Aircraft Type and Registration:	Bell 206B Jetranger III, G-OSUE
No & Type of Engines:	1 Allison 250-C20J turboshaft engine
Year of Manufacture:	1982
Date & Time (UTC):	14 August 1992 at 1137 hrs
Location:	Nr Crowthorne, Berkshire
Type of Flight:	Public Transport
Persons on Board:	Crew - 1 Passengers - 4
Injuries:	Crew - Fatal Passengers - 1 Fatal, 3 Serious
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Airline Transport Pilot's Licence (Helicopter)
Commander's Age:	46 years
Commander's Flying Experience:	8,754 hours (of which 2,590 were on type) Last 90 days - 87 hours Last 28 days - 25 hours
Information Source:	AAIB Field Investigation

Circumstances

The helicopter was flown from Blackbushe Airport to position at a private house near Newmarket. However, it experienced an electrical problem and a replacement aircraft was flown to the site, carrying a licensed engineer. The planned sortie was then flown in this replacement aircraft by the original pilot.

The electrical problem on G- OSUE was traced to a faulty battery relay, which the engineer by-passed in order to allow the engine to be started. Following engine start, the pilot commented on a high frequency vibration which was apparent through the pedals. The engineer leaned down and, holding the pedals with his hands, felt a slight high frequency vibration. He offered to check the tail rotor, but the pilot replied that they would check it when they had returned to base. Once the aircraft had lifted into the hover, the vibration could no longer be detected and the helicopter departed Newmarket at about 1040 hrs to return to Blackbushe. On board were the commander, the engineer, the commander's two sons and their friend. The engineer occupied the front left seat and the three boys occupied the rear bench seat.

The aircraft was flown down the Lee Valley, along the river Thames, and left helicopter route H3 at Bagshot to fly direct to Blackbushe Airport. At this point it would have been normal procedure for the commander to have climbed the aircraft to 1,500 feet amsl.

Analysis of data recorded from the Heathrow Air Traffic Control Radar indicated that at 1130 hrs the helicopter was approaching Bagshot, tracking 250° towards Blackbushe Airport at a groundspeed of about 100 kt. Shortly after 1133 hrs a short duration noise was made by the helicopter which was variously described, by witnesses on the ground, as a 'sharp crack', 'similar to a car gearbox breaking up' and 'stuttering like a car misfire'. At about 1134 hrs, the helicopter began a gentle right turn to the north, towards the town of Crowthorne. The ground speed appeared to reduce to between 80 and 85 kt in this turn.

The Airfield Flight Information Services Officer (AFISO) on duty at Blackbushe Airport reported that, at 1135 hrs, he received a MAYDAY call from G-OSUE in which the commander stated that he had a 'tail rotor failure'. A subsequent transmission said that he was able to maintain height but had a yaw control problem, and that he was going to try to land at Broadmoor Hospital. This was the last transmission reported from G-OSUE. The air traffic frequency at Blackbushe Airport had no recording facility.

Radar data showed the helicopter in the area of Broadmoor Hospital just before 1136 hrs. No height information was available from the radar, but the helicopter was seen by a witness on the ground to manoeuvre at low level before moving to the east of the hospital where it crashed on wooded heathland. The last radar contact was close to the accident site, at 1136:11.7 hrs.

The boy in the rear left seat was thrown clear at impact but the other four occupants were trapped in the wreckage and had to be released by the emergency services.

Post mortem examination of the commander revealed no pre-existing medical condition which could have contributed to the accident.

An aftercast obtained from the Meteorological Office at Bracknell indicated that visibility was 20 km, or more, and there was no significant weather. The wind at 2,000 feet was 360°/15 kt and at the surface was 340°/07 kt.

The impact

The helicopter was descending at about 45 degrees, rotating in a clockwise direction about the main rotor mast (viewed from above), and moving in a south easterly direction when it crashed in an area of scrub, sparsely populated with tall conifer trees. The helicopter was pitched-up about 30 degrees, and banked approximately 45 degrees to the right when it struck the trunk of a conifer tree with the left side of the tail boom, at a point approximately 23 metres above ground level. This impact caused separation of the rear half of the tail boom, including the horizontal stabiliser, vertical fin, and tail rotor. Fractionally later, the main rotor blades cut through the trunk of the tree and also struck the separated tail boom, severing it just behind the horizontal stabiliser.

The impact of the left side of the tail boom against the tree arrested the clockwise rotation of the helicopter, but the aircraft continued to descend on a south-westerly path towards the trunk of a second tree situated some 10 metres beyond the first. Witness marks on this second tree suggest that the front section of one of the landing gear skids had hooked around the trunk, causing the aircraft to fall in a spiralling motion about the tree before impacting the ground heavily in a nose-down attitude, banked somewhat to the right.

The impact forces resulted in the engine, main rotor and gearbox assemblies moving downwards, forcing the top of the fuselage down into the cabin space, particularly in the area of the rear centre seat which is situated underneath the heavy main gearbox and rotor assembly.

Examination of the wreckage on site

The tail rotor blades were completely undamaged. There was no evidence of rotation under power on any of the tail rotor drive shaft sections associated with the severed wreckage of the tail boom, all of which were found within the area of main wreckage. However, damage to the tail rotor drive shaft bearing hangers indicated that all drive shafts aft of the *aft short shaft* were intact at the time when the tail boom struck the tree.

The top fuselage skins and the oil cooler cowling were heavily damaged in the vicinity of the Thomas coupling at the rear of the *aft short shaft*. [The Thomas couplings comprise a stack of thin stainless steel discs to which the drive shaft flanges are connected, each by means of two bolts secured by self-locking nuts, see figure 1. Special washers with rounded corners are used at the interfaces with the thin flexor discs to avoid damaging the discs.] The damage consisted of multiple contact marks and penetrations of both the top fuselage skin and the oil cooler cowling, consistent with 'flailing' of a partially disconnected coupling against the inside of the cowling and the top of the fuselage. This evidence comprised the sole indication of tail rotor shaft rotation, and strongly suggested that a disconnection of the coupling at the rear of the *aft short shaft* had occurred during flight, with consequent loss of drive to the tail rotor.

Both the *forward short shaft* and the *oil cooler fan shaft* were intact and still connected after the accident. However, neither the *aft short shaft* nor the forward half of the *No 1 drive shaft* could be found in or around the main wreckage. A search of the surrounding undergrowth successfully located all of the missing pieces within a radius of 25 metres from the main wreckage, except for the forward half of the *aft short shaft* which was not recovered.

The *aft short shaft* drive flange was completely disconnected from the coupling and both connecting bolts and nuts were missing. In addition, one of the sets of connecting bolt holes was essentially undamaged whereas the other set of holes was heavily bruised and enlarged (see Plates 1a and 1b). This evidence, together with the *flailing* type damage to the fuselage top skins and the oil cooler cowling immediately adjacent to the coupling, indicated that one of the bolts joining the *aft short shaft to* the coupling had come out shortly before the impact, causing the *aft short shaft* to rotate about the other remaining bolt as shown in figure 2, rather than both shafts rotating in unison. As a consequence, the drive to the tail rotor had been lost and the forward shaft section had whirled in a conical motion inside the cowling, cutting into and through the top skins of the fuselage and the oil cooler cowling. This process was almost certainly the source of the noise heard by witnesses on the ground.

The relative motion of the shafts during the whirling phase would have generated binding and frictional loads which would have tended very rapidly to unscrew the nut on the remaining bolt. (The drive shaft rotates at approximately 6000 RPM and the time taken for the second nut to be spun off by this means is likely to have been a matter of a few seconds, at most, after the first bolt came out.)

Bruise marks on the fuselage top skins and other localised damage suggested that the *aft short shaft* had bowed outwards due to centrifugal loading as it whirled about the remaining bolt, prior to the second nut coming off, causing the shaft to fracture at approximately the mid position. The rear section of the shaft then appears to have become jammed partially underneath the coupling, with one of the flanges penetrating through the fuselage top skin, until it was released in the impact. The forward half of the broken shaft was not found and it is likely that this was thrown out of the hole in the cowling whilst the aircraft was still in flight.

Close examination of the *undamaged* bolt hole in the connecting flange revealed a helical thread form which had been worn into the side of the hole, consistent with long term fretting, under load, of the bolt whilst in a partially retracted state (Plate 2).

A careful search of the wreckage at the accident site revealed one bolt and two washers trapped in the forward right hand corner of the cowling, together with a single nut which was found inside the fuselage immediately beneath, and slightly behind, the hole in the fuselage produced by the flailing coupling. None of the other items missing from the coupling were found, and it was presumed that they were ejected whilst the aircraft was still in flight.

The bolt recovered from inside the cowling was of the same type as the missing bolts from the Thomas coupling. Inspection under high magnification showed that the threads were essentially undamaged and the bolt appeared to be in good overall condition. An accumulation of compacted fretting deposits filled the thread grooves, consistent with the wear grooves observed in connecting flange (Plate 2), and it was thus apparent that this was the bolt which had initially migrated out of the coupling.

Of the washers found inside the cowling, one had a special rounded edge as used on the Thomas couplings, and was completely undamaged, and the other was a standard washer of the type fitted under the nuts on the coupling. The latter had been deformed in a manner which matched the raised lip of the *damaged* hole on the connecting flange, indicating that this washer had been fitted under the nut which was the second to come undone, after the shaft had partially disconnected and had started to whirl.

The nut found loose inside the tailboom was undamaged and displayed no unusual features. It was not possible to positively identify its origin on the aircraft, but the position in which it was found suggested that it was one of the two nuts missing from the coupling. Its overall condition, however, suggested that it was more likely to have been the nut which was the second to come undone, ie. after the loss of the first nut and bolt, as the shaft coupling whirled about the second bolt.

The remaining sections of tail rotor drive shaft

All of the remaining tail rotor drive shaft couplings were checked for correct assembly, in terms of washer stacking order and orientation of the washer radii, and the nuts were checked for manufacturer's identification marks.

All of these couplings were correctly assembled but out of a total of 32 nuts from the couplings, 16 had no markings at all and the others had a manufacturer's mark in the form of a very small raised lip on the skirt of the nut which, so far as could be ascertained, was not amongst the trade marks used by Bell Helicopter approved nut manufacturers.

Detailed examination of the coupling components

The bolt

The bolt was an AN 174-7A cadmium plated steel bolt which carried a standard marking on the head indicating that it was a steel close tolerance bolt intended for aircraft applications. Dimensional checks at the metrology department of DRA Farnborough showed that it was of the required thread form and overall dimensions. The thread diameters fell fractionally outside of the specified limits, but this minor deviation had no bearing upon the accident.

Marks were evident along the shank length of the bolt, consistent with contact with the edges of the flexor disc plates as the bolt had migrated out of the coupling over a period.

The nut

The overall shape and dimensions of the nut were consistent with those of the MS21042L4 nut specified by the manufacturer. However, despite careful examination, no manufacturer's identification mark could be found.

Dimensional checks, using a thread gauge, showed that the thread form was within limits and the general shape of the nut was essentially as indicated in the MIL Spec (US Military Specification) drawing.

The Thomas coupling

<u>Flexor plates:</u>

Witness marks on the Thomas coupling flexor plates in the area of the initially loose bolt indicated that the special washers had been properly fitted, with the rounded side of the washer in its correct orientation. The *alternate grain* stacking order of the flexor plates was also correct and there was no evidence of any damage or abnormality on the plates themselves.
The *suspect* bolt holes in the flexor plates were undamaged and free of fretting or corrosion products.

Drive shaft connecting flange:

Under magnification, crescent-shaped surface indentations (see Plate 3) could be seen on the *aft short shaft* connecting flange in the area around the undamaged bolt hole, ie. in the region which would normally be situated beneath the nut and washer. These marks did not extend around the complete circumference and were not typical of marks produced in normal circumstances by an intact washer, or by an intact nut without a washer.

Other instances of loose nuts on Thomas couplings

Subsequent to this accident, two other instances of loose nuts on Thomas couplings were drawn to the attention of the AAIB.

In the first case, the loose nut was found during a precautionary fleet check in the aftermath of the accident. This nut was sufficiently loose to allow the bolt to be rotated by hand, but it had not unwound sufficiently to allow significant axial movement of the bolt. It is understood that no approved manufacturer's mark was found on the nut in question. Fretting debris was noted on the flexor plates in the contact area under the loosened nut and washer.

The second case involved an aircraft on which all of the tail rotor drive shaft nuts and bolts had been replaced with new items supplied by Bell Helicopter Textron, as a precautionary measure following this accident. However, some 43 flying hours afterwards, one of the bolts on the Thomas coupling at the forward end of the forward short shaft was found to be loose, allowing the bolt to be rotated by hand and moved an estimated 0.002 inch axially. Dismantling of the coupling revealed extensive fretting debris around all flexor plate bolt holes associated with the loose bolt, and also around the opposite bolt hole (ie. the *other* bolt on the same connecting flange), whereas no such fretting was evident around the bolt holes from the opposing coupling flange.

Cause of bolt disengagement on G-OSUE

To date, it has not been possible to determine the reason why the nut initially separated from the bolt on the Thomas coupling, nor to satisfactorily explain the peculiar marks and indentations on the coupling flange at the interface with the nut/washer. However, the marks are not consistent with those which would be expected from an intact washer and/or nut, or from a complete absence of either. This evidence, together with the relative absence of fretting debris on the flexor plates from G-OSUE compared with those from other Thomas couplings on which a nut is known to have progressively worked loose, raise the possibility that the nut had cracked or failed, or partially failed, producing a sudden release of clamping pressure rather than the nut having progressively backed-off.

The period of bolt migration

The migration of the bolt out of the coupling had apparently taken place progressively over a period of time, as evidenced by the thread form which had been worn into the side of the bolt hole as the bolt progressively withdrew.

During the period of migration, the loads imposed on the bolt during normal flight would have tended to hold it in place, aided during the intermediate and latter stages of migration by the engagement of the bolt threads into the mating grooves worn into the side of hole in the connecting flange. The greatest potential for bolt movement would have occurred during engine start up and shut down and, to a lesser extent, during manoeuvring in the hover, when the loads being transmitted through the coupling would have been changing.

Whilst the bolt remained engaged, albeit partially, the coupling would have transmitted power satisfactorily and it is unlikely that there would have been any discernable symptoms except perhaps at a very late stage, when the bolt was only just engaged in the coupling. Under these conditions, 'cocking' of the bolt could have allowed slight misalignment of the shafts, possibly to the extent that a slight high frequency vibration, similar to that felt through the pedals immediately after engine start up, might be produced.

It was not possible to determine, with certainty, how long it took for the bolt to migrate out completely but it is likely to have been a period of many hours of operation, probably tens of hours, rather than of minutes.

Maintenance history

The aircraft was built in 1982 and was first placed on the UK register as G-BKBY, but was subsequently re-registered as G-OSUE in August 1987. It had a current Certificate of Airworthiness in the Public Transport (Passenger) Category, which was valid until 29 July 1994. The maintenance documents indicated that the aircraft had been regularly maintained in accordance with UK Civil Aviation Authority approved maintenance schedules.

It was not possible to say when, or whether, the bolts and/or nuts on the tail rotor drive had been changed during the aircraft's lifetime. These items are replaced only when they are found to be damaged or worn, or in the case of the nut when its *stiffness* has been lost (judged subjectively by *trying* the nut on the bolt by hand).

The most recent maintenance inspection was an annual inspection carried out on 21 July 1992 at 1141:30 hrs total time, some 40 hrs flying time prior to the accident. During this inspection, the coupling in question was disconnected in order to facilitate lubrication of the drive shaft spline fittings. However, it was not possible to establish whether this had involved the disconnection of the two bolts implicated in this accident, or the other pair of bolts securing the opposing drive flange (disconnection of either flange on the coupling would have facilitated separation of the splines for lubrication purposes).

No evidence was found which called into question the standard of G-OSUE's maintenance, which appeared to have been satisfactory.

Control problems following a tail rotor drive failure

This accident, which involved a very experienced helicopter pilot (albeit with relatively low recent experience on the Bell 206,) has raised questions concerning the possible problems associated with a total loss of drive to the tail rotor, as distinct from a tail rotor pitch control disconnect, or control jam. These problems include the directional stability from the fixed vertical tail surfaces after the loss of the 'flat plate fin effect' of a rotating tail rotor.

These aspects, and the question of the security of the Thomas coupling securing bolts, are being pursued and a Safety Recommendation on the security of such coupling bolts will be made to the CAA, and will be included in the Addendum. An addendum to this Bulletin will be published in due course.

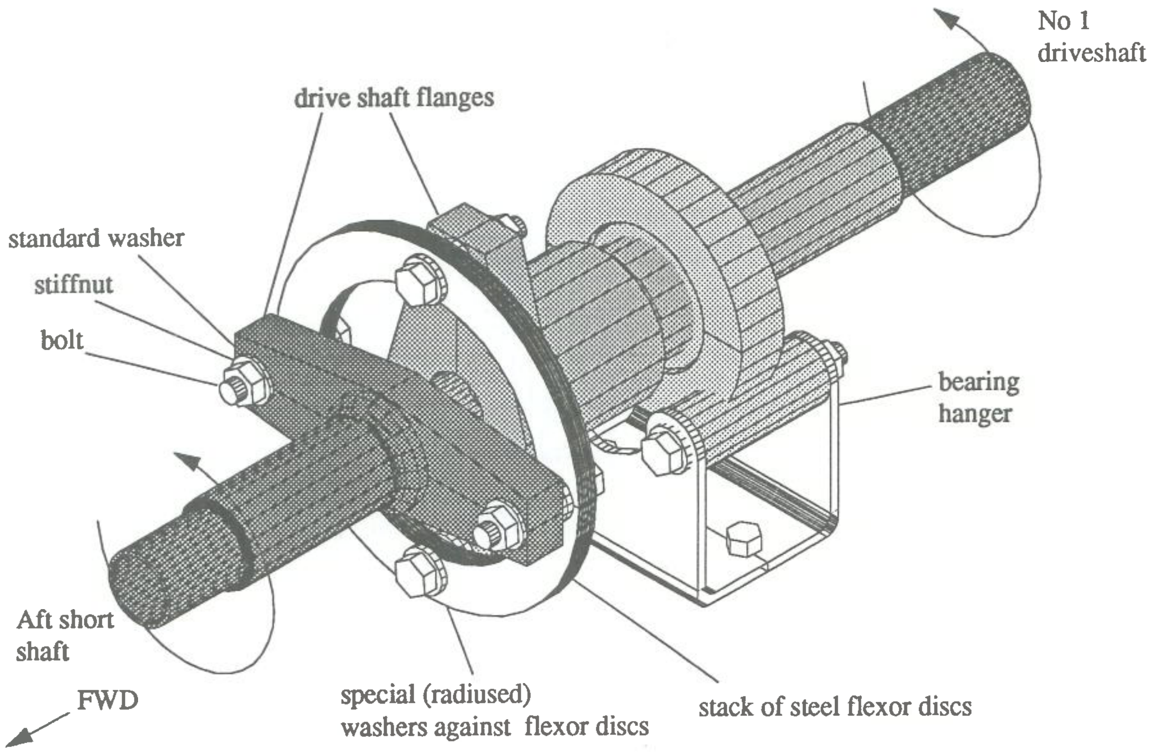

Figure 1
Thomas coupling arrangement at junction of aft short shaft and No 1 drive shaft

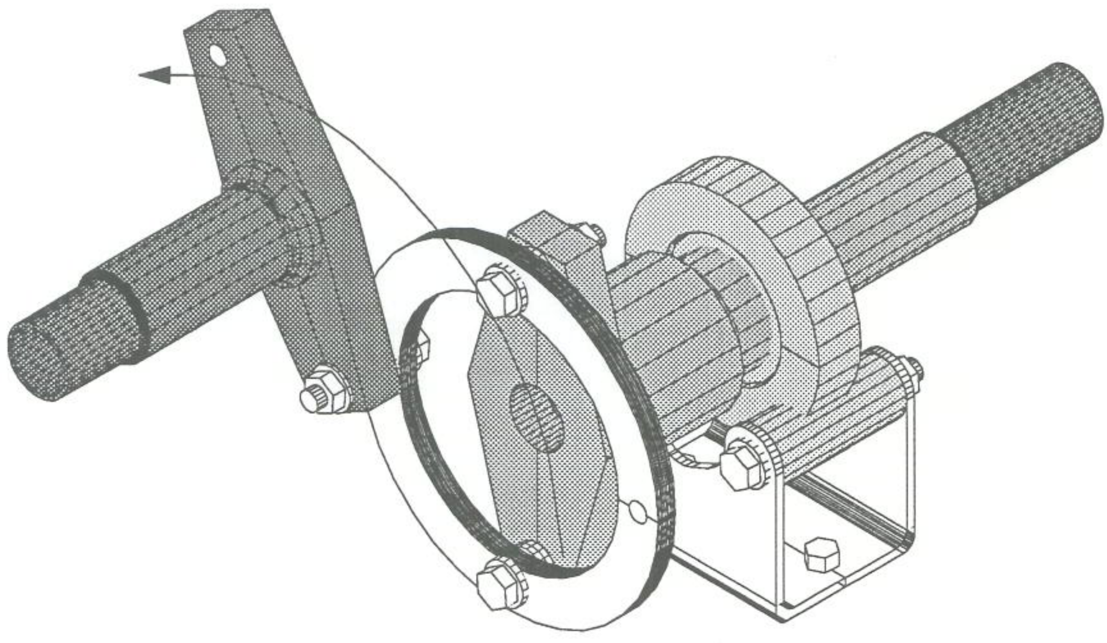

Figure 2
Showing whirling motion of aft short shaft about remaining bolt, following loss of first bolt

Plate 1a
Undamage bolt hole through flexor plate stack from Thomas Coupling

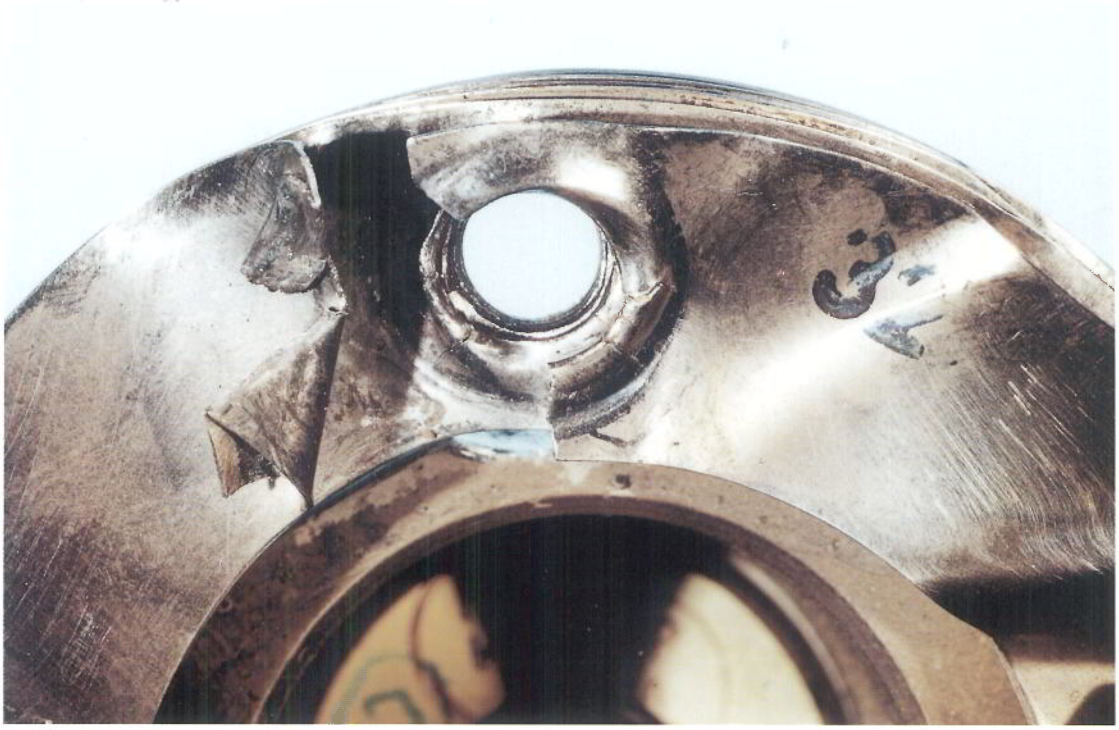

Plate 1b
Damaged bolt hole in flexor plate stack

Plate 2
Close up of thread form worn into bolt hole in connecting flange as bolt progressively migrated out over time (view onto aft face of flange)

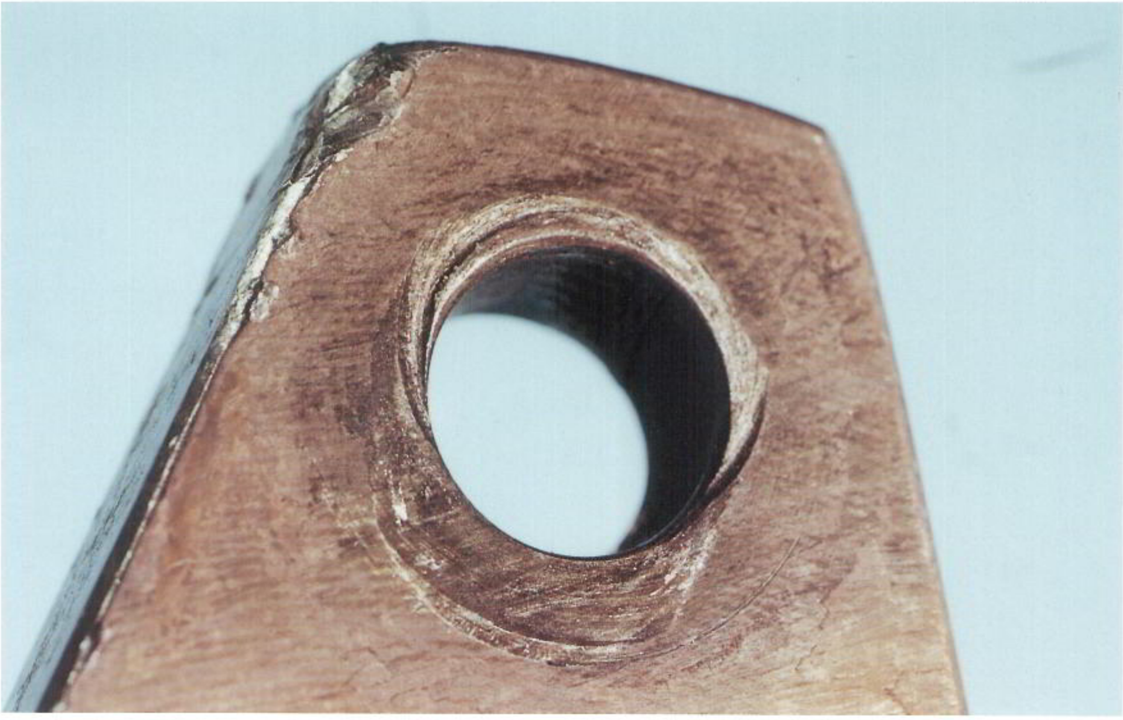

Plate 3
Close up of curious surface features on drive flange in area under nut/washer from bolt which migrated out (view onto forward face of flange)