NJASAP

PARTY SUBMISSION OF NJASAP

TO THE

NATIONAL TRANSPORTATION SAFETY BOARD

749QS

Stewart-Newburgh, New York

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SUBMITTED BY Suzanne Danielson, NJASAP Party Coordinator

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I. Introduction

The purpose of this submission is to provide the NetJets Association of Shared Aircraft Pilots (NJASAP) analysis and conclusions regarding the circumstances and causes of the EJA749 landing incident to the National Transportation Safety Board. NJASAP reserves the right to supplement this submission. This investigation has yielded viable information and analysis. The data demonstrates, and all parties seem to agree, that the landing gear selector valve and the emergency gear extension system did not function normally. It is also clear that the relevant checklist procedures were incomplete and misdirected or failed to direct the crew to additional steps, although these procedures did not directly cause the incident. The investigation revealed that the landing gear selector valve did not function correctly and the emergency gear system did not function properly. As a result, the manufacturer, Gulfstream, has issued a new emergency procedure to correct the system problem that exists in the Gulfstream 200 hydraulic system. In addition, Gulfstream has written additional emergency procedures to deal with the ambiguities present in the former checklist. This NJASAP submission does not analyze possible causes that were investigated and found not to be a factor. Instead, this submission concentrates on the hydraulic system and potential single point of failure, the checklists utilized by the crewmembers and actions of the flight crew and facts that establish that the flight crew acted properly in responding to this emergency.

I. Executive Summary

A. Accident Summary

On May 27, 2011, at 0928 eastern daylight time, an Israel Aircraft Industries Gulfstream 200, N749QS, managed by NetJets Aviation Inc. (NJA), incurred minor damage when the right main landing gear collapsed during an emergency landing at Stewart International Airport (SWF), Newburgh, New York. The two certificated airline transport pilots and one passenger were not injured. The personal flight was conducted under the provisions of 14 Code of Federal Regulations Part 91K. Visual meteorological conditions prevailed and an instrument flight rules flight plan was filed for the flight destined to Westchester County Airport (HPN), White Plains, New York. The flight originated from Greenville Spartanburg International Airport (GSP), Greer, South Carolina, about 0730.

B. Flight Crew Qualifications

The crew of EJA749, PIC Jeffrey Cox and SIC Christopher Fry, are experienced, highly qualified and fully trained pilots. They have a combined total of over 18,000 hours of flight time, including nearly 3800 hours in the G200. Captain Cox has flown with NetJets for over 15 years, and Captain Frey for over 9 years. Each has had extensive aviation experience prior to their NetJets employment. NetJets flight training records and interviews confirmed that the crew has been properly trained, capable, well respected, and approached their duties with exemplary professionalism.

C. Flight Crew Performance

The investigation group reviewed several aspects of aircraft and pilot performance in an attempt to determine whether the flight crew had performed the proper checklists and

checklist items. The facts developed in this investigation support a conclusion that the flight crew followed the checklists available and correctly performed the emergency landing. These actions were proper and consistent with existing knowledge and procedures but unbeknownst to the flight crew, the hydraulic emergency gear extension system was operable but unable to override the pressure created by the bypass of the Landing Gear Selector Valve (LGSV).

D. Conclusions

The data revealed during this investigation demonstrates that abnormal behavior of the hydraulic system and Landing Gear (L/G) system during the event is likely to have occurred due to LGSV being at an intermediate position. For these reasons, NJASAP concludes that the probable cause of the incident was the improper positioning of the landing gear selector valve, which was most likely due to improper rigging. Contributing to the incident were the inadequate checklist procedures to address the cockpit indications and the lack of information and procedures to advise operators of the G200 regarding the potential for a single point of failure in the emergency gear extension hydraulic system. Overcoming this failure was not possible using techniques known or procedures published at the time.

II. Factual Information

A. History of 749QS

On May 27, 2011, at 0928 eastern daylight time, an Israel Aircraft Industries Gulfstream 200, N749QS, managed by NetJets Inc., incurred minor damage when the right main landing gear collapsed during an emergency landing at Stewart International Airport (SWF), Newburgh, New York. The two certificated airline transport pilots and one passenger were not injured. The personal flight was conducted under the provisions of 14 Code of Federal Regulations Part 91K. Visual meteorological conditions prevailed and an instrument flight rules flight plan was filed for the flight destined to Westchester County Airport (HPN), White Plains, New York. The flight originated from Greenville Spartanburg International Airport (GSP), Greer, South Carolina, about 0730.

The pilot-in-command (PIC) stated that during approach to HPN, the landing gear lever was selected to the extend (down) position. Sounds associated with landing gear transit were heard; however, the landing gear cockpit indications remained three red lights. He aborted the approach and entered a holding pattern to complete the appropriate checklist items. Approximately 20 to 40 seconds later, a "R HYD OVERHEAT" message illuminated on the engine indicating and crew alerting system. At that time, hydraulic pressure was about 1500 psi (normal is 3000 psi), where it remained for the remainder of the flight. The flight crew then completed the checklist items for a right hydraulic overheat and decided to divert to SWF due to a longer runway and less traffic.

The flight crew subsequently performed the emergency gear extension checklist items and utilized the emergency gear blow-down bottle. The resultant cockpit indications were nose gear green, but the right and left main landing gear remained red. Before diverting

to SWF, HPN tower personnel reported that they observed the airplane's three landing gear in the extended position. The flight crew declared an emergency, flew toward SWF, and reviewed the right hydraulic failure checklist. Upon landing on runway 27, the airplane remained level for 2 to 3 seconds and then began slowly tilting to the right. The airplane then settled on its right wing and slid to a stop on the runway.

III. Investigation and Analysis

A. G200 System Performance

The 11-seat airplane, serial number 165, was manufactured in 2007. Two Pratt & Whitney Canada PW306A engines, each capable of generating 6,040 pounds of thrust, powered it. The airplane was maintained under an approved inspection program. The most recent inspection of the aircraft was completed on May 14, 2011. At that time, the airplane had accumulated 2,982 total hours of operation, and it had been operated an additional 23 hours since that inspection.

1. Landing Gear System

a) Introduction

The on-scene group investigated the possibility of a component failure within the hydraulic system, or the landing gear system, or both. The testing and reports indicate that the components within the system worked correctly but were out of position.

b) Factual

The examination revealed that the landing gear selector handle was found approximately 1/8 to 1/4 inch from the full down position. However, the position of the gear handle at the conclusion of the flight is unknown as multiple personnel accessed the cockpit prior to the investigation. Prior to the aircraft being relocated to the hangar a FBO maintenance employee entered the cockpit to verify that the gear was down and locked. We do not know if the handle was disturbed at between the time the crew vacated the cockpit and the beginning of the investigation. The airplane was placed on jacks and supplied electrical power and hydraulic pressure from ground carts. The landing gear selector handle was then positioned full up, followed by full down, and the landing gear cycled successfully. As documented in the field notes on page 5-day 1 and page 14 human factors, there was no tactile feel of a detent during the operation of the landing gear handle, which is inconsistent with the normal operation of the landing gear. Subsequently, an emergency gear extension test (blow-down) was performed and all three landing gear moved to the down and locked position as documented in the field notes on page 11 test 5 step 5. Gulfstream subsequently stated that the system should not have overcome the hydraulic pressure to lock all three gear in

the down position. NJASAP requested a verification test be conducted to verify the actual system operation. Gulfstream flight test / flight operations and engineering reviewed the request to try to repeat the flight conditions found on G200 s/n 165 on the day of the event and determined that there is no benefit to conducting such a test in flight.

During the post incident investigation, the LGSV, landing gear emergency blow-down valve and right main landing gear side brace actuator were removed from the aircraft for testing. Prior to removal of the LGSV, only a cursory visual inspection of the rigging was performed (with photographs taken) with no anomalies observed. No detailed measurements were taken regarding rigging of the LGSV and no inspection for the presence of foreign objects was performed. The landing gear selector valve, landing gear emergency blow-down valve, and right main landing gear side brace actuator were forwarded to their respective manufacturer facilities for testing and examination under government supervision. Utilizing the individual component acceptance test procedures, testing of the units did not reveal any mechanical malfunctions, nor did the subsequent teardown examinations.

According to a representative of the airplane manufacturer, most Gulfstream models have a landing gear selector handle that must be moved left out of detent, then down, then right into detent to extend the landing gear. The Gulfstream 200 however, was formerly an Israel Aircraft Industries Galaxy and the detent mechanism is not located on the handle itself, but on the landing gear selector valve instead. As shown on Israel Aircraft Industries Drawing *Westwind 1125-ASTRA #34510000000*, the G200 LGSV has a ball and spring type detent which holds the valve in either the extend or retract position. The drawing further indicates that a torque of 25 in-lbs is required to move the valve out of either of the detent positions. Post incident analysis of the LGSV by the manufacturer revealed that the valve, including the detent mechanism were fully functional (report TR 4AS710/111165). Discussions with numerous type-rated and experienced G200 pilots indicate that the landing gear detent normally has a noticeable and distinct feel.

On May 23, 2011, the rod end on the LGSV was replaced by Gulfstream Savannah (Repair Station FAA CRS GR4R216M) as a result of corrosion found during a maintenance inspection. This repair is documented by Gulfstream work order SC238654. The aircraft was released from maintenance and flew its next flight on May 27, 2011 from SAV to GSP to pick up one passenger. The aircraft subsequently launched on the incident flight with a planned destination of HPN but diverted to SWF for the longer runway.

a) Analysis

NJASAP accepts the Gulfstream analysis (report TR4AS710/111165, page 18) that concludes that the abnormal behavior of the hydraulic and landing gear systems during this incident likely occurred due to the LGSV being in an intermediate (neither extend nor retract) position. This report contains no analysis regarding why the LGSV was in an intermediate position.

NJASAP believes that the LGSV was in an intermediate position at the time of the incident as a result of improper rigging between the valve and the landing gear handle. The lack of a noticeable detent when operating the handle with a properly working detent mechanism on the LGSV indicates a problem with the rigging that connects the handle and the valve.

NJASAP is of the opinion it is likely that this improper rigging occurred when the LGSV rod end was replaced at Gulfstream Savannah on May 23, 2011. This incident occurred on the second flight following completion of that maintenance (Work Order 238654).

NJASAP believes it is very unlikely the cause of this incident was inadvertent midpoint positioning of the gear handle by the flight crew. There is no conclusive evidence to support this theory and as previously noted, the flight crew had considerable experience and flight time in the type of aircraft. Additionally, this theory does not explain why the investigators could not detect a detent when operating the landing gear handle during the post incident investigation. *Additional G200 crews were questioned concerning gear handle operation and detents within the NetJets fleet and they stated that once the gear handle was selected down, there wasn't a way to select it midpoint or "almost" all the way down.*

2. Hydraulic System

a) Introduction

The investigation team also examined the G200 hydraulic and landing gear systems. After extensive testing and engineering analysis, a single point of failure was found with a specific aircraft configuration that prevents the emergency landing gear extension system to fully extend and lock the main landing gear.

b) Factual

The pilot-in-command (PIC) stated that during approach to HPN, the landing gear lever was selected to the extend (down) position. Sounds associated with landing gear transit were heard; however, the landing

gear cockpit indications were that all gear were unsafe (three red lights). He aborted the approach and entered a holding pattern to complete the appropriate checklist items. Approximately 20 to 40 seconds later, a "R HYD OVERHEAT" message illuminated on the engine indicating and crew alerting system. At that time, hydraulic pressure was about 1500 psi (normal is 3000 psi), where it remained for the remainder of the flight. The flight crew then completed the checklist items for a right hydraulic overheat and decided to divert to SWF due to a longer runway and less traffic.

The flight crew subsequently performed the emergency gear extension checklist items and utilized the emergency gear blow-down bottle. The resultant cockpit indications were nose gear safe (green), but the right and left main landing gear remained unsafe (red). Before diverting to SWF, HPN tower personnel reported that they observed all three landing gear in the extended position. The flight crew declared an emergency, flew toward SWF, and reviewed the right hydraulic failure checklist. Upon landing on runway 27, the airplane remained level for 2 to 3 seconds and then began slowly tilting to the right. The airplane then settled on its right wing and slid to a stop on the runway.

c) Analysis

NJASAP accepts the Gulfstream analysis (report TR4AS710/111165, page 18) that concludes that the abnormal behavior of the hydraulic and landing gear systems during this incident likely occurred due to the LGSV being in an intermediate (neither extend nor retract) position. In layman's terms, the report provides the following analysis:

The LGSV in an intermediate position allows hydraulic pressure to leak to both the extend and retract sides of the landing gear actuators. The pressure on the extend side is sufficient to cause the gear to extend, but the pressure on the retract side prevents the gear down locks from engaging. This results in the initial gear unsafe indications after gear extension.

The hydraulic fluid leaking through the LGSV causes the hydraulic pressure to drop below normal and causes a rise in fluid temperature that activates the hydraulic overheat light.

Activation of the emergency gear blow-down system did not result in down and locked indications on the main gear because the emergency system does not have sufficient pressure to overcome the hydraulic pressure leaking through the LGSV to the retract side of the system.

NJASAP believes that this investigation reveals a design flaw in the G200, which allows failure of a single component (LGSV) to disable both

the normal and emergency landing gear extension systems. NJASAP further believes that this constitutes a failure of the G200 to meet FAA Part 25.729(c)(1) certification standards.

> *Part 25.601 General.*
>
> *The airplane may not have design features or details that experience has shown to be hazardous or unreliable. The suitability of each questionable design detail and part must be established by tests.*
>
> *Part 25.729 Retracting mechanism.*
>
> *(c) Emergency operation. There must be an emergency means for extending the landing gear in the event of—*
>
> > *(1) Any reasonably probable failure in the normal retraction system; or*
> >
> > *(2) The failure of any single source of hydraulic, electric, or equivalent energy supply.*

The G200 Maintenance Training Manual, G200 Pilot Training Manual and the standard training administered to NJA flight crews' references that the emergency extension system will "create a return path for fluid from the gear actuators to the hydraulic reservoir. This allows emergency gear extension even in the event of mechanical jamming of the landing gear control lever." Prior to this incident no training or documented procedure contemplated the emergency extension system failing to overcome the hydraulic pressure associated with the normal extension system. Flight crews have been consistently trained to use the emergency extension system for all failure modes.

In addition, it is reasonable to expect that the certification standard for the aircraft would allow for a failure of the landing gear selector valve alignment failure. Mis-rigging, foreign debris in the detent, jamming of the handle in an intermediate position, failure of the cable between the handle and the LGSV are all realistic points of failure for the primary extension system. Therefore, under Part 25 certification, the emergency extension system must be capable of locking the gear down in the event of a failure of the normal retraction system.

B. G200 Checklists

1. Introduction

The investigation shows that the crew properly executed procedures and adhered to applicable company policies while dealing with the abnormal conditions in flight. However, the checklists did not provide the adequate guidance to correctly identify and address the abnormal conditions. Post flight data shows gear might have come down had the crew executed selected steps out of various checklists (recycle gear) that specified different cockpit indications than what the crew actually had. However, flight crews are trained to adhere to written policy and procedure in order to avoid exacerbating abnormal conditions.

The investigation shows the crew followed the G200 checklists, the NJA FOM directives and exhausted all viable means to correct the aircraft configuration and address any safety concerns without question. The following are excerpts from the FOM indicating the crew performed with accuracy and adhered to any company direction:

1.5.1 General

a. The policies, procedures and practices outlined in this manual are applicable to all personnel with responsibility for NJA flight operations activities.

b. Use of active voice in directive sentences indicates mandatory procedures or actions.

c. The words 'shall,' 'will,' and 'must' indicate mandatory procedures or actions.

d. The words "Do not..." in directive sentences indicate prohibited actions.

3.2 Safety Considerations

Policies in this chapter are not intended, and shall not be construed, as limiting authority of the PIC, nor as relieving pilots from compliance with applicable abnormal or emergency procedures.

PIC is responsible for determining if the situation is abnormal or an emergency.

3.3.3 Use of Abnormal/Emergency Checklists

Exercise sound judgment when completing an abnormal/emergency checklist. Accomplish abnormal/emergency

procedures checklist for each existing condition, in the following sequence:

1. Immediate action/memory items

2. Emergency checklist

3. Abnormal and Normal checklists

Follow procedures as written; abnormal/emergency checklists represent the manufacturer's best guidance for handling emergency or abnormal situations. Use the checklist to accomplish and verify each step of a single abnormal or emergency condition, and perform one item at a time, in sequence. Multiple failures may require analysis of the situation and prioritization of checklists.

Additionally, the crew decided on the alternate (longer) runway at Stewart-Newburgh due to their perception and analysis of cockpit indications that the hydraulic system was unreliable and had the potential to cause a fire or completely fail. This decision is in accordance with current training standards and FOM direction:

3.5 *Emergency Situations*

Declare emergency when distress or any condition jeopardizes safety of flight, or an inflight medical emergency requires diversion. Pilots are responsible for determining suitability of a diversion airport, If conditions permit, notify the SOC Hotline prior to landing, otherwise, notify after landing.

2. Landing Gear locked down indication failure checklist

a) Introduction

The Landing Gear locked down indication failure checklist is located in the G200 QRH and the AFM section III. This checklist has since been revised and approved due to this incident.

The Landing Gear locked down indication failure checklist is utilized when the landing gear will not lock in the down position. The checklist has several notes that lead to recycling the landing gear during cold soak conditions. This checklist is considered routine and as noted in step 6 the flight crew is only required to document the procedure and anomaly if the procedure must be repeated several times.

b) Factual Investigation

At 0903, as the PIC continued flying, the SIC initiated the Landing Gear Lock Down Indication Failure checklist contained in the quick reference handbook. He completed items No. 1 and No. 2, pertaining to the flaps and airspeed, respectively. Item No. 3 pertained to right hydraulic pressure, to which the SIC noted that there was a problem. Additionally, before addressing item Nos. 4 and 5, which instructed the SIC to cycle the landing gear selector handle, a master caution activated due to a right hydraulic overheat condition. Seconds later, the SIC also noted a burning smell. The PIC then expressed the need to get the airplane on the ground.

At 0907, the SIC returned to the Landing Gear Lock Down Indication Failure checklist, item No. 3, and noted that if hydraulic pressure is "normal," proceed to item No. 4 (cycle gear); however, hydraulic pressure was not "normal." Additionally, the SIC also noted that item No. 7 instructed that the emergency landing gear extension should be performed if the hydraulic pressure was "low."

c) Analysis

Review of the CVR confirms that the crew properly executed the NetJets normal checklists prior to up to and including the "Before Landing" checklists. In reviewing crew statements and notes taken during questioning, it was noted that the PIC observed the gear handle being selected full down by the SIC. Additionally, the PIC observed the SIC place his hand on top of the gear handle during step 3 of the Emergency gear extension checklist.

The normal checklist was terminated at the point that the landing gear did not fully extend and lock into position. The abnormal checklists associated with the landing gear failing to properly extend was then initiated. The NJA Flight Operations Handbook states that in the event of an abnormal landing gear indication that the crew must comply with the applicable checklist and operating limitations. The caution note prohibits the cycling of the landing gear unless specifically directed by the AFM abnormal or emergency procedure.

The Landing Gear Lock Down Indication Failure procedure as published in the G200 AFM at the time of the incident directed the flight crew to recycle the gear only if the right hydraulic pressure was checked and found to be normal. The G200 AFM states that the normal pressure range for the hydraulic system is 2700 to 3250 PSI. When the crew checked the hydraulic system the pressure was noted to be 1670 and "not normal." The crew adhered to the written guidance in both the NJA Flight Operations Manual (FOM) and checklist, which indicated that

recycling the gear, was not permissible with the hydraulic system indicating abnormal pressure. The procedure then references the emergency landing gear extension checklist if the landing gear has not successfully been locked in the down position. Therefore the crew then transitioned to the emergency landing gear extension checklist.

Since this checklist is routinely utilized to obtain a gear down and locked condition after the landing gear has been cold soaked and slow to extend/lock into position it is a conditioned response both through training and repeated application that step 7 directs the use of the emergency extension system in order to lock the gear into the down position.

3. Hydraulic System Overheat checklist

a) Introduction

The Hydraulic System Overheat checklist is located in the G200 QRH and the AFM section III. This checklist has since been revised and approved due to this incident.

b) Factual Investigation

At 0904 the right hydraulic overheat EICAS message illuminated. At 0905 the SIC/PM noted that he could smell something burning. Subsequently at 0905, the SIC diverted from the Landing Gear Lock Down Indication Failure checklist, to the Hydraulic System Overheat checklist. That checklist included the instruction to reduce the affected engine to idle power and the PIC reduced the right engine thrust to idle power.

c) Analysis

In reviewing the CVR summary and crew statements, all indications show the crew properly identified cockpit indications and interpreted the checklist (as written at the time) correctly. Furthermore, the crew also reviewed additional checklists that would affect their landing in case the current indications increased or a complete failure occurred during the critical landing phase.

The flight crew elected to complete the hydraulic overheat checklist immediately due to the burning odor and hydraulic overheat message. The crew recognized that the risk of fire was a greater and more immediate threat than the landing gear not being down and locked while in flight. The checklist in this situation was ambiguous, did not address the displayed indications and did not provide adequate guidance for the overheat condition in a realm of flight not associated with enroute operations. In this case, securing the right engine may have caused the landing gear to lock into the down position. However, restarting the

engine as directed in step 5 may have also caused the gear to unlock and the restart the hydraulic overheat condition.

The NetJets FOM lists specific guidance on actions to be taken during an emergency. The crew followed these directives and adhered to the NetJets and Flight Safety flight-training standards throughout the procedure. The following is an excerpt from the NetJets FOM:

> **3.5.3 Fire/Smoke/Fumes**
>
> Any actual or suspected fire, or presence of smoke or fumes identified as being fire-related, is considered an emergency. Quickly evaluate the situation; gain access to, and attack the fire using all available resources. These actions must be taken even when indications dissipate in a short period of time.

If a procedural checklist requires a different mode selection, with or without additional actions (i.e. mode selection of AUX pump and manipulating flight controls), an explanation of why these many steps are occurring should be in the AFM. If the crew understands that there is a possibility of a single point of failure and the checklist is trying to reduce the HYD pressure on a component or within the system, then the constant AUX pump switching and the shutting down of an engine makes sense and decreases the stress factor of the unknown.

4. Emergency Landing Gear Extension checklist

a) Introduction

The Emergency Landing Gear Extension checklist is located in the G200 QRH and the AFM section III. This checklist has since been revised and approved due to this incident.

b) Factual Investigation

At 0908, the flight crew switched duties due to the location of the emergency landing gear extension controls. The PIC read the Emergency Landing Gear Extension checklist, including item No. 3, which stated that the landing gear lever is in the down position. He then performed item No. 4, which was the release, turn, and lift of the emergency gear extension handle. Although item No. 5 stated that the landing gear was down and

locked with a three-light indication, the flight crew noted that only the nosegear was down and locked. The checklist did not include additional instructions pertaining to a situation where all three landing gear were still not down and locked.

c) Analysis

The emergency landing gear extension checklist did not adequately address the condition that existed in the cockpit at the completion of the checklist. Step 5 of the emergency landing gear extension checklist indicates that the gear will be down and locked with 3 DN indications. There are two notes following step 5 that state the gear must stay in the down position and may not be retracted after utilizing this procedure. However, the checklist did not reference any procedure or action to be accomplished if the landing gear was not down and locked.

The NetJets FOM lists specific guidance on actions to be taken during a landing gear emergency. The crew followed these directives and adhered to the NetJets and Flight Safety flight-training standards throughout the procedure. The following are excerpts from the NetJets FOM:

> **3.4.9 Landing Gear Indications**
>
> If abnormal landing gear condition is indicated, comply with applicable checklist (if published) and any applicable operating limitations.
>
> ***CAUTION:*** *Do not cycle landing gear with an abnormal indication unless specifically directed by the AFM abnormal or emergency procedure*.
>
> **Extension Abnormal Indication** – Any condition that shows the gear is not locked in the down position is an extension abnormal indication. At the completion of the checklist, if desired, request ATC approval to execute a low approach by the tower for assistance in visually identifying the status of the landing gear.

In the many changes made during this process some checklists contain numerous “skip ahead to” and “return to” directives. This issue arises in many other portions of the AFM checklist. This type of directive is confusing and makes it difficult to determine where one was in the checklist or what the next step is during critical phases of flight, radio calls and aircraft maneuvering. The checklist should contain directives that are clear, readily accessible and allow for completion in a timely manner with a limited amount of maneuvering required within a single checklist. The checklist also fails to give the crews indications that the procedure is

complete, even when redirecting them to another checklist. For example, some of G200 procedures require the crew to reference another checklist and then expects them to return to the original checklist while procedures require the crews to reference another checklist with no need to return to the original checklist.

5. Right Main Hydraulic System Failure checklist

a) Introduction

The Right Main Hydraulic System Failure checklist is located in the G200 QRH and the AFM section III. This checklist has since been revised and approved due to this incident.

b) Factual Investigation

At 0919, the SIC began to read the Right Main Hydraulic System Failure checklist, but the flight crew agreed that the hydraulic system had not failed.

c) Analysis

It was found that within some of the checklists (to include the Right main HYD system failure III-62) the checklist required the crew to reference it throughout the landing configuration phase as well as referencing additional checklists to complete during different phases of flight. If the checklist for a failure contained ALL of the required steps throughout all phases of flight (and contained a directive to duplicate another checklist, if necessary, within that checklist), it would reduce the potential to miss a step or lose one’s place in an unending checklist.

C. FLIGHT CREW QUALIFICATIONS

1. CAPTAIN (PIC) Jeff Cox

a) Factual Investigation

The pilot-in-command (PIC), age 45, held an airline transport pilot certificate, with a rating for airplane multiengine land and a commercial pilot certificate, with a rating for airplane single-engine land. He also held a type rating for the Gulfstream 200. The PIC reported a total flight experience of 10,013 hours; of which, 3,244 hours were in the Gulfstream 200. He flew 105 hours and 25 hours during the 90-day and 30-day periods preceding the incident, respectively. The PIC's most recent Federal Aviation Administration (FAA) first-class medical certificate was issued on January 6, 2011.

b) Analysis

NetJets hired Captain Cox in May 1996. He flew the Citation S-2 and was upgraded to captain in February. 1997. During his tenure at NetJets, Captain Cox received type ratings in the Citation Ultra, the Hawker 1000 and is currently in the G200 fleet. He was a "Line Oriented Trainer" (LOT) captain in Ultra from July 1998 to July 1999, and also performed duties as an I.O.E. captain in the G-200 from May 2003 to mid 2005. At time of incident, Captain Cox had accumulated 12,348 total flight hours, 6,980 hours as a NetJets pilot. 3,202 hours of that time is in the G-200 with 2,927 hrs as PIC and 275 as an SIC.

Prior to his NetJets career, Captain Cox flew freight and corporate charter for Gordon Air out of CAK in twin engine Cessna’s, King Airs, and Westwind aircraft. He accumulated 1,100 hours as a flight instructor out of Freedom Field, Medina, Ohio in addition to flying as a traffic watch pilot.

To a pilot with such experience, the routine of selecting gear down, running checklists and selecting the best course of action during emergency situations would not pose any significant difficulty in recognition or recovery. The facts brought to light in this investigation show clearly that Captain Cox was fully qualified and trained per NetJets and Flight Safety syllabi and his experience indicates he possesses the skill and training needed to recognize, analyze, and successfully perform any abnormal procedures to land a normally functioning aircraft in an abnormal landing configuration.

2. CAPTAIN (SIC) Chris Frey

a) Factual Investigation

The second-in-command (SIC), age 41, held an airline transport pilot certificate, with a rating for airplane multiengine land; and a commercial pilot certificate, with ratings for airplane single-engine land, rotorcraft helicopter, and instrument helicopter. He also held a type rating for the Gulfstream 200. The SIC reported a total flight experience of 5,800 hours; of which, 604 hours were in the Gulfstream 200. He flew 65 hours and 37 hours during the 90-day and 30-day periods preceding the incident, respectively. The SIC's most recent FAA first-class medical certificate was issued on December 30, 2010.

b) Analysis

NetJets hired Captain Frey January 2002. He flew the Citation XL and was upgraded to Captain September 2005. Captain Frey transitioned to the G200 fleet as a Captain in September 2008. At the time of the incident, Captain Frey had accumulated 5,800 total flight hours, 604 of that time is in the G-200 with 240 hrs as PIC and 364 as SIC.

Prior to his NetJets career, Captain Frey flew freight and corporate charter for Beaver Aviation out of PIT in a PA-44's. He also flew BE1900D's for CommutAir, a Part 121 operation out of Plattsburgh, NY. During his military career, he has accumulated over 1,700 hrs flying UH-1's and UH-60's as a Unit Trainer, OPFOR pilot and MEDEVAC pilot, including combat operations in Bosnia and Kosovo.

The risk management and prioritization stressed by military training is second to none. Constant risk assessment is stressed as well as constant analysis of the situation. Strict parameters of checklist usage, Standard Operating procedures and systems awareness are the core of all military training. Because of his extensive experience, ensuring proper positioning of levers, switches and adhering to checklist steps would be run without question and with little difficulty. The facts brought to light in this investigation show clearly that Captain Frey was fully qualified and trained per NetJets and Flight Safety syllabi and his experience indicates he possesses the skill and training needed to recognize, analyze, and successfully perform any abnormal procedures to land a normally functioning aircraft in an abnormal landing configuration.

V. Conclusions

After review of the field notes, the crew statements and the CVR summary, it is indicated that the crew followed checklist in a meticulous manner. NetJets crews are trained not to "freelance/troubleshoot" while airborne. And the NetJets FOM guidance specifically states: "*Follow procedures as written; abnormal/emergency checklists represent the manufacturer's best guidance for handling emergency or abnormal situations."*

Also, the crew felt pressure to land without undue delay due to the right hydraulic fluid temperature cycling as well as the increasing hydraulic temperature and the initial burning odor. In fact, the crew stated a concern for a potential fire or failure of the hydraulic system. The FOM also states that if there is any suspected fire, it becomes an emergency.

In reviewing all of the G-200 checklists, it is evident that these checklists are due for updating and review. According to current and reliable research, it has been found that there are many problems with older generation checklists. For example, latent failures as well as illogical procedures are present in the checklists. In some operations, checklists from older but similar type aircraft are transferred and adjusted for newer aircraft procedures. This subsequently results in maintaining the presence of latent failures in the checklists and does not necessarily address the newer cockpit configuration, system enhancements and pilot training.

A checklist that includes items which do not run in conjunction with the activities occurring around the aircraft generates a distinct disadvantage. Oversight of certain checklist items may occur when the crew defers an item to be completed at a later time, which could not be completed in sequence because of distractions or illogical sequencing. Because a paper checklist does not promp the pilot about the skipped or incomplete steps, the pilot attempts to store the deferred items in memory. However, due to the limitations of human memory, paired with time constraints, external pressures, existing distractions and additional duties and activities, the likelihood of these items being overlooked or forgotten is high.

The order of the checklist items is the only indicator regarding the pilot's point of progress in the checklist ("where are we on the checklist...?"). Therefore, order is an important structural format in an effort to reduce the potential for failure while conducting this procedure. Likewise, the use of a structured flow in conducting the actual (as opposed to initial) checking procedure can enhance the checklist task in the following ways: Making the checklist sequence parallel to the initial set up flow-patterns ensuring the checklist actions are logical and consistent (as opposed to intermittent) in the motor movement of the head, arms and hands providing greater accuracy by combining two processing channels: spatial (flow patterns) and verbal (challenge-response) (Booher, 1975).; and providing an association between location and sequence, making it more difficult to overlook an item.

When a checklist is run in a controlled or "known" environment, certain failures tend to stay hidden and will not come up until the crew is under pressure. When this crew ran the select checklists, latent failures became active giving the crew ambiguous direction and incomplete steps within the procedure. *Latent failures* are ones "whose adverse consequences may lie

dormant within the system for a long time, only to becoming evident when they combine with other factors to breach the system's defenses. Their defining feature is that they were present within the *socio-technical* system well before the onset of an accident sequence" (Reason, 1988). Reason borrows a term from medicine, referring to latent errors as "resident pathogens" because they reside within a system in the same way biological pathogens reside within a living body, only to manifest themselves as a result of unique set of unexpected conditions. Dr Reason also has studied the many aspects of human factors within cockpit and checklist design. He, and others, has found that resident latent pathogens lie within the system in which the crew and aircraft operate, only to manifest themselves with a unique interaction of human failure and machine failures. There are many engineering defenses, such as configuration, warning, and alerting systems that do not assure protection against nor identification of these pathogens. Additionally, the inherent pressures that surround checklist usage make these pathogens even more difficult to identify or control. The distinctive interaction between humans, humans, aircraft, checklists and the operational environment, makes the checklist problem a true human factors issue.

A. Findings

1. Crew

a. Nothing in the flight crew's background suggests they would have problems with any normal or abnormal procedures involving the control of the incident aircraft.

b. The flight crew's performance was not affected by illness, fatigue, or personal or professional problems.

c. Based on information known to them and the procedures documented and in place at the time, the flight crew reacted correctly.

2. Aircraft

a. The Landing Gear Selector Valve (LGSV) being out of position will cause the emergency gear extension system to fail.

b. Tactile landing gear handle detents were not present in the incident aircraft.

c. The rigging of the LGSV in the incident aircraft was not checked prior to LGSV removal during the investigation. The aircraft was released from maintenance for the LGSV the morning of the incident.

3. Checklists

a. The G200 checklists in general are ambiguous or reference other checklists and do not give clear steps and/or direction.

b. The G200 checklists contain many “if” scenarios in steps within the procedures, but do not provide adequate direction if the parameter is not met (i.e. Emergency Bus Failure).

c. The G200 checklist does not address the logic of shutting down the engine to restore the emergency landing gear capability

d. New checklists

i. Introduction

After the incident, the airplane manufacturer revised several of its normal and emergency checklists. Specifically, terms such as "normal" and "low" were replaced with actual numerical values. Additionally, a newer revision was published, which included more guidance in the event that the landing gear selector handle was placed in a position other than the full up or full down position, causing a hydraulic bypass flow situation. Lastly, the checklist was expanded to include a situation where an emergency blow-down procedure failed to extend and lock all three landing gear.

ii. Analysis

During the review of the new and existing checklists, we noted that overall the G200 checklists are confusing and do not state “Procedure complete.” In addition, it is important to identify the new and corrected procedures as a viable engineering work-around for a potential single point of failure design flaw that might exist between the Landing Gear Selector Valve (LGSV) being improperly positioned and the emergency gear extension system being unable to overcome that failure.

Also, while reviewing additional checklists and associated caution notes, it was found that a specific QRH checklist that existed prior to the incident (dated February 19, 2010) references a caution that indicates a potential conflict of the two landing gear systems. The CAUTION statement reads:

> ***CAUTION****: DO NOT USE EMERGENCY LANDING GEAR EXTENSION UNLESS BOTH R HYD PUMP PRESS LOW AND AUX HYD PRESS LOW MESSAGES ARE ILLUMINATED.*

This caution indicates the potential of the Emergency Gear Extension not functioning without the Right Hydraulics and Aux Hydraulics OFF.

B. Probable Cause

1. Primary cause

The probable cause of this incident was the improper positioning of the landing gear selector valve (LGSV) that placed the aircraft in an unsafe landing gear configuration from which recovery was not possible using published procedures. This is due to single point of failure within the hydraulic system, which prohibits the emergency landing gear extension system to operate properly.

2. Secondary Causes

One of the contributing causes of this accident was the manufacturer's failure to advise operators that there was a potential single point of failure within the system and work around procedures were not in place to counteract the failure. Another contributing cause is inadequate guidance in the QRH and AFM checklist procedures. Moreover, another possible cause is improper rigging of the LGSV causing improper positioning of the valve.

C. Recommendations

1. Issuance of an AD to correct the single point failure in system with a new valve/system design. Not a viable long-term solution to trade one emergency landing for another especially in higher risk operating profiles (i.e. mountainous operations, winter operations, etc).

2. Training for Gulfstream maintenance. Because of the new procedure used as a work around for the potential of a single point of failure, additional training for the G200 maintenance technicians concerning the importance of proper rigging because of the importance of LGSV positioning would be beneficial. Adding CAUTION notes in the maintenance manual and training manual would also assist in mitigation of potential error.

3. Restructure G200 training modules to address the logic in the new emergency procedures located in the AFM and QRH and training the proper sequence for the new procedures. Address the logic and safety concerns for the trade off one emergency configuration for another (i.e. single engine operations vs. unsafe gear landing).

4. Restructure/redesign of all Gulfstream checklists.

   a. Upon researching checklist design and recognizing the ambiguity that exists, and considering the uniqueness of the G200 checklists, we recommend the following guidelines found in many publications utilized for designing and using flight-deck checklists. Each guideline should be carefully evaluated for its relevance to operational constraints.

i. Checklist responses should accurately depict the desired status or the value or range of the item being considered, not just "checked" or "set."

ii. A long checklist should be subdivided to smaller checklists or into related sections that can be correlated by systems and/or functions within the cockpit.

iii. Sequencing of checklist items should follow physical or logical location of the items in the cockpit, and be performed in a logical flow. Checklists should be able to be run to completion without referring to other checklists mid-point then referring back to the initial checklist for procedure completion.

iv. The most critical items on a task-checklist should be listed as close as possible to the beginning of the checklist in order to improve the probability of proper item completion before interruptions occur.

v. The completion call of a checklist should be written as the last item on the checklist, allowing all crewmembers to move mentally from the checklist to other activities with the assurance that the checklist has been completed.

vi. Checklists should be designed in such a way that their execution will not be closely coupled with other tasks. Every effort should be made to provide a safeguard for recovery from breakdown and a way to "take up the slack" if checklist completion does not keep pace with the external and internal distractions and procedures.

vii. Flight crews should be made aware that the checklist procedure is highly susceptible to production pressures. These pressures set the stage for errors by possibly encouraging substandard performance, and may lead some to downgrade checklist procedures to a second level of importance, or not use them at all.

b. The Air Transport Association (ATA), an industry-wide trade organization, has also stated its recommended checklist philosophy:

"Checklists should contain, in abbreviated form, all the information required by the trained flight crew to operate the airplane in most normal and non-normal situations. Normal checklists should be organized by segments of flight. The checklist should contain the minimum cues required for the trained crewmember to verify that the appropriate actions have been completed. Only procedural

steps which, if omitted have direct and adverse impact on normal operations, are included. Items annunciated by crew alerting systems are not included." (ATA, 1986, p. 46)

5. Redesign of landing gear handle.

a. The G200 maintenance and pilot training manual state the landing lever has "Two positions: Up and Down". This indicates that the handle can only be selected up or down and not at any median point between (unless the rigging is set to not allow proper positioning).

b. Many aircraft have noticeable tactile detents, both hydraulic and mechanical, for the up and down position of the gear handle. Some aircraft have over center features that will not allow any median setting of the gear handle. Another mitigation strategy employed is gear handles that illuminate red until the handle is completely in the down detent and the red light is extinguished. There are many mitigation strategies, including training, that can assist in this issue.