**SERIOUS INCIDENT**

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|---|---|
| **Aircraft Type and Registration:** | Airbus A300-B4-622R, TF-ELK |
| **No & Type of Engines:** | 2 x Pratt & Whitney PW4158 turbofan engines |
| **Year of Manufacture:** | 1989 |
| **Date & Time (UTC):** | 10 January 2011 at 2150 hrs |
| **Location:** | East Midlands Airport |
| **Type of Flight:** | Commercial Air Transport (Cargo) |
| **Persons on Board:** | Crew - 2 Passengers - 1 |
| **Injuries:** | Crew - None Passengers - None |
| **Nature of Damage:** | Tailskid and fuselage skin |
| **Commander's Licence:** | Airline Transport Pilot's Licence |
| **Commander's Age:** | 45 years |
| **Commander's Flying Experience:** | 5,282 hours (of which 4,600 were on type)<br>Last 90 days - 103 hours<br>Last 28 days - 45 hours |
| **Information Source:** | AAIB Field Investigation |

**Synopsis**

An approach to East Midlands Airport was being flown in gusty crosswind conditions. Reverse thrust was selected immediately after touchdown, but the aircraft subsequently bounced and the commander decided to go around. During the go-around the No 2 (right) engine thrust reverser failed to stow, and the engine thrust was maintained at idle by the FADEC system. The aircraft's tail struck the ground during the rotation. The aircraft became airborne at low speed in a high drag configuration and its acceleration and climb performance did not increase appreciably until 47 seconds after lift off. The No 2 engine was subsequently shut down and the aircraft diverted to Stansted Airport, where a single-engine landing was carried out. The No 1 thrust reverser was selected during the landing at Stansted, but did not fully deploy. The investigation found that the most likely reason for the No 2 thrust reverser failure to stow was an intermittent loose connection in the auto-restow circuit. It was further determined that conflicting operational guidance exists with respect to selection of reverse thrust and go-around procedures. A number of safety actions have been taken as a result of this serious incident.

**History of the flight**

The aircraft took off at 2043 hrs for a scheduled flight from Belfast to East Midlands Airport. The commander acted as handling pilot for the sector. In addition to the co-pilot, a company engineer was also onboard, positioning as a passenger, and was seated in a designated area within the cabin.

The initial part of the flight proceeded without incident and the crew prepared for an ILS approach to Runway 09. The weather at East Midlands Airport, as reported by ATC, was: surface wind from 170° at 22 kt, visibility 15 km, cloud broken at 1,500 ft, slight rain with a wet runway and a temperature of 7°C. The surface wind report was later updated to 160° at 20 kt, gusting 30 kt[1].

The FMS calculated approach speed ($V_{REF}$) of 135 kt was increased by 9 kt to allow for the gusting nature of the wind, giving an FMS approach reference speed ($V_{APP}$) of 144 kt.

The crew were given radar vectors by ATC to establish on the ILS and they configured the aircraft for a normal full-flap landing. On passing about 1,000 ft the co-pilot requested a wind check which was given as 160° at 22 kt.

The commander stated that, as usual, he began to flare at about 30 ft agl and, at about 20 ft agl, closed the throttle control levers. However, he considered that the aircraft's rate of descent was excessive and so increased the nose-up pitch. The aircraft touched down and then bounced. The commander reduced the pitch attitude slightly to allow the aircraft to settle back onto the runway, without adjusting the thrust. The aircraft touched down again, heavily, before bouncing back into the air. Neither pilot recalled reverse thrust being selected during the landing attempt.

After the second bounce, the commander decided to go around and commanded full thrust on both throttle control levers. The aircraft remained configured with full flaps and the gear down as it commenced the go-around.

An air traffic controller who witnessed the landing stated that the touchdown had seemed firm and that he had seen a shower of sparks emanating from the rear of the aircraft. He described the aircraft appearing to fly very slowly over the runway during the go-around, rolling from side to side and not climbing above more than about 200 ft. He was sufficiently concerned that he pressed the crash alarm. He refrained from contacting the pilot, so as not to distract him, until the aircraft was about 3 nm to the east of the airfield, when it was then seen to be climbing.

The commander stated that he experienced considerable difficulty getting the aircraft to accelerate during the go-around. Eventually the speed started to increase and he instructed the co-pilot to reduce the flap setting to FLAP 20. The aircraft then started to climb, at which time the gear was raised, and as the aircraft continued to accelerate, the flaps were retracted fully.

The crew stated that at this point they noticed that the ECAM was showing an ENG 2 REVERSE UNLK caution message. The commander reported that as the aircraft continued to climb away he moved the No 2 throttle control lever to look for a thrust response and operated the No 2 thrust reverser lever to try and get the thrust reverser to lock. This appeared to have no effect. The crew stated that they completed the ECAM checklist, followed by the QRH checklist; finally shutting down the No 2 engine. After considering the weather conditions, the crew elected to divert to Runway 22 at Stansted where the wind was given as 170° at 19 kt. They carried out an uneventful single-engine ILS approach and touched down at 2203 hrs.

After landing, reverse thrust was selected on the No 1 (left) engine by the commander. The co-pilot believed that reverse thrust had not engaged properly and informed the commander, who then cancelled it.

**Footnote**

[1] Equivalent to a maximum crosswind component of 28 kt. The Operator's crosswind limit was 30 kt.

Upon subsequent inspection at Stansted it was noted that the aircraft had suffered a tailstrike.

## Damage to aircraft

The tailskid shoe on the underside of the rear fuselage showed evidence of scraping consistent with having contacted the runway. In addition there was a 3 mm deep dent and local buckling of the fuselage skin approximately 23 cm to the right of the tailskid shoe.

## Background information

*Thrust reverser system overview*

The thrust reverser system provides aerodynamic braking during landing rollout by redirecting engine fan air to produce a forward airflow. The system is electrically controlled, pneumatically driven and mechanically actuated. When the thrust reverser is deployed, two translating sleeves move rearwards on tracks to expose a fixed cascade. Simultaneously, blocker doors are rotated into the fan airstream to block the normal fan airflow path and redirect the air outwards and forwards through the cascades. If a reverser is unlocked or in transit, logic in the Full Authority Digital Engine Control (FADEC) system limits the engine thrust, in some cases, to idle thrust. The reverser deployment stroke takes approximately 2.5 seconds and stowing takes about 5 seconds.

*Thrust reverser controls*

The thrust reverser levers, Figure 1, are mounted on the throttle control levers and can be operated when the throttle control levers are in the idle position. To deploy the system the thrust reverser levers are rotated upwards from the stowed position. A mechanical friction point indicates that the reverse idle threshold is reached. Electrical signals from microswitches under the throttle quadrant then command the thrust reverser actuation system and the translating sleeves move rearwards. For reverse thrust application, the mechanical friction point must be overridden and the thrust reverser levers pulled rearward towards the full reverse position; engine thrust increases accordingly. To cancel reverse thrust operation, the thrust reverser levers are returned to the stowed position.

*Thrust reverser status indications*

The status of the thrust reverser operation is indicated by two annunciator lights on the cockpit centre instrument panel. An amber REV UNLK warning caption illuminates in the cockpit, during the stow and deploy cycles, as soon as the translating sleeves are unlatched. The REV UNLK signal can be generated by the unlatching of the Pneumatic Drive Unit (PDU) primary brake or the master actuator secondary locks or the closing of the stow switch contacts. The REV UNLK caption remains on while the sleeves translate and until they have reached 93% to 97% (nominally 95%) of their travel. This indication is replaced by a green REV caption when the translating sleeves are

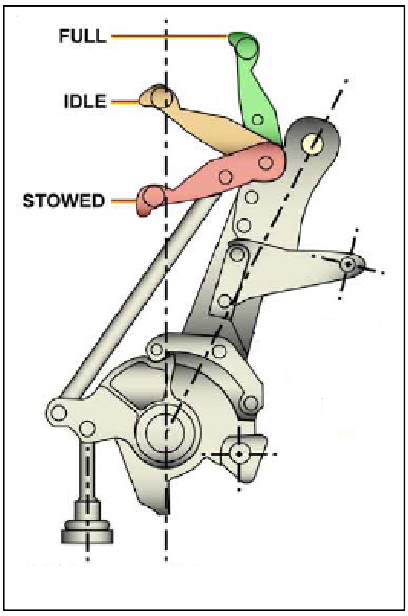


**Figure 1**

Throttle control levers showing reverse thrust controls beyond 95% of their travel on the deploy stroke, and the deploy limit switch in the master actuator feedback module is open. There is no cockpit indication when the sleeves are fully stowed. The REV UNLK and REV signals also generate discrete parameters recorded by the Flight Data Recorder (FDR).

**Control speeds during go-around**

A number of critical speeds are determined during certification of aircraft such as the A300 which must be achieved for full control to be assured. These take into account the loss of the 'critical engine', considered for aerodynamic reasons to be the engine on the into-wind side of the aircraft.

During a single engine go-around an aircraft should not be rotated below $V_{APP}$ in order to ensure an adequate climb gradient is achieved. In addition, the aircraft must be flown above its minimum control speed in the air ($V_{MCA}$), with no more than five degrees of bank, to ensure that it remains controllable.

**Recorded information**

The aircraft was fitted with a Cockpit Voice Recorder (CVR) and FDR. Both recorders were downloaded by the AAIB. The operator also operated a Flight Data Monitoring (FDM) programme from which the Quick Access Recorder (QAR) download was also recovered.

The 30-minute voice recording downloaded from the CVR was of extremely poor quality, to the extent that the recording could not be used in the investigation. The FDM download revealed an empty data file which was later attributed to a hardware failure of the QAR.

The FDR recorded over 25 hours of operation, including the incident. The status of each thrust reverser lock (corresponding to the amber cockpit REV UNLK caption) was recorded once a second. The discrete confirming that each thrust reverser had achieved its deployed position (corresponding to the green REV caption) was recorded every four seconds. In addition, throttle control lever position and engine speeds were recorded every four seconds but thrust reverser sleeve position was not recorded. This parameter is normally available on the QAR recording.

The aircraft touched down on Runway 09 at a computed airspeed (CAS) of 135 kt and groundspeed of 138 kt (Figure 2). The aircraft bounced, characterised by the normal acceleration reversal; this was followed by a second, heavier, touchdown at 1.8g. At some point between the first and second touchdown, the recorded No 1 engine throttle resolver angle reduced to 24.5°. At almost the same time as the second touchdown, the No 2 engine throttle resolver angle reduced to 26°. According to the aircraft manufacturer, a throttle resolver angle of less than 32.4° will activate the thrust reverser deployment, and any angle below 30° represents commanded reverse thrust above idle. Due to the sampling rate of the engine speeds, it is unknown whether the engine speed advanced in line with the throttle control lever position.

The recorded landing gear squat switches did not register 'on ground' for the first touchdown[2] and one second after the second touchdown, both reversers became unlocked but neither achieved the deployed position. The throttle control levers were then advanced to the takeoff thrust position; again, the exact timing could not be confirmed due to the four second sampling rate of lever position.

**Footnote**

[2] Landing gear 'on ground' discretes are sampled once per second.

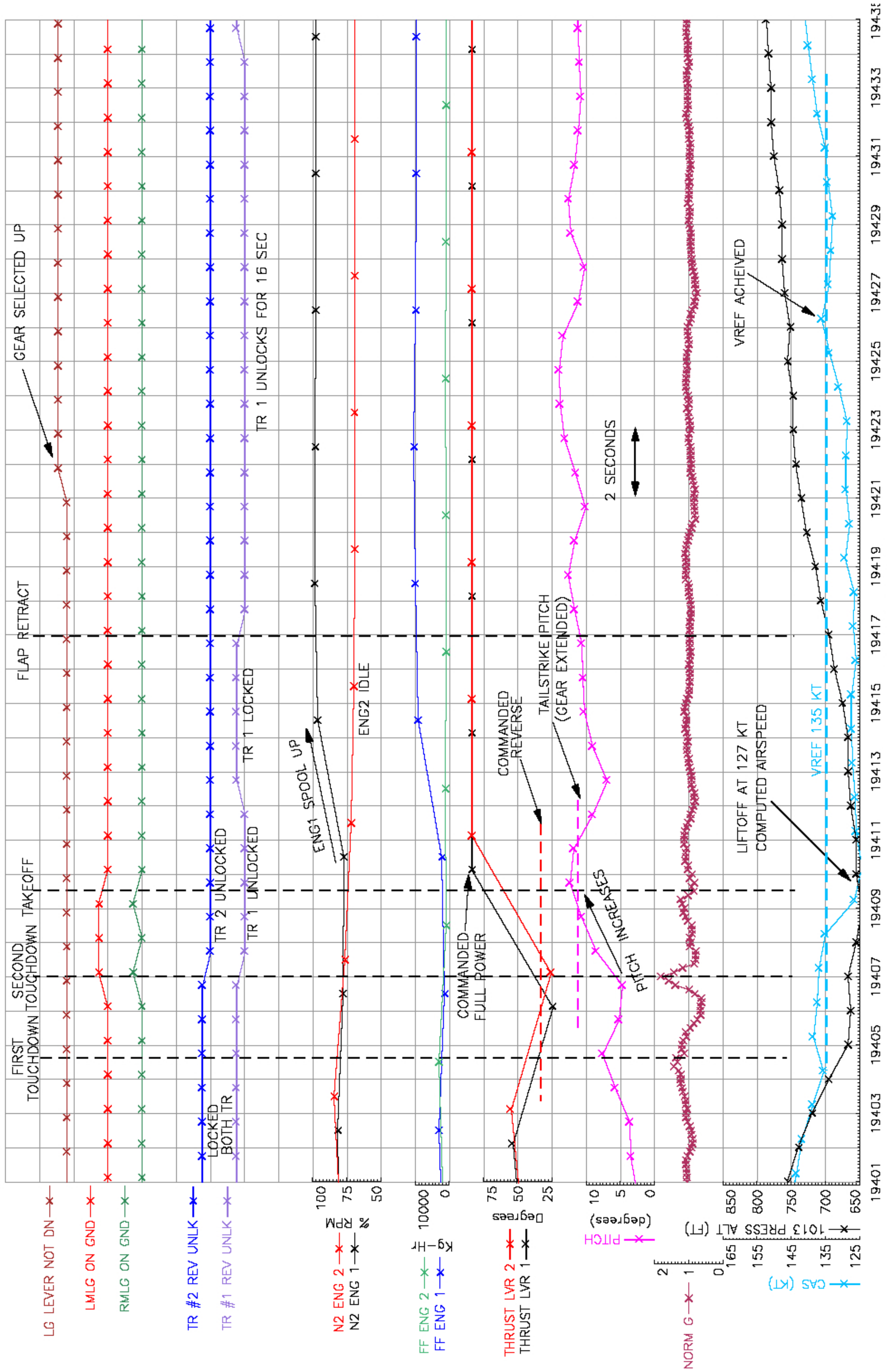


**Figure 2**

TF-ELK touchdown and go-around at East Midlands Airport: relevant FDR parameters

The main wheels remained on the ground for approximately two seconds, during which the aircraft pitched up from 5° to 12.5°, finally lifting off at an airspeed of 127 kt[3]. At no point did the nose landing gear oleo compress. The point at which the tailstrike occurred could not be identified from the recorded data, but the aircraft manufacturer confirmed that with the main landing gear oleos extended, a tailstrike can occur at a pitch attitude of 11.2°.

After both throttle control levers were advanced to the takeoff position, the No 1 engine thrust reverser locked but the No 2 engine thrust reverser remained unlocked for the rest of the flight. Engine thrust increased on the No 1 engine but the No 2 engine remained at idle thrust. The pitch attitude reduced and the aircraft began to climb away, gaining 92 ft during the first 13 seconds, during which the airspeed remained below the $V_{REF}$ of 135 kt. Seven seconds after takeoff, the flaps were retracted one setting and five seconds later, the landing gear was selected to UP. During this period, the No 1 engine thrust reverser was recorded as being unlocked for 16 seconds, however the engine remained at full thrust. The aircraft then levelled for a few seconds and the speed increased to $V_{REF}$ before the climb continued.

The next 100 ft of climb took a further 25 seconds and the speed increased to 152 kt. The aircraft then levelled off at approximately 200 ft aal for eight seconds as the speed increased to 160 kt, after which the rate of climb increased significantly.

Just over two minutes after lift off, the recorded No 2 engine throttle resolver angle reduced to the idle position. There were subsequently no further recorded movements of the No 2 engine throttle control lever.

Eleven minutes after the lift off from East Midlands Airport, the No 2 engine was shut down. During the landing at Stansted, reverse thrust was commanded on the No 1 engine. The thrust reverser unlocked but failed to achieve the deployed position despite being unlocked for 15 seconds, and engine speed did not increase in response to the reverse thrust command.

The 25-hour FDR recording contained data for 11 other landings which were reviewed. The landings on the two sectors prior to the incident flight revealed that the thrust reverser 'lock' and 'deployed' discretes recorded on the FDR behaved as expected. Reverse was successfully achieved on the No 1 engine but the No 2 engine speed did not increase in line with the command from the recorded throttle position. All other recordings of reverse thrust on landing were at reverse idle, so correct operation of the No 2 engine thrust reverser on these flights could not be confirmed.

**Airbus Flight Operations Briefing Notes**

In May 2005 Airbus published information on bounce recovery and rejected landings as part of a series of Flight Operations Briefing Notes. These were not formally made available to flight crews by the operator but were freely available online. The information emphasises that after thrust reversers have been selected the aircraft is committed to a full-stop landing. The information further states that thrust asymmetry resulting from one thrust reverser failing to restow have led to instances of significantly reduced rates of climb or departure from controlled flight.

The co-pilot stated that he had seen the relevant Briefing Note, although not recently, whilst the commander stated that he was not aware of its existence.

**Footnote**

[3] $V_{MCA}$ for the aircraft in this configuration is 111 kt CAS (114.5 kt IAS).

**Flight Crew Operating Manual (FCOM)**

The operator used the Airbus A300-600 FCOM. The following sections are relevant to this investigation and both pilots reported that they were aware of their contents.

**Landing Standard Operating Procedures - FCOM Section 2.03.22**

These procedures state that the thrust reverser levers should be pulled to select idle reverse '*immediately after touch down of main landing gear'*. They further state that after reverse thrust is initiated a full-stop landing must be performed.

Additional notes include a warning not to move thrust reverser levers towards the stowed position while reversers are in transit as this may cause damage to the system.

**General recommendations for takeoff and landing – FCOM Section 2.02.01**

The FCOM recommends that in cases of light bounce (5 ft or less) at touchdown, landing should be completed. In cases of high bounce (more than 5 ft) a go-around should be initiated. Should a go-around be necessary it states that aircraft pitch and configuration should be maintained in order to soften any subsequent touchdown and prevent aircraft damage. The configuration should not be changed until the aircraft is '*safely established in the go-around and no risk of further touchdown exists*'.

The recommendations also include a warning that landing should not be attempted after a high bounce as the remaining runway may not be sufficient to allow the aircraft to stop.

Procedures in this section on rejected landings warn that if reverse thrust has been selected, a full-stop landing must be completed.

**Go Around Standard Operating Procedures – FCOM Section 2.03.23**

The go-around procedure requires that the aircraft be rotated at a typical rate of 3º per second up to an initial pitch angle of 18°.

**Thrust reverser warnings - FCOM section 2.05.70**

Abnormal configuration of the thrust reversers such as an in-flight thrust reverser deployment is accompanied by a master caution light and single aural chime and an ENG 1 (2) REVERSE UNLK ECAM message. In this incident the system logic would have inhibited the master caution and ECAM message until the aircraft had climbed through 400 ft agl.

The associated ECAM checklist actions, described in FCOM section 2.05.70, require the throttle control lever of the affected engine to be set to idle. If the engine thrust is automatically set to idle by the FADEC thrust limiting function, an ENG 1 (2) AT IDLE ECAM message is also displayed.

**Thrust reverser system description**

*Thrust reverser actuation system*

The key components of the actuation system are shown in Figure 3.

The Pressure Regulating and Shutoff Valve (PRSOV) regulates inlet bleed air pressure and airflow to the PDU and initiates the unlocking sequence of the master actuators. It is electrically controlled and pneumatically operated.

The electrical solenoid selector valve ports regulate air from the PRSOV to the deploy or stow ports of the PDU. This moves the directional valve to the deploy or stow position, causing the air motor to turn in the commanded direction and also pressurises the PDU brake release chamber to release the air motor brake. The two-position valve receives a 28 V DC signal from the throttle quadrant microswitches. There are two solenoids: one for the stow command and the other for the deploy command.

The PDU provides pressure-regulated air to the air motor which drives a series of flexible driveshafts at rotational speeds up to 20,000 rpm. These are connected to the master and slave ballscrew actuators that move the translating sleeves and blocker doors.

Three separate system locks prevent the reversers from operating unless commanded. The primary means of locking the translating sleeves in the stowed position is the PDU brake which locks the air motor. Normally the brake release chamber is depressurised and the brake is spring-loaded in the brake applied position.

The master actuators convert flexible drive shaft rotary motion from the PDU to linear motion for

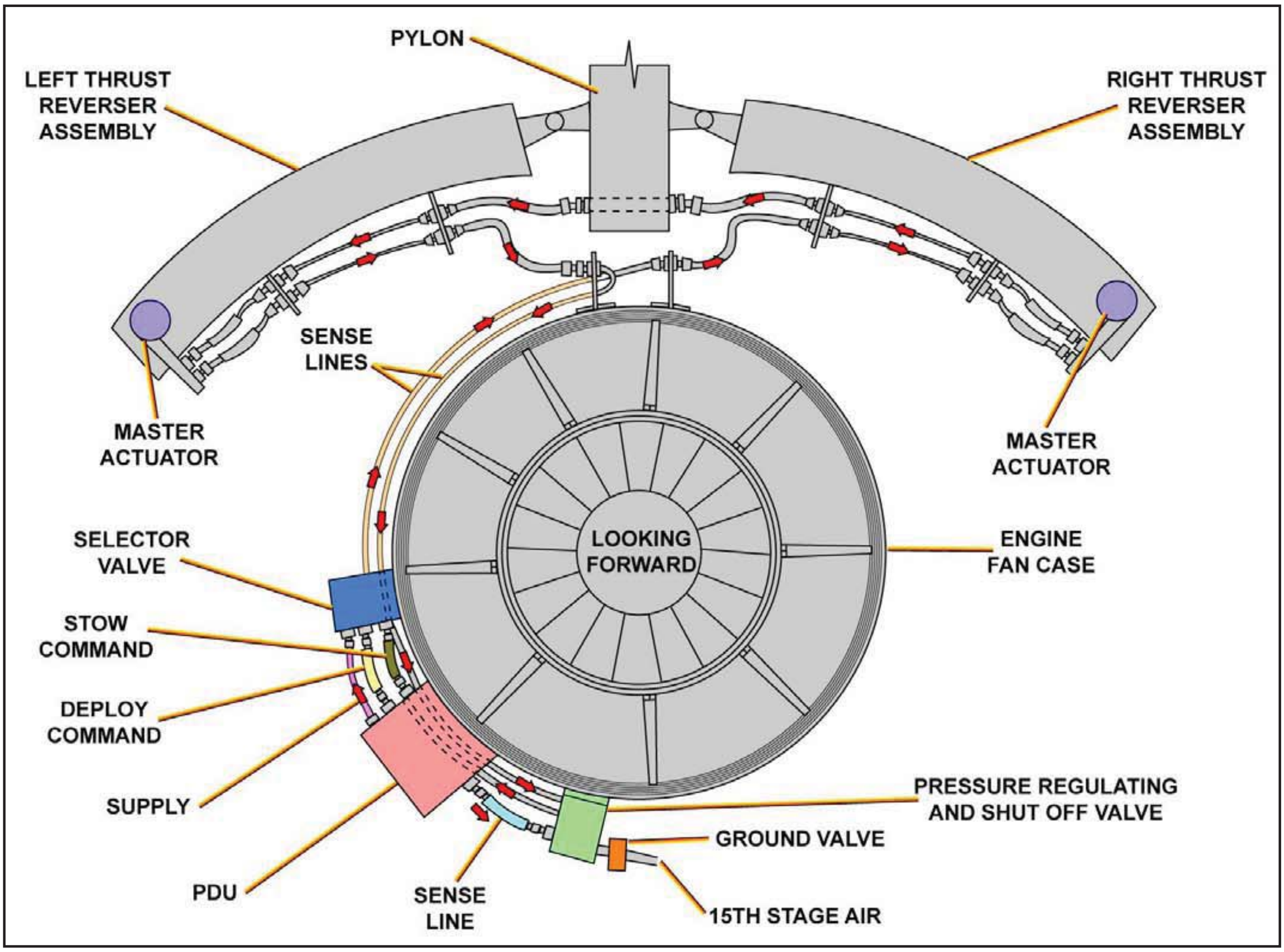


**Figure 3**

Thrust reverser system components (view looking forward) driving the translating sleeves via ballscrews. Each master actuator powers two slave actuators through flexible driveshafts. A feedback module located on the master actuator contains a Rotary Variable Differential Transducer (RVDT) and limit switches which indicate the stowed and deployed position and also control the arming solenoid of the PRSOV. The RVDT is driven by the master actuator internal gearbox in direct relation to the translating sleeve travel and provides a sleeve position signal to the FADEC system, proportional to the actuator percentage deployed.

The secondary system locks are incorporated into each master actuator. The master actuator locks only function when in the reverser stowed position and pressurisation of the lock actuator chambers is required to release the locks.

The third locking mechanism comprises two synchronous shaft locks, one per sleeve, installed between the master actuator and lower slave actuator and connected to them through flexible shafts. They are electrically controlled and the dedicated command circuit is independent from the other thrust reverser system controls. The synchronous locks are locked to restrain the flexible shaft system and hold the translating sleeves in the stow position, except when reverse thrust is commanded.

*FADEC interface*

The FADEC system interfaces with the thrust reverser system to provide engine thrust limiting when the reverser sleeves are in transit. The FADEC receives a signal proportional to the reverser sleeve position from each of the dual channel RVDTs in the master actuator feedback modules. During the deploy command, the FADEC software logic restricts the fuel flow to approach idle fuel flow until a signal indicating 78% of full deployment is received, regardless of throttle control lever position. Maximum fuel flow cannot be attained until 90% of full deployment is indicated. In the stow cycle, the FADEC software logic maintains idle fuel flow until an 85% stow signal is received. Maximum forward thrust cannot be attained until a 90% stow signal is received.

*Auto-Restow circuit*

During the deploy cycle the PRSOV arming solenoid is energised by an electrical signal from a microswitch in the throttle quadrant. A loss of electrical signal while the sleeves are translating will result in the arming solenoid becoming de-energised and the air supply to the PDU will be isolated causing the sleeves to stop their transit. The auto-restow circuit provides a continuous electrical path, independent of thrust reverser lever position, to energise the PRSOV arming solenoid when both stow switches are closed (ie thrust reverser sleeves not stowed). The stow switches remain closed throughout the entire thrust reverser operation cycle, from the deploy command until the reverser sleeves have been fully stowed. In this way, the auto-restow circuit ensures the closing operation during normal thrust reverser operations and also acts as a safety feature to return the thrust reverser sleeves to the stowed position in the case of an in-flight reverser deployment. A separate circuit provides the electrical path to energise the stow solenoid, when the thrust reverser levers are in the stow position.

**Post-incident actions**

After arrival at Stansted the engineer, who had been on-board during the incident flight, conducted an aircraft walk-round. He observed that the No 2 engine thrust reverser sleeves were deployed by approximately 25 cm (full deploy is 53 cm). After opening the fan cowl doors he noted that the upper flexible driveshafts from the splitter gearbox to the master actuators on both sides were twisted and the secondary locks were not engaged. The thrust reverser sleeves were then hand-cranked to the stowed position. As the flexible shafts from the splitter gearbox to the master actuators were still twisted, they were disconnected at the master actuator ends to release the tension and then reinstalled.

**Aircraft examination**

*General*

The aircraft was examined by the AAIB after the No 2 thrust reverser had already been stowed manually. It was therefore not possible to examine the No 2 thrust reverser in its immediate post-incident state. A FADEC ground test confirmed that the RVDTs on both reversers correctly indicated the stowed position.

*No 2 Engine*

Visual inspection of the No 2 thrust reverser system did not reveal any mechanical defects and the flexible shafts were all observed to be in good condition and adequately lubricated.

Electrical continuity checks revealed that, following a reverser stow command, no voltage was present on Pin 4 of electrical connectors DH16 and DH17 (synchronous lock solenoids). Voltage should have been present at these pins for a period of 10 seconds. The correct voltage was detected following a repeat test. These findings suggested the presence of a potential intermittent fault on relay 46 KM, which was removed for further testing and replaced. Relay 46 KM provides the electrical path, via two other relays to the synchronous locks and during the deploy cycle to the PRSOV arming solenoid. A disruption in voltage to relay 46 KM would result in an instantaneous loss of air to the PDU, causing the motor to stop turning and a loss of electrical signal to the synchronous lock causing the solenoids to de-energise. If this occurred while the sleeves were in a transit it would result in a 'crash engagement' of the synchronous locks, which would be evidenced by distinctive witness marks inside the lock.

A function check of the No. 2 thrust reverser was performed a number of times by pneumatically deploying and stowing the reverser using APU bleed air. The system operated as expected.

*No 1 Engine*

Visual inspection, electrical continuity checks and pneumatic functional checks of the No 1 thrust reverser system did not identify any defects that would have prevented correct operation of the system. However a temperature label on the PDU indicated that the unit had experienced an overheat and it was removed for further testing.

*Engine runs*

During post-incident engine ground runs both reversers were observed to deploy and stow correctly and to generate the appropriate REV UNLK and REV cockpit status indications, but the No 2 engine thrust did not increase above reverse idle when commanded. This was indicative of the FADEC system limiting the thrust, based on the RVDT feedback of reverser sleeve position.

*Subsequent inspections*

Following the initial aircraft examination the aircraft was returned to service with No 2 thrust reverser inoperative pending removal of components for testing. After removal of the components, the operator subsequently experienced further problems with thrust reverser operation resulting in a number of incidences of flexible shaft failure. These issues were determined to be related to rigging of the thrust reverser system following component removal and replacement, and were not considered relevant to the incident. In addition, subsequent electrical continuity tests were carried out to support the ongoing investigation. During these checks, upon inspecting the auto-restow circuit wiring and electrical connectors, a loose wire was found on Pin F of connector D5010P in the thrust reverser junction box (Figure 4). The effect of the loose wire would be an interruption of the electrical signal to the PRSOV arming solenoid during the stow operation. There was no relevant Trouble Shooting Manual (TSM) task to aid identification of such a fault.

**Component Testing**

Several components were tested at the respective manufacturers' facilities. The findings are outlined below.

*No 2 thrust reverser components*

Relay 46 KM was tested and it functioned correctly and conformed to specifications. Testing and internal examination of the synchronous locks did not reveal any evidence of a crash engagement, which would be apparent if the solenoids had instantaneously de-energised while the reverser sleeves were in transit.


**Figure 4**

Loose wire at Pin F of connector D5010P in the auto-restow circuit

The master actuators were received and examined in the stow position with the feedback modules attached. Although the actuators were visibly in the stow position, as confirmed by the stow switch and examination of the internal gearing, the Channel A and Channel B output voltage indications on both RVDTs were significantly outside limits, such that they indicated approximately 50% and 88% deployed, respectively. The master actuator gearbox drives the RVDT and the stow switch assemblies using the same input shaft; the disagreement between the RVDTs and stow switches was therefore considered abnormal. After the RVDT resolvers had been removed from the feedback module and physically reset to indicate the stow position, the test was repeated and the output voltages were found to be within limits. Electrical tests and examination of the internal gearing did not reveal any evidence which could account for the anomalous output voltages. The manufacturer considered that the only possible explanation for the gross anomalies with the RVDT output voltages was that the RVDT had been separated from the master actuator at some point, such that they were no longer aligned. However this could not be confirmed and there was no evidence of the RVDT mounting screws having been removed.

Further testing of the RVDT resolvers revealed that they did not conform to the manufacturer's specifications, displaying a small shift in alignment between Channel B and Channel A outputs. However the manufacturer considered that the results were not uncommon for RVDTs of that age (approximately 19 years). The findings on the RVDTs were not considered causal to the failure of the No 2 thrust reverser to stow as their only function is to provide feedback on thrust reverser sleeve position to the FADEC.

The PDU failed after the aircraft was returned to service. Inspection at a repair facility revealed an area of cut packing in an internal pneumatic line and dirt contamination in another. The PDU manufacturer determined that these findings may have resulted in insufficient air pressure to release the PDU brake fully, preventing the unit from functioning correctly. The unit performed satisfactorily after removal of the dirt and replacement of cut packing.

*No 1 thrust reverser components*

The PDU failed the manufacturer's Acceptance Test Procedures (ATP) as the pressures required to actuate the brake switch and the directional control valve exceeded the maximum permissible values. The air motor also failed the test which measured its stopping accuracy. The unit failed the minimum operating pressure test and was slow to function at low pressures. Although the temperature label had turned black, there were no indications of thermal distress to the unit.

**Additional information**

*CVR serviceability*

The operator's FCOM defined a daily test of the CVR system via a 'CVR TEST' pushbutton in the cockpit. There were no reported failures of this test prior to this incident and there was no reason for the operator to suspect a fault with the CVR. The fact that the recording quality was extremely poor suggests that this daily check, which records a test tone to each channel, was not capable of detecting a poor quality recording. The Airbus Maintenance Planning Document (MPD) also defined a detailed operational check by assessing the recorded quality of each recorded channel, required every 6,000 flight hours or four years. This operational check was successfully performed in July 2009.

Regulations concerning CVR serviceability are covered in several documents. ICAO Annex 6[4] Appendix 8 requires a daily check of the CVR built-in test (BIT) features in the cockpit (where fitted) and an annual read-out to assess the recording quality. EU OPS Part 1 contains no serviceability regulations for the CVR. The latest Minimum Operation Performance Specification (MOPS) for airborne recorder systems, ED112, recommends a daily activation of any test function/BIT monitoring, alongside a six-monthly operational test of the system and an annual recorder download.

As EU OPS Part 1 represents the mandatory regulations for this aircraft type aircraft operating from Iceland, the only requirement to perform CVR functional tests are through those imposed by the aircraft manufacturer. Some national airworthiness authorities, including the UK CAA, provide guidance notes[5] on the continued airworthiness of flight recorder systems which recommend operational checks, but these are not mandatory.

In December 2009, EASA issued Safety Information Bulletin 2009-28 highlighting the problem of dormant failures in flight recorders. In this bulletin it was recommended that the servicing interval guidelines in ICAO Annex 6 should be considered by design approval holders for the CVR installation, operators, maintenance organisations and national airworthiness authorities.

The detection capability of the daily CVR check on TF-ELK was insufficient to detect the poor quality audio recording. An annual download interval of 6,000 flight hours or four years for a system critical to accident investigation allows a significant exposure time for a dormant failure to appear in the CVR system. This is recognised by investigation authorities worldwide and is the reason why the ICAO and ED112 requirements are proposed.

The current EU OPS requirements do not reflect the current ICAO or ED112 operational requirements. EASA is in the process of revising EU OPS and draft proposals have included the introduction of a mandatory annual replay of the CVR.

**Analysis**

*Operational aspects*

Neither pilot believed reverse thrust had been selected after touchdown at East Midlands Airport, but the physical and FDR evidence showed that the reversers were selected and did deploy. However, the low sampling rate of throttle control lever position parameter on the FDR data did not allow an accurate determination of when during the landing sequence reverse thrust was selected. The only recorded sample of throttle resolver angle between the two touchdowns at East Midlands Airport suggests that reverse thrust was selected at some point between the first and second touchdowns. This is consistent with the standard procedures contained in FCOM section 2.03.22, which state that the thrust reverser levers should be pulled to select idle reverse '*immediately after touch down of main landing gear'*.

The wind conditions at the time of their attempted landing, whilst within the aircraft's operating limits, were challenging. It is likely the crew's lack of appreciation that reverse had been selected was due to distraction caused by the difficult handling conditions, the selection being an automatic and subconscious action by the commander on touchdown.

**Footnote**

4 Ninth edition.

5 CAP 731 Approval, Operational Serviceability and Readout of Fligt Data Recorder Systems and Cockpit Voice Recorders.

As a result of this incident the operator has provided a verbal brief on the circumstances of the event to all of its A300 pilots and has introduced a crosswind landing exercise into recurrent simulator training. They have also provided them with Airbus Flight Operational Briefing Notes relevant to this incident.

During the first touchdown, the landing gear squat switches did not register 'on ground' and there were no recorded indications of the thrust reverse becoming unlocked. This may be due to the low FDR sampling rates for these parameters. On the second touchdown, both main gear squat switches registered 'on ground' and both thrust reversers were recorded as being unlocked within one second, consistent with thrust reverser deployment.

Recorded data indicated that the second touchdown was harder than the first, with the normal acceleration reaching 1.8g. The commander, considering that conditions were not suitable to continue the landing, decided to execute a go-around. During the course of applying takeoff thrust and going around, the No 2 reverser failed to restow, seriously compromising the aircraft's climb performance.

The absence of a functional CVR undermined the AAIB's ability to determine crew actions during the landing and go-around phase.

The FCOM procedures caution against going around once reverse thrust has been selected, because of the possibility of damage occurring to the system. The Airbus Flight Operations Briefing Notes give more specific information about the possible effects of cancelling reverse thrust whilst the reversers are in transit and performing a go-around, stating that thrust asymmetry resulting from one thrust reverser failing to restow has led to instances of significantly reduced rates of climb or departure from controlled flight. In this case the crew were not fully aware of the contents of the Briefing Notes and it is possible that other crews may not be aware of the reported consequences. In order to remind all operators of A300 aircraft of the possible adverse effects of cancelling reverse thrust whilst it is in transit and the safety implications associated with performing a go-around should a reverser fail to restow, Airbus intend to deliver a presentation on this event to operators at their next annual Safety Conference in March 2012. In addition Airbus will publish an article about the event in the June 2012 edition of their safety publication '*Safety First*'.

FCOM section 2.03.22 states that the thrust reversers should be deployed immediately after touchdown. It also states that once the reversers are deployed, a go-around should not be attempted; advice which would appear to be justified in light of this incident but which may be interpreted to contradict the advice in FCOM section 2.02.01 regarding bounced landing recovery. By requiring the reversers to be deployed immediately, the existing procedures mean that flight crews are therefore committed to continuing with the landing, which may be unsafe in certain circumstances. On the other hand, as this incident shows, aborting the landing might bear considerable risks. This leaves no options available to the crew. In order to avoid this possibility, Airbus intend to update the FCOM section 2.02.01 'Bouncing at Landing' to reflect the fact that the 'At touchdown procedure' supersedes the 'Bouncing at Landing' procedure, re-emphasising the need, under all circumstances, to complete a full stop landing if reverse thrust has been selected. These amendments will be incorporated in the June 2012 revision of the FCOM.

The commander reported that he had cycled the No 2 thrust reverser lever and throttle control lever during the climb. These actions were not in accordance with the required ECAM checklist actions. The recorded FDR data does not show any evidence of the thrust reverser lever or the throttle control lever being moved during the climb, but given the sampling rate it is possible that any such control lever movement occurred between samples.

Without the system protection afforded by a correctly functioning FADEC in limiting the No 2 engine thrust to idle, the effect of these actions on aircraft controllability would have been significant. Given the circumstances faced by the crew it is possible that they were not fully aware of the nature of the problem.

*Aircraft performance*

The decision to go around resulted in the aircraft becoming airborne in a high drag configuration at an airspeed of 127 kt. At the same time, whilst full power had been commanded on both engines, only the No 1 engine was providing full thrust. The No 2 engine thrust reverser remained unlocked with FADEC limiting power to idle.

Whilst the rotation speed was above $V_{MCA}$, it was considerably below the certified rotation speed required of 144 kt, and would have resulted in reduced control effectiveness. The higher angle of attack associated with the aircraft's low speed would have increased the aerodynamic drag, further compromising the aircraft's acceleration and climb performance, which were marginal. This was evidenced by the air traffic controller's observations of the aircraft's low rate of climb while rocking from side to side, the crew's observation that the aircraft was slow to accelerate, and the recorded data.

During the first 13 seconds of being airborne the aircraft climbed only 92 ft, with the airspeed failing to increase significantly and remaining below $V_{REF}$. The aircraft then levelled for a few seconds, allowing the airspeed to increase to $V_{REF}$, acceleration being further assisted by the reduction in drag afforded by selecting FLAP 20 and retracting the landing gear. A significant increase in the climb rate was finally achieved 47 seconds after lift-off, by which time the airspeed had increased to 160 kt and the aircraft was climbing through an altitude of 875 ft (approximately 220 ft aal). The absence of high ground in the path of the aircraft was fortuitous, given the aircraft's severely compromised performance.

During the go-around, pitch was not maintained but was allowed to increase to 12.5° at the normal rotation rate, with the main wheels still on the ground. Whilst the exact point at which the tailstrike occurred could not be identified, this pitch angle exceeded that required for a tailstrike to occur.

*Thrust reverser behaviour*

General

The FDR data showed that both thrust reversers became unlocked in response to the reverse thrust command. However neither thrust reverser had time to deploy fully prior to thrust levers being advanced to the takeoff position. The deploy stroke typically takes 2.5 seconds, therefore it is considered that the full forward thrust command occurred within this 2.5 second window, while the reverser sleeves were still in transit towards the deploy position. It is not possible to be more precise about the exact sequence of the reverse thrust commands and the response of the reverser sleeves, due to the limited FDR sampling rates.

No 2 thrust reverser

Inspection of the No 2 thrust reverser ruled out damage of the mechanical actuation elements of the thrust reverser system as a cause of its failure to restow. As the twisted flexible driveshafts had been uncoiled and the thrust reverser manually returned to the stow position by the mainenance engineer following the incident, evidence regarding the precise status of the components within the thrust reverser system was lost. It was not possible to determine whether the twisting in the flexible shafts was causal or contributory to the No 2 reverser's failure to restow, or simply a secondary effect of other components in the system stopping suddenly when the stow command was made.

The operational guidance in FCOM section 2.03.22 states that when reverse thrust is commanded, the thrust reverser levers must not be moved towards the stowed position while the sleeves are in transit as this may cause damage to the system. The thrust reverser manufacturer considered that binding or severing of a flexible driveshaft or a mid-stroke stall of the mechanical or pneumatic elements of the system were possible outcomes.

The pneumatic elements of the system were observed to function adequately during function testing and engine ground runs. However the PDU subsequently failed during function checks performed by the operator following component removal. Strip examination of the unit revealed an area of cut packing and some contamination, considered by the manufacturer to be sufficient to compromise the performance of the PDU. This may have resulted in insufficient air pressure to release the PDU brake and therefore could not be ruled out as a possible cause of the reverser sleeves stopping at mid-stroke.

Initial testing of the RVDTs revealed that the output voltages supplied to the FADEC system were grossly out of limits. In this condition, the FADEC would have been receiving anomalous signals regarding thrust reverser position and the engine could not have functioned effectively for any length of time in either the forward or reverse thrust regimes prior to the incident. Yet it is evident that FADEC functioned correctly to limit the No 2 engine thrust during the incident. It was therefore considered that this condition could not have existed prior to the incident. The manufacturer considered that the only possible explanation for the gross anomalies was that the RVDTs had been separated from the master actuators causing mis-alignment (possibly during component removal) and subsequently reinstalled.

The RVDTs indicate correctly the thrust reverser stowed position when the FADEC ground test was performed on initial examination of the aircraft, however thrust was limited on the No 2 reverser during engine ground runs. The RVDT resolvers underperformed when tested in isolation, but not significantly so. Recorded data for the two flights prior to the incident flight indicated that the FADEC thrust limiting function had activated on the No 2 engine despite the thrust reverser being fully deployed. This suggests that a possible issue with the validity of the RVDT feedback signals existed prior to the incident flight. In summary, there is contradictory evidence from testing, observations and flight data regarding the performance of the the RVDTs. However as their only function is to provide feedback to the FADEC on thrust reverser sleeve position, none of these findings can be considered causal to the failure of the No 2 reverser to stow. Correct RVDT output voltages are, however, fundamental to the FADEC logic with respect to thrust limiting. None of the observations made on RVDT performance appear to have adversly affected the operation of the FADEC thrust limiting function during the incident.

Interruption of the electrical path to the synchronous locks was ruled out as a cause of the reverser sleeves stopping mid-travel, based on the results of component testing.

The most significant finding was the identification of a loose wire in the auto-restow circuit, which is designed not only to ensure the stowing of the thrust reversers during normal operation, but also in the case of an in-flight thrust reverser deployment. Loss of electrical signal to the PRSOV arming solenoid following the mid-stroke stow command, as a result of the loose wire, is considered the most likely reason for the No 2 thrust reverser stopping in the mid-stroke position. The loose connection is considered to have been an intermittent issue; had this been a permanent condition, the normal stowing function of the thrust reversers would have been compromised prior to the incident and this would also have been evident during the post-incident function checks and engine runs and following the aircraft's return to service.

The loose connection on the auto-restow circuit was not detected during initial electrical continuity testing on the thrust reverser system, but was discovered after the aircraft had been returned to service. There were no TSM tasks specifically relevant to this circuit to facilitate identification of this fault. As a result of this incident, Airbus intends to update the TSM to include a specific electrical check of the auto-restow circuit.

No 1 thrust reverser

The No 1 engine fuel flow and engine speed increased as commanded during the go-around. The thrust reverser remained in the locked condition for a period of four seconds but then became unlocked for a period of 16 seconds, re-locking as the aircraft was passing through 180 ft aal. As the FADEC did not command a reduction in fuel flow on the No 1 engine, it was concluded that if the thrust reverser sleeves were out of position (stow switches closed), they were less than 10% deployed. Had the thrust reverser sleeves been more than 15% deployed, the FADEC would have also limited the fuel flow to the No 1 engine and both engines would have been limited to idle power during this critical phase of flight. The REV UNLK caption can be generated by release of the PDU or master actuator brakes, or if the translating sleeves leave the stow position and the stow switch contacts close. It was not possible to determine which of these conditions caused the REV UNLK indication. The aircraft manufacturer considered the most likely scenario was that the thrust reverser sleeves correctly achieved the full stow position when commanded, however vibration associated with the aerodynamic loads during the go-around manoeuvre caused a transient REV UNLK indication.

During the diversion landing at Stansted the No 1 thrust reverser never reached the fully deployed position when commanded, despite being unlocked for a period of 15 seconds. The PDU did not function adequately at low pressures when tested after the incident. The engine pneumatic system should have provided enough pressure to make up for any deficit but it could not be determined whether these findings may have contributed to the behaviour of the thrust reverser during the incident landing and the subsequent landing at Stansted.

The poor quality of the CVR recording, the absence of QAR data and maintenance intervention on the thrust reverser system immediately following the incident resulted in the loss of valuable evidence, which hampered the investigation.

**Conclusions**

This incident highlights the potentially serious consequences of attempting to go around after selection of reverse thrust. In this instance the failure of the No 2 thrust reverser to restow was most likely caused by a latent intermittent loose connection in the auto-restow circuit. However, even in the absence of this particular failure, the FCOM advises damage to the thrust reverser with equally significant consequences may still occur as a result of stow command being made while the reversers are in transit. The investigation identified a number of other anomalies with thrust reverser components, which may have contributed, either in isolation or combination, to the failure of the No 2 thrust reverser to restow.

This event also highlights the need for the operational procedures for use of thrust reversers and for performing a go-around to be unambiguous.

Furthermore, it illustrates the value of conducting annual downloads of CVRs in identifying dormant failures in these units, which have the potential to compromise the quality of safety investigations.