight controls will continue to be controlled by the Right hydraulic system)

To determine if both the left system and the aux system have failed, the emergency procedures require that the crew actuate the aux pump for at least 30 seconds to determine if the aux pump is capable of holding pressure. The aux pump is the only pressure source for charging the brake accumulator.

Without aux pressure available, the aircraft can only be stopped with emergency brakes and with whatever normal braking remains as the result of residual pressure in the brake accumulator. Performance calculations for this condition are equivalent to the calculation used for antiskid off braking, applying 1/3rd the braking coefficient of normal braking to compute braking distance. The emergency brakes operate through actuation of the emergency/parking brake handle. To modulate the brake pressure to no more than the 400 psi application recommended by the emergency procedure, the pilot is required to subtly manipulate the brake handle. If the emergency brake pressure exceeds 400 psi, the likely result is failure of all of the main wheel tires due to lack of antiskid protection.

Fleet experience and type certification flight testing has demonstrated that the failure of all four main tires through the use of the emergency brakes will not adversely affect the ability to bring the aircraft to a full stop.

Loss of both the left hydraulic system and the aux hydraulic system will also result in the loss of not only braking (and differential braking) but also Nose Wheel Steering (NWS). Full aerodynamic directional control through the rudder is available down to 80 kts with decreasing effectiveness down to 60kts. Below 60 kts there is no significant directional control available.

2.3 Accomplishment of Emergency Procedures Checklist

As set out above, the amber **L Hydraulic System Fail** message directs the crew into the QRH emergency procedure checklist for "Left Hydraulic System Failure Loss of Pressure and Fluid". Because the failure of the Left Hydraulic System occurred after the aircraft was configured to land, there was not sufficient time to complete all of the required steps in the emergency procedure checklist if the landing was to continue as planned. The PNF skipped the initial portion of the emergency procedure checklist and began reviewing the steps of the checklist at the point that matched the aircraft's configuration for landing, i.e. "landing gear down and flaps 20".

By entering the emergency checklist at this step, the PNF did not read the specific caution at the beginning of the checklist: "**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**."

In accordance with the Before Landing Checklist and prior to entering the emergency checklist, the PNF had momentarily turned on the aux pump to charge the brake accumulator after the landing gear was extended. This may have led the PNF to a false confidence that the Aux system was operating even as he later would notice left hydraulic system warning messages.

Had the crew noted and followed the caution at the very beginning of the procedure, they would have noticed that the pressure could not be maintained and would therefore be

directed to a different emergency procedure checklist for "**Left System and Auxiliary Hydraulics System Loss of Fluid**." This checklist directs the crew to select a runway that is at least 7000 feet long and 150 feet wide, plan a shallow approach, and to land within the first 1000 feet of the runway. It further states that ". . . for use of the Emergency Brake, increase pressure slowly to maintain 400 PSI. However it may be necessary to exceed this pressure in order to stop the airplane on the runway. The pilot should devote his attention to airplane control and brake application, while the copilot should monitor applied brake pressure, advising the pilot of corrections required to maintain optimum brake pressure." (see Appendix B for complete checklist)

3 Crew Resource management

Crew Resource Management (CRM) refers to a system which looks to optimize all the resources that the crew has available to allow for minimization of human error. Central to optimizing performance is open communications to provide for better situational awareness, problem solving and teamwork.

A major contributor to the accident was the communications breakdown in CRM. The PNF who was responsible for running the emergency checklists, suggests that the landing be aborted, but did not verbalize to the pilot that his recommendation was based upon the time constraints of satisfactorily completing the emergency checklists, and was not forceful enough in communicating his opinion to the pilot. The PF meantime unilaterally decided to continue with the landing for a variety of reasons that were probably not verbalized to the PNF, but regardless did not justify landing without completing the checklists. There was no compelling safety of flight condition that required an immediate landing since the right hydraulic system was operational, as further evidenced by the crew having full flight controllability at all times, but the crew did not apparently discuss this fact either.

The decision to land without determining beforehand the availability of braking capability defeated the CRM principal of maintaining situation awareness of the true nature of the problem, and the likely issues that may manifest themselves upon landing. The crew did not discuss alternatives and inoperative systems, including emergency braking procedures, and did not coordinate who was to activate the emergency brakes.

Upon landing, the PF felt it took a long time to get nose gear touch down following MLG touchdown, apparently unaware that the aircraft's ground spoilers would not deploy automatically with this hydraulic failure, and as a result of poor CRM, the PNF was not prepared to deploy the speed brakes manually.

As the landing continued to develop, the PF made a unilateral decision to attempt a balked landing and moved the throttles forward. The PNF noted the airspeed was not accelerating fast enough with the end of the runway approaching and pulled the throttles to idle to avoid what he felt was a worst case scenario of continuing the takeoff and going off the end of the runway at an ever higher speed. This unilateral action by the PNF, while not representative of good CRM, probably saved the lives of the crew.

A better result would have resulted from better CRM. Successful emergency response requires proper preparation, and a critical component of proper preparation is effective

communication. The PF, although aware to the loss of the Left Hydraulic system, was not considering the attendant possible loss of the Aux system, and the PNF was not convinced that they were fully aware of the nature of the problem. The PNF made a statement of his concern about continuing to a landing when he suggested to the PF about doing a go-around while still airborne during approach. The lack of a forceful and direct statement of concern by the PNF did not allow any opportunity to change the PF's view of the situation. This CRM failure did not allow for further analysis and complete understanding of the actions required to diagnose the problem and agree on the proper response.

4 Post Touchdown -- Emergency Brake and Balked Landing Performance

After the accident, Gulfstream performed the analysis of balked landing or the emergency brake stop options available to the crew The additional conditions were:

Weight = 51,400 lbs

Airport Pressure Altitude = 900 ft

OAT = 0C/32F

6 Knots headwind (Winds 10 kts at 340 degrees)

0.9% uphill slope (Runway 30)

Flaps 20°, no spoilers

Low Engine Idle

4.1 Balked Landing Performance Option

The balked landing was initiated at 102 knots ground speed with flaps 20, and the engines at low ground idle. Based on aircraft performance data for this condition, the engines would require 8 seconds to accelerate to 10% thrust, and an additional 5 seconds to rapidly accelerate to takeoff thrust.

Gulfstream's post accident analysis shows that after the first 8 seconds of the balked landing command, there would be a brisk acceleration to rotation speed of 117 KCAS. Therefore the distance required to accelerate from the initiation of the balked landing to 117 KCAS is 2100ft in 13 seconds. The normal rotation distance requires an additional 500ft, resulting in a total distance of 2600ft for takeoff from the noted conditions. The FDR data indicated there was about 1777ft remaining available; therefore a successful balked landing could not be accomplished.

4.2 Emergency Brake Option

The Park/Emergency Brake checklist procedure in the Quick Reference Handbook, states:

Park/Emergency Brake……AS REQUIRED TO MAINTAIN 400 PSI

Slowly apply park/Emergency Brake, increasing pressure to 400 PSI.

However, it may be necessary to exceed this pressure in order to stop the airplane on the runway. The pilot should devote his attention to airplane control and brake application,

While the copilot should monitor applied brake pressure, advising the pilot of corrections required to maintain optimum brake pressure.

There was no point during the landing that the crew attempted to use the emergency brake to stop the aircraft. The aircraft touched down with 4453 feet remaining of the 6501 feet runway length at 137 knots (132 knots ground speed). Approach speed for the weight and flaps 20 configuration was 125 knots. The pilot's first attempt to brake was at 122 knots ground speed with 3000 feet remaining using normal pedal brakes, which were inoperative. For purposes of analysis, if the pilot had initiated braking through the use of the emergency brakes at 122 knots ground speed the analysis showed that it was not possible to stop the aircraft. Following the checklist procedure with the right thrust reverser deployed and using 400 psi with the emergency brake handle, the stopping distance from brake initiation at 122 knots ground speed to full stop is 4702 ft. This point of initial brake application analysis coincides at the same time the crew received oral RAAS 3000 feet remaining callout.

In addition, had CRM been properly conducted, the crew would have followed the QRH instructions for "**Left System and Auxiliary Hydraulics System Loss of Fluid",** the pilots would have selected the 8002 ft. runway at ATW, landed within the first 1000 feet of the runway threshold, and had over 7000 feet to execute a successful stop using 400 psi of emergency brake pressure.

5 SWIVEL FUNCTIONALITY, HISTORY, AND FAILURE

5.1 Component Functionality

The Nose Landing Gear swivel (P/N 7438-4) serves as a fluid transfer vessel, transferring hydraulic fluid from the Landing Gear Selector Dump Valve (LGSDV) out to the Nose Wheel Steering System. The swivel is attached on its aft end by way of a clamped block to the side brace. The block is not keyed, and therefore does allow for minimal rotation when mounting to the strut. The nominal grip length of the Clamp Block fastening bolts provides sufficient restriction to eliminate rotation of the swivel. On the swivel forward end a mounting flange attaches to the Nose Gear Strut. This is a fixed rotational constraint about the Nose Gear Strut axis. Translational movement is minimized by the tolerance between the attaching bolt and the flange. In the Nose Wheel Steering swivel assembly; there are three swivel housings each of which contains a spool. The spool/housing interface separates pressurized and return fluid using seals imbedded in the spool grooves. The swivel provides uninterrupted flow of hydraulic fluid during gear extension, Nose Wheel Steering, and gear retraction.

5.2 Component Material

The swivel has three main housings, one at each of the forward and aft attachments, and one at the center of the assembly. The three housings are connected by fluid transfer Tubes made of 6061-T6. The center housing and spool are made from 6061-T6, and the aft and forward housings and spools are made from 7050-T74.

5.3 Swivel History

The 7438-1 swivel was part of the original Nose Landing Gear installation for the GIV-X, GV, and GV-SP. The revision history is provided in Table 1 for convenience. In 2002 the 7438-4 replaced the -3. The -4 swivel revisions included the routing of a new path connecting the pressure and return ports on the aft housing, and the insertion of a relief valve into that passage between the two channels. This change was the result of an investigation in 2001 which revealed a pressure build and lock scenario for the swivel in flight that could result in rupture failure of the swivel housing. The addition of the orifice provided a path to return for pressure built up during flight, and eliminated the pressure lock.

TABLE 2 SWIVEL HISTORY

P/N	Date	Change	Reason for Change
7438-1	May-96	N/A	N/A
7438-1A	Oct-99	Reworked -1 swivels remaining in stock at PDI to avoid part scrappage. Rework consisted of boring a larger hole in one of the mounting holes, inserting an aluminum plug and redrilling the hole in the revised location.	GAC experiencing "a minor interference problem between the swivels and the Nose gear drag brace member" -- SEM 20035. The -1A modification accomplished same change as -2 using remaining -1 stock.
7438-2	Oct-99	Relocation of mounting holes	GAC experienceing "a minor interference problem between the swivels and the Nose gear drag brace member" -- SEM 20035
7438-3	Jun-00	The -3 added a requirement for dye penetrant inspection after machining, brazing and heat treat operations. -3 also changed from forging to bar stock for Housing component, and corrective action was taken to control the concentricity of the part.	A failure of a -1A swivel assembly (S/N 112) occurred on aircraft 602 on 4/20/00. Investigation found there was a thin walled condition that occurred due to uncontrolled eccentricity of OD and ID of failed parts.
7438-4	Nov-01	Holes added to 73123 Shaft to allow for flow through new bypass orifice which was inserted between the pressure and return lines.	Pressure and return ports connected to relieve "pressure lock" in flight

5.4 Removal History

While there have been 29 swivels (P/N 7438) removed from in-service aircraft since 2001, the majority of the swivels removed to date have been due to leakage due to non-structural seal degradation issues. Gulfstream and PneuDraulics, Inc. (PDI) have record of three 7438-4 swivels prior to S/N 0748 (accident swivel) that were removed due to leakage resulting from failure of the transfer tubes or other structural failures.

5.4.1 Failure Data: S/N 0540 Damaged Prior to Installation

Swivel S/N 0540 was removed from the landing gear as received from Goodrich prior to Nose Landing Gear being installed on any aircraft in initial production in Savannah, GA on 29 April 2008. GAC records indicate that the swivel was discovered “warped”. The swivel condition was verified by PDI upon delivery from GAC.

5.4.2 Failure Data: S/N 0039 Damaged during Improper Installation During Aircraft Maintenance

On 12 June 2007 swivel S/N 0039 was being reinstalled on an in-service aircraft. The unit was previously removed to facilitate another maintenance activity. Prior to re-installation, the swivel assembly was inverted (i.e. Center Body rotated out of required installation orientation). This misalignment resulted in failure of the unit upon the initial swing of the required operational gear cycling checkout following maintenance. The unit was returned to PDI where the damage to the unit was recorded to include failed “connecting rods”. This failure is expected if the swivel is installed in the inverted position.

5.4.3 Failure Data: S/N 0689 Failure During Production Test (Gear Swings)

On 07 April 2010 S/N 0689 was removed from a production GIV-X. The technicians had completed an initial gear swing clearance check, and were in the process of a 60 cycle required operational gear cycling checkout following initial installation on the production line, using full pressure supplied by an external hydraulic cart. The specific number of completed cycles prior to the failure is unknown, however, the failure did not occur during the initial gear swing. The Aft Left Connecting Rod failed on the bottom side of the tube just aft of the Center housing body joint. The Center housing and spool were documented to be “seized”. No movement of this joint could be accomplished. In a failed attempt to rotate the center member, the GAC investigation team sheared the Connecting Rod and its adjacent Rod at the opposite end of the original failure zone. The unit was sent to PDI for investigation. While PDI reported that the failure was due to an external load, the matter was not investigated further and the unit was scrapped. This failure scenario is most consistent with the accident failure, and Gulfstream now believes that the root cause was likely the same as the accident swivel.

FIGURE 1 FAILED SWIVEL S/N 0689

5.5 Fleet Swivel Review

In support of the investigation of S/N 0748 (swivel on accident flight) Gulfstream took action to remove nine operating swivels from other aircraft in the Gulfstream fleet for inspection to assess condition of the swivel and determine the need for action on in-service aircraft. Eight of the units were removed from the same manufacturing Lot as S/N 0748 (in this instance the "Lot" was ten swivels). One additional unit was removed from a high flight time/high cycle aircraft. Two of the lot swivels and the one high time swivel (three total) were disassembled and inspected at Gulfstream. The two lot swivels disassembled by Gulfstream and the remaining five intact lot swivels were sent to an independent laboratory for disassembly and inspection. One of the Lot swivels remains intact and at Gulfstream for further investigation if needed. The results are provided in detail in Applied Technical Services (ATS) Job # D177714, but are summarized here.

5.6 Swivel Inspection Results

Evidence of contact between the housing and spool was observed for all seven units sent to ATS. There was no evidence of the required anodic coating identified for the non-grooved surface of the housing inside diameter as required by the type design drawing

(PDI drawing # 7438-4). There was evidence of the required anodic coating identified in the grooved surfaces of the housing inside diameter. The spools exhibited the required anodic coating for all internal surfaces grooved and non-grooved. The inspected units ranged in aircraft time from 54 to 235 aircraft landing cycles (pursuant to Gulfstream Computerized Maintenance Program records). No dimensional abnormalities of significance were noted, but there was evidence of galling found on all units inspected by ATS. Two units, S/N 0747 and 0749 were noted to exhibit “severe galling” on matching surfaces of the spool and housing inner-diameter.

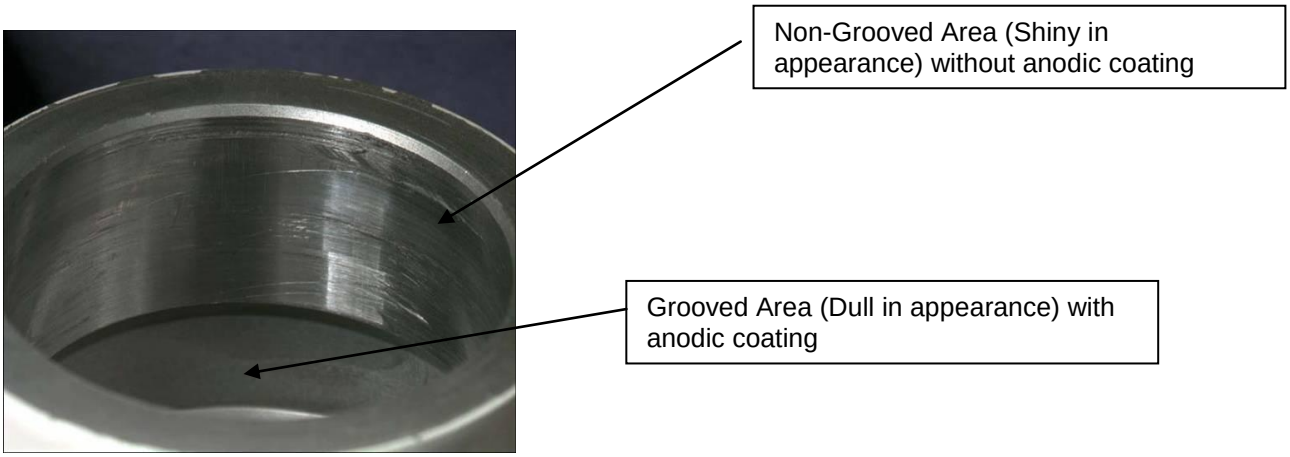


FIGURE 2 ANODIC COATING MISSING FROM NON-GROOVED SURFACE OF HOUSING INSIDE DIAMETER

5.6.1 Inspection Swivel S/N 0163

The high flight time/cycle unit swivel S/N 0163 had over 4,000 aircraft landing cycles completed before it was removed from a fleet aircraft. Upon disassembly, GAC discovered that unlike the units sent to ATS; the anodic coating was still intact for the housing ID (grooved and non-grooved surfaces). There was also evidence of spool to housing contact at the outboard landings. The contact pattern was similar to that identified on the seven units sent to ATS.

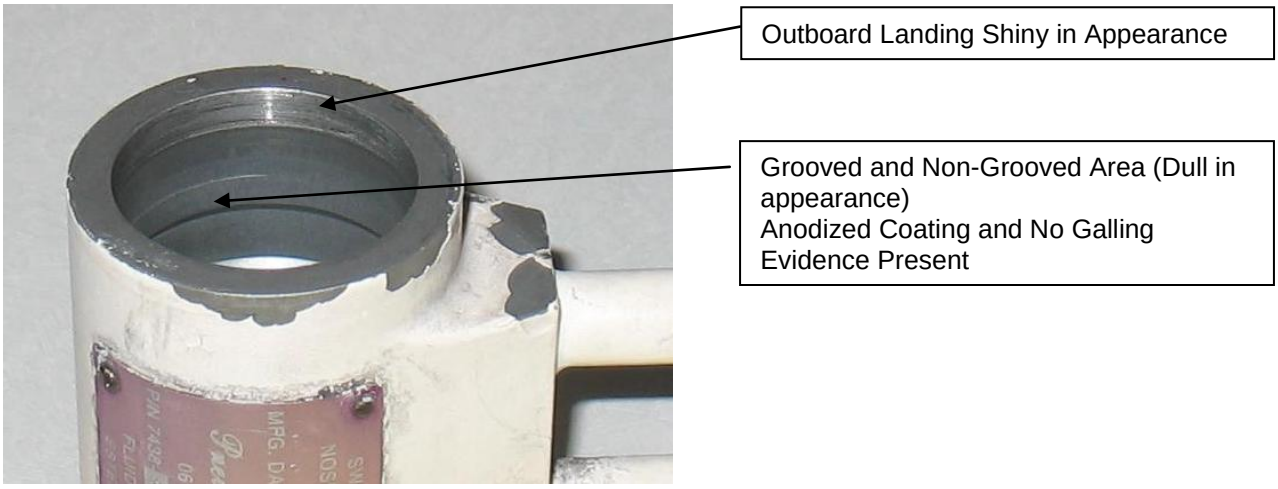


FIGURE 3 ANODIC COATING CAN BE SEEN ON HOUSING INSIDE DIAMETER (S/N 0163)

5.6.2 Inspection Swivel S/N 0783

Two days after the accident aircraft was recovered to a hangar, technicians removed S/N 0748 (accident swivel) and replaced it with S/N 0783; a swivel from a subsequent lot of swivels. Unit S/N 0783 had never been installed on an aircraft prior to its installation on the accident aircraft. The landing gear was cycled 50 times before the unit was removed for investigation. Upon disassembly at Gulfstream, the anodic coating was discovered throughout the housing inner-diameter. There were typical witness marks revealing contact between the spool and housing inner-diameter, but no indication of galling. These findings demonstrate at a minimum that the accident swivel unit failure did not result from Nose Landing Gear installation or operation.

5.7 Gulfstream Internal Testing

In addition to the independent lab investigation, GAC selected a unit (S/N 0784) for testing. The unit was installed on a GAC test aircraft, and instrumented with strain gauges at all four Connecting Rods. The purpose of the test was to identify any swivel distortion that may result from the installation and operation of the swivel on aircraft; and to determine if the strain applied to the Connecting Rods during gear cycling exceeded the yield strength of the Rod material. The gauge readings upon installation were recorded and eliminated to distinguish the strain impact resulting from cycling the Nose Gear.

5.7.1 Test Configuration

Three different installation scenarios were tested to determine the impact of a standard installation versus an intentional preload condition due to misalignment. The first test configuration required a “normal installation” of the swivel. No intentional preload was added for this configuration, and the aft clamp was attached per the maintenance manual requirements. The second and third configurations included the addition of a wooden shim to the clamp block. The shim was added to induce an asymmetric load at the clamp block

that would result in a load increase upon installation completion and during cycling of the Nose Landing Gear. The addition of the shim also minimizes self alignment of the swivel.

5.7.2 Test Results

Test data revealed that all recorded Connecting Rod strains under all configurations were over 30% below the material yield strength. When comparing the strains at different zones for a given instance, the data revealed a pattern of adjacent tubes in opposing strain vectors for the same zone on the aft connection point of the Center housing. Similar patterns were observed on all test runs. GAC concluded that the strain patterns are evidence of swivel Body distortion that occurs during gear cycling. This distortion likely resulted in contact observed between the swivel housing and spool. Disassembly of the Center housing for the test article revealed the witness marks between the housing and spool after approximately 100 cycles. The anodic coating to the housing inner-diameter was intact. As a result of this investigation, Gulfstream has determined that potential misalignment of the swivel to the landing gear in initial installation in production (or in proper maintenance reassembly) cannot lead to the failure noted in the accident unless another anomaly is present in the swivel such as the lack of the required anodic coating in the housing inside diameter.

5.8 Fleet Swivel Review

On aircraft test data indicates that the Connecting Rod loading due to installation and cycling does not exceed the yield strength of the Rod material. Over 15 years of operation in the GAC fleet support the test results. Data from all disassembled units to date reveals a pattern of contact between the spool and housing inner-diameter that can be identified by witness marks between the two surfaces. The cause of the galling which led to the swivel seizing has not been identified, but the seizing event is the differentiating factor between the two failed units identified, and the units currently operating in the fleet. The failure mode identified for these two units appears to be an issue of infant mortality. Both units failed with less than 20 on aircraft cycles. In contrast, GAC has removed units from the fleet in support of this investigation with over 4000 cycles completed without issue prior to removal. As previously noted, all units removed for inspection to date have revealed evidence of internal contact; very few units have shown galling. No unit reviewed has had the degree of damage observed with S/N 0748. GAC will work with PDI to identify the cause of the anodic coating removal from the housing inner-diameter, and to determine how the lack of coating may have contributed to the galling/ seizing condition.

5.9 Gulfstream Audit of Swivel Manufacturer

Subsequent to the accident Gulfstream performed a quality audit of the PDI operations associated with the manufacturing of the Nose Wheel Steering swivel. The results of that audit are attached at Appendix A and summarized below.

- PDI personnel do not perform “in process” assembly inspections; inspection is essentially an end item review of completed work documentation and acceptance.

- PDI does not document "rework" actions; each step of the process is worked and reworked until required acceptable product conditions are met. This is of particular notice during the Acceptance Test Procedure (ATP) for the pull test where a value of 25 pounds pull force (or less) is required. (i.e. – if a pull test exceeds the 24 pound force – the NWS swivel is removed, disassembled – evaluated – reassembled and retested.

If subsequent attempts to pass the pull test are not successful; the technician will provide the discrepant unit to the supervisor for action and it is then returned to the technician for retest – which Gulfstream believes is when additional honing may occur and remove the anodize surface. This is non-compliant to the PDI Quality Manual that requires the documentation of rework actions. (QSP 13.101)

There is no documented required or allowed process in PDI manufacturing processes for "additional honing" after the initial fabrication / machining of the housings / spools and their placement in stock for future assembly.

- One 72740 housing was found in stock awaiting assembly with oversized inner diameter (ID) (Drawing 1.178/1.180 ID; actual 1.183) with no discrepancy paperwork. Measurements were made using a bore gage and measured in numerous locations to ensure article meet the concentricity requirement.
- While no evidence of rework was found or additional honing identified – Gulfstream believes the PDI manufacturing, inspection and undocumented rework processes provide an opportunity for the anodic coating to be removed during honing following anodize (see process flow in Audit document) if units do not successfully complete the pull test requirements or other binding during the assembly process at PDI.

5.10 Swivel Failure

Gulfstream has determined that the NWS swivel failed because of a manufacturing defect. The defect was a lack of the specified anodic coating most likely resulting from an undocumented rework process which removed the original anodic coating from the housing ID. The anodic coating provides corrosion protection and wear protection on the surfaces in the event of contact between the spool and housing ID. In the accident NWS swivel, the required anodic coating on the inside diameter of the center swivel housing was missing.[4] The absence of anodic coating allowed galling to occur during incidental contact during normal G550 NWS swivel operation. The galling which occurred in the accident NWS swivel eventually resulted in the swivel housing and spool seizing upon gear extension during the accident landing. The NWS swivel housing and spool seizing caused the left aft fluid transfer tube in the swivel to crack open upon nose landing gear extension. The crack in the left aft fluid transfer tube allowed all of the hydraulic fluid in the Left System Reservoir, to fully deplete within 40 seconds of the transfer tube cracking upon landing gear extension. The Aux System Hydraulic Reservoir was also depleted through the crack at the transfer tube at some point prior to touchdown.

[4] See ATS Report D166449 Dated 17 May 2011.

6 FDR Issues

Synopsis of the FDR concerns raised from the flight data recorder (FDR) group convened on March 8, 2011.

National Transportation Safety Board (NTSB) felt the Gulfstream FDR documentation was "insufficient to decode the flight data" and "difficult to understand". Therefore, the NTSB called an "FDR Group" to have Gulfstream's assistance in decoding and verifying the data.

Two areas of contention with respect to the Gulfstream FDR exist in the FDR documentation GVSP-GER-6098 and the recording of aircraft parameters. The following sections provide detail.

6.1 FDR Documentation

As the NTSB noted in the FDR Group Report (DCA11FA193) FDR data frame correlation documentation is not required for 14 CFR Part 91.609 but is required for 14 CFR Part 135.152(f)(2). As the Gulfstream GV-SP fleet operates under both Part 91 and Part 135 rules, Gulfstream has developed an FDR data frame document, GVSP-GER-6098 (rev h), and thus provided a copy to the NTSB to aide in the investigation. As stated above, the NTSB felt they could not use this document to decode the FDR data without the assistance of Gulfstream engineering.

The FDR Group Report (DCA11FA193) contains a list of aspects of GVSP-GER-6098 (rev h) that the NTSB felt were insufficient. The FDR group worked through these areas of concern to decode the FDR data.

Subsequent to the FDR Group Meeting, Gulfstream revised GVSP-GER-6098 (rev j) [note: revision letter "I" is not used], 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. Revision k is to be included in the Gulfstream Party Submittal. While rev k is improved, Gulfstream recognizes that this document will need a thorough re-examination and modification. Gulfstream has accepted this as a follow-on task and will execute appropriately.

6.2 FDR Parameter Recording

Seventy five (75) aircraft parameters were decoded and studied as part of the accident investigation. An outline of the parameters is provided in the FDR Group Report (DCA11FA193). GMT time contained in the A717 word #256 was decoded first. The FDR recorded time at a rate of once per second but was updated at a rate of once per 4

seconds. 14 CFR 91 appendix F, 14 CFR 121 appendix M and 14 CFR appendix F were referenced as containing the minimum requirements for FDR parameter recording.

An excerpt of section 4.1.2 of the FDR Group Report (DCA11FA193) is below.

> ***4.1.2. Recording Description***
>
> *The FDR recording contained approximately 73.5 hours of data. Timing of the FDR data is measured in subframe reference number (SRN), where each SRN equals one elapsed second. The event flight was the last flight of the recording and its duration was approximately 3 hours.*
>
> *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.*
> FDR Group Report (DCA11FA193)

The FDR Group Report (DCA11FA193) notes that there appears to be a discrepancy in the requirements as Part 91 as published has more stringent requirements, with respect to the sampling of time, than that of Part 135 and Part 121. Below is a table to better illustrate the condition.

TABLE 3 DFDR REQUIREMENTS TABLE

	Time or Relative Time	**Pressure Altitude**
14 CFR part 91 (Appendix E)	Once every 1 second	11 samples per second
14 CFR part 121 (Appendix M)	Once every 4 seconds	Once every 1 second
14 CFR part 135 (Appendix F)	Once every 4 seconds	Once every 1 second
ED-112 MOPS for FDR	Once every 4 seconds	Once every 1 second
Foxtrot (512wps FDR)	Once every 4 seconds Does not meet Part 91	Once every 1 second Meets all Parts

Background: Historical revisions of the FARs, going back to September 30, 1963, have the same timing requirements for the recording of Relative Time and Pressure Altitude. These parameter requirements have not changed since initial release.

Evidence that the appendix in 14 CFR Part 91 is incorrect comes from the Minimum Operational Performance Specification (MOPS) For Crash Protected Airborne Recorder Systems ED-112. ED-112 is the basis for all FDR requirements.

ED-112 requires that the replay of a recording made by any required recorder shall be capable of being synchronized in time with any other required recording to within 1 second. The recording of time at the rate of once every 4 seconds is sufficient for resolving FDR data down to the second. The Gulfstream GV-SP FDR meets the system requirements of the MOPS. The FDR has an internal counter that is updated every second and referenced to the recorded GMT Time parameter which is recorded every 4 seconds. This is referred to as the SRN number in the NTSB FDR tool.

Gulfstream believes that the published 14 CFR Part 91 Appendix E is typographically incorrect as it does not harmonize with the MOPS 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.

Similarly, Gulfstream believes that the 11 samples per second is a typographical error, and that the requirement should be 1 altitude sample per second for Part 91 just as it is for Parts 135 and 121 operations. Gulfstream complies with the 1 sample per second requirement. The 14 CFR Part 91 Appendix E should be corrected to avoid further confusion.

7 Changes to Quick Reference Handbook

The Quick Reference Handbook 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.

8 Conclusions and Proposed Findings

This accident could have been avoided with proper crew management of the hydraulic failure.

The accident sequence began when the NWS swivel failed upon gear extension for landing at ATW on the accident flight which led to the depletion of fluid from both the Left Hydraulic System and the auxiliary hydraulic system causing numerous systems used for normal landing to become inoperative. The NWS swivel failure was caused by a manufacturing defect where the required anodic coating on the inside diameter of the center swivel housing was missing, allowing galling to occur during swivel operation which eventually resulted in the swivel housing and spool seizing upon gear extension during the accident landing. The NWS swivel housing and spool seizing caused a fluid transfer tube in the swivel to crack open upon nose landing gear extension. The fluid from the left hydraulic system, including the attached auxiliary hydraulic system, then fully ported through this cracked transfer tube, depleting the system of all fluid prior to touchdown. The failure of the NWS swivel and loss of left and auxiliary hydraulic system established an emergency condition that was defined in the pilots' QRH that when poorly managed by the flight crew caused the accident.

While the crew was alerted to the left hydraulic system failure by the aircraft's crew advisory system, the crew did not take the necessary time to complete the emergency checklists prior to landing. By failing to complete the required checklists, the crew unknowingly landed without normal ground spoiler and brake operation. Had the crew decided to go-around prior to landing, there would have been sufficient time to execute the required emergency checklists set out in the QRH in response to the CAS messages, As a result, the crew would have been advised on how to properly configured the aircraft, coordinate their cockpit duties, and execute a safe landing. The failure of the crew to perform this go-around before landing to brief themselves fully on the emergency and conduct proper Crew Resource Management preparations is the primary cause of this accident.

Following the accident, Gulfstream determined that the emergency checklists for the relevant CAS messages displayed during the accident, while correct, required the crew to check whether or not the Auxiliary Hydraulic System was functional. A simpler emergency checklist which assumes a dual left hydraulic system failure and auxiliary system failure was published by Gulfstream in the Quick Reference Handbook for the G550 and will soon be published in other Gulfstream aircraft with similar dual system failure possibilities. The new emergency checklist and its assumption of auxiliary hydraulic system failure, reduces the number of checklists required and the new combined checklist quickly prepares the crew for landing without automatic deployment of ground spoilers, left Thrust Reverser, Nose Wheel Steering, and normal braking, preparing them to select a long runway, take a shallow approach, land within the first 1000 feet of the runway threshold, manually deploy speed brakes and prepare to deploy emergency brakes if normal braking is unavailable. If the hydraulic failure is not a dual failure disabling the auxiliary hydraulic system, the crew will be able to stop the aircraft using normal braking. Gulfstream believes this revision is a safety enhancement. Gulfstream does not believe that the emergency checklists as they existed at the time are a contributing factor to the accident.

Putting aside the crew resource management issue addressed above, this accident could have been avoided by proper airmanship on the part of the experienced production/completion test pilot who was flying the aircraft. The PF has ultimate responsibility for determining whether a landing is safe to continue, and he should have aborted the landing on the first display of an amber caution message on the CAS. Having failed to do that, the PF was the crewmember responsible for brake application on touchdown and therefore the first crew member who was aware that the normal brakes were not working. The PF should have applied the emergency brakes as necessary to stop the aircraft on the runway, as he reports was his first intention. If he had done so, the likely result would have been that the aircraft would have been brought to a stop on the runway with little damage other than blown tires. Gulfstream believes the PF's failure to apply emergency brakes is a contributing factor in this accident. Additionally, the PF's decision to attempt to take off after he recognized the brake failure, and after the engines had been retarded to idle and the thrust reverser deployed, with less than 2000 feet of runway remaining, displayed very poor airmanship judgment. There was simply not enough runway left to get this aircraft airborne at this point in time. Gulfstream believes the PF's decision to attempt to take off with this configuration and at this location on the runway was a contributing cause of the accident.

Putting aside the crew resource management issue addressed above, a portion of which was the responsibility of the experienced production/completion test pilot who was not flying the aircraft; we commend the airmanship of the PNF for countermanding the PF's decision to attempt to take off by unilaterally retarding the throttles and aborting the attempted take off. The PNFs proper action at this late stage in the accident sequence prevented even more serious damage to the aircraft and the possible loss of life of the three crew members aboard the aircraft.

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.

Appendix A PDI Trip Report

PneuDraulics, Inc. Trip Report
Nose Wheel Steering Swivel (p/n 7438-4)

I. Purpose

a. The scope of this investigation was to understand the manufacturing, special processing, assembly, and documentation of the 7438-4 Nose Wheel Steering Swivel (NWSS). Areas addressed included:

i. Reviewed engineering documents that applied to the manufacturing, build and specifications that applied to the build
ii. Reviewed manufacturing planning
iii. Reviewed manufacturing operation documentation to include Material Review Board (MRB) actions
iv. Reviewed a total of 24 completed records, 12 on either side of serial number 0748
v. Witnessed/walked through the build process, to include Acceptance Test Procedure (ATP)
vi. Understanding the PneuDraulics, Inc. (PDI) "honing" process, and ensuring dimensional accuracy is maintained
vii. Understanding what is manufactured or special processed by a PDI sub-tier suppliers and how does PDI control that process
viii. Determine potential root cause and corrective actions for past NWSS failures where the housing tubes were broken and possible impact to fleet reliability / safety.

II. References

Appendix 1	Photograph of Swivel at Detail Part Level
Appendix 2	Flow Chart of 7438-4 Build Process
Appendix 3	Table 1.0 Drawing List
	Table 1.1 Swivel Chart
	Table 1.2 Stock Sweep

III. Background

Gulfstream Aerospace has experienced approximately thirteen "broken, leaking" swivels on part number 7438-4. Out of the group, at least two swivels exhibited a binding condition where the short tube had broken away from the housing assembly part number 72741. During the tear down investigation it was noted that the inner diameter of the housings exhibited "galling or metal to metal" contact between the shaft and housing. In both cases the short tube had broken away from the housing.

IV. Who / When / Where

August 8-9 2011

Attendees:
Pneudraulics, Inc (PDI):
Dain Miller, President
Greg Burns, Director of Quality

Gulfstream Aerospace (GAC):
Max Mills, Director-Quality & Product Safety
Danny Smith, Procurement Project Manager
Keith Nesheim, Supervisor Procurement Quality
Jay Bias, Procurement Quality Engineer

Goodrich Aerospace:
Carol Blaine Supplier Control

V. Review and Discussion

a. Review of Engineering Documents:

i. Engineering documents noted in table 1.0 (Appendix 3) were reviewed to understand how the assembly is manufactured, assembled and tested.

ii. Item of interest during the review of drawing 72749 indicated a flash hard anodize to .0001/.0002 per Mil-A-8625 Type III class I (interest in both the term "flash anodize and the thickness callout).

iii. Visual Work Instructions (VWI) note on slide 6 of 24 stated "round corner of each backup must face "GT" ring. If not installed correctly it will increase the seal squeeze; resulting in failure of ATP pull test.

b. Manufacturing Planning:

i. PDI incorporates proprietary drawing and ATP engineering data into a manufacturing plan including operations, special processing, assembly, and inspection validations. Discussion and review of planning documents were found to be acceptable.

ii. Manufacturing documents for assembly operations are at a high level with no in process quality buyoffs of operations or witnessing of the ATP process.

c. Manufacturing Operation Documentation:

i. Visual Work Instructions (VWI) are used at PDI as an electronic work instruction in lieu of paper build instructions as utilized in the past. In discussion with PDI, it appears this lean process should provide enhanced configuration control for the fabrication of the article it addresses, as any information that is added to the work instruction is provided immediately to the technicians on the floor.

ii. Numerous work orders (WO) were reviewed with the following results (Note - A work order is associated with a series of NWSS that are built for a customer purchase order; this is not a continuous flow process; NWSS are only made "on demand.")

1. WO A70658 for 7438-4 serial number 0667 reviewed, found "hard anodizing requirement not per blueprint requirement." Actual was .0002 to .0004, blueprint requirement is .0001 to .0002. Document was complete but many inconsistencies were noted throughout the document. Stamping off, initial sign off, and dates were not consistently applied to the document. ATP records appeared to be in order; detail article records were archived and not reviewed.

2. WO 77166 regarding serial number 0806, 0807 detail part 72741(housing) reviewed. Work instruction indicated an out of round condition (article measured 1.1803 should have been 1.178-1.180). Article was found acceptable and noted on WO documentation.

3. WOA75794 reviewed, no discrepant conditions were noted.

iii. Receiving Inspection missed drawing requirement for Hard Anodizing while reviewing sub-tier supplier certifications. Certification indicated .0002-.0004. The acceptance of this incorrect anodize thickness had been accepted by PDI inspection personnel through approximately March 21 of 2011, following Quality visit.

iv. MRB action was not noted on the records the investigation team asked to review. PDI was asked to explain the process and provide any MRB actions regarding the 7438-4 swivel. PDI furnished MRB actions for:
   1. Part number 72741 Housing - ID label Issue (1 tag) - Issue was noted as closed Corrective Action was not noted for discrepant condition.
   2. Part number 72738 Shaft –Thread Issue (5 tags) - Issue was noted as closed. Corrective action was not noted for discrepant condition.
   3. I/R D30697 was generated for the Hard Anodizing .0002/.0004 non-conformance on 02/21/11, which had an engineering disposition “use as is.” It wasn’t clear at what effectivity level non-compliant units started or when compliant units were issued. (Mixed and matched housings and shafts). Note this non-conformance was noted during the Gulfstream investigation conducted on 02/19/11. Gulfstream Aerospace requests a formal corrective action for this condition.

d. Review of Maintenance Records Addressing ATP Force Check Requirements

See Appendix 3 for Table 1.1

e. Walk Through of Build (fabrication), Assembly and Test Area

Process flow chart see appendix 2.

i. Walk-through- Detail part.

1. Raw Materials – Raw material storage was not observed. Material is moved into the fabrication area when requirement is identified.

2. Fabrication- Raw material is fabricated to the required engineering data,

   a. Fabrication area appeared to be congested but clean and organized. Certifications were noted with the raw stock witnessed in the fabrication area. Tooling appeared to be in serviceable condition, stock rooms within the area were congested but neat.

3. First Piece Inspection - 100% inspection of blueprint characteristics.

4. Lot Detail Part Inspection Report (DPIR) is created - One piece out of the lot receives 100% inspection to the engineering data.

5. Stock part - Articles moved into stock after DPIR process. (Articles in stock are expected to meet the engineering requirements.)

6. Brazing - Articles removed from stock and sent to PDI approved supplier for brazing. PDI requirements are flowed down to their supplier by notations on the purchase order.

7. Receiving Inspection - Receives articles and validates certifications that were issued with the article; and validates the article per the engineering/purchase order requirements. Article received into PDI stock.

8. Anodizing - Article sent out for anodizing; again the engineering requirement is flowed down to a PDI approved supplier by notations on the purchase order.

9. Receiving inspection – Receives article per purchase order requirements and performs conductivity check to verify the anodizing process has been completed (not the thickness of the anodized layer.)

10. Inspection DPIR - Lot inspection of one article preformed and documented on received articles after receiving inspection is completed.

11. Stocked - Articles are stocked and based on the sample DPIR, all assumed to meet engineering requirements.

12. Kitted - Articles are removed from stock and kitted when there is a demand for the article.

ii. Walk–through - Assembly (Rework/Replace)

1. Assembly - Area was noted as extremely congested. Team did witness the re-assembly of serial number 844 which was assembled in accordance with the VMI. Work traveler indicated a torque call out on the attachment nuts in which the VMI did not call out. The team did witness the torque of the nuts to the engineering data being properly stamped indicating completion. The Director of Quality indicated the VMI would be up-dated per the requirement. This issue pertains to document control regarding information transfer from the engineering requirement to the VMI. (Gulfstream is requesting a root cause corrective action pertaining to this issue.) As noted above, the unit s/n 844 was reassembled; during this process previously used seal packing was used.

2. Break In - Article is assembled and a break in period of 60 cycles is conducted, twenty cycles @ 1500 PSI, twenty cycles @ 3000 PSI, and twenty cycles @ 4500 PSI. (PDI indicated without break in step units probably would not pass ATP.)

3. ATP - Article moves into testing, ATP witnessed on serial number 0843, unit was powered up to 4500 PSI to seat seals and leak check. Pressure is lowered to 3000 PSI and force check is complied with and 25 pounds of force were noted. The requirement for the force check is for the unit to swivel (extend, travel) one inch and not exceed 25 pounds of force. The

demonstration technician number 1435 was well versed in the assembling and ATP process. Finding: when asking the technician about how rework was documented, he indicated the nature of the rework was not documented. The unit was disassembled and reworked until it passed ATP. Asking PDI Quality how they tracked discrepant conditions or issues that require teardown for rework, their response was that they did not document the actual condition but tracked all re-work through a "time charge". The time charge addressed the time the issue took to rework but did not address the actual condition that caused the rework. PDI quality manual QSP 13.101 directs non-conformances to be documented.

4. Paint - Article is sent out to an approved PDI supplier for paint, again the requirement is flowed down by notations on the purchase order.

5. Final Inspection - Article is received from approved supplier where the article receives a "final inspection". Final inspection reviews all associated documentation of the article. Inspection buy off to any assembly or testing function was not noted. PDI indicated inspection buy off was document review only.

f. Understanding the Honing Process and How PDI ensures articles are Concentric to the Drawing Requirements.

i. The "honing" process is actually an element of the detail fabrication process for the 72738, and 73123 spool and 72749 and 72741 housings. There is no defined manufacturing process for additional honing once the initial fabrication / honing to engineering requirements are complete.
ii. Articles were pulled from stock to verify to validate inspection of the articles. Inspection results noted in table 1.2 of appendix 3. Measurements were made using a bore gage and measured in numerous locations to ensure article meet the concentricity requirement.
iii. PDI did verify the bore gage used to inspect the ID was in calibration and was in serviceable condition. PDI committed to issuing an IR to address the discrepant material as well as existing stock. This finding requires a Corrective Action. Results are to be reported to Goodrich Aerospace (Carol Blaine)

g. PDI Special Process

i. PDI does not perform any special processing in house but subcontracts process out to NADCAP approved sources. PDI does flow the process requirement down on the purchase order and verifies the article through receiving inspection by reviewing the received document to the requirement. Danco was the process house used to perform the anodizing process and was verified to be an approved supplier to PDI. PDI agreed that the PDI receiving and inspection process had missed the incorrect anodizing thickness requirement; and that PDI subsequently met with Danco to correct the interpretation issue and also recorded this outcome in the PDI IR processes.

VI. Conclusion:

The audit findings and observations showed a lack of discipline in following the PDI Quality procedures and process. This was evident when looking at the quality system pertaining to

documentation of non-conforming product, rework, and quality system breakdowns regarding detecting non-conforming products and identifying documentation errors.

In conclusion the review processes of the quality system indicated it will not prevent non conforming product from leaving the facility and being sent to customers if rework is performed.

VII. Corrective Actions

a. PDI Actions debriefed

i. Stock sweep of housing assembly 72740 that was found to be Out Of Tolerance - IR disposition
ii. Define the serial number range where proper anodizing of the compete assembly started.
iii. Establish a metric that addresses rework and type of rework performed, follow prescribed PDI quality requirement QSP 13.101.
iv. Requested force check for serial numbers 440, and 540.
v. Define when PDI is obligated to inform its customer of a non-conforming article.

b. Summary of Corrective actions to be recorded by GAC Procurement Quality for communication with Goodrich / PDI for follow up.

i. PDI failed to furnish a disclosure/escape letter to the “Anodizing nonconformance.” GAC quality expects Goodrich to address this escape and identify the serial number range of “Anodizing non-conformance”.
ii. VWI did not address all engineering requirements pertaining to the assembly of the 7438-4 swivel (torque of the attachment nuts) GAC quality requires Goodrich to provide root cause and corrective action addressing PDI’s configuration control and data transfer to PDI fabrication, assembly, and testing documents. (written or electronic).
iii. Goodrich to provide corrective action for the housing assembly 72740 that was found to be Out Of Tolerance (found during the stock sweep).
iv. Goodrich to provide corrective action addressing PDI receiving Inspection procedures and verification of received product to PDI engineering requirements.
v. Goodrich action to ensure PDI is following their own quality procedures in addressing non-conformities (QSP 13.101).

c. Understand drawing requirement regarding parallelism pertaining to the 72740 housing or spool assemblies in all axis to assure continued free movement of absence of the opportunity for binding of the spool and housing.

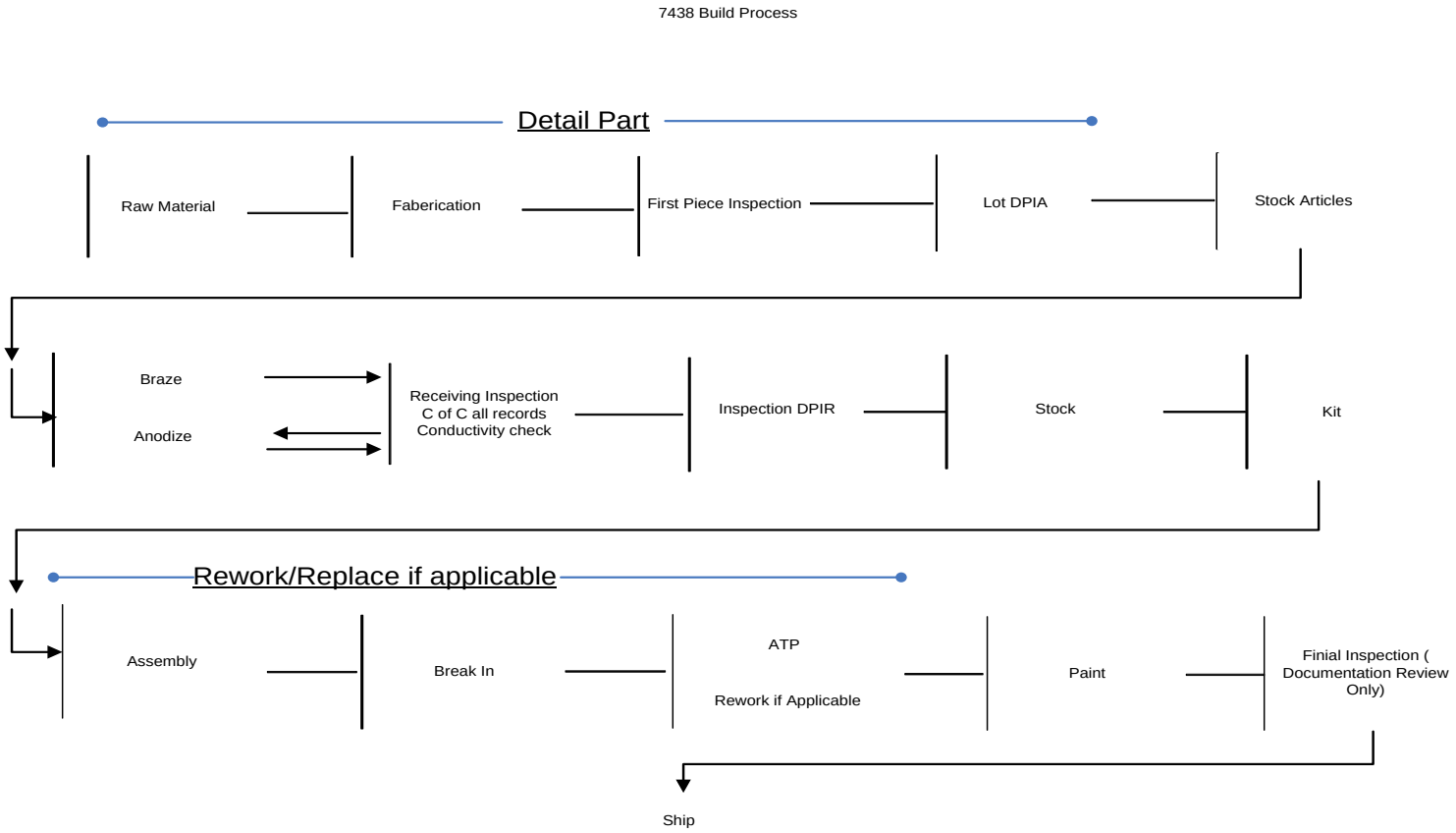
Appendix 1 – Photos

Photograph of Swivel @ Detail Part level and Manufacturing Process

72749 Housing **72741 Housing**

72737 Shaft Assembly **73122 Shaft Assembly**

Appendix 2


7438 Build Process
Detail Part
Raw Material
Fabrication
First Piece Inspection
Lot DPIA
Stock Articles
Braze
Anodize
Receiving Inspection
C of C all records
Conductivity check
Inspection DPIR
Stock
Kit
Rework/Replace if applicable
Assembly
Break In
ATP
Rework if Applicable
Paint
Finial Inspection (Documentation Review Only)
Ship

Appendix 3
Table 1.0

Drawing #	Noun (nomenclature)
7438-4 (Revision C)	Swivel Assembly
72738	Shaft
73123	Shaft
72749	Housing
72741	Housing
7438-4 (Revision 4)	ATP
Visible (Visual) Work Instruction (Revision A) (VWI)	Same

Table 1.1 **Review of Maintenance Records Addressing ATP Force Check Requirements (* indicates production lot that included serial number 0748).**

Serial Number	Pounds of Force	Serial Number	Pounds of Force
731	**25**	***749**	**24**
732	**24**	***750**	**25**
733	**25**	**751**	**25**
734	**25**	**752**	**24**
735	**24**	**753**	**25**
736	**24**	**754**	**24**
737	**25**	**755**	**24**
738	**25**	**777**	**24**
739	**25**	**778**	**24**
740	**24**	**779**	**24**
***741**	**24**	**780**	**24**
***742**	**22**	**781**	**24**
***743**	**23**	**782**	**24**
***744**	**20**		
***745**	**24**		
***746**	**25**	**689**	**23**
***747**	**24**	**440**	**Archived**
***748**	**Archived**	**540**	**Archived**

Table 1.2

Part Number	Noun	Drawing Requirement	Actual Measurement	Lot Number of Article Inspected
72740	Housing Assembly	1.178/1.180 ID	1.1803	27822U
72738	Shaft	2.45 + 005 -000 Length	2.452	20061T
72741	Housing	Not Available		

Appendix B Quick Reference Handbook Changes

Pre-Accident: L Hydraulic Sys Failure – Loss of Pressure & Fluid

Left Hydraulic System (L SYS) Failure – Loss of Pressure and Fluid

AFM 03-15-10

Continue flight to nearest suitable airport and land.

CAUTION: 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 Left (L SYS) and Auxiliary Hydraulic System (AUX) Loss of Fluid PAGE EE-7.

1. FGC ..... SELECT FGC 2
2. Hydraulic Synoptic / Quantity ..... DISPLAY / CHECK
3. Power Transfer Unit (PTU) ..... NOT ARM

If a hydraulic leak in the flaps system is not suspected, proceed to Step 5. Otherwise, disable flaps by performing Step 4.

4. FLAP / STAB (L and R) DC Circuit Breakers ..... PULL
   FLAP/STAB LEFT DC: POP, C-6 (see page S-44)
   FLAP/STAB RIGHT DC: CPOP, C-6 (see page S-44)
5. AUX Pump ..... SELECT ON FOR 30 SECONDS
   With a complete loss of Left Hydraulic System fluid and the gear handle selected up, the L SYS reservoir will show approximately one gallon of fluid and the Auxiliary Hydraulic System (AUX SYS) reservoir will continue to indicate full.
   When the gear is selected down, the L SYS reservoir will indicate zero (0) and an amber "X" will be displayed over the AUX SYS reservoir. For either case, the only way to verify availability of AUX SYS fluid is to select the AUX pump on and observe that pressure can be maintained.
   If loss of L SYS fluid and AUX SYS fluid is suspected or has occurred, see Left (L SYS) And Auxiliary Hydraulic System (AUX) Loss Of Fluid, page EE-7.
6. AUX PUMP ..... ON
7. Flap Handle (If CBs Were Not Pulled in Step 4) ..... 20°
   Twenty degrees (20°) flaps should be planned for approach and landing.
   NOTE: Flap extension from UP (0°) to 20° will take at least one (1) minute. A Aux Hydraulic Fail message will be displayed on CAS during flap movement.

Continued on next page →

Left Hydraulic System (L SYS) Failure – Loss of Pressure and Fluid, ctd...

AFM 03-15-10

For approach and landing:

8. Airspeed ..... 175 KCAS MAXIMUM
9. Landing Gear Handle ..... DOWN
10. EMER LDG GEAR HANDLE ..... PULL
    CAUTION: DO NOT RESET EITHER THE EMERG LDG GEAR HANDLE OR DUMP VALVE PRIOR TO LANDING.
11. Landing Gear ..... DOWN / 3 GREEN
12. Flaps Position (If Available) ..... VERIFY 20°
13. VREF ..... APPROPRIATE TO CONFIGURATION
    Plan a wide approach and observe VREF speed appropriate to configuration as shown in G550 Performance Handbook (section PC) or AFM Section 05: Approach and Landing Speeds Charts and Landing Field Length Charts.
    Minimum VREF for abnormal flaps condition is 125 KCAS.

To clear Steer By Wire Fail message:

14. AUX Pump ..... VERIFY ON
15. NOSE WHEEL STEERING POWER ..... CYCLE OFF THEN ON

Prior to touchdown:

CAUTION: ENSURE THAT THE FLAPS HAVE REACHED THE 20 DEGREE POSITION PRIOR TO TOUCHDOWN. IF FLAPS ARE STILL IN TRANSIT, DELAY THE LANDING UNTIL THE FLAP MOVEMENT HAS STOPPED. IF UNABLE TO DELAY THE LANDING, PULL THE FLAP / STAB LEFT DC (POP, C-6 – SEE PAGE S-44) AND FLAP / STAB RIGHT DC (CPOP, C-6 – SEE PAGE S-44) CIRCUIT BREAKERS TO STOP FLAP MOVEMENT. LANDING WITH THE FLAPS IN MOTION DRIVEN BY THE AUXILIARY HYDRAULIC PUMP WILL CAUSE A LOSS OF BRAKES DURING LANDING ROLLOUT.

16. GPWS/GND SPLR FLAP ORIDE ..... ON
    Select the ORIDE switch to ON if landing with flaps less than 22 degrees. This prevents the nuisance 'TOO LOW FLAPS' aural alert and provides backup capability to deploy the ground spoilers with wheel spin-up.

Continued on next page →

Pre-Accident: L Hydraulic Sys Failure – Loss of Pressure & Fluid

Pre Accident: L Sys & Auxiliary Hydraulic System Loss of Fluid

Left System (L SYS) and Auxiliary Hydraulic System (AUX) Loss Of Fluid

AFM 04-15-20

Continue flight to nearest suitable airport and land.

CAUTION: TO VERIFY THE AVAILABILITY OF AUXILIARY SYSTEM FLUID, SELECT THE AUX PUMP ON FOR MINIMUM OF 30 SECONDS AND CHECK FOR AUXILIARY SYSTEM PRESSURE. IF PRESSURE CAN BE MAINTAINED, ASSUME THAT THE AUXILIARY SYSTEM IS AVAILABLE AND PROCEED TO Left Hydraulic System (L Sys) Failure – Loss of Pressure and Fluid, PAGE EE-10.

In case of complete fluid loss to the Left Hydraulic System and the Auxiliary Hydraulic System, proceed as follows:

1. FGC ..... SELECT FGC 2
2. PTU ..... NOT ARM
3. AUX PUMP ..... CHECK OFF

Approach:

Select a runway that is at least 7,000 feet (2133.6 m) long and 150 feet (45.7 m) wide. Minimize crosswind component to less than 5 knots if possible. If crosswind is present, plan the landing on the downwind side, as the airplane will weather vane into the wind as rudder effectiveness is lost. Plan a shallow approach to land within the first 1,000 feet (305 m) of the runway.

4. GPWS / GND SPLR FLAP ORIDE ..... ON / AS REQUIRED
5. NOSE WHEEL STEERING POWER ..... OFF
6. Airspeed ..... 175 KCAS OR LESS
7. Landing Gear Handle ..... DOWN
8. EMER Landing Gear Handle ..... PULL

   CAUTION: DO NOT RESET THE EMER LDG GEAR HANDLE OR LANDING GEAR DUMP VALVE PRIOR TO LANDING.
9. Landing Gear ..... DOWN / 3 GREEN
10. Anti-Skid ..... OFF
11. Ground Spoiler ..... OFF
12. Brake System Page ..... SELECT

Continued on next page →

Left System (L SYS) and Auxiliary Hydraulic System (AUX) Loss Of Fluid
AFM 04-15-20

13. VREF ..... APPROPRIATE TO CONFIGURATION

    Plan a wide approach and observe VREF speed appropriate to configuration as shown in **G550 Performance Handbook (section PC)** or **AFM Section 05: Approach and Landing Speeds Charts** and **Landing Field Length Charts**.

    Minimum VREF for abnormal flaps condition is 125 KCAS.

Landing:

After landing, deploy the right thrust reverser as required to slow the airplane, maintaining aerodynamic directional control with the rudder. Aerodynamic control will not be available below 60 knots and will begin diminishing at around 80 knots. Depending on winds, runway crown, etc. the airplane may veer as rudder effectiveness is lost. The right thrust reverser may mitigate a veer to the left. A slight thrust increase on the right engine (forward thrust) may mitigate a veer to the right **but with a corresponding increase in landing roll**. In either case, cautious application of reverse or forward thrust if required should only be considered if a runway departure is likely.

14. Speed Brakes ..... EXTEND
15. Right Thrust Reverser ..... DEPLOY / AS REQUIRED

    CAUTION: IT IS NORMAL FOR DECELERATION TO INCREASE AS THE STOP PROGRESSES. THIS MAY RESULT IN LOCKED WHEELS AND BLOWN TIRES. REDUCE PRESSURE AS REQUIRED TO MAINTAIN CONSTANT DECELERATION. THERE WILL BE A SIGNIFICANT INCREASE IN LANDING DISTANCE WITH ANTI-SKID INOPERATIVE.
16. Park / Emergency Brake ... AS REQUIRED TO MAINTAIN 400 PSI

    Slowly apply Park / Emergency Brake, increasing pressure to 400 PSI. However, it may be necessary to exceed this pressure in order to stop the airplane on the runway. The pilot should devote his attention to airplane control and brake application, while the copilot should monitor applied brake pressure, advising the pilot of corrections required to maintain optimum brake pressure.

Continued on next page →

Pre Accident: L Sys & Auxiliary Hydraulic System Loss of Fluid

Left System (L SYS) and Auxiliary Hydraulic System (AUX) Loss Of Fluid **AFM 04-15-20**

After landing:

CAUTION: LANDING GEAR SAFETY PINS SHALL BE INSTALLED PRIOR TO RESETTING DUMP VALVE.

17. Landing Gear Safety Pins.....INSTALL

END

essure and/or Fluid

Left Hydraulic System (L SYS) Failure – Loss of Pressure and / or Fluid

AFM 04-15-20

NOTE: This procedure plans for the worst case scenario of losing all Left and Aux fluid upon touchdown. If the Aux System remains functional, landing and braking operations will be normal.

1. FGC Selection ..... FGC 2
2. HYDRAULICS Synoptic ..... DISPLAY
3. AUX PUMP Arm Switch ..... ARM

Approach:

4. Flaps (One Detent at a Time) ..... SET TO 20° IF POSSIBLE BUT DO NOT USE AUX PUMP

   If flaps reach selected flap handle position of 20°, proceed to Step 7.

   If flaps fail or stop moving prior to 20°, proceed to Step 5.

   CAUTION: PULLING THE FLAP/STAB CIRCUIT BREAKERS WILL RESULT IN THE FOLLOWING:

   - Amber CAS message:
     - Stick Push Unavailable and Flaps Failed
   - Blue CAS messages:
     - GPWS 1-2 Fail
     - A/T Inhibit AFCS if autothrottle selection attempted
   - PFD indications:
     - AOA dashes (---)
     - Red X on Flap/Stab indication
     - AT 1/2 flashing red if autothrottles engaged
     - Thrust Director disappears

5. FLAP / STAB DC CBs ..... PULL
   FLAP / STAB LEFT DC: POP, C-6
   FLAP / STAB RIGHT DC: CPOP, C-6
6. Flap Handle ..... MOVE ONE DETENT TOWARDS UP (TO PROVIDE AN ACCURATE DISPLAY OF V_{REF})
7. PTU ..... NOT ARM
8. Landing INIT ..... PERFORM
9. Flaps 39 Unfactored Landing Distance ..... NOTE

Continued on next page →

Left Hydraulic System (L SYS) Failure – Loss of Pressure and / or Fluid, ctd...

AFM 04-15-20

FLAPS 39 UNFACTORED LANDING DISTANCE: LSK 1R ON LAND/GA DATA PAGE	MINIMUM REQUIRED RUNWAY LENGTH USING PARKING BRAKE AND SPEED BRAKES WITHOUT REVERSE THRUST			
	FLAPS 39	FLAPS 20	FLAPS 10	FLAPS 0
1,500 FT	3,700 FT	4,400 FT	4,600 FT	4,950 FT
2,000 FT	4,950 FT	5,900 FT	6,100 FT	6,600 FT
2,500 FT	6,150 FT	7,400 FT	7,650 FT	8,250 FT
3,000 FT	7,400 FT	8,850 FT	9,200 FT	9,900 FT
3,500 FT	8,650 FT	10,300 FT	10,700 FT	11,550 FT
4,000 FT	9,850 FT	11,800 FT	12,250 FT	13,200 FT
4,500 FT	11,100 FT	13,300 FT	13,750 FT	14,850 FT
5,000 FT	12,300 FT	14,750 FT	15,300 FT	16,500 FT

*Flaps 39 column would only be used if Left System Hydraulic failure occurred after flaps were set at 39.

NOTE: Minimize crosswind component to less than 5 knots, if possible. If crosswind is present, plan landing on downwind side of runway, as the airplane will weather vane into the wind as rubber effectiveness is lost. Aim to touchdown within the first 1000 feet of the runway.

10. Airspeed ..... 175 KCAS OR LESS
11. GPWS/GND SPLR FLAP ORIDE ..... ON
12. NWS POWER ..... OFF
13. Landing Gear Handle ..... DOWN
14. EMER LDG GEAR Handle ..... PULL
15. Landing Gear ..... DOWN / 3 GREEN
16. V_{REF} ..... APPROPRIATE TO CONFIGURATION
17. Ground Spoiler ..... ARMED

WARNING: **IT IS ESSENTIAL TO REMAIN PREPARED FOR THE WORST CASE SCENARIO OF ALL LEFT SYSTEM AND ALL AUX SYSTEM FLUID BEING DEPLETED IMMEDIATELY UPON WHEEL BRAKE APPLICATION. WHEEL BRAKE APPLICATION WILL ALSO ACTIVATE THE ARMED AUX PUMP AND PROVIDE FOR FULL ANTI-SKID BRAKING UNTIL THE AUX FLUID IS DEPLETED. IF THE PILOT FEELS NO BRAKING OCCURING WITH NORMAL BRAKES, IMMEDIATE ACTIVATION OF THE EMER BRAKES IS ESSENTIAL.**

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Left Hydraulic System (L SYS) Failure – Loss of Pressure and / or Fluid, ctd... AFM 04-15-20

PRIOR TO THE LANDING, THE CREW SHALL DECIDE WHICH PILOT WIL APPLY THE PARKING BRAKE SHOULD IT BE NECESSARY TO BE USED TO STOP THE AIRPLANE:

LANDING:

NOTE: The Required Runway Length shown in the table above does not account for the use of a Thrust Reverser. If its use is desired after landing, deploy the right thrust reverser as required to slow the airplane, maintaining aerodynamic directional control with the rudder. Aerodynamic control will not be available below 60 knots and will begin diminishing at around 80 knots. Depending on winds, runway crown, etc. the airplane may veer as rudder effectiveness is lost.

18. Speed Brake Handle .....EXTEND UPON TOUCHDOWN
19. Right Thrust Reverser ..... AS REQUIRED
20. Normal Brakes.....USE AGGRESSIVELY UNTIL DEPLETED

CAUTION: WHEN USING THE PARK / EMERGENCY BRAKE, IT IS NORMAL FOR DECELERATION TO INCREASE AS THE STOP PROGRESSES. THIS MAY RESULT IN LOCKED WHEELS AND BLOWN TIRES. REDUCE PRESSURE AS REQUIRED TO MAINTAIN CONSTANT DECELERATION.

21. Park / Emergency Brake.....APPLY UP TO 400 PSI IF NORMAL BRAKES FAIL
22. Steering ..... USE RUDDER UNTIL INEFFECTIVE
23. Differential Braking (If Available).....AS NEEDED FOR ADDITIONAL STEERING

AFTER LANDING:

24. Landing Gear Safety Pins..... INSTALLED

CAUTION: GEAR PINS SHALL BE INSTALLED PRIOR TO RESETTING DUMP VALVE.

END

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Appendix C Landing Incident

Landing Incident - KATW - Runway 30

February 14, 2011

Counter	Main TD (seconds)	Gear Down (seconds)	Function
11876	* 50	213	Engine run switches selected to OFF *Gap in data prior to this event*
11871	* 45	208	WOW to Air - *(One of the three WOW switches went to the air mode. Left gear failed)*
11851	25	188	End of runway - *(Accel Data)*
11851	25	188	R TR deployed - Aircraft at end of runway
11850	24	187	L Throttle resolver angle to -5.0
11849	23	186	R Throttle resolver angle to -5.0 *(472 feet remaining)*
11849	23	186	L/R brake Pedals depressed - *(Discrete)*
11847	21	184	L/R Throttle resolver angle to 0 *(798 feet remaining)*
11844	18	181	**RAAS 1000 Feet - *(CVR)***
11842	16	179	R TR NOT deployed
11841	15	178	L/R Throttle resolver angle to +39 - *(+39 = full forward thrust))*
11841	15	178	L/R brake Pedals NOT depressed *(1777 feet remaining)*
11838	12	175	**RAAS 2000 Feet - *(CVR)***
11837	10	173	WOW, left, right , and nose WOW on gnd *(Combined WOW)*
11837	10	173	R Throttle resolver angle to -22 - *(Discrete)*
11835	9	172	Pitch Attitude Angle -0.6
11834	8	171	L/R brake Pedals depressed - *(Discrete)*
11833	7	170	Pitch Attitude Angle 0.0
11833	7	170	L/R brake Pedals NOT depressed - *(Discrete)*
11832	6	169	**RAAS 3000 Feet -*(CVR)***
11832	6	169	L/R brake Pedals depressed - *(Discrete)*
11831	5	168	Pitch Attitude Angle 1.5 - *(Approx -0.5- -1.5 = normal on ground attitude)*
11831	5	168	R TR deployed
11829	3	166	L/R Throttle resolver angle goes to -5.0 degrees *(4028 feet remaining) (Reverse)*
11826	0	163	Main Gear Touchdown *(4453 feet remaining)* *(Vertical and Long Accel data)*

CVR Data used for A/C ground speed and position display.

Gulfstream
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Landing Incident - KATW - RNAV (GPS) Runway 30

February 14, 2011