

SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 747-443, G-VROM	
No & Type of Engines:	4 General Electric CF6-80C2B1F turbofan engines	
Year of Manufacture:	2001 (Serial no: 32339)	
Date & Time (UTC):	29 December 2014 at 1334 hrs	
Location:	Near London Gatwick Airport	
Type of Flight:	Commercial Air Transport (Passenger)	
Persons on Board:	Crew - 18	Passengers - 447
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Damage to right wing landing gear door and strike board	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	47 years	
Commander's Flying Experience:	12,279 hours (of which 9,771 were on type) Last 90 days - 162 hours Last 28 days - 95 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The aircraft departed from London Gatwick Airport for a scheduled flight to Las Vegas. Following retraction of the landing gear after takeoff, low quantity and pressure warnings occurred on hydraulic system 4, due to a hydraulic fluid leak. The required checklists were completed and the aircraft returned to land at London Gatwick Airport. As the landing gear extended during the approach, the right wing landing gear struck the gear door, preventing the gear leg from fully deploying. The crew carried out a go-around and, following a period of troubleshooting and associated preparation, a non-normal landing was successfully completed. It was subsequently determined that the hydraulic retract actuator on the right wing landing gear had been incorrectly installed. Four Safety Recommendations have been made.

History of the flight

The flight was scheduled to depart at 1120 hrs on 29 December 2014. Three pilots were rostered for the flight, a commander, a co-pilot and a relief co-pilot. The pre-flight planning was uneventful and no defects on the aircraft were advised to the crew.

On their arrival at the aircraft the flight crew learned that maintenance had been carried out overnight. The relief co-pilot, who conducted the pre-flight walkround inspection, noticed that the landing gear locking pins were still in place and a request was made for these to

be removed. Passenger boarding was completed on time and the aircraft was ready to depart on schedule, but there was a short delay while final maintenance paperwork was completed. The aircraft pushed back from the stand at 1129 hrs.

The aircraft commander, occupying the left seat, was the Pilot Not Flying (PNF) and the co-pilot, occupying the right seat, was the Pilot Flying (PF). The relief co-pilot was seated on the flight deck jumpseat.

The takeoff commenced from Runway 26L at 1143 hrs. As the aircraft climbed towards 1,000 ft aal, with the landing gear retracted and the autopilot not engaged, there was a 'HYD QTY LOW 4' Engine Indicating and Crew Alerting System (EICAS) advisory message. The pilots checked the associated hydraulic system synoptic page and noted the system 4 hydraulic quantity was decreasing rapidly. As the aircraft climbed, the flap retraction was carried out and the autopilot was engaged.

The relief co-pilot started to review the paper Quick Reference Handbook (QRH), but as he was doing so the 'HYD PRESS SYS 4' EICAS caution activated. The checklist for this failure was called for and actioned as the aircraft continued to climb to FL320. Once all the required checklist actions had been completed, the crew reviewed the status of the aircraft. They determined that the failure had been contained and that it would be possible to continue to their destination.

The relief co-pilot contacted the operator's maintenance control department on the company communication frequency and advised them of the hydraulic system problem. The operator requested that the aircraft should return to London Gatwick Airport.

The aircraft was too heavy for an immediate return to land, so the crew advised Air Traffic Control (ATC) of their intention and subsequently held for around 40 minutes as fuel was jettisoned.

During this time the crew reviewed the QRH to understand the procedures that would be required for landing and to calculate the required landing distance. The inoperative items associated with the loss of hydraulic system 4 are shown in Figure 1.

The cabin crew and passengers were briefed on the situation and when the fuel jettison had been completed, the crew notified ATC that they were ready to return to London Gatwick Airport. The weather conditions were clear with a surface wind from 280° at 6 kt, CAVOK, temperature 4°C, dewpoint 1°C and pressure 1040 hPa. A 20 nm final approach was requested to allow time for the anticipated slow flap extension and alternate gear extension. At 1325 hrs the crew started to configure the aircraft for the approach.

The aircraft was on the extended centreline for Runway 26L, with flap deployed to 10°, when the alternate gear extension procedure was started. The QRH procedure for alternate gear extension is shown in Figure 9.

System 4
Note: Inoperative Items
Right outboard elevator inop Pitch control is reduced.
Outboard trailing edge flap hydraulic operation inop Trailing edge flaps move in secondary mode. Secondary extension from flaps 1 to 5 requires approximately 4 minutes. During approach, allow extra time for flap extension.
Two inboard spoiler panels on each wing inop Roll rate and spoiler capability are reduced.
Wing gear hydraulic extension and retraction inop Alternate gear extension is needed.
System 4 normal brake source inop System 1 and system 2 alternate brake sources are available.
Autobrake inop Manual braking is needed.

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Figure 1

Hydraulic System 4, inoperative items (from QRH)

After the procedure was carried out the flight crew realised that the right wing landing gear had failed to lock down. The aircraft was levelled at 3,000 ft and continued to fly straight ahead. The commander made a radio call to ATC to advise they had experienced a problem with the landing gear and requested a visual inspection as they passed in front of the tower. The flight crew were advised by ATC that the right wing landing gear was not visible.

The aircraft was given radar vectors to an area south of the airport where an extended period of troubleshooting took place. The QRH checklist for alternate gear extension (see Figure 9) did not offer an option for the case where all the gear are not DOWN after extension. The flight crew discussed this inconsistency and decided to select the landing gear lever DOWN. A GEAR DISAGREE EICAS message was generated.

The flight crew contacted the company Integrated Operations Control Centre (IOCC), who were able to establish direct contact with an advisor from the aircraft manufacturer. The flight crew consulted the onboard manuals, liaised further with the IOCC, briefed the cabin crew and the passengers on the aircraft status, and briefed themselves on how the approach should be conducted and the handling implications. They commented afterwards that having an additional pilot was very helpful in the task sharing process.

The crew read through the 'GEAR DISAGREE' QRH checklist, part of which required the gear lever to be selected UP. They decided not to action this item but instead, as recommended by the manufacturer through the IOCC, selected the gear lever to OFF and recycled the alternate gear extend switches. This had no effect. Several unsuccessful attempts were made to lock the gear out by manoeuvring the aircraft, in a climb, a descent and in turns. Following these manoeuvres the crew prepared for a non-normal landing on the available landing gear in accordance with the 'GEAR DISAGREE' and 'Emergency Landing' QRH checklists.

The commander was concerned that the fuel should be reduced to a minimum level whilst leaving sufficient for a go-around if required, and aimed for approximately one hour endurance. He also considered it preferable to land in daylight; sunset was at 1601 hrs. Accordingly the aircraft remained in a holding pattern until sufficient fuel had been consumed, and the time of sunset was approaching.

Once again a 20 nm final approach segment was requested and the second approach started at 1540 hrs. The commander assumed the PF role, in accordance with their briefing, at around 10 nm inbound and the aircraft landed at 1545 hrs. On the landing roll the aircraft maintained the runway centreline and came to a stop, in a right wing low attitude of approximately 4°. The commander assessed the situation and decided that a passenger evacuation was not required. The passengers were requested to remain seated while the aircraft was given an external inspection, first by the attending fire crews and subsequently by the operator's maintenance personnel. The engines were shut down and the crew liaised with the Rescue and Fire Fighting Service (RFFS) on frequency 121.6 MHz.

The passengers remained on-board while the aircraft was checked for stability, to ensure that the disembarkation could be completed safely. The aircraft remained on the runway and disembarkation started under the supervision of the RFFS at 1630 hrs and was completed an hour and a half later.

Initial aircraft inspection

Once the passengers had been disembarked, an initial inspection of the landing gear was conducted. The right wing landing gear door was partially open, with the outboard rear wheel of the wing gear resting on the outboard section of the door. The outboard section of the door was significantly deformed, but the door itself was still firmly attached and the gear was securely held in a partially deployed position. (Figure 2) Evidence of leaking hydraulic fluid was found around the upper section of the gear leg, but there was no obvious damage to the wing gear in the areas visible during initial inspection. The lower section of the strike board in the right wing landing gear bay was missing.

The left wing gear door was in the fully open position, as were the two body landing gear doors. None of the landing gear doors showed evidence of contact with the ground. Both the body landing

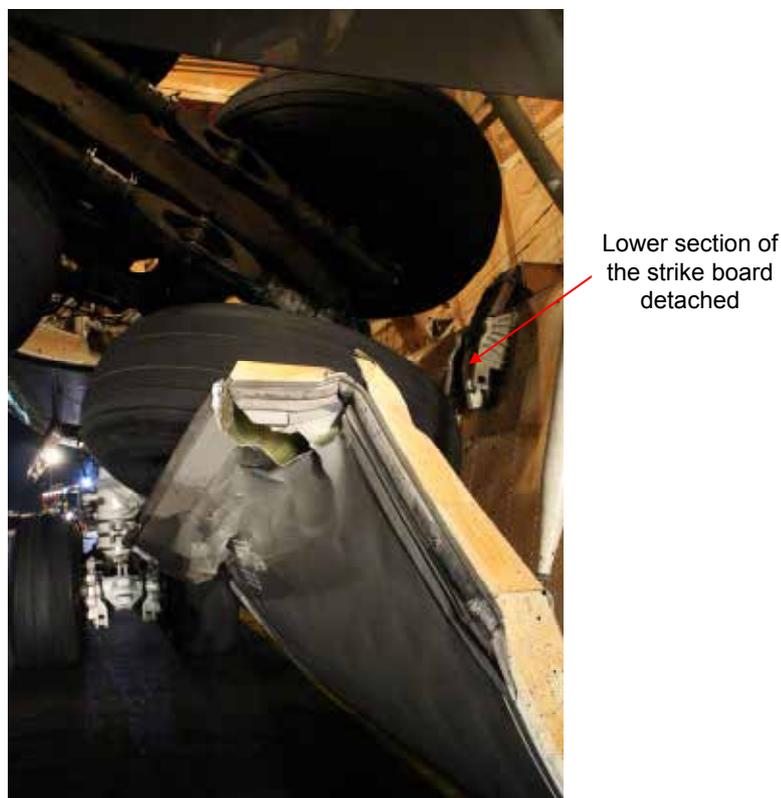


Figure 2

Right wing landing gear door and gear leg as found just after landing.

gears and the left wing landing gear were undamaged, although the uneven weight distribution caused by the non-weight bearing right wing landing gear, meant the aircraft was canted over to the right, such that the outboard wheels of the left wing landing gear were no longer in contact with the ground. This also resulted in the engine nacelle of the number three engine on the right wing being significantly closer to the ground than normal. However, no evidence was found that the engine had contacted the ground during the landing.

Detailed inspection of the wing landing gear

The aircraft was recovered from the runway and towed to the operator's hangar for further investigation. The damaged wing landing gear door was removed and the right wing landing gear leg fully extended. The right wing landing gear actuator was found installed 180° out of alignment. The hydraulic port boss fitting on the head end of the actuator was distorted and damaged (see Figure 3).



Figure 3

Damaged hydraulic port on landing gear actuator

Missing strike board

Approximately three months after the incident, an object was found by a farmer in his field near Tonbridge in Kent. He reported this to the CAA, who recovered the item. Whilst there were no identification numbers on the component, it was visually confirmed as a strike board from a Boeing 747, and was passed to the AAIB. Using data from radar and the aircraft FDR, a comparison of the flight path and timing of the original gear extension showed this coincided exactly with the location where the strike board was found, giving a high probability that the recovered item was from G-VROM.

Recorded data

Flight Recorders

The aircraft was fitted with a solid state flight data recorder (FDR) and cockpit voice recorder (CVR). These were downloaded at the AAIB where the recordings were analysed. The duration of the CVR was two hours and consequently the recording only captured the latter two hours of the flight (which lasted just over four hours) starting at 1348 hrs when G-VROM had descended to 3,000 ft, and was in a holding pattern.

Relevant data from the FDR is presented in Figure 4 for the whole flight although for the landing gear, these were restricted to gear lever position, all gear down and locked, and gear disagree discrettes. Alternate gear selection or individual gear positions were not recorded. The radar track for the flight is presented in Figure 5.

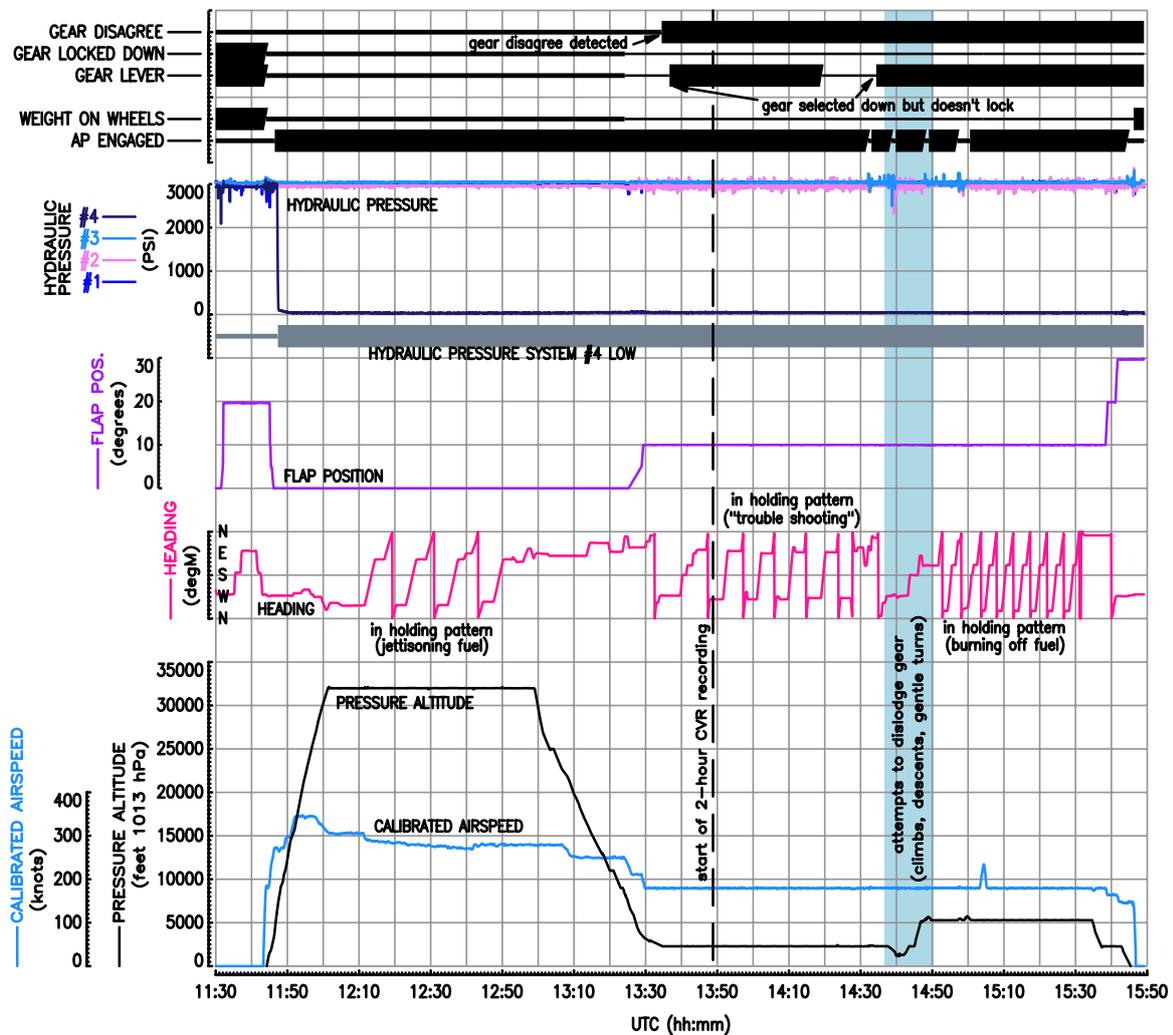


Figure 4
Salient data from FDR

The analysis of the recorded data provided the following timeline:

●	1129 hrs	-	G-VROM pushback from stand at London Gatwick Airport
●	1144 hrs	-	G-VROM airborne
●	1147 hrs	-	Climbing through 6,000 ft amsl, hydraulic system 4 starts to lose pressure, falling from 3,000 psi to 120 psi in 30 seconds
●	1201 hrs	-	Levels off at FL310
●	1212 hrs	-	In holding pattern for about 40 minutes
●	1259 hrs	-	Start of gentle descent reaching 3,000 ft 35 minutes later
●	1334 hrs	-	Gear disagree as G-VROM levels off at 3,000 ft and remains in this state for the rest of the flight
●	1337 hrs	-	Gear lever selected gear down – gear does not lock down
●	1344 hrs	-	In holding pattern as crew attempt to troubleshoot problem
●	1419 hrs	-	Gear lever selected gear up/off
●	1434 hrs	-	Gear lever selected gear down – gear does not lock down
●	1438 hrs	-	Descent to 2,000 ft then climb to 6,000 ft with gentle turns in an unsuccessful attempt to lock the gear down
●	1451 hrs	-	In holding pattern to burn off fuel
●	1535 hrs	-	Begin approach to land
●	1546 hrs	-	G-VROM touches down in a right-wing low attitude of about 4°

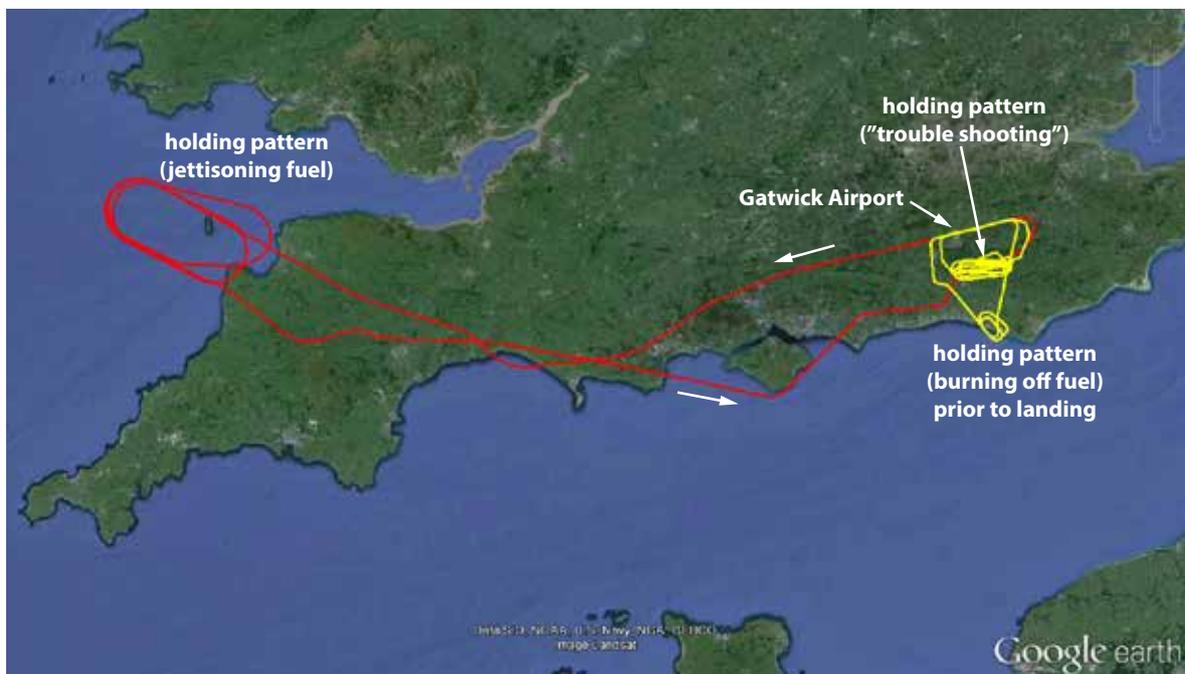


Figure 5

Radar track with portion of flight when the gear disagree was detected highlighted in yellow

Communications

The Radiotelephony (RTF) communications with ATC were straightforward. The RTF communications, on the shared¹ frequency of 131.42 MHz, with the IOCC were often interrupted and broken. A lot of time was spent, and several misunderstandings occurred, as the crew tried to describe the EICAS information being displayed. The crew considered the option of using the onboard satellite telephone but in the event decided it was not required.

The Flight Service Manager² (FSM) was briefed directly by the flight crew and liaised with the rest of the crew and the passengers. The commander also made a number of passenger announcements during the flight. Most passengers reported that they had both heard and understood these announcements from the flight deck.

Aircraft information

Hydraulic system

The aircraft has four independent hydraulic systems. Hydraulically actuated components, such as flying controls, landing gear extension and retraction and wheel braking systems are distributed between the four hydraulic systems, such that a loss of one hydraulic system does not result in a complete loss of function of the component system. Landing gear extension and retraction and the associated gear door actuation is distributed between systems 1 and 4, with the nose and body gear powered by system 1 and the wing landing gear powered by system 4. However, in the event of system 4 being inoperative, with the landing gear retracted, the QRH check list requires the crew to use the alternate extension system for all the landing gear. Other systems which become inoperative with the loss of system 4 are shown in Figure 1.

Wing landing gear actuator

Extension and retraction of a wing landing gear leg is achieved by means of a hydraulically powered actuator piston. The head of the actuator is attached to a hanger within the structure of the wing, with the rod end of the actuator attached to the gear leg trunnion. When the gear leg is in the retracted position, the actuator piston is also retracted and fits within an enclosed location created by 'walking beams', which run either side of the actuator, and the top of the landing gear bay (see Figure 7). The actuator is a large component weighing approximately 85 kg. In order to accommodate movement of the actuator body during the extension/retraction cycle, the actuator is attached to the aircraft hydraulic system by means of two braided flexible hoses. Each hose is connected to a port on the body of the actuator, one located on the top and the other on the bottom at the opposite end of the actuator body. The port at the head end of the actuator is labelled 'UP' and is located on the bottom of the actuator, whilst the port labelled 'DN' is located on the top of the actuator at the opposite end. Apart from a bleed valve on the opposite side of the head of the actuator to the port, there are no other distinguishing labels or features on the actuator to assist with orientation.

Footnote

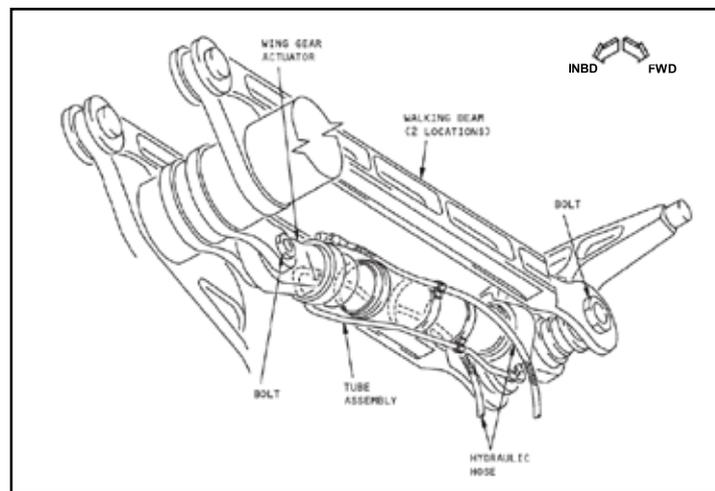
¹ Frequency used by several airlines for internal company communications messages.

² Senior cabin crew member on-board.



Figure 6

Wing landing gear actuator



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Figure 7

Wing landing gear actuator location

System status indications

Hydraulic controls and indicators are located on the overhead hydraulics panel, on which discrete lights illuminate in the event of system faults. Hydraulic systems status information is displayed on the EICAS hydraulic synoptic display and also on the status display. Information is provided to the crew about the landing gear status on the EICAS gear position indicator and gear synoptic display.

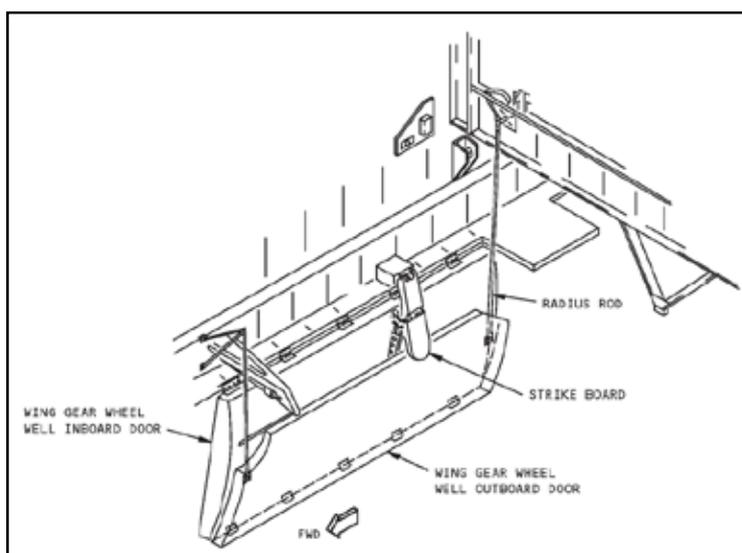
The low quantity warning for each of the hydraulic systems is triggered by a sensor within the respective hydraulic fluid reservoir. A significant loss of fluid will result in a loss of pressure, making the system inoperable, despite some fluid remaining distributed within the system pipework and components.

Landing gear alternate extension system

The alternate system for extending the landing gear allows the landing gear legs to extend under gravity until they lock in place. There are two switches in the cockpit to initiate the process, one for the wing landing gear and one for the nose and body landing gear.

There are two position sensor switches in the alternate extension system associated with the operation of each wing gear door: a door-unlock switch, and a door-open-40 degrees-or-more switch. When the pilot selects the wing gear alternate extension, a valve in the hydraulic system allows hydraulic fluid to port to the system return pipe. The door actuator then unlocks, releasing the door. This triggers the door unlock switch to open, removing power from the alternate extension actuator and preventing the gear from extending. This provides a delay to allow the gear door to swing open under gravity. As the door passes the 40-degree position it closes the associated switch, triggering the door unlock switch to close again. The alternate extension actuator is then re-energized, unlocking the gear from the uplock hook and releasing the gear leg to extend under gravity. A pressure-operated restrictor valve in the hydraulic system functions to dampen and significantly slow the wing gear extension rate. The pressure-operated restrictor valve is designed with a pressure-induced time delay of approximately 6 seconds (after gear release from uplock), after which its internal bypass valve begins to open and allows flow back to return as normal.

The strike board mechanism, located in the landing gear bay, extends a strike board over the wing gear door as it opens, lifting it from vertical to approximately horizontal as the outer section of the door passes underneath, back to just less than vertical when the door folds into the fully open position (see Figure 8). The board is designed to guide the wheel past the door should contact occur during alternate system extension of the landing gear. Delaying release of the wing gear from the uplock hook until the door is open at least 40° helps to



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Figure 8

Wing gear door and strike board (right door design is identical in mirror image)

ensure the strike board is positioned properly, so that the gear door is pushed out of the way, if the tyre contacts the board. The hydraulic damping of the rate of extension helps to reduce the loads on the strike board during contact. The strike board is a solid aluminium structure weighing approximately 5 kg.

Aircraft certification

During design and certification of the 747-400, a 'hang-up' of the wing landing gear leg on the gear door was considered as part of the aircraft System Safety Assessment. The design of the aircraft is such that only two of the main landing gear legs (wing or body)⁴ are necessary to safely support the aircraft during a landing at maximum landing weight. The wing gear doors were designed with sufficient strength to support the weight of the landing gear should a 'hang-up' occur, to ensure that the door did not fail and release the gear in an uncontrolled manner at a critical point in the landing sequence. A landing with only two³ or three of the four main gear legs deployed and locked was classified as 'minor' in the manufacturer's Functional Hazard Analysis. The airworthiness regulatory definition of 'minor' is provided below:

'Minor: Failure Conditions which would not significantly reduce aeroplane safety, and which involve crew actions that are well within their capabilities. Minor Failure Conditions may include, for example, a slight reduction in safety margins or functional capabilities, a slight increase in crew workload, such as routine flight plan changes, or some physical discomfort to passengers or cabin crew.'

ICAO Annex 13 definition

Whilst the large aircraft certification regulations provide a framework definition for manufacturers identifying the risks to the airframe and passengers from failures, Annex 13 to the Convention on International Civil Aviation – '*Aircraft Accident and Incident Investigation*' provides a broader public safety definition of what constitutes an accident in the context of aircraft operations. It defines '*accident*', in part, as follows:

'Accident: An occurrence associated with the operation of an aircraft with the intention of flight until such time as all such persons have disembarked, in which:

a) a person is fatally or seriously injured as a result of:

- direct contact with any part of the aircraft, including parts which have become detached from the aircraft'

Footnote

³ Two body gear, or two wing gear, or one body gear and one wing gear on opposite sides of the aircraft.

Operations documentation

The QRH provides guidance and procedures for landing with an abnormal gear configuration although it does not include a checklist for the specific circumstances of this event. The checklists for both the hydraulic system pressure loss and gear disagree are lengthy, comprising 7 and 5 pages respectively. A number of options dependent upon condition are provided which require careful reading. Additional guidance is provided in the Flight Crew Training Manual which includes the information:

'Failure of one wing or one body gear to extend will not cause adverse impact on directional control during touchdown and landing rollout.'

The operator's QRH also provides a specific checklist entitled '*Emergency Landing*'. It is intended for use in any non-normal landing situation and contains information about briefings, checklists and emergency landing readiness.

Alternate Gear Extension

Landing gear lever OFF

Do not exceed the gear EXTEND limit speed
(270K/.82M).

Action is irreversible

 ALTN GEAR EXTEND
WING switch ALTN

Action is irreversible

 ALTN GEAR EXTEND
NOSE/BODY switch ALTN

Reduction of speed to below 0.60 Mach may be
needed for the wing gear to lock down.

When all gear are down:

Landing gear lever DOWN

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Figure 9

QRH procedure for alternate gear extension

Engineering documentation

The Approved Maintenance Manual (AMM) task for removal/installation of the wing landing gear actuator is detailed in chapter 32-32-01 PB 401. In Paragraph 1 'General', section D of this task states:

'The actuator for the wing landing gear is between the trunnion and the walking beam and the hanger. You must remove the walking beam before you remove the actuator. Because the actuator is very heavy, you must use a hoist adapter to remove it.'

Paragraph 2 'Wing landing gear actuator removal' Section G, items 6 and 7 continues:

'(6) Install the wing gear retraction sling.

'(7) Use the fishpole hoist to remove the load.'

Paragraph 3 'Wing landing gear actuator installation' section G has a warning and a caution note at the start:

'WARNING: Make sure the attach point for the hoist is correctly in the keyhole slot. Failure to do this can cause the hoist to fall and cause injury to persons and damage to equipment.

CAUTION: Make sure the hydraulic ports are in the correct location. You can cause damage to the actuator if you do not install the ports correctly.'

Item 1 then states:

'Use the wing gear retract actuator sling and the fishpole hoist to put the actuator in the correct position between the trunnion and the hanger

NOTE: You must put the actuator in the position with the rod end adjacent to the shock strut trunnion. The UP port faces must be on the lower side of the actuator. The DN port faces must be on the top side of the actuator.'

Pre-flight maintenance activity

G-VROM had a history of hydraulic fluid leakage from the gear actuator piston rod gland seal on the right wing landing gear. In order to rectify this, a Technical Services Work Order (TSWO) was raised by the operator's engineering department. The actuator removal and installation was scheduled to be carried out in the operator's hangar at London Gatwick Airport, during the day shift on Sunday 28 December. The certifying engineer who led the day shift team stated that he spent considerable time trying to locate the fishpole hoist specified in the AMM, but in the end withdrew a hoist designed for installation/removal of the aircraft Auxiliary Power Unit (APU) from the tool store. He reported difficulty in sourcing the correct tooling for other elements of the task as well and raised a Ground Occurrence Report (GOR) to highlight this to the operator's safety department. However, the team stated that the actuator was eventually removed from the aircraft without using either the sling or hoist. They identified that the AMM did not contain instructions on how to use the sling or how to use the hoist and sling combination to manoeuvre the actuator. Once the unserviceable actuator had been removed from the aircraft, the associated fittings were transferred to the replacement actuator on the work bench.

Delays caused by the late arrival of the aircraft to the hangar and a requirement for additional parts to be sourced for the replacement actuator, meant that it could not be installed by the day shift team, so the task was handed to the night shift team who came on duty that evening. An additional engineer, with some experience of installing a landing

gear actuator, was reassigned to assist due to the additional workload this task placed on the team. The night shift team reported that the task handover provided by the day shift team was “excellent”.

The installation procedure commenced at approximately 2145 hrs and began with the team positioning a set of steps and a lifter platform, carrying the replacement actuator, underneath the aircraft. In order to install the actuator it had to be passed through a section of structure in the wing. The team positioned spill bags to prevent damage from any contact between the actuator and the wing structure. The sling and hoist were not used by the team, who instead manhandled the actuator between the two technicians standing in the lifter and the engineer standing on the steps. The weight of the actuator was then supported by the two technicians, while the engineer attempted to install the pin which secured the actuator to the hanger. After 20 minutes of unsuccessful effort, the team’s positions were rotated and they tried again to locate the pin for a further 10 minutes. Eventually the actuator was successfully secured in place by one of the technicians.

The team then continued to work through the night to reconnect the hydraulic hoses and leak check the hydraulic system. The AMM did not require a full operational test of the landing gear actuator following replacement, just a selection of the gear lever UP with the gear locking pins in place, to check the gear leg began to move before being restrained by the locking pin and to check for leaks. The aircraft was then prepared and released for service that morning.

Other information

The passengers from the incident flight were offered the opportunity to complete an AAIB questionnaire after landing and information from the replies received was used in the investigation. The passengers had been briefed by the commander and were aware of a fault with a hydraulic system and initially were not unduly concerned. When the additional problem with the landing gear became apparent there was an increased level of concern. Much of this was mitigated by the frequent updates from the commander about the situation, and through the positive influence of the cabin crew.

Safety actions

The operator conducted a detailed investigation following the incident and issued a comprehensive internal report. The report included 28 recommendations. The majority of these related to internal improvements in process, but a number also related to possible improvements in the aircraft manufacturer’s documentation to remove ambiguity.

Analysis

Operations

The successful outcome of this event hinged on good communication and co-operation in a number of areas. The additional pilot on the flight deck enhanced the task sharing and reduced the workload on the co-pilot and the commander. The crew were able to spend time working through all the possible options available to them and to be sure that everything had been considered before the landing.

The consideration of available options was assisted by the input from the operator's IOCC facility. In being external to the aircraft the IOCC personnel were able to contribute from additional resources, which included expertise from the aircraft manufacturer. However, communication with the IOCC was not straightforward because of the interruptions and interference from other stations on the shared frequency. Shared frequencies for company communications are a normal arrangement and in most cases interruptions constitute a nuisance and are not critical. The Very High Frequency (VHF) frequencies allocated to aviation are a resource with limited capacity but it would have been useful in circumstances such as these to have been able to switch to a dedicated frequency.

Many of the questions from the IOCC needed to be repeated and it proved difficult for the crew to describe accurately information shown on a visual display. It would have been a useful facility to have been able to send and receive photographs from on-board the aircraft. This facility might also have been useful for the crew, as photographs were available in the public domain several hours before the eventual landing, showing the position of the landing gear.

The aircraft was airborne for a total of 4 hours. The first approach took place 1 hour 40 minutes into the flight and the second approach was 2 hours 15 minutes later. Frequent information updates and a calm professional manner on behalf of the crew contributed to the maintenance of a safe on-board environment.

Engineering

There are two separate aspects to this incident; the maintenance issues which led to the in-flight hydraulic leak, and the circumstances which resulted in the right wing landing gear becoming 'hung-up' on the gear door.

Maintenance issues

Replacement of landing gear actuators is not a common maintenance task on the 747-400. As such there is limited opportunity for individual maintenance organisations to develop internal "best practice" techniques or to identify and rectify weaknesses or missing information within the manufacturer's AMM instructions. The maintenance teams tasked with the replacement of the gear actuator on G-VROM faced a number of problems. They were not able to locate a number of the specialist tools required by the AMM, including the hoist which the manufacturer specified for safe lifting of the weight of the actuator whilst it was being manoeuvred into place. The operator's internal investigation has made a

recommendation within the company to address this issue. However, the team identified that even if the hoist had been available, the manual did not specify how to operate the sling, or how best to utilise it together with the hoist in the difficult task of manoeuvring the actuator through the wing structure surrounding the actuator location. The AMM is the main source of guidance for completing any maintenance task. If specific guidance is not found in the AMM, then engineers and technicians might develop improvised techniques to accomplish a task, particularly outside normal office support hours such as during night shifts.

Ultimately, the maintenance team working on G-VROM elected not to use any form of mechanical support, thus greatly increasing the difficulty and risk associated with installing the replacement actuator. The result of this decision was that the task became so physically demanding that the maintenance team became entirely focused on just attaching the actuator to the aircraft, in order to relieve themselves of the 85 kg weight they had manually supported for over 30 minutes. As such, they had no remaining capacity to ensure they installed the actuator in the correct orientation. It was subsequently determined that they had rotated it 180° about its long axis during installation, effectively installing it upside down.

The significance of this maintenance error was that the hydraulic fluid ports on the actuator were now transposed, with the port at the head end of actuator facing upwards. The AMM did not require the gear to be fully cycled following maintenance. Consequently, the insufficient clearance between the hydraulic port and the top of the landing gear bay, when the gear was in the retracted position, was not identified until the first time the gear was retracted fully during the incident flight the following morning. The force exerted on the hydraulic port as the gear retracted, caused it to distort and release hydraulic fluid at the full system pressure of 3,000 psi. This rapidly depleted the reserve of hydraulic fluid in system 4, generating a low quantity and then low pressure warning in the flight deck.

Whilst the manner in which the actuator was installed by the maintenance team significantly increased the likelihood of a maintenance error occurring, the design of the actuator itself increased the probability of the error remaining undetected. The actuator was virtually uniform in shape and colour, such that there was no obvious top or bottom to it. The structural connections could be installed in either orientation and the use of flexible hoses meant the hydraulic connections could be made to fit an incorrectly installed actuator. Finally, the hydraulic port on the bottom of the actuator was labelled 'UP', with the one on the top labelled 'DN', which was inherently open to misinterpretation. As a result of these human factors issues being identified the following two Safety Recommendations are made:

Safety Recommendation 2015-026

It is recommended that Boeing amend the 747-400 Approved Maintenance Manual task for removal and installation of the wing landing gear actuator, to provide clear instructions for the safe manoeuvring of the actuator in or out of its location in the wing landing gear bay.

Safety Recommendation 2015-027

It is recommended that Boeing modify the 747-400 wing landing gear actuator to reduce the likelihood of incorrect installation occurring or remaining undetected.

Failure of the wing landing gear to extend fully

Due to the location of the leak on G-VROM, the right wing landing gear system was drained of hydraulic fluid. The landing gear alternate extension system is designed to work with hydraulic fluid present in the system. Most significantly for this event, the rate at which the gear leg descends, when deployed using the alternate system, is controlled by slowing the flow of hydraulic fluid around the system by means of a restrictor valve. When the hydraulic fluid is lost, the descent of the gear leg is undamped and accelerates under gravity. This has two potential implications for the wing landing gear, as demonstrated by the G-VROM event. Firstly, the gear door may not have fully opened prior to the arrival of the descending gear leg. Given the concertina design of the door, this will result in the gear leg becoming 'hung up' on the door, with no way of releasing it prior to landing. Secondly, as a result of the door being partially open, the strike board is mechanically held in the horizontal position when the tyre strikes it. The strike board attachment hinge was not designed to withstand the load imparted when the board is stuck in this orientation by an undamped gear leg. On G-VROM, this caused the hinge to fail and the board to be released from the aircraft. The aircraft was at an altitude of approximately 3,000 ft and travelling at 180 kt when this occurred. The 5 kg strike board would therefore have reached the ground with sufficient energy to cause significant damage or injury.

The aircraft manufacturer advised that they had considered the risks associated with the 'hang-up' of a gear leg following an undamped freefall of the wing landing gear in their System Safety Assessment for the aircraft, and assigned it a hazard severity classification of 'minor'. It was not clear whether detachment of the strike board from the aircraft was anticipated as part of this scenario. However, given that the certification design regulations only require manufacturers to consider the safety implications of a failure to the aircraft and its occupants, it is unlikely this would have altered the classification. The approach paths to London Gatwick Airport mostly overfly farmland, but many other airport approaches, pass over densely populated urban areas. Release of the strike board from an aircraft has the potential to cause serious injury or death should it hit someone on the ground, which constitutes an accident as defined by Annex 13 and is in any case undesirable. To prevent such an accident occurring, the following Safety Recommendation is made:

Safety Recommendation 2015-028

It is recommended that Boeing modify the design of the 747-400 wing landing gear door mechanism to prevent release of the strike board from the aircraft when the alternate gear extension system is used following a loss of hydraulic fluid.

During the G-VROM event, the crew did not know why the wing landing gear had not locked down correctly and subsequently spent almost 15 minutes performing flight manoeuvres in an attempt to use aerodynamic loads to force the gear to lock. The manufacturer confirmed it had anticipated the possibility of the landing gear becoming 'hung-up' on the gear door following an alternate system deployment due to a loss of hydraulic fluid, and designed the door to ensure that the gear remained in this position, should it occur. However, there was no guidance in the aircraft QRH checklists to make flight crew aware of this possibility. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2015-029

It is recommended that Boeing amend the 747-400 Quick Reference Handbook to warn flight crews of the potential for, and provide guidance in the event of, an unsuccessful extension of the wing landing gear, when the alternate gear extension system is used following hydraulic system 4 low quantity and pressure warnings.