A&C-11-649
December 15, 2011

Mr. Robert Gretz
National Transportation Safety Board
Eastern Region Aviation
181 Howard Blvd Suite M #228
Mt Arlington, NJ 07856

Subject: Gulfstream Submission to NTSB Investigation ERA11IA316

Enclosure: 1) Gulfstream G200 S/N 165 Incident Summary & Conclusions
2) IAI Root Cause Analysis for G200 S/N 165 (TR 4AS710/111165 Rev A)

Mr. Gretz,

Please find attached enclosures 1 & 2 noted above which form Gulfstream's submission to the above subject NTSB investigation.

Please do not hesitate to contact us should you have any questions, need any additional information or reports or require any clarification regarding this submittal.

Sincerely,

Richard J. Trusis, Director

Airworthiness / Certification & Data Integrity

Gulfstream G200 SN 165 Incident Summary & Conclusions

Accident

Location: Stewart International Airport, Newburgh NY
Date: May 27, 2011, 0928 Eastern Standard Time
Aircraft: Gulfstream 200, N749QS, S/N165

Summary

On May 27, 2011 a Gulfstream 200, N749QS departed Piedmont Triad International Airport, Greensboro, NC with intended destination of Westchester County Airport, White Plains, NY. After receiving a GEAR NOT DOWN warning red message while on approach at White Plains, the crew diverted to Stewart International Airport, Newburgh, NY. On landing, the aircraft's right main landing gear collapsed and the aircraft sustained minor damage. The landing gear not fully down and locked was the result of the landing gear handle not being placed in the full down position. The details of the incident are formulated from the following information:

- Investigation Field Notes (Attachment 1)
- Cockpit voice recorder (CVR summary, Document 2, NTSB docket),
- Root Cause Analysis for G200 S/N 165 Israel Aircraft Industries (IAI) Report # TR 4AS710/111165 Rev A (Attachment 2)
- Photo land gear selector valve as found (Document 15, NTSB docket),
- Photo landing gear selector valve in the full down position (Document 16, NTSB docket),
- Photo landing gear selector handle (Document 14, NTSB docket),
- Pilot written statement (Document 3, NTSB docket).

Details

The discovery of the landing gear handle not in the full down position in the post accident investigation along with CVR and crew statement concerning hydraulic pressure indications provided investigators with information to evaluate functionality of landing gear system.

The landing gear system is mechanically controlled and hydraulically actuated. The landing gear system components are the landing gear handle (LGH), landing gear selector valve (LGSV), landing gear dump valve (LGDV), and the gear extend / retract actuator.

The main landing gear extend / retract actuator has an internal locking device that is responsible for maintaining the gear in a down and locked position. When the internal locking device is engaged (locked), it depresses a switch which provides a discreet signal to the pilot in cockpit that the gear is down and locked. The internal lock requires that the hydraulic return pressure to be <240psi. Investigations of the gear extend / retract actuator found no faults. However further investigation was completed to determine why the internal locks did not engage.

The LGH is mechanically connected to the LGSV through a flexible control cable. The flexible control cable is attached to the LGSV with a threaded clevis. The threaded clevis is used to adjust (rig) the LGH to the LGSV. The field testing documented in Attachment 1 is used to summarize the findings in the following paragraphs.

The LGSV was found out of position on initial visual inspection (photo land gear selector valve as found, Document 15, NTSB docket). The landing gear handle was discovered by a NetJets representative during the initial day of the investigation (Photo landing gear selector handle, Document 14, NTSB docket). The NetJets representative moved the handle before any actual measurements could be taken. After the LGH was found to be out of position, then moved to full down, the LGSV moved to its normal down position (photo landing gear selector valve in the full down position, Document 16, NTSB docket). Therefore all field testing was accomplished by estimating the location of the LGH in its out-of-position location. There was no attempt to verify the rigging of the LGH to the LGSV.

The aircraft was configured to field test the normal gear extension and retraction. The landing gear was cycled numerous times without failure, gear handle fully down and up. It should be noted that the right main gear could not be allowed to cycle up into its gear well because of the damage incurred during the incident. The LGH was located in the out of position location and the gear verified extended but not locked. The LGH was then moved to the fully down position and the gear successfully locked.

The pneumatic system was verified to be available at the landing gear actuators with pressure gages before emergency gear testing. The aircraft was configured to field test the emergency gear extension with the LGH out of position. The pneumatic pressure was verified to be 2000 psi before simulating the event with gear handle out of position. Normal pneumatic pressure is 3000 psi. The landing gear emergency extension was simulated in the configuration that the pilots experienced. The gear successfully extended to the down and locked position. Due to factors unknown during the simulation, the auxiliary pump was not operated and / or the flow rate from the hydraulic power cart was not accurately measured. This difference in flow rate may have given different outcome as documented in the root cause analysis report (Attachment 2).

The LGSV was removed from the aircraft for investigation. The LGSV has a drawing requirement that it shall have no interflow between ports the last 10° of travel plus 5° of over-travel at its P to C1 and P to C2 positions. The LGSV investigation determined that there was no interflow between ports until 20° of travel of the LGSV handle from its nominal position. This is 10° better than the requirement. The LGH travels approximately 45° from the gear down to gear up position. The LGSV travels approximately 90° with the LGH movement. Therefore approximately 2° of LGSV travel is equal to 1° travel of the LGH. When the LGSV handle was moved to 20.5° the interflow was 3 gpm and was 10 gpm at 22.5. The LGH not being fully down caused the LGSV to be out of position and caused the interflow to be present. The high flow of hydraulic fluid caused a system pressure drop followed by a rise in hydraulic temperature.

When the pilots elect to perform an emergency gear extension, the LGDV is responsible for redirecting the hydraulic return flow for the gear extension side of the gear actuators. The LGDV was investigated and no faults were found. The affect the LGDV has on the hydraulic return pressure is detailed in the root cause analysis report (Attachment 2).

The root cause analysis report (RCAR) is an analytical explanation for the high hydraulic return back pressure which caused the main gear retract / extension actuator internal locks not to lock. Typical normal engine driven pump (EDP) hydraulic pressure is 3000 psi. When the hydraulic system pressure drops below 1300 psi an electrical hydraulic auxiliary pump is activated. This normally occurs when the EDP fails to produce hydraulic pressure. Normally a message is displayed to the pilots 1 sec after the EDP fails and the hydraulic pressure drops below 1300 psi. However the EDP had not failed. The excessive interflow through the LGSV caused the system hydraulic pressure drop. The auxiliary pump will activate in 50 msec to provide added flow to the hydraulic system. The EDP was allowed to build hydraulic pressure above 1300 psi since the EDP had not failed and had the added flow from the auxiliary pump. Therefore no hydraulic low pressure message would have been displayed to the pilots and the auxiliary pump would have remained operating also not annunciated to the pilot. The RCAR concludes that the hydraulic return pressure before emergency extension would be approximately 727 psi and approximately 327 psi after emergency gear extension. These high pressures would not allow the internal locks in the main gear retract / extension actuator to lock even though the gear is fully down. Normal return pressure after a gear extension is approximately 30 psi.

Before looking at the aircraft on the first day of the investigation at the initial team meeting, Gulfstream representative asked the NetJets team if the pilot recycled the gear. Their response was “No” (Field Notes, Attachment 1). We train our pilots to only do what the checklist says. Gulfstream representative also asked if the pilot yawed the aircraft in an attempt to obtain gear lock indications. NetJets answer was yes, but not aggressively due to one engine at idle. According to the cockpit voice recorder, the crew discussed whether to turn or yaw the aircraft after accomplishing the Emergency Landing Gear Extension checklist. The PIC/PM confirmed there was no such action in the checklist and no yaw was accomplished.

After the SIC/PM acknowledge the gear not down message, he told tower he had a gear issue and asked for a level off. The PIC/PF asked SIC/PM to leave gear down and run “the” checklist (0+21 seconds sec after gear handle selected down). All future times will be reference as min+sec from the gear down selection and are from the CVR summary. The SIC/PM began to search the QRH (1+12). The Landing Gear Lock Down Indication Failure checklist was started at 2+11. When the SIC/PM read item 3 of the checklist, right hydraulic pressure – check, he noted there was a right hydraulic problem (1400-1500 PSI from pilot statement).

At the time of the event, normal hydraulic pressure was listed as 2700-3250 PSI in the flight manual limitations section and taught that way by FSI. During the event, the hydraulic pressure varied from 1400-2300 (CVR summary, Document 2, NTSB docket and Pilot written statement, Document 3, NTSB docket) and reason the pilot said hydraulic pressure was not normal.

The lack of a hydraulic low pressure CAS message indicates acceptable pressure but the crew’s training had them thinking otherwise. If the crew had placed the LGH to the up position as the next step of the checklist directed, the event would not have occurred. To eliminate confusion over inadequate hydraulic pressure available for system operation, the limitation section has been revised to show the expanded range of acceptable hydraulic pressure: Normal 2700-3250, Advisory 1200-2700/3250-3500, and Caution is below 1200 or above 3500. Gulfstream has updated the abnormal checklists to specify action if pressure is less than 1200 PSI.

At this point of the event (2+30), the “R HYD OVERHEAT” CAS Message illuminated. The PIC/PF noted the temperature was 87˚C (trip point is 85˚C), the SIC/PM noted he could smell something burning (2+44), and the PIC/PF expressed the need to get the aircraft on the ground. SIC/PM begins reading the hydraulic overheat checklist (3+14). Both pilots confirm the right engine should be reduced to idle per checklist (3+22). They completed the checklist and agreed that engine shutdown was not required since they were at low altitude where denser air may assist in lowering fluid temperature as noted in the checklist (4+31). SIC/PM returns to the landing gear lock down failure checklist that starts at item 3 (5+22). He reads bold face item after item 3, if pressure indication is normal; then item 4, “landing gear lever…up; monitor indication changes; after 30 seconds minimum—but it is not normal”. PIC/PF said “it is 1670” and SIC/PM agreed (5+31). SIC/PM reads item 6, “If hydraulic pressure is normal…repeat steps as necessary (5+41), He then read item 7 that refers to emergency gear extension procedure.

The crew next decided to switch roles to perform the Emergency Land Gear Extension checklist since the emergency gear down handle is at the left seat pilot position (5+59). Crew performed the checklist and confirmed nose was down (6+53). Crew then requested a flyby of tower to check for gear, discussed diverting to longer runway, and noted no further smell of burning and that the power back on the right engine seemed “better”. They also noted they had 4,000 pounds of fuel (8+04). This would have been the perfect opportunity to call for in-flight assistance to troubleshoot their problem. Tower reported seeing three gear down.

While diverting to Stewart International, the crew began to read the Right Main Hydraulic System Failure checklist since the system was “degraded” but they did not have a hydraulic level low light (17+35). There are three places in this checklist that have the conditional statement “if the pressure is below 1200 psi.” The PIC/PF note the hydraulic system was just degraded on pressure and the SIC/PM concurred. The SIC/PM began running the checklist, but confused himself by miss-reading the conditional statement before item 1 thinking it was asking about hydraulic pressure when it was asking about hydraulic fluid quantity. He ran the checklist and step 3 has the AUX HYD PUMP switch placed to OVRRD (18+35). Pressure went to 2300 psi and SIC/PM noted after reading item 3 twice about turning off aux pump if pressure stays below 1200 psi and noted the pressure did not fall below 1200 psi (18+56). He then read the conditional statement above step 4, “If pressure rises to normal, aux pump motor thermal protection may have been previously activated.” The SIC/PM then noted “which it has” and placed the aux pump switch back to AUTO per item 4 and noted “it dropped back down and something is going on back there” (19+12). Crew continued with this checklist to touchdown (25+40).

<u>Conclusion</u>

The post accident cockpit investigation showed that the gear handle was not in the full down position. The field testing investigation showed that if the gear handle is positioned correctly to the full down position, normal gear extension is achieved. The component investigation found no evidence to determine why the main gear did not achieve a down and locked position other than the gear handle being positioned incorrectly from the full down position.

Basic airmanship requires that pilots reconfirm the positioning of the gear handle ("LGH") if the initial gear handle down action did not give the desired result (i.e. 3 "DN" indicators on the CAS display). This is especially true, if the result was accompanied by the posting of a red CAS message "GEAR NOT DOWN". This basic action is no different than the one that occurs when placing the flap handle to command a specific flap position and there is no corresponding movement. A pilot would be required to check the handle for proper position.

Having failed to confirm this basic step that the LGH was down, the crew then ran the QRH checklist for the red message, GEAR NOT DOWN, but soon became distracted by running the checklist for the yellow CAS message, HYD OVERHEAT. Having already become focused on running emergency checklists, instead of paying attention to basic airmanship issues, the crew then made a wrong, but understandable, assumption while running the GEAR NOT DOWN checklist that since the hydraulic pressure wasn't in the normal range, as referenced in the aircraft's flight manual and taught by Flight Safety International, they should not proceed with the GEAR NOT DOWN checklist which would have had them recycle the landing gear, giving them a second opportunity to put the LGH in its full down position. The crew allowed the assumption of low hydraulic pressure to distract them from the fact that all hydraulic systems on the aircraft were functioning correctly and no hydraulic issue was in fact present, nor was any hydraulic pressure message on the CAS. The focus on the QRH instructions distracted them from the checklist requirement, and indeed the common airmanship requirement, to push the LGH fully down until 3 DN indications appear on the CAS. One final opportunity was available to the crew when they returned to the Emergency Landing Gear Extension checklist where step 3 calls for Landing Gear Lever- Down. This step is specific in calling out the landing gear lever to be positioned to the down position whereas the Before Landing checklist in step 5 states Landing Gear…..Down and Locked, and does not specifically reference the gear lever. Landing with both main gear indicating not down and locked without exhausting further investigation was not warranted based on fuel availability or the hydraulic temperature. The crew therefore created their own emergency, which the checklists were not designed to correct.

There was opportunity for the crew to call the phone number in their Quick Reference Handbook for technical assistance from Gulfstream's 24 hour Tech Operations hot line. This service provides engineering and technical pilot support for in-flight emergencies to assist crews in fully covering all options in addressing an abnormal condition.

To assist crews from overlooking an error of not selecting the LGH to the full down position, Gulfstream has added text to the Landing Gear Lock Down Indication Failure checklist, the Emergency Landing Gear Extension checklist, the Hydraulic System Overheat checklist, and the Right Main Hydraulic System Failure checklist with steps to verify landing gear handle lever is at full extent of travel in down position. Should a crew end up with an abnormal gear configuration after attempting all corrective actions, Gulfstream has added a checklist to prepare crew for landing with abnormal gear conditions.

SECURITY CLASS : Unclassified

COML. CLASS : Unclassified

DOCUMENT IDENTIFIER: TR 4AS710/111165

Root Cause Analysis for G200 S/N 165

Collapsed Landing Gear, During Landing

CONTRACT: **S/CDRL:**

SECURITY CLASS: Unclassified

COML. CLASS: Unclassified

REVISION STATUS

Rev.	Total Number of Pages	Affected Pages	Description of Change	Approved
-		All Pages	N/A	T. Babi
A	24	7	5.1.1 De-spin function description added	T. Babi
		9	Para. 5.2.1 - Revised	
		16	Para. 7.1 – available pressure sources discussion was added	
		17	Para. 7.1.1 – EMP logic description was added	
		18	Para. 7.2 - revised	
		19	Para. 7.3 – Back Pressure Calculation Revised And Relocated To Appendix 1	
		20	Para. 8 - revised	

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APPENDIXES

1. Scope

The report herein provide the IAI estimation regarding the root cause for the G200 S/N 165 collapsed RH L/G (landing gear) during landing at White Plains NY on May 27,2011

2. Event Description (Per pilots report)

- At arrival at HPN requested gear down. Gear was selected down, but all three gear indicators stayed red.
- We broke off our approach and asked for holding. About 20-40 seconds later the R/HYD OVRHEAT EICAS illuminated. The temperature was amber and 85 degrees on EICAS page 2.
- Co-pilot started read checklist for R/OVERHEAT. After completion, started reading Gear Extension Failure checklist. During the process the temperature never went to safe temps.
- Right hydraulic pressure was 1400 to 1500 psi. QRH directs to take affected engine to idle. Which where it remained for the duration of the rest of the flight.
- After emergency gear extension process was initiated and completed, the main gear remained indicating red and nose gear indicated down and green.
- We flew by the HPN tower and they said they could three gears down.
- We diverted to SWF for a longer runway.
- Enroute we initiated the hydraulic failure checklist. This checklist added that we will not have normal braking. Prepared for EMER braking per the QRH.
- On landing, at 128kias, flaps 40, right main gear collapsed.
- Aircraft came to stop on runway.

3. NTSB Investigators Preliminary Findings And Actions

- RHS reservoir was found filled with hydraulic fluid.
- Emergency L/G handle was found at open position (activated).

- Lending gear control handle was found approximately 0.25 inch from the "fully" extend position.
- EMP was activated and found to operate properly.
- After the A/C was placed on jacks, normal gears cycling was performed, gears operated properly.

4. L/G System General Description

The L/G system is hydraulically operated by a single manual selector valve. All sequencing is implemented mechanically. The MLG (main L/G) actuators are downlocked by internal mechanical locks. The NLG (nose L/G) is downlocked by brace geometry and by jury brace, which is spring loaded in the locked and unlocked positions.

In case of Right Hydraulic System (RHS) failure, the emergency L/G extension is achieved by using nitrogen compressed at 3000psi in a pneumatic pressure vessel. The emergency L/G extension is controlled by a mechanically operated selector valve with separated pneumatic lines which connected to the L/G actuators through shuttle valves installed on the actuators.

5. L/G System Operation Description

Extension and retraction of the L/Gs is controlled by a two position LGSV (landing gear selector valve) mechanically linked to the L/Gs control handle located on the instrumented panel.

5.1 Normal Retraction (see Figure 1)

When L/G control handle is placed in the up position RHS pressure is applied through the dump valve to unlock and to retract the L/Gs.

Pressure is applied to both chambers of the MLG actuators and the movement (actuator retraction) is achieved by differential areas on the actuator.

On the NLG, pressure is applied to the extend chamber and retract chamber is connected to return pressure.

The MLG in up position is locked by means of two uplockes (forward and aft) of the fuselage door.

The NLG in up position is locked up by means of spring loaded mechanical load.

The L/Gs are continually pressurized toward retract direction during flight (as long as gear handle is in up position)

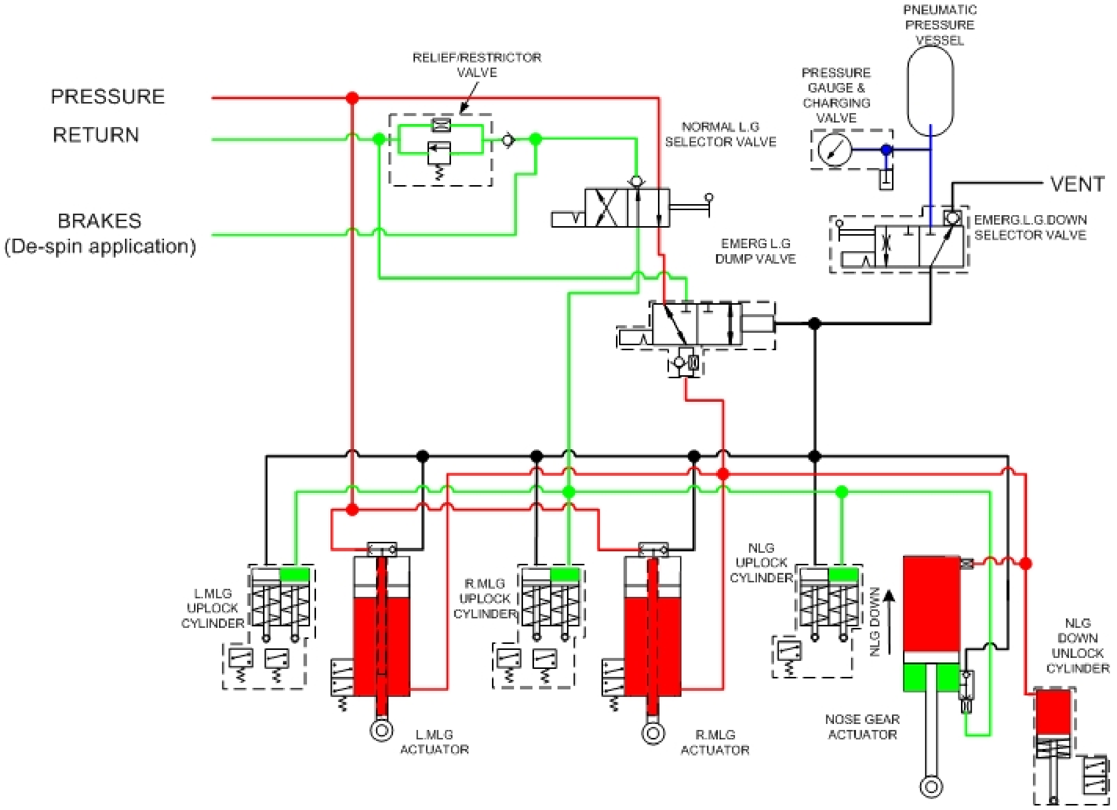

Figure 1-L/G Retracted Hydraulic Schematic

5.1.1 De-Spin Function

The de spin function is achieved via restrictor/relief valve which installed on a common return line of the L/G and brake systems. During retraction, the return flow pressure of the NLG actuator is raised to relief pressure of 230±10psi which also routed to the brake via power brake valve return port. The relief valve also provide restriction function of 250±10psi/(cis)^2 for pressure equilibrium after the completion of the de-spin function

5.2 **Normal Extension (see Figure 2)**

When L/G control handle is placed in the down position, pressure is applied to unlock the L/Gs uplocks (all three) while retract chambers of the MLG actuators are connected to return pressure, The MLG extend chambers which continually connected to high pressure then pushes the MLGs toward down position.

On the NLG actuator, high pressure is ported to retract chamber while extend chamber is connected to return system as a result, NLG actuator retracts and NLG extends

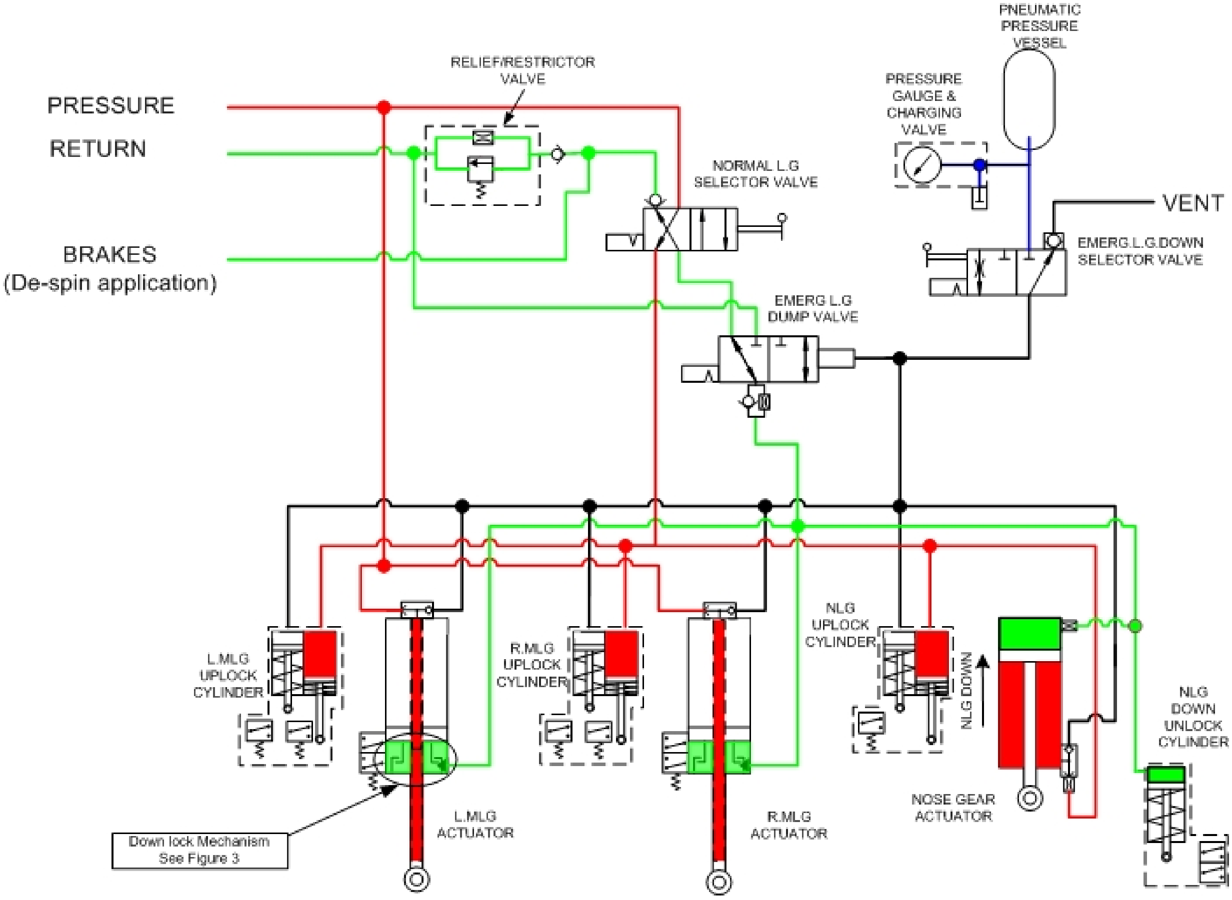

Figure 2-L/G Extended Hydraulic Schematic

5.2.1 Down Lock Mechanism (see Figure 3)

The MLG actuator is provided with internal lock segment which is locked automatically in fully extend position.

The down lock segment threshold ATP requirement for unlocking is ~240 psi (min) for no load condition, as a result, if the back pressure of the system is higher than the value above, down lock segment will remain triggered (unlocked) continually regardless of operation mode (normal or emergency).

During ATP which performed for the right MLG actuator of A/C 165 the measured down lock threshold was ~280psi (within requirements)

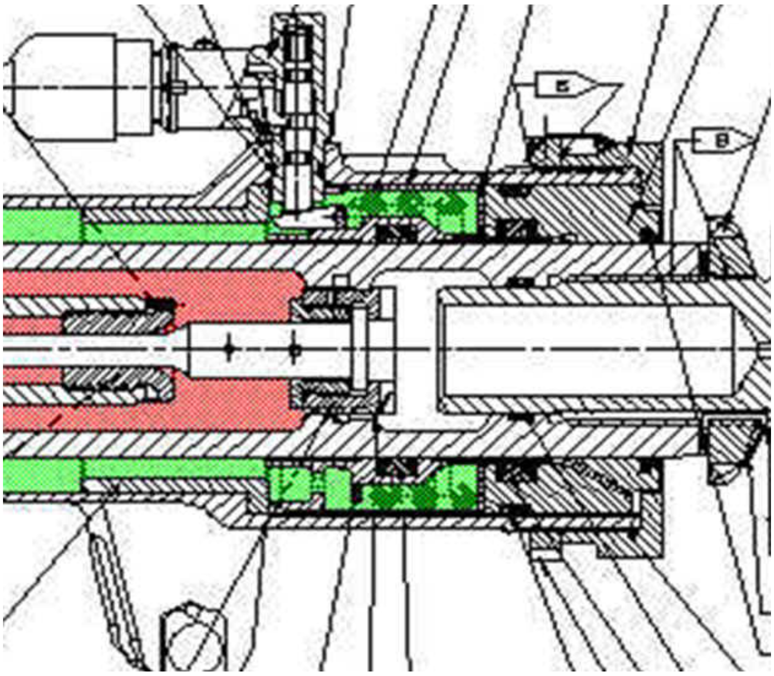

Figure 3 – MLGs Down lock Mechanism Cross Section

5.3 **Emergency Extension**

Emergency extension of the L/Gs is accomplished by placing the landing gear control handle in down position and then releasing and pulling the emergency gear down handle, which in its turn opens emergency selector valve to supply nitrogen pressure to extend the L/Gs. In addition, nitrogen pressure triggers the L/Gs dump valve which connects the L/Gs actuators retract chambers to return pressure in order to by-pass the L/G selector valve and De-spin restrictor relief.

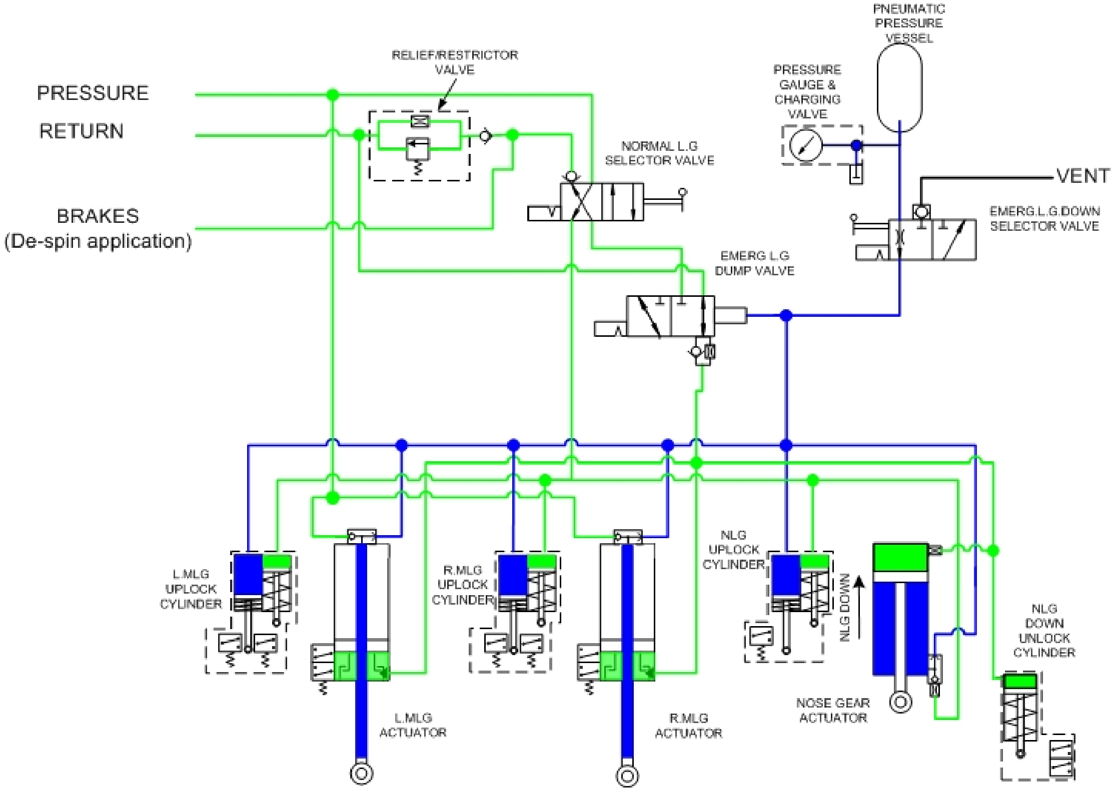

Figure 4- L/G Emergency Extension Hydraulic Schematic

6. L/G System Fail to Lock Down Root Cause Analysis

6.1 General Discussion

As reported by the flight crow, after Gears selected down, RHS pressure dropped to ~1450psi and all three gears indicators stayed red (transient phase), followed by hydraulic fluid over heat message.

The extent of Gears travel before emergency extension is unclear, and is not relevant due to the fact that during landing phase all gears were extended to full travel and MLG actuators failed to lock down in both normal and emergency operation modes.

The absence of MLGs lock down indication when all gears are extended to full travel with indication system operate properly, indicates that the downlocks were triggered for some reason (both downlocks are unlikely to fail simultaneously).

System pressure drop which followed by hydraulic fluid over heat with no hydraulic fluid loss is likely to indicate for internal by-pass condition which expected to raise system back pressure depending on by-pass flow rate and resistive characteristics of the return system.

The fact that sequence of events initiated upon gear extension (hydraulic system properly functioned up to that point) strongly indicates that the abnormal behavior is related to the L/G circuit.

6.2 Possible Root Cause Discussion

Two elements in the L/G circuit has a sufficient passage area which can result system pressure drop as occurred on the event, LGSV and the emergency dump valve.

All other components either connected only to a single pressure medium (such as uplocke/downlock actuators and shuttle valves) thus internal by-pass can't occur or doesn't have sufficient flow passage between Pressure and Return cavities to reduce system pressure as occurred in the event (such as NLG actuator which incorporated with restrictors that restrict flow to 1.2gpm max.)

MLG actuators are designed in a way that by-passed fluid through the piston will vent out of the system and hydraulic fluid loss is expected to occur (not the case).

6.2.1 Dump Valve Possible Failure Modes (see Figure 5)

a. Internal by-pass flow:

During gear extension P port is connected to return pressure through LGSV in order to evacuate the retract chambers fluid which enters at C port toward return system. At that phase all ports are connected to the return system and internal by-pass condition will not affect gear extension function.

In addition, if emergency dump valve had suffered from internal by-pass condition RHS was expected to abnormally operate after gear retraction (when P connected to high pressure).

b. Hydraulic lock:

In order to have internal lock on the emergency dump valve, pressure poppet should drift to the left and seat against return poppet while return poppet remains seated in its normal poison (deactivated), this mode can't occur due to differential area and pressure poppet spring, which act toward the opposite direction (normal position). In addition, hydraulic lock at the dump valve, would have no effect on the RHS pressure (RHS pressure drop should not occur).

c. Conclusion:

The analysis above shows that there is no failure mode related to the emergency dump valve which can result abnormal behavior as occur during the event.

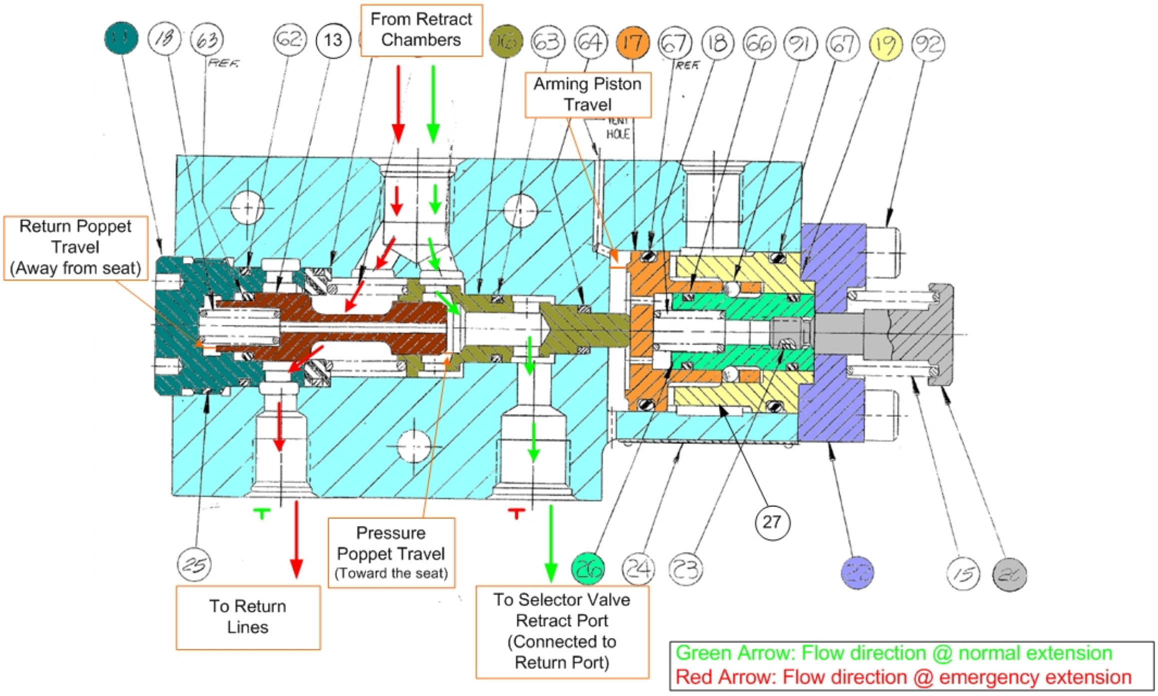

Figure 5-dump valve cross section

6.2.2 L/G Selector Valve (see Figure 6)

LGSV is a rotary valve type which activated mechanically by the L/G handle. During rotation form "up" to "down" position (and vice versa) the valve has two phases which ports P, C1 and C2 are connected to R and internal by-flow occurs.

According to LGSV ATP, internal by-pass flow is allowed when LGSV lever angle exceeds 15º (from the up or down positions) in both directions.

Actual testing during on LGSV which installed on A/C 165 (S/N IL-179) showed that initial by passing begins at 20° of LGSV lever angle.

Full flow condition occur at 22.5° of LGSV lever angle, with 10 gpm by pass flow (which was the maximum test bench capabilities)

At intermediate position (Figure 7) the LGSV can result a massive by pass flow (depend on selector valve position) followed by a system pressure drop, hydraulic fluid over heat (as reported) and a significantly higher back pressure.

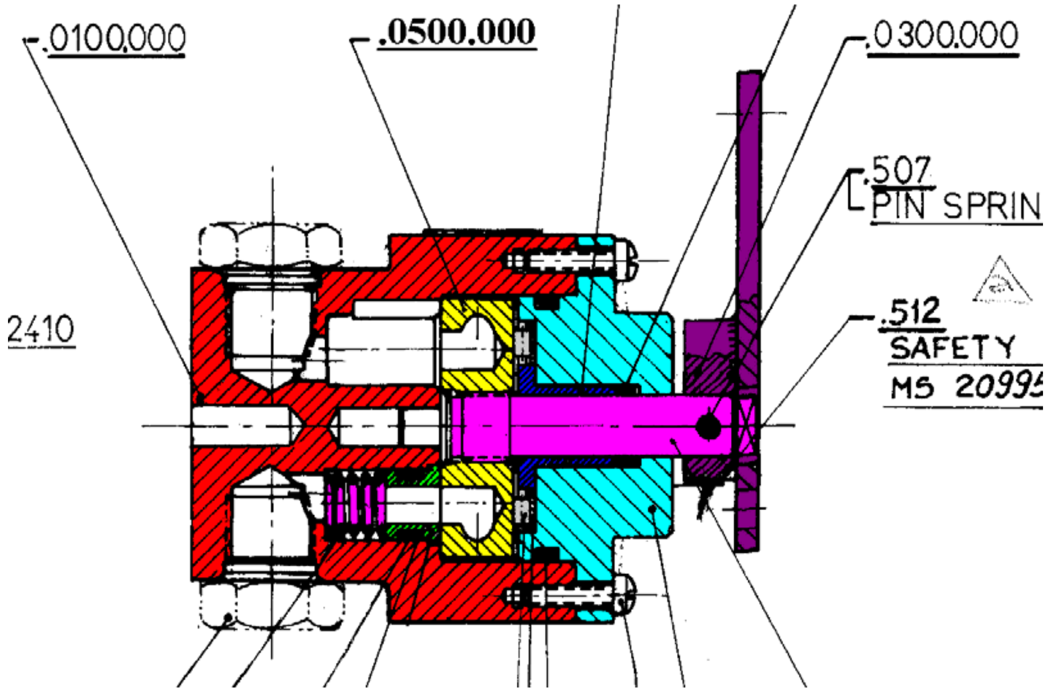

Figure 6-selector valve cross section

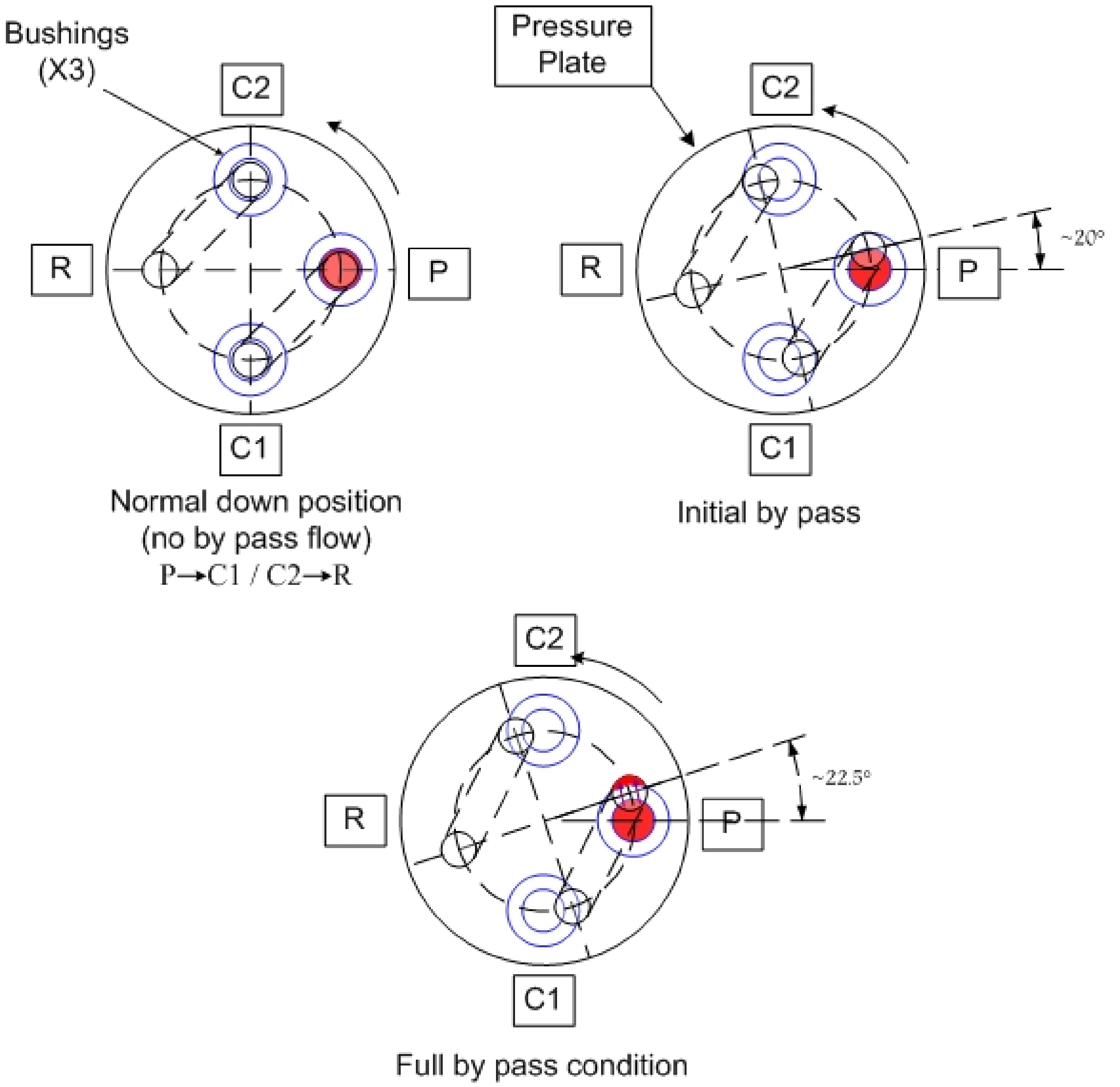

Figure 7- selector valve cavities kinematics (down position to full by pass flow)

7. Estimated Back Pressure During The Event(Figure 11 -)

7.1 Available Pressure Sources

The RHS of G200 is provided with two hydraulic pumps which provide hydraulic power during normal and emergency operation, the Engine Driven Pump (EDP) is a variable displacement, pressure compensated flat cut-off type (see Figure 8) which receives its input power via engine accessory box and continually operated when engine is running.

The Electric Motor Pump (EMP) is a variable displacement, pressure compensated soft cut-off type operated by electrical motor. EMP control is performed via control switch for Off, Auto and Override modes which is located at the pedestal in the cockpit. The EMP dynamic respond is 50 ms.

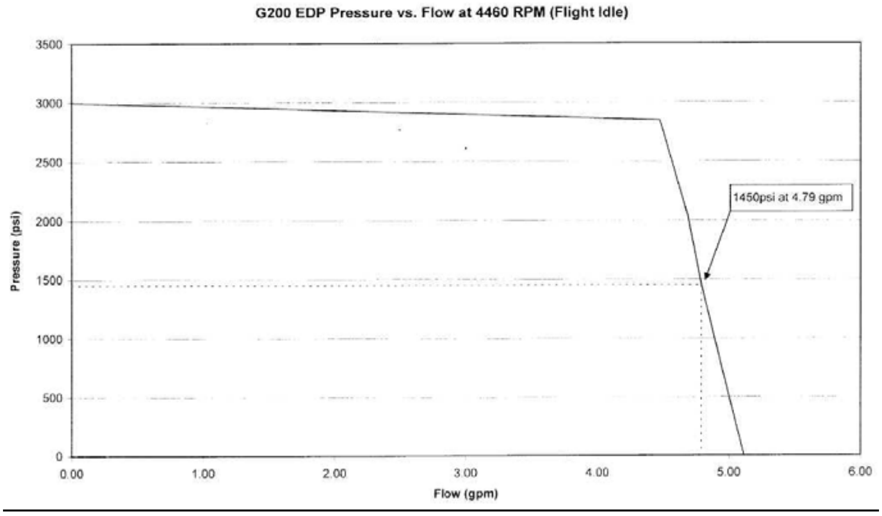

Figure 8-G20 EDP flow vs. pressure curve

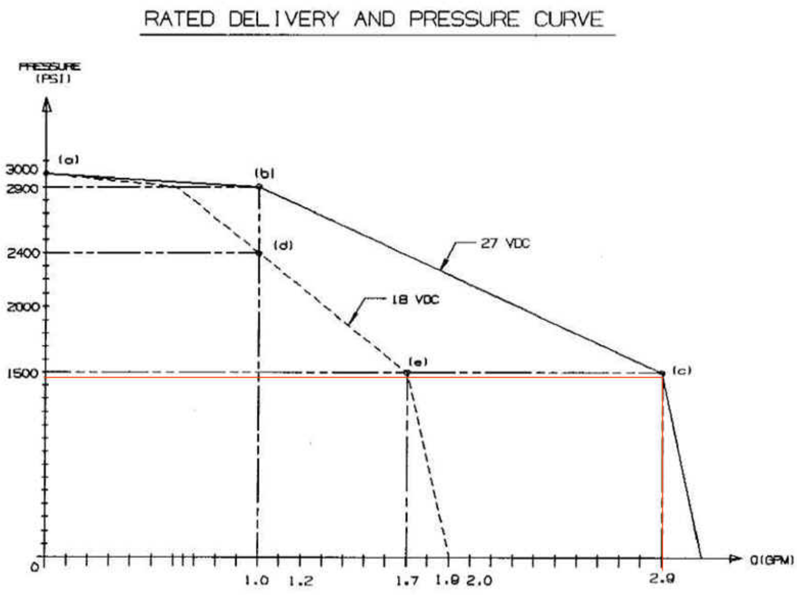

Figure 9-G200 EMP flow vs. pressure curve

7.1.1 EMP Actuation Logic (see Figure 10)

In auto mode, EDP pressure switch which installed on the pressure manifold is responsible for EMP activation and deactivation in case of system pressure drops below 1300±100 psi or raise above 1600±100 psi respectively, EMP deactivation has an additional 3 minutes delay. In addition, the EDP pressure switch is responsible for triggering the "HYD PUMP PRES LOW" CAS message. The message is incorporated with 1 sec delay in order to avoid triggering during momentary pressure drop which can occur upon actuation of large hydraulic consumers.

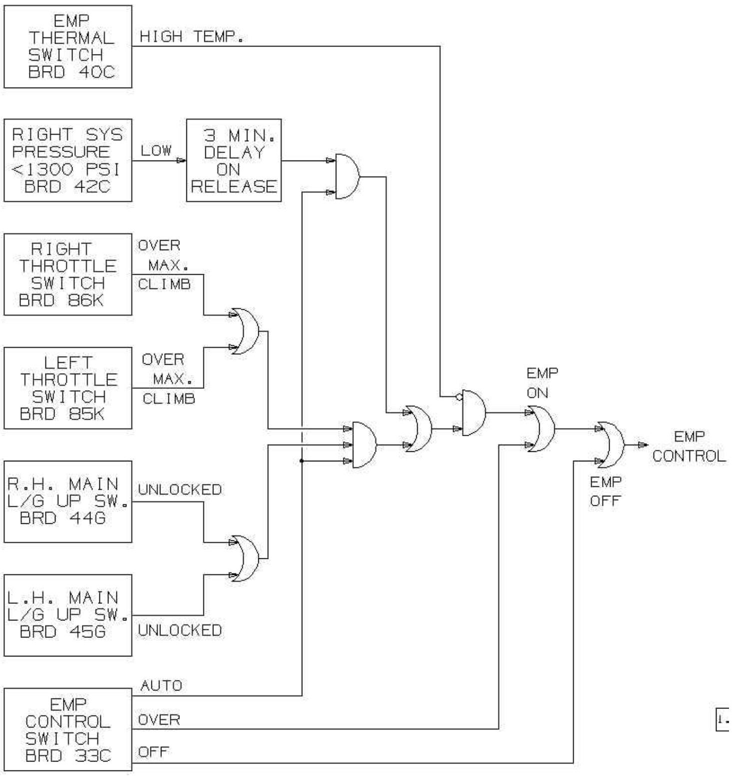

Figure 10 – EMP Actuation Logic

7.2 **Flow Rate Condition During The Event:**

As reported by the pilots, after gears were selected "down" and before engine RPM reduced to idle, system pressure stabilized at ~1400-1500 psi.

Pump with flat cut off characteristics (such as the EDP) will suffer from a rapid discharge pressure drop upon reaching its maximum flow delivery capabilities.

System pressure of ~1400-1500 psi indicates that the EDP was at the flat cut off curve after gears were selected down (before engine throttling to IDLE), in these initial conditions, after engine RPM was reduced to IDLE, the EDP would have likely to suffer from additional discharge pressure drop.

The calculated back pressure (see Table 1 in Appendix 1) after emergency gear extension with EDP as a single pressure source is ~156psi, well below the required 280psi for the right MLG down lock unlocking pressure which measured during the ATP after the event.

However, the calculated back pressure with both EDP and EMP operating simultaneously (see Table 2 in Appendix 1) is ~727psi and ~327psi before and after emergency gear extension was initiated respectively.

Therefore, IAI analyze that the most likely sequence of events is as follow:

1. Landing handle was not placed on fully down position and consequently the LGSV internally by passed fluid.
2. RHS pressure dropped to 1400-1500psi (see note below) and the internal by pass condition raised RHS back pressure to ~450psi (see note below), which prevented from the down locks to lock.
3. Engine RPM was reduced to IDLE and consequently RHS pressure dropped below 1300±100psi.
4. EMP was automatically actuated as dictated by its actuation logic.
5. The fast dynamic response (50 ms) of the EMP, raised system pressure to above the required 1600±100psi in less then 1 second which prevented from "HYD PUMP PRES LOW" CAS message to appear.
6. EMP activation consequently raised RHS back pressure to ~727psi, which prevented down locks from locking.
7. The EMP continuously operated for an additional 3 minutes as dictated by the EMP actuation logic.
8. After EMP deactivated, EMP actuation cycle was repeated.
9. Emergency gear extension actuation reduced RHS back pressure to ~327psi which prevented down locks from locking.

Note: The sequence of events, which presented above assumes, that the EMP was automatically activated after engine RPM was reduced to IDLE (3) however, it is possible that the EMP was actuated after gears selected down (1), in both cases same effect is expected.

It is important to note that in "normal" EDP discharge pressure failure the described sequence of events could not occur due to pressure manifold EDP check valve which would have isolate the EDP pressure switch from system pressure (which provided by the EMP).

8. Root Cause Summary

- IAI engineering concludes that abnormal behavior of the hydraulic system and L/G system during the event; more than likely occurred due to LGSV at intermediate position.
- NTSB investigators findings on the A/C after the event (LG handle position) correlate with the assumption above.
- LGSV which installed on A/C 165 (S/N IL-179) during the event was subjected to ATP on July 28th 2011 and was found to operate properly.
- Back pressure calculations shows that the expected back pressures with both EDP and EMP operating with selector valve at intermittent position are 727 psi before emergency gear actuation and 327 psi after emergency gear extension.
- Back pressures at the values above, will trigger the down lock segment continually (regardless of operation mode) and MLG actuator will not lock down though fully extended.
- According to the analysis, system operation with EDP, as a single pressure source after emergency extension was initiated, would have resulted in reduced system back pressure of ~160 psi (after emergency gear extension). Thus, MLG's would have locked down.
- The analysis herein doesn't deal with the root cause for why the selector valve was positioned at intermediate position.

Appendix 1 – Back Pressure Analysis

1. Back Pressure Calculation:

Pressure drop calculations were performed for two possible flow conditions, EDP as a single power source and both EDP and EMP are operating in parallel.

Two cases were considered for each flow condition, before and after emergency gear extension due to the change in the return cavities passages after dump valve triggering upon emergency extension actuation (dump valve triggers and connect the C port to R thus, changing return pressure path (see Figure 11 - .

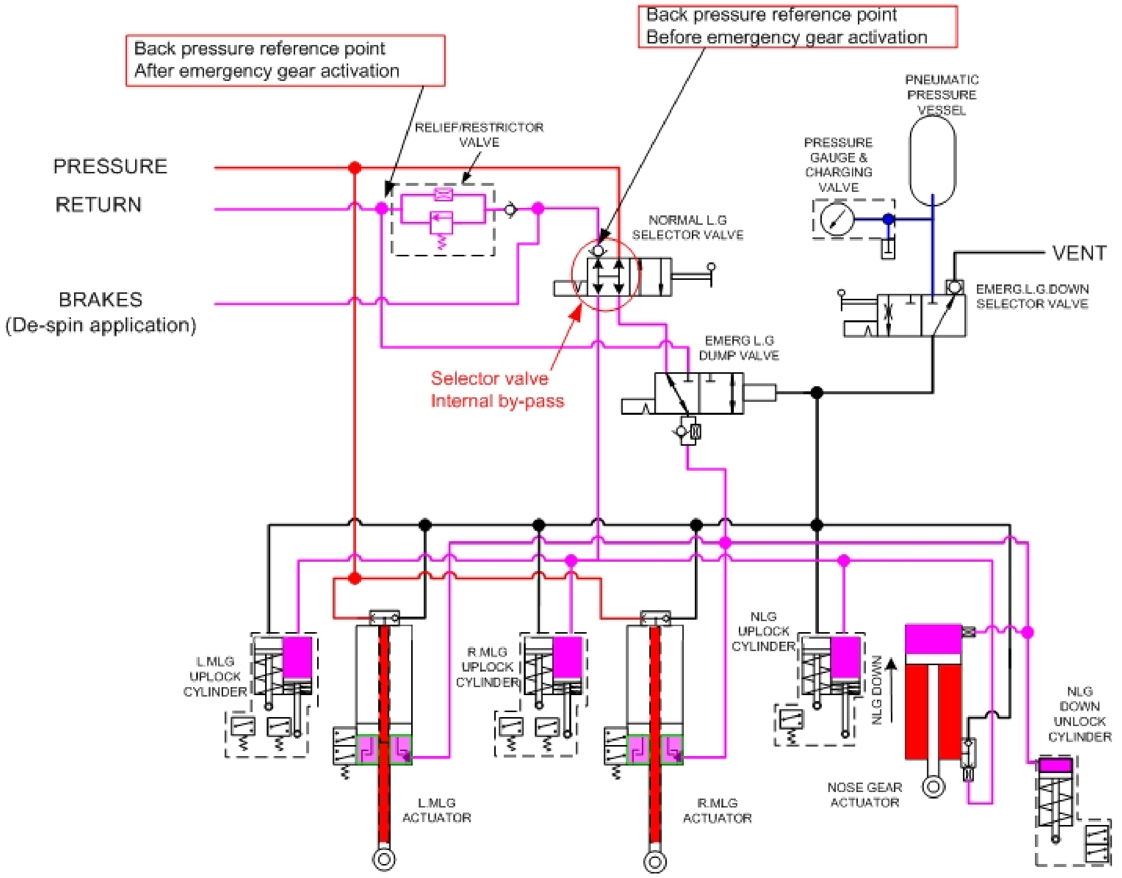

Figure 11 - L/G schematic with selector valve at intermediate position

(Shown before emergency extension actuation)

Return Filter Considerations

If contaminated, return filter can result for a significant back pressure raise in high flow through conditions however; there is no indication that deferential pressure pop out indicator was triggered therefore, it is likely that the return filter functioned properly during the event however, pressure drop calculations assumes a used filter with flow characteristics of 40psid at 6.2gpm (instead of 26psid)

Return filter Flow characteristics:

- Pressure drop: 26psid at 6.2gpm for new filter
- ΔP Indicator pop out pressure: 50±7psid
- By pass cracking pressure: 70±10psid
- Dirt capacity (min): 2 grm at 6.2gpm at 50psid

$$V_{tube} = \frac{Q}{A_{tube}}$$

$$R_n = V_{tube} \cdot \frac{ID}{\nu}$$

$$f_{lam} = \frac{64}{R_n}$$

$$f_{tur} = \frac{0.316}{R_n^{0.25}}$$

$$\Delta P = \left(\frac{f \cdot l_{tube}}{ID}\right) \cdot \frac{\rho \cdot (V_{tube})^2}{2}$$

$$k\left(\frac{psi}{cis^2}\right) = \frac{\Delta P}{Q^2}$$

Skydrol LD-4 Properties		
Temp °C	ν Cst	ρ (lb/cu.ft)
85	4	59.93

Components in Return Flow Path				
Component	Rated Flow (gpm)	ΔP at rated flow (psi)	k psi/(cis)^2	k psi/(cis)
Return Filter	6.2	40		1.676
Rliefe Restrictor	5.0	60.0	0.162	
Check Valve	3.6	10.0	0.052	

Table 1 – pressure drop calculation with EDP as single pressure source

Dash No.	OD (inch)	Material	Wall Thickness (inch)	Q (gpm)	length (inch)	V_{tube} (inch/sec)	R_n	$f_{lam/tur}$	ΔP
Reservoir pressure									27.5
-8	0.500	Al	0.035	4.8	23.5	127.0	8807.4	0.033	1.3
Return Filter				4.8					30.9
-8	0.500	Al	0.035	4.8	4.2	127.0	8807.4	0.033	0.2
-6	0.375	Al	0.028	4.8	4.3	230.7	11872.0	0.030	1.0
-6	0.375	Al	0.028	4.3	9.4	206.7	10632.7	0.031	1.8
-6	0.375	Al	0.028	4.3	25.9	206.7	10632.7	0.031	4.8
-6	0.375	Al	0.028	4.3	23.2	206.7	10632.7	0.031	4.3
-6	0.375	Al	0.028	4.3	68.2	206.7	10632.7	0.031	12.8
-6	0.375	Al	0.028	4.3	23.2	206.7	10632.7	0.031	4.3
-6	0.375	Al	0.028	4.3	33.0	206.7	10632.7	0.031	6.2
-6	0.375	Al	0.028	4.3	14.4	206.7	10632.7	0.031	2.7
-6	0.375	Al	0.028	4.0	33.2	192.2	9889.2	0.032	5.5
-6	0.375	Al	0.028	4.0	36.4	192.2	9889.2	0.032	6.0
-6	0.375	Al	0.028	4.0	25.9	192.2	9889.2	0.032	4.3
-6	0.375	Al	0.028	4.0	70.6	192.2	9889.2	0.032	11.6
-6	0.375	Al	0.028	4.0	128.3	192.2	9889.2	0.032	21.2
-6	0.375	Al	0.028	4.0	63.8	192.2	9889.2	0.032	10.5
-6	0.375	Al	0.028	4.0	4.3	192.2	9889.2	0.032	0.7
Relief Restrictor		ΔP Due to Flow		4.0					38.2
		Cracking Pressure							240.0
-6	0.375	Al	0.028	4.0	3.1	192.2	9889.2	0.032	0.5
Check Valve				4.0					12.3
-6	0.375	Al	0.028	4.0	13.5	192.2	9889.2	0.032	2.2

After Emergency Gear Down

Before Emergency Gear Down

Back Pressure Before Emegency Gear Down (psi)	**450.8**
Back Pressure After Emegency Gear Down (psi)	**156.8**

Table 2 - pressure drop calculation with both EDP and EMP operated

Dash No.	OD (inch)	Material	Wall Thickness (inch)	Q (gpm)	length (inch)	V_{tube} (inch/sec)	R_n	$f_{lam/tur}$	ΔP
Reservoir pressure									27.5
-8	0.500	Al	0.035	7.7	23.5	203.9	14139.6	0.029	3.0
Return Filter				7.7					49.6
-8	0.500	Al	0.035	7.7	4.2	203.9	14139.6	0.029	0.5
-6	0.375	Al	0.028	7.7	4.3	370.4	19059.6	0.027	2.2
-6	0.375	Al	0.028	7.2	9.4	346.4	17820.4	0.027	4.3
-6	0.375	Al	0.028	7.2	25.9	346.4	17820.4	0.027	11.9
-6	0.375	Al	0.028	7.2	23.2	346.4	17820.4	0.027	10.7
-6	0.375	Al	0.028	7.2	68.2	346.4	17820.4	0.027	31.5
-6	0.375	Al	0.028	7.2	23.2	346.4	17820.4	0.027	10.7
-6	0.375	Al	0.028	7.2	33.0	346.4	17820.4	0.027	15.2
-6	0.375	Al	0.028	7.2	14.4	346.4	17820.4	0.027	6.7
-6	0.375	Al	0.028	6.9	33.2	331.9	17076.8	0.028	14.2
-6	0.375	Al	0.028	6.9	36.4	331.9	17076.8	0.028	15.6
-6	0.375	Al	0.028	6.9	25.9	331.9	17076.8	0.028	11.1
-6	0.375	Al	0.028	6.9	70.6	331.9	17076.8	0.028	30.3
-6	0.375	Al	0.028	6.9	128.3	331.9	17076.8	0.028	55.0
-6	0.375	Al	0.028	6.9	63.8	331.9	17076.8	0.028	27.4
-6	0.375	Al	0.028	6.9	4.3	331.9	17076.8	0.028	1.8
Relief Restrictor		ΔP Due to Flow		6.9					113.9
		Cracking Pressure							240.0
-6	0.375	Al	0.028	6.9	3.1	331.9	17076.8	0.028	1.3
Check Valve				6.9					36.6
-6	0.375	Al	0.028	6.9	13.5	331.9	17076.8	0.028	5.8

After Emergency Gear Down

Before Emergency Gear Down

Back Pressure Before Emegency Gear Down (psi)	**727.0**
Back Pressure After Emegency Gear Down (psi)	**327.5**