Boeing 747SP-100, N204 AE

AAIB Bulletin No: 6/98 Ref: EW/C96/8/10Category: 1.1

Aircraft Type and Registration:	Boeing 747SP-100, N204 AE
No & Type of Engines:	4 Pratt and Whitney JT9D turbofan engines
Year of Manufacture:	1989
Date & Time (UTC):	24 August 1996 at 1120 hrs
Location:	Near London Heathrow Airport
Type of Flight:	Public Transport (Passenger)
Persons on Board:	Crew - N/A - Passengers - N/A
Injuries:	Crew - N/A - Passengers - N/A
Nature of Damage:	Right off-wing escape slide torn away; minor damage to wing-to-fuselage fairing
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	N/A
Commander's Flying Experience:	N/A
Information Source:	AAIB Field Investigation

History of flight

During final approach to Runway 28R at London Heathrow Airport,the right 'off-wing' emergency escape slide deployed into theslipstream and was ripped from its fixings. The flight crew wasunaware of the occurrence and the remainder of the approach andlanding was accomplished without incident. After landing, a memberof the cabin crew informed the commander that an unusual noisehad been heard on the right side of the cabin during the approach. The flight engineer then checked his panel and found that theright off-wing escape slide compartment door warning light wasilluminated. An external inspection revealed that the slide wasmissing and minor damage was found on the wing root fairing immediatelyaft of the slide compartment. The detached slide was later found,deflated, lying on the canopy of a petrol station forecourt some3 miles from the runway threshold.

Previous maintenance

In May 1996, the aircraft had undergone routine maintenance duringwhich the off-wing slide compartments had been opened for inspectionand adjustments made to the slide door latch rigging. The slidesystem was not disturbed subsequently.

Off-wing slide system

The aircraft was equipped with off-wing escape slides on eachside of the fuselage. These provided for passenger emergencyegress, via the overwing exit doors (doors 3L and 3R), and descentfrom the wings to ground level. The following description andexplanatory diagrams apply to the right hand slide; however, theslide system on the left side was identical.

The slide pack was fixed to the inside face of the slide stowagecompartment door, which was located in the aft section of thewing-to-fuselage fairing (see Figure 1). The pack comprised aconventional rubberised fabric triple-channel escape slide housedwithin an integral cover, which also provided the attachment ofthe slide to the inside face of the compartment door. The coveralso housed a pair of injector pumps to inflate the slide afterdeployment. These pumps were driven by compressed 'cool gas'from a storage cylinder located in the body landing gear wheelwell, immediately beneath the slide compartment.

The slide system is normally deployed automatically via the overwingexit door actuating system, which triggers a pyrotechnic thrustermechanism in the lower fuselage. This, in turn, is linked viaa connecting cable to the deployment mechanism within the slidecompartment. Alternatively, the slide can be deployed manuallyfrom within the cabin by means of an operating handle positionedalongside the overwing exit door, which acts on the slide deploymentcable directly.

The principal components of the slide system are shown in Figure1. The slide pack (shown in simplified form in the diagram) wasfixed to the inside face of the compartment door, which was hingedalong its lower edge. A series of four claw-type latches, spacedat intervals along the upper edge of the door aperture, engagedspecially shaped button-head fittings on the top edge of the compartmentdoor. The claw mechanism within each latch was operated by acam plate which slides fore and aft inside the latch housing. The cam plates of each of the latches were linked together bya series of connecting rods, which were connected at their forwardend to an integrator unit located just forward of the slide compartmentdoor. Rearward movement of the cam plates, via the interconnectingrods, draws the latch claws into their tapered housings and causesthem firstly to close over the button-heads of the door fittings,and then to pull these fittings back inside the latch housing,thus pulling the compartment door tightly closed. The rear latchmechanism incorporates a mechanical indicator comprising a spring-loadedpin, the inner end of which bears against the tapered end of thecam plate, and the outer end progressively moves outward, proudof the skin line, as the latch mechanism disengages. The latchtrain incorporates a microswitch which brings up the appropriateescape slide warning caption on the flight engineer's panel. A detent spring in the linkage adjoining the rearmost latch helpsresist uncommanded movement of the latch operating mechanism.

The integrator unit forms the mechanical interface between thelatching and deployment mechanisms within the slide compartmentitself, and the slide deployment cable. Deployment of the slide,from either the cabin overwing exit door or the manual deploymenthandle, pulls the slide deployment cable forward; this movementis transferred to the door latches via the integrator unit, unlatchingall four door latches. The unlatched compartment door is thenopened by a pair of pyrotechnic thruster units, one at the forwardend of the compartment triggered by a linkage from the integratorunit, and the other at the rear end of the compartment triggeredby a short linkage

connected to the rearmost door latch. Thethruster pistons are connected via pulleys to extensions of theadjoining compartment door hinges. Extension of the thrusterscauses outward rotation of the door, assisted by gravity, exposingthe slide which is packed on the inside face of the door (thesituation shown in Figure 1).

The slide inflation process is triggered by an independent linkageattached to the inner face of the compartment door. As the doorapproaches the fully open position, movement of this linkage operatesa bellcrank lever mounted just inside the slide compartment. The hooked output end of this bellcrank engages a 'T' bar attachedto the upper end of an operating cable connected to the cool gasdischarge valve on the stored gas bottle. High pressure gas thendischarges via tubes to the two-stage gas injector pumps, whichinduce atmospheric air into the slide. The nominal inflationtime is 8 seconds.

System integrator

Opening of the slide compartment for routine maintenance is achievedvia the system integrator, which is accessed via a small hingedaccess door located immediately forward of the main compartmentdoor (see Figure 1). The integrator unit comprises a series oflost-motion interlinks which allow the main door latches to beunlatched manually, without disturbing the deployment cable systemforward of the compartment. When the compartment door is unlatchedmanually via the integrator, a separate cable system operatesa disconnect mechanism in the inflation linkage attached to thedoor, allowing the compartment door to be opened fully withoutthe slide inflating. Upon completion of maintenance, the maindoor is closed and locked via the integrator, and the integratoraccess door is closed. The integrator incorporates a simple mechanicalinterlock mechanism which is intended to prevent closure of theaccess door with the integrator in the unlatched (unsafe) condition. Figure 2 shows the integrator unit with each of the parts colourcoded for ease of identification. The unit comprises:

a housing fixed to the fuselage structure.

a lost-motion mechanism connecting the deployment cable systemto the door latch mechanisms.

a spring-loaded positive lock, to prevent the latch mechanismfrom 'back-driving' the integrator mechanism.

various subsidiary levers and cranks, the purpose of which willbe described separately.

The actuating cables on the input side of the integrator unitare connected to the forward end of the piston (coloured greenin the diagrams), which slides horizontally inside the housing. The aft end of this piston comprises a parallel blade section,in which there is a longitudinal slotted hole as shown in theexploded view at Figure 2. Sharing the same bore within the housingis an output shaft (coloured blue) connected to the door latchoperating rods. Rearward sliding motion of the output shaft withinthe housing thus causes the door latches to lock, and forwardmotion disengages the latches. The forward section of the outputshaft, ie the part which slides inside the housing, has a centralslot which accommodates the projecting blade part of the piston. A horizontal cross pin (coloured orange) passes through a holein the forward end of the output shaft, and also through the slottedhole in the blade part of the piston, providing a lost-motionconnection between the two. The cross pin projects from bothsides of the housing via longitudinal slots, to allow the crosspin to move fore and aft as the output shaft slides back and forthinside the housing (see lower diagram in Figure 2). Within thelimits imposed by the slotted hole in the piston blade, the outputshaft can slide

inside the housing without this movement beingtransferred to the piston, ie the output linkage (and latchingmechanisms) may be moved independently of the input mechanism(and deployment cable system).

A spring-loaded lock pin (coloured red in the exploded view atFigure 2) descends behind the forward end of the output shaftwhen the latter moves to the fully aft (latches locked) position,preventing subsequent unlatching movement of the output shaft. A small cut-out in the top edge of the piston blade (see explodedview) provides the necessary clearance for the lock pin to descendbehind the shoulder of the output shaft.

Forward movement of the deployment cable, via the cabin door thrusteror the manual deployment lever in the cabin, pulls on the integratorpiston; this motion is then transferred via the output shaft tothe door latch mechanisms, and the slide inflates as the dooropens. The integrator manual latching and unlatching pawls (colouredgold and purple respectively) comprise simple hand operated levermechanisms, into which can be inserted a square-head socket-drive. These provide a means of access to the slide compartment formaintenance purposes. A secondary lever, formed integrally withthe unlatch pawl (see lower diagram in Figure 2) is linked tothe disconnect mechanism in the slide inflation linkage. Thedetailed operation of the integrator in both modes is complex,and is fully described in the accompanying explanatory diagrams. Figures 3a to 3d show the normal unlatch sequence, ie when deploymentis initiated from the cabin door mechanism or the manual inflationhandle in the cabin. Figures 4a to 4c illustrate the operatingsequence when the compartment door is opened manually for servicingvia the integrator unit.

Instructions for re-latching the compartment door and checkingthe integrator for proper engagement of the positive lock pinare provided in the form of an instruction placard fixed to theinside of the integrator access door. On the aircraft in question,the instructions comprised an explanatory diagramaccompanied by the following text:-

"OPERATING INSTRUCTIONS - INTEGRATOR

To latch or unlatch: Insert a 1/4 drive wrench in the proper leverand rotate approximately 90° to end of stroke.

Before closing access panel, check latch system as follows:

1 Cross pin full aft in housing slot

2 Locking pin in detent (see detail)

3 Black marks aligned

4 Unlatch lever rotated aft to stop

5 "Door open" light on engineers panel extinguished

6 Latch position indicator if installed not protruding from fairing"

AAIB examination of the aircraft

Right hand slide

The right hand slide compartment door was fully open, with theremnants of the slide hanging from it. The inflation cable mechanism(not the slide deployment cable) had been pulled by the door actuatedcrank, and the cool gas cylinder had discharged. A small regionof the wing-to-body fairing immediately aft of the compartmentdoor was damaged by flailing of metal parts attached to the slideremnants. The integrator access door was fully closed.

The mechanical latch indicator pin was protruding by approximately6 mm from the face of the fairing, indicating an unsafe conditionof the latches, and the latch operating rods were displaced forwardby approximately 15 mm from their most rearward position, evidencedby a witness line in the grease. When manually pulled outward,the claws of the latches could be opened by an amount sufficientto release the door button fittings. Neither door opening thrusterhad fired, and the slide deployment cable running forward fromthe integrator to the cabin door and the manual deployment handlewere in their normal safe positions.

The integrator access door was opened and inspection of the integratorrevealed that the manual unlatch pawl was incorrectly positioned; this being found rotated partially clockwise, toward the unlatchposition, where it held the lock pin lifter in a raised position(see Figure 8). As a consequence, the positive lock pin had disengaged. This had evidently allowed the door latch mechanism to back-drivethe output shaft slowly over time, eventually reaching a pointwhere the latches released the door. The door had then fallenopen under gravity, and had actuated the slide inflation mechanism. Figure 6 shows the state of the mechanism as found.

The operator later reported that whilst undertaking post-incidentrepairs and rigging checks in preparation for the installationof a new right hand off-wing slide, it was found that the detentspring at the rearmost latch (see Figure 1) had been insertedupside down. This would have rendered the system even more proneto unlatching in the absence of an effective positive lock inthe integrator itself.

Left hand slide

The left hand slide compartment door was found closed and latched. However, upon opening the service access panel it was found thatthe unlatch pawl on the left side integrator was incorrectly positionedin precisely the same way as that found on the right integrator,with the lock pin lifter raised and the lock pin disengaged. Although the latches on this side had remained engaged, it waspossible with relatively little effort to pull the latch rodsmanually rearward and unlatch the door, confirming that the integratorpositive lock pin was not engaged.

Examination of other Boeing 747 off-wing slides

A Boeing 747 operated by a UK operator was examined for comparativepurposes. Overall, no significant differences were found in thecondition of the mechanism, or the integrator. However, it wasnoted that both the explanatory diagram and the instructions onthe inside of the service access door differed significantly,the text reading:

"TO UNLATCH FAIRING DOOR, INSERT 1/4 IN. SOCKET DRIVE WRENCHIN UNLATCH LEVER & TURN CLOCKWISE 90° TO STOP PIN.

TO CLOSE: INSERT SOCKET DRIVE IN LATCHING LEVER, LIFT UP LIFTER& ROTATE UNTIL SPRING PIN SEATS IN AFT END OF INTEGRATOR HOUSINGSLOT. CHECK THAT

THE BLACK MARK ON THE PISTON IS IN LINE WITHBLACK MARK ON HOUSING & THAT NO RED ON PISTON IS OUTSIDE OFHOUSING."

It was noted that there was no specific instruction to check 'Unlatchlever rotated aft to stop', and that the check 'no redon piston is outside of housing' was not included on the instructionsplacard on N204 AE.

Probable cause of the unsafe condition of the integrator

Rotation of the manual latch pawl drives the cross pin rearward,moving the output shaft rearward and engaging the door latches. Unless the operative ensures that the unlatch pawl is rotatedback to its original position manually, this rearward movementof the cross pin will also rotate the unlatch pawl back towardsits original position; however, it can do this only until thecross pin reaches the end of its slot in the housing. This sequenceis detailed in Figure 5. It can be seen from Figure 5 that oncompletion of the latching motion of the latch pawl, the doorwill be fully latched. However, the unlatch pawl will not havebeen returned fully to its original position, preventing the positivelock pin from engaging. If, having rotated the latch pawl fullyand confirmed that the output shaft is full back and the latchindicator pin is not showing, the operative rotates the latchpawl back to its original position without manually completingthe movement of the unlatch pawl, the integrator will be leftin an unsafe condition and the latch mechanisms could subsequentlymigrate forward and unlatch the door during flight. The lattercondition is illustrated in Figure 6, and is identical to the'as found' condition of both integrators on N204 AE. It shouldbe noted that with the integrator in the unsafe condition illustratedin Figure 5, the cross pin is fully aft in its slot in the housingand consequently the access door interlock lever will have beenlifted back down to its safe position, allowing the access doorto be closed even though the mechanism is actually unsafe.

It was noted that the placard item in the operating instructionson the incident aircraft, 'Unlatch leverrotated aft to stop', was not givenany special prominence, despite this being one of the most importantactions in the latching sequence. This would appear to be ofsome significance, given that this action had not been carriedout in this case. Much prominence was given to the need to ensureproper engagement of the positive lock pin by visually checkingits position through the slot in the housing, but in practicethis inspection would have been difficult to carry out effectivelybecause:

The area in question is visually very restricted.

The slots in the housing and the relevant parts of the mechanismare invariably clogged with grease, making it extremely difficultto perform a meaningful inspection without first clearing allthe recesses of grease and dirt.

Assessment of position is made difficult by the very smalltravel of the lock pin; ie approximately 2 mm.

Figure 9 shows a close up view of a typical in-service unit whichhas been set up to replicate the condition found on the subjectaircraft. The difficulty of judging accurately the state of thelock pin is clearly apparent.

Additional safety implications arising from incorrect positioningof the unlatch pawl

With the integrator in the as found condition shown in Figures6 and 8, the misplaced unlatch pawl creates restrictions in theintegrator mechanism which limit the available travel at severalpoints within the mechanism. This could potentially inhibit orprevent deployment of the slide in an emergency. Figure 7 showsthe mechanism at the limit of travel when the system is actuatedin an emergency via the deployment cable. The incorrectly positionedlock pin lifter creates a foul between the underside of the thrusteractuating lever and the top of the lifter at 'G' in Figure 7. This foul has the following effects:

a) The thruster lever is unable to achieve full travel, potentiallypreventing the forward door thruster from firing.

b) Forward movement of the cross pin beyond the position shownin Figure 7 is restricted by the bottom end of the thruster actuatinglever, restricting movement of the output shaft and door latchmechanisms.

c) The restricted motion of the latch mechanism limits movementof the connecting link to the aft door thruster, potentiallypreventing it from firing.

d) The piston is prevented from reaching full travel, due to therestriction on cross pin movement.

Additional safety issues arising from the design of the integrator

Further safety issues were apparent in relation to possible mispositioningof the input piston, the correct setting of which relies heavilyupon the alignment of painted reference lines on the piston bodyand the integrator housing (see lower diagram at Figure 2). Forexample, if the piston is displaced rearward by an amount equivalentto 1/4 of the black reference line's thickness, then the lockpin will sit on the shoulder of the piston blade cut-out, ratherthan dropping down into the cut-out as intended. The output shaftwill then be free to slide forward into the unlatched position. In these circumstances, the requirement for the red part of thepiston to be inside the housing would be met fully and there wouldbe no obvious misalignment of the black reference lines, yet therewould be no positive lock to prevent the door from unlatching. Similarly, if the output shaft were to be displaced forward bymore than about 1 mm from its fully aft position, then the lockpin would sit on the shoulder of the output shaft, with exactlythe same result. This condition could arise in practice if theoutput shaft failed to be driven fully rearward during manualrotation of the latch pawl. It could even occur without any explicitinterference to the integrator itself, eg if the deployment cablewas disturbed in such a way as to move the piston forward by about5 mm. This would be sufficient to lift the locking pin (via theramped cut-out in the piston blade) and pull the output shaftforward by about 1 millimetre, sufficient for the lock pin tosit on the shoulder of the output shaft. In these circumstances,even if the movement of the deployment cable system was reversedand the piston returned to its original position, the lost motionmode of operation would prevent the output shaft from being returnedto a safe position, and the lock pin would continue to sit onthe shoulder of the output shaft.

Previous occurrences

A previous instance of slide deployment occurred near London Heathrowon 28 April 1996. This incident was investigated by the AAIBand reported in Bulletin 9/96 with associated Safety Recommendations. On that occasion, it was found that the latch mechanism had migratedopen sufficiently to release the door. It was found that stiffnessin the indicator pin mechanism at the rearmost latch gave theimpression of a false detent when the door was closed and latchedmanually

via the integrator, and as a result the mechanism hadnot been driven back into the fully latched position. The microswitchon the forward latch mechanism was also found to be out of adjustment,resulting in a failure to illuminate the warning caption on theflight engineer's panel. The report noted that some 30 instancesof in-flight loss of the off-wing slide were believed to haveoccurred on Boeing 747 aircraft over a period of 20 years, generallyfollowing maintenance. These were mainly attributed to improperclosing of the slide compartment, incorrect indications of latchingand improper rigging.

Discussion

The design of the integrator mechanism is such that it is extremelysensitive to the smallest misalignment of the various operatingparts affecting the positive lock pin, and clear and unambiguousinstructions on correct use are vital. At least two versionsof the instructions on the access door placards appear to exist,neither of which provides consistent, clear and unambiguous informationfor users.

The sensitivity of the integrator to slight misalignments whichcould result in failure of the lock pin to engage, in combinationwith numerous potential rigging errors in the complex set of serialof linkages and lost-motion mechanisms within the slide deploymentsystem overall, makes the system extremely vulnerable to riggingand maintenance errors which could lead to deployment of the slidein the air. Whilst such an event will probably cause no greaterdamage than occurred in this case, other potentially criticalpossibilities do exist. In particular, the possibility must beconsidered that an inflated, or partially inflated, slide couldadopt an attitude at separation which could cause it to lift upinto the path of the horizontal stabiliser, and become wrappedaround the leading edge. A large bulky object of this kind, evenif deflated, could seriously degrade tailplane aerodynamic efficiency,possibly to the extent of causing a loss of pitch control.

Safety recommendation

As a result of these findings, the following Safety Recommendationis made:

Recommendation 98-23

The FAA and the manufacturer should review the maintenance practicesand instructions pertaining to servicing of the off-wing slidesystems on Boeing 747 series aircraft so equipped, with a viewto:

1 Introducing a more reliable and consistent means of checkingfor secure latching of the off-wing slide compartment door.

2 Introducing a more reliable and consistent means of confirmingthat the integrator positive lock pin is fully engaged.

3 Ensuring that in the event of any inadvertent (even very small)movement of the slide actuating cable, the system integratoris subject to a full check for integrity of the lock mechanism.