SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 737-36E Freighter, TF-BBF
No & Type of Engines:	2 CFM International CFM56-3B2 turbofan engines
Year of Manufacture:	1992 (Serial no: 25264)
Date & Time (UTC):	3 February 2017 at 0015 hrs
Location:	East Midlands Airport, Leicestershire
Type of Flight:	Commercial Air Transport (Cargo)
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Overheating of rear equipment bay
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	50 years
Commander's Flying Experience:	9,889 hours (of which 8,087 were on type) Last 90 days - 94 hours Last 28 days - 26 hours
Information Source:	AAIB Field Investigation

Synopsis

Shortly prior to engine start the aircraft suffered an APU bleed air duct leak in the rear equipment bay. The leaking bleed air heated corrosion-inhibitor material in the rear equipment bay, resulting in scorching and the release of smoke within the main cargo deck. The flight crew shut the APU down. The cause of the bleed air leak was a failed V-band clamp that had fractured due to stress corrosion cracking. The operator is currently replacing V-band clamps at the failure location on its fleet of 737-300 and 737-400 freighter aircraft.

History of the flight

The aircraft was conducting a scheduled cargo flight from East Midlands Airport to Edinburgh Airport, with the co-pilot as Pilot Flying. At approximately 0015 hrs the flight crew completed their pre-departure checklist and requested pushback, which ATC approved. The crew reported that the aircraft was configured for engine start, with the APU running, both air conditioning packs switches in the OFF position[1], the engine bleed air switches both set to ON and the APU bleed air valve switch in the ON position. The aircraft's exterior doors were closed.

Footnote

1 Boeing's FCOM procedure puts both pack switches to AUTO. Boeing later commented that some operators perform one pack takeoff or pack off takeoff to gain higher thrust.

Shortly before the pushback was due to commence, the fire warning bell sounded. The crew looked at the indications on the fire warning panels, both on the centre console and the P5 overhead panel, but did not see any fire warning lights on either panel. The co-pilot cancelled the fire warning bell and then pressed the master caution recall button, and later stated that he could not recall if any fire warning lights were illuminated. The commander also stated that he did not see any fire or overheat warning lights.

Approximately 10 seconds after the first fire warning bell, the fire bell sounded for a second time, again without the crew recalling observing any smoke or fire warning indications on the fire warning panels. The commander asked the ground crew, via the pushback headset, whether they could see any smoke or fire coming from the aircraft; the ground crew reported that smoke was emanating from the rear of the aircraft. Whilst this message was being received, the crew observed and smelt smoke entering the cockpit, despite the cockpit door being closed.

The commander shut down the APU. The co-pilot walked to the forward galley and found that the smoke was thickening rapidly and was getting hotter, with the source of the smoke beneath the cargo deck floor. He returned to the flight deck and informed the commander, whereupon the commander called ATC requesting the immediate response of the airport fire and rescue service (AFRS). The co-pilot opened the forward left cabin door and signalled to the ground crew to bring steps to the aircraft. He then went to the forward galley and opened the forward right cabin door in order to further expel the smoke. The commander signalled to the ground crew to reconnect the ground power unit and the pilots then departed the aircraft via the steps. The AFRS arrived at the aircraft at 0023 hrs and began investigating the source of the smoke.

Aircraft information

The Boeing 737-300 is equipped with a wing-body overheat detection system, consisting of a number of heat detector elements located in close proximity to the aircraft's bleed air ducts and a monitoring system that detects a drop in electrical resistance of a detector element when that element is subjected to excessive heating. When triggered, the system activates a WING-BODY OVERHEAT light on the air conditioning overhead panel[2] and the MASTER CAUTION warning and AIR COND annunciator lights on the cockpit glareshield, Figure 1. No audio warning is associated with the system. Tests performed by the operator's maintenance personnel following the incident showed that the wing-body overheat detection system was serviceable.

During the flight crew operations manual (FCOM) pre-flight procedures, the co-pilot is required to set the aircraft's bleed air valves and air conditioning packs. The procedure requires that one air conditioning pack switch should be switched from OFF to AUTO or HIGH, whilst the other should be set to OFF. The isolation valve switch should be set to AUTO and the engine bleed air switches set to ON, Figure 2.

Footnote

2 An overheat detection of the APU bleed air duct will cause the left WING-BODY OVERHEAT caption to illuminate.

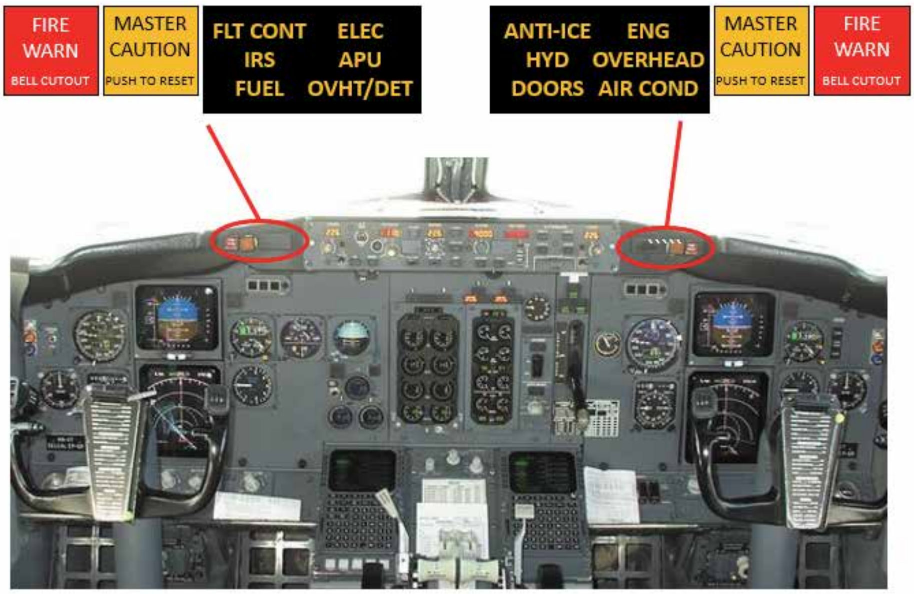

Figure 1

Boeing 737-300 cockpit glareshield fire warning buttons, master caution buttons and system annunciator captions

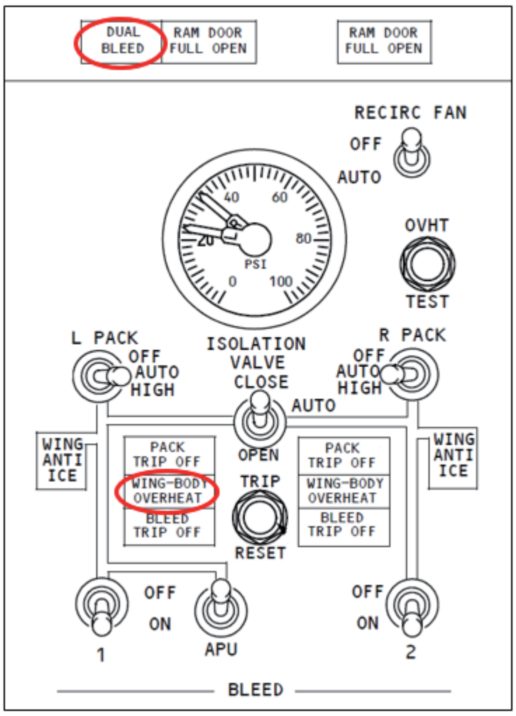

Figure 2

Boeing 737-300 air conditioning control panel, showing positions of the DUAL BLEED and left WING-BODY OVERHEAT captions

Once this has been completed, the APU bleed air switch should be set to ON; this causes the DUAL BLEED warning light to illuminate on the air conditioning overhead panel, accompanied by illumination of the cockpit glareshield MASTER CAUTION warning lights and AIR COND annunciator light, Figure 2. This is a normal part of the pre-flight procedure, as the APU bleed air valve is open at the same time as the left engine bleed air valve, allowing possible back-pressure of the APU if the left engine is operated above idle power whilst the bleed air valves are in this configuration, Figure 3.

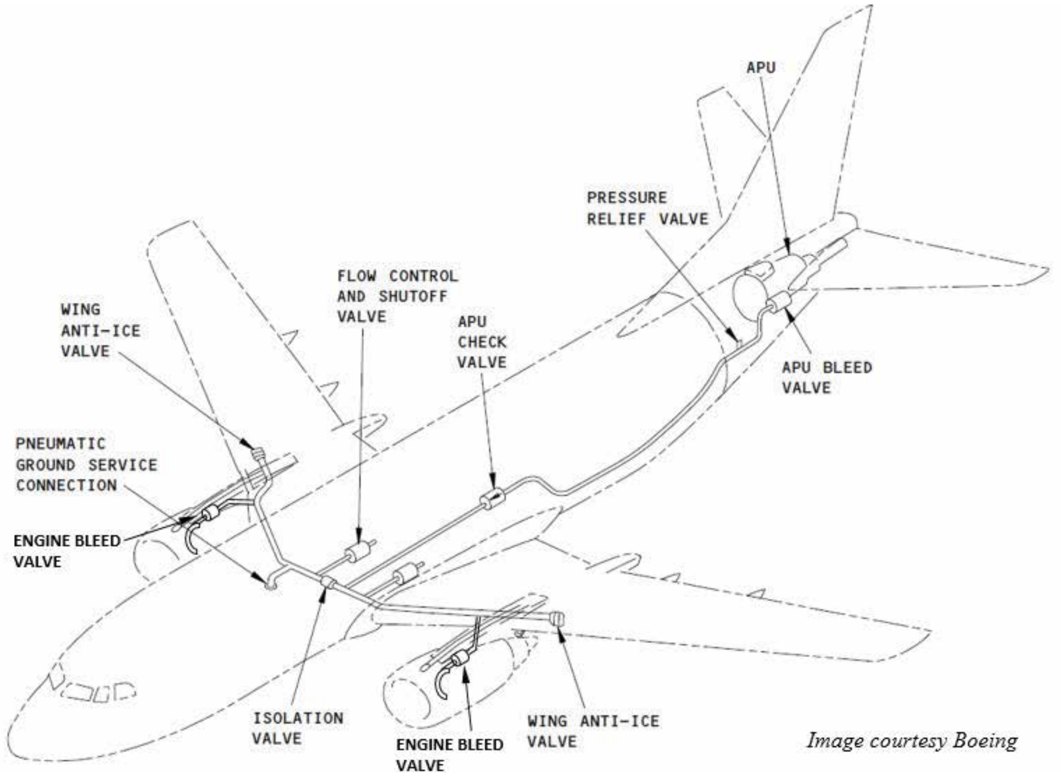

Figure 3

Boeing 737-300 bleed air pneumatic system

The aircraft is equipped with independent smoke detection systems on both the main cargo deck and lower cargo hold. Both systems are integrated with the aircraft's master caution and fire warning systems to alert the crew. The presence of smoke in the main cargo deck will cause the fire bell to sound, the SMOKE warning light to illuminate on the main deck smoke detection system panel, located on the aft overhead P5 panel, and the glareshield MASTER CAUTION and FIRE buttons to illuminate.

The presence of smoke in the lower cargo hold will cause the fire bell to sound, the FIRE warning light to illuminate on the lower hold fire warning system panel, located on the co-pilot's P5 overhead panel, and the glareshield MASTER CAUTION and FIRE buttons to illuminate. Tests on both main cargo hold and lower cargo hold smoke detection systems carried out after the event showed that both systems operated normally and were serviceable.

The aircraft's lower cargo hold is classified as a *'Class D'*[3] hold that is fully sealed in order to passively suppress fires within the compartment through oxygen starvation. The aircraft's rear equipment bay is immediately to the rear of the lower cargo hold, behind a bulkhead, and is immediately beneath the main cargo deck floor. A floor grating in the main cargo deck floor permits the passage of air from the rear equipment bay into the main cargo deck.

As neither of the aircraft's engines were running during the smoke event, neither the FDR nor quick access recorder (QAR) were recording data when the event occurred.

Aircraft examination

Investigation by the operator's engineering personnel revealed that a V-band clamp[4] had separated from a joint on the APU bleed air duct in the rear equipment bay, immediately forward of the aft pressure bulkhead, beneath the main deck cargo floor in the vicinity of fuselage station (STA) 1016, Figure 4.

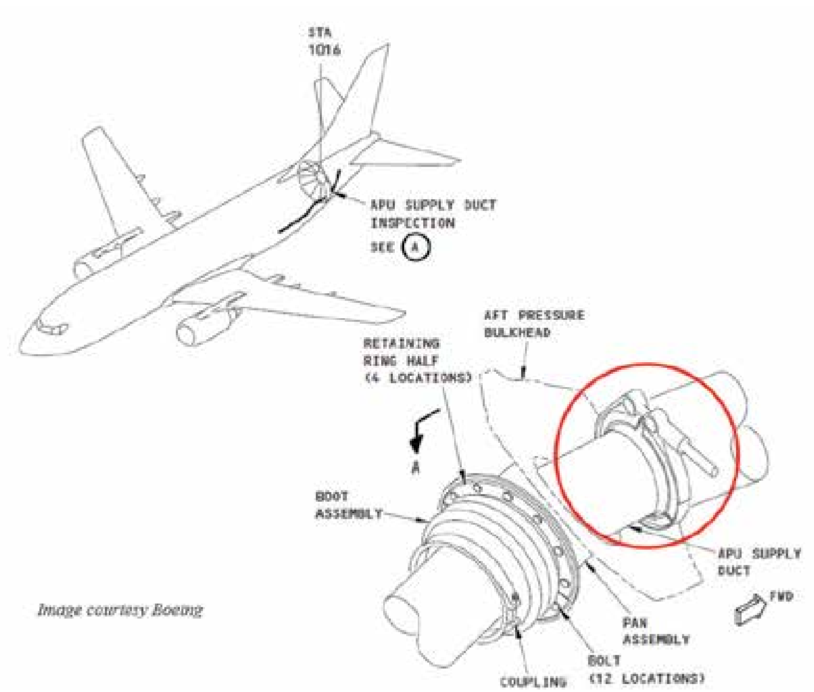

Figure 4

Location of the APU bleed air duct leak and failed V-band clamp

The aft pressure bulkhead adjacent to the leaking APU bleed air duct joint showed evidence of overheating and scorching due to ignition of the Ardrox AV8 corrosion-inhibitor coating on the aircraft's internal structure in this location, Figure 5.

Footnote

3 Federal Aviation Regulation 25.857, Cargo Compartment Classification.

4 A V-band clamp consists of a series of profiled segments welded within a tensioned outer strap. They are commonly used to connect the flanged ends of pipe segments together.

Figure 5

Overheating damage to the aircraft's structure adjacent to the APU bleed air duct leak

The aircraft manufacturer stated that, when the aircraft's APU is running, the air within the APU bleed air duct, at the point of rupture, can reach a maximum temperature of 376°C. The material safety data sheet for Ardrox AV8 states that the material has an auto-ignition temperature of 200°C.

The failed V-band clamp was marked with part number *BACC10DU400AB Rev. T* and a date of manufacture of March 1989. The aircraft manufacturer confirmed that it was the correct part number clamp for the application. The clamp is not marked with a serial number and is considered an on-condition part, with its service life not tracked in the aircraft's maintenance programme (AMP). It was unclear how long the clamp had been installed on TF-BBF. The only maintenance inspection for the clamp defined within the AMP, and Boeing documentation, was a zonal inspection[5], performed at 1C and 2C check intervals. This zonal inspection had last been carried out on TF-BBF in July 2015; the inspection contained the following requirement:

> *'Visually check all systems and installations in the aft cargo equipment bay area (Zone 220) for defects/damage, cleanliness, loose and missing fasteners, cracks, corrosion, degradation of protective coatings, condition and security.'*

The aircraft's maintenance planning document defines a visual examination as:

> *'Visual examination of defined internal or external structural areas from a distance considered necessary to carry out an adequate check… Internal applies to obscured structure requiring removal of fillets, fairings, access panels and doors etc. for visibility. Adequate lighting is required and where necessary aids such as mirrors etc., surface cleaning and access procedures may be required to gain proximity.'*

Footnote

5 Task Card 53-420-21-01.

Metallurgical analysis

The broken clamp was recovered from the rear equipment bay, Figure 6 and subjected to detailed examination.

The clamp's tension band had fractured at the point where the upper folded part of the band is attached to the main lower part of the band by two staggered rows of spot welds, Figure 7.

Figure 6
Broken V-band clamp

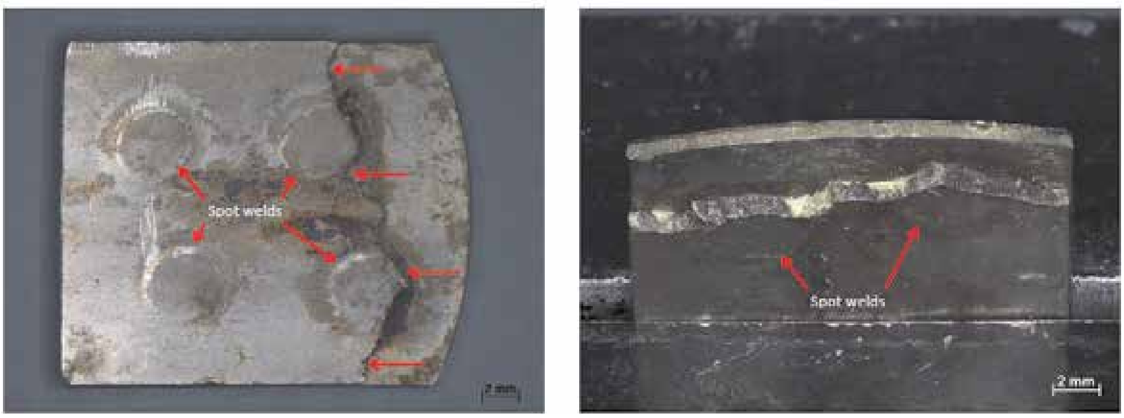

Figure 7
V-band clamp fracture location at spot welds

In addition to the main fracture, three further cracks in the clamp's band were identified, Figure 8. These additional cracks were located at points on the band between where the inner profiled segments were attached, at points where the band bending loads were highest.

Figure 8

Other cracks identified in the V-band clamp band

The clamp band material was specified by the manufacturer as 21-6-9 CRES steel[6], to specification BMS 7-191. The material composition of the clamp was checked by a specialist laboratory and found to be within specification, apart from trace levels of additional sulphur, aluminium and vanadium. The additional sulphur was deemed most likely to be present due to the products of combustion generated during the overheating event.

The fracture surface was heavily corroded, indicating that the crack had been present for a considerable period of time and that the clamp had been exposed to a corrosive environment. After cleaning, scanning electron microscopy analysis of the fracture surface revealed small areas of ductile overload at the outer edges of the crack, and large areas of intergranular cracking, which is consistent with stress corrosion cracking (SCC). SCC is a progressive crack growth mechanism that occurs in certain metals that are subjected to tensile loading in a corrosive environment. The presence of intergranular cracking was further confirmed by a metallographic section of the fracture face, Figure 9, which showed a branching crack path that is typical of SCC. It was not possible to determine exactly when the cracks had formed, and whether they would have been large enough to detect visually when the 1C maintenance inspection was performed in July 2015.

Footnote

6 A corrosion resistant (CRES) stainless steel with major alloying elements chromium, nickel and manganese.

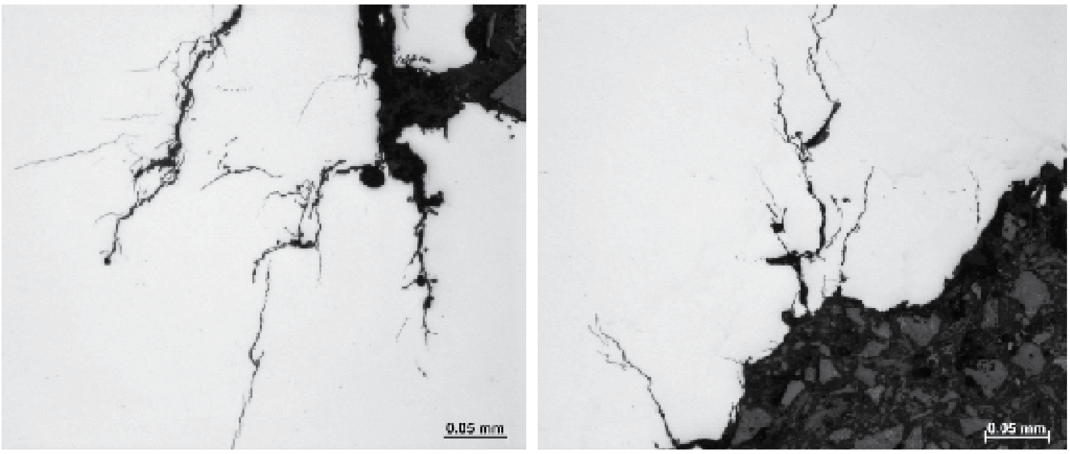

Figure 9

Metallographic section of band fracture face, showing branching crack paths

Analysis

The available evidence suggests that shortly after the APU bleed air valve was opened as part of the engine start procedures, the V-band clamp joining two sections of APU bleed air duct in the rear equipment bay failed, releasing hot bleed air into the rear equipment bay. The bleed air was of sufficiently high temperature to cause auto-ignition of the Ardrox AV8 corrosion inhibitor present on the aircraft's structure in the rear equipment bay. This in turn caused scorching, possibly a localised fire and generation of a significant quantity of smoke. Once the crew was aware of the presence of the smoke emanating from the rear of the aircraft, the action of shutting the APU down removed the source of leaking bleed air.

Human factors

Following the event the crew did not recall observing a WING-BODY OVERHEAT warning light on the air conditioning overhead panel, however when later tested the wing-body overheat detection system was found to be serviceable. One possibility is that the MASTER CAUTION and air cond annunciator light remained lit after the APU bleed air valve was opened, as normal, but when the V-band clamp failed the only indication of an overheat condition was the additional WING-BODY OVERHEAT warning light on the overhead panel. As no aural warning accompanies the WING-BODY OVERHEAT light, and the warning light is in the co-pilot's peripheral vision during engine start, it may not have been observed.

A second possibility is that the first MASTER CAUTION was cancelled but when it recurred, together with the air cond annunciator, the co-pilot looked at the overhead panel and observed the DUAL BLEED warning light, which is what he expected to see, and did not notice the WING-BODY OVERHEAT warning light.

The cause of the fire warning bell to sound was probably due to the presence of smoke in the main cargo deck, entering the cargo deck via the floor grating above the rear equipment bay. As the main cargo deck smoke detection system was found to be serviceable after the event, it is probable that the glareshield FIRE warning buttons and the main cargo deck

SMOKE caption were illuminated, but by this time the crew was aware of the smoke in the rear of the aircraft and were already taking mitigating actions.

Clamp failure

The metallurgical evidence shows that the V-band clamp failed as a result of stress corrosion cracking, and that the crack propagation had taken place over a considerable period of time. The tensile loading in the clamp's outer band, necessary for securing the duct joint, is applied by tightening the clamp's locking nut. Whilst the projection of the clamp's bolt beyond the locking nut as found after the incident did not indicate over-tightening of the clamp, it was not possible to eliminate previous over-tightening of the clamp as a contributory factor in the clamp's eventual failure. The position of the clamp in the rear of the rear equipment bay, in close proximity to the aft pressure bulkhead, renders visual examination for cracking difficult. Furthermore it was not possible to determine exactly when the cracks had formed in the clamp's outer band and it is possible that they were below the size detectable by visual inspection when the aircraft underwent its most recent 1C maintenance inspection.

Safety action

The operator is replacing the V-band clamps at the failure location on TF-BBF across its fleet of 737-300 and 737-400 aircraft. This is being carried out on a rolling programme, as the aircraft undergo scheduled C-check maintenance inspections. The operator is also considering replacement of other V-band clamps on their aircraft where the release of bleed air may create a hazard.

Conclusion

Shortly prior to engine start, a V-band clamp failed on the APU bleed air duct in the rear equipment bay. This led to a leak of hot bleed air which heated corrosion-inhibitor material in the rear equipment bay, resulting in scorching and the release of smoke into the main cargo deck. The flight crew were made aware of the presence of the smoke and shut the APU down. The V-band clamp failed due to stress corrosion cracking and the operator is currently replacing this clamp on its fleet of 737 aircraft during scheduled C-check maintenance inspections.