Schweizer 269C-1, G-ODNH

AAIB Bulletin No: 8/2004	**Ref: EW/C2003/05/02**	**Category: 2.3**
Aircraft Type and Registration:	Schweizer 269C-1, G-ODNH	
No & Type of Engines:	1 Lycoming HO-360-C1A piston engine	
Year of Manufacture:	2000	
Date & Time (UTC):	7 May 2003 at 0930 hrs	
Location:	Pateley Bridge, Yorkshire	
Type of Flight:	Training	
Persons on Board:	Crew - 2	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Damaged horizontal stabiliser and elongation of bolt holes in tail-boom skin locating tail rotor gearbox mounting. Failure of attachments between tail-boom and rear fuselage structure. Fractured tail-rotor drive fork hinge bolt	
Commander's Licence:	Not known	
Commander's Age:	54 years	
Commander's Flying Experience:	3,100 hours (of which 530 were on type)	
	Last 90 days - 83 hours	
	Last 28 days - 25 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The aircraft was climbing out when severe vibration prompted the commander to carry out an immediate autorotative landing in a field. The helicopter incurred little damage during the landing although the vibration, caused by a fatigue failure of the tail rotor teeter pivot bolt, also known as the fork bolt, probably induced secondary damage to the tail boom. The method used to install the bolt has since been superseded by an improved procedure which involves achieving a measured stretch in the bolt. There is also a requirement for a torque check on the nut following a period in service.

History of the flight

The pilot reported that the aircraft was on an instructional flight. Whilst climbing from 1,500 to 2,500 feet QNH, (passing through approximately 1,500 feet agl), a sudden, extreme vibration began. The pilot's perception was that it was transmitted through the collective lever at a high frequency and through the structure at a lower frequency. He immediately put the aircraft into auto-rotation, transmitted two distress calls and requested assistance (as he believed a component was about to separate from the aircraft, leading to total loss of control). Fortunately the aircraft remained controllable and an engine-off landing was performed with the throttle in the idle detent. The aircraft was run-on to the ground at a low forward speed and the touchdown was reported as very gentle.

The machine came to rest in an area of long grass, in which no significant ground markings were reported. The tail-skid was resting against the ground, failure having occurred to both attachment lugs at the forward end of the tail-boom, allowing the latter to droop until supported via the skid. Consequently the tail rotor drive shaft was disengaged at its forward end. The leading-edge skin of the horizontal stabiliser was fractured such that the outboard section of the unit was close to separating.

The bolt attaching the tail rotor hub to the rotating fork, about which the rotor is free to teeter, was found to have fractured.

Design of the tail rotor hub

The tail rotor consists of two blades mounted on a hub assembly (see Figure 1) which is in turn mounted in a rotating fork. The fork incorporates two conical bearings and a bolt passes through the hub and both bearings. Teetering motion of the rotor is enabled by the presence of the bearings. The bolt, in addition to passing through the bearings and the basic hub trunnion, passes through a shoe, within the hub, which locates the straps holding the two blades against centrifugal force. It also passes through an insert threaded into the hub. Shim washers of various thicknesses bear against the protruding inner races of the conical bearings and enable the pre-load to be adjusted. Two washers of larger diameter, acting as dust shields, are positioned on either side of the hub.

Figure 1: Layout and Details of Tail Rotor Hub Components

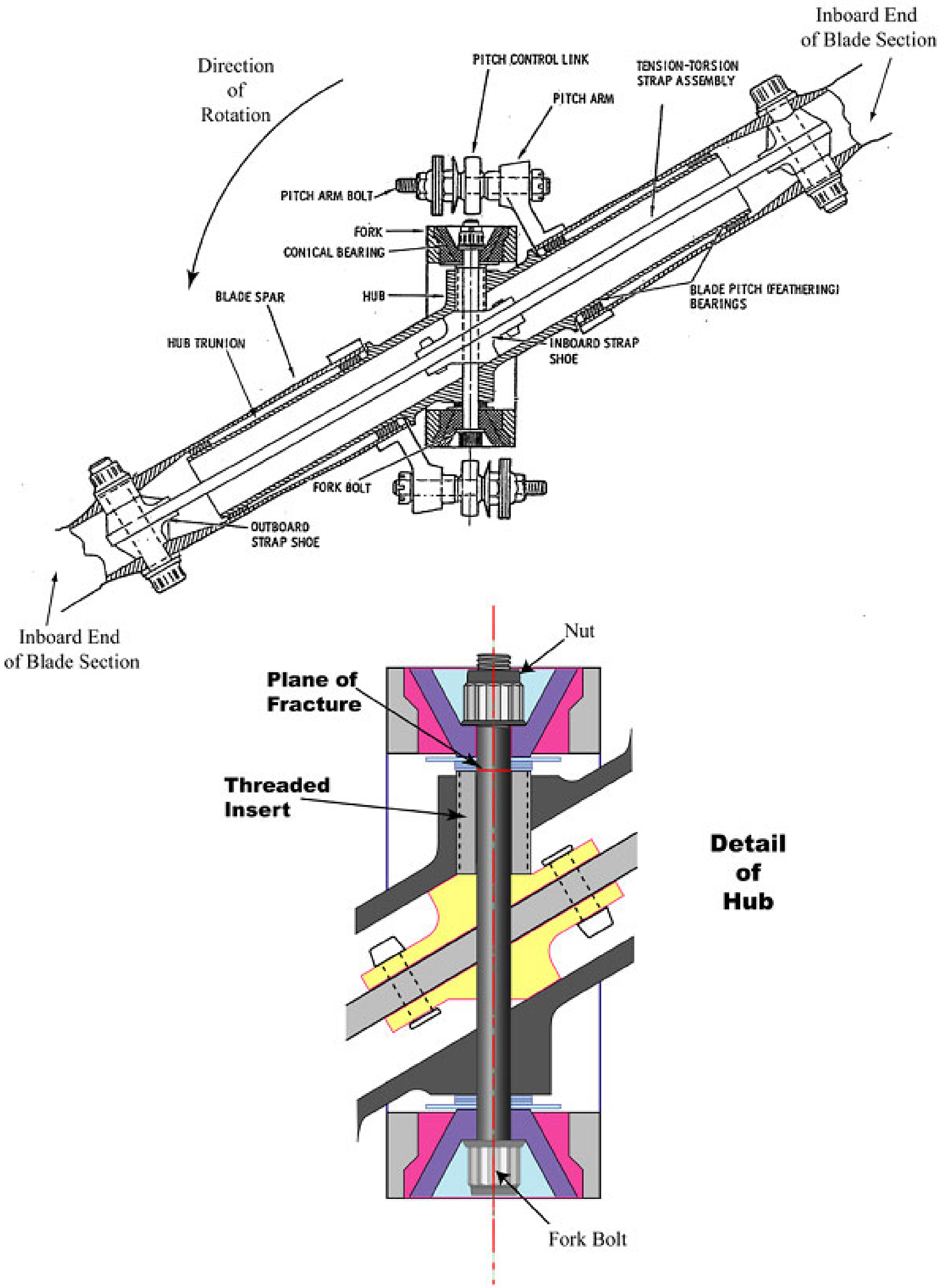

Figure 1 Layout and Details of Tail Rotor Hub Components

The bolt is secured and tensioned by a nut which, when the assembly is correctly installed, ensures that the inner races, (ie the smaller diameter elements of the hub bearings) the nut, bolt, hub, shoe, threaded insert, shim washers and the dust shields all oscillate in unison relative to the fork as the rotor rotates during forward flight.

Details of tail-boom assembly

The forward end of the extruded tubular aluminium alloy tail-boom terminates in a casting incorporating two lugs through which bolts pass securing the unit to tubular structural members behind the occupied section. An additional pair of larger diameter tubes brace the boom further aft to the structure below and behind the occupied section (see Figure 2).

Figure 2: General view showing location of tail boom attachment lug failure

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Detailed examination

Examination of the fracture faces of the failed tail boom attachment lugs (see Figure 3) revealed no evidence of fatigue and suggested that overload had occurred.

Figure 3: Detail of tail boom attachment failure

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Examination of the fracture face of the fork bolt showed that it had failed in a plane very close to the exposed face of the threaded insert (see Figure 1 and Figure 4), allowing the dust shield and washers on one side of the hub to be lost. The insert is screwed into the hub forging. The fracture face incorporated a raised angular peak and trough at one edge with a ridge or step extending from the peak across the section separating the two halves of the fracture. Each half occupied a slightly different, though parallel, plane and the two were thus independent fracture surfaces. Scanning Electron Microscope (SEM) examination revealed that fatigue cracking had initiated at the side of the shank opposite that of the peak and trough. It appeared to have propagated at different angles on each half of the cross-section, culminating in ductile overload at the angular peak. The fatigue had the characteristics of torsional shear stressing applied in two distinct directions. The torsional evidence was, however, not orientated about an axis coincident with that of the bolt.

Figure 4: Fracture face of tail rotor fork bolt

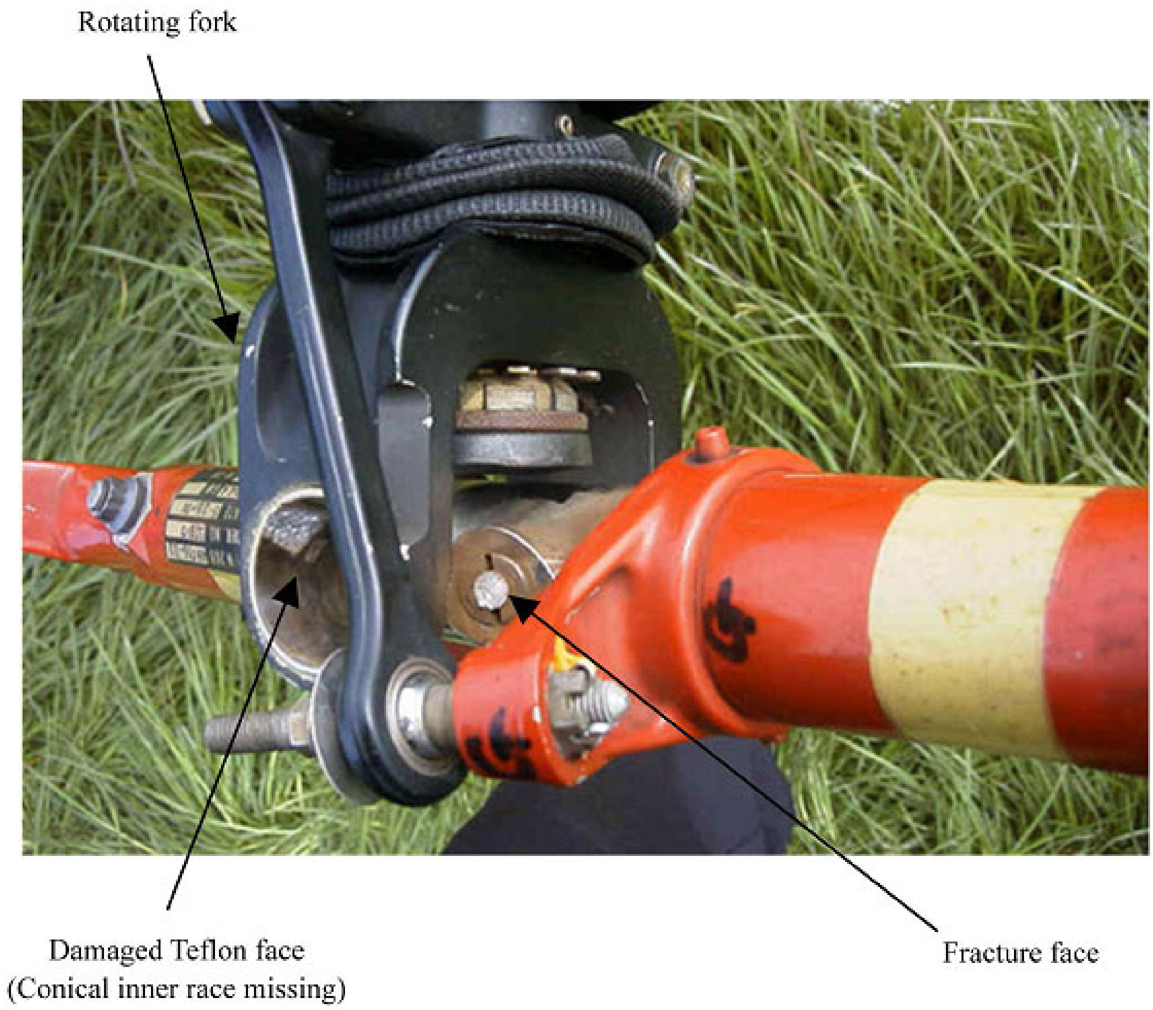

Figure 4 – Fracture face of tail rotor fork bolt

The end face of the threaded insert, almost in plane with the two fracture faces, was extensively coated with a brown powdery deposit.

In order to examine the shank and head of the bolt, and to create a sufficiently small specimen for the above-mentioned SEM examination to take place, it was necessary to extract the remainder of the bolt from the hub. It became evident that it was tightly secured and to drive it out would damage the fracture face and the cylindrical surface of the shank, and obscure or destroy existing evidence on the cylindrical surface.

Consequently, the hub structure was sectioned through its centre. This involved cutting diagonally through the hub, the shoe and the blade support straps as well as the bolt, where the latter passed through the plane of the straps. Before doing so, measurements were made to the hub, including the alignment of the blade pitch change bearings. These measurements confirmed that no distortion was present.

The hub was cut in half through the bolt shank (at 45° to the axis of the hub at the mid point) and further hub material cut away to render the specimen sufficiently small to enable SEM examination of the fracture described above to take place. Further cutting of the hub material (on the separated portion containing the fractured section of bolt shank) more fully exposed the section of the shoe assembly still firmly attached to that half of the bolt. The exposed end of the rivet joining the two halves of the shoe was ground away to release the visible shoe segment.

Once these actions had taken place, it was found that the section of bolt shank incorporating the fracture was still firmly installed in both the shoe segment and in the threaded insert, whilst the latter was free to rock about its threads in the remaining portion of the hub. By cutting and wedging, it was possible to free and remove the attached half of the shoe and then unscrew the insert from the hub. Thereafter it was necessary to slit the insert and wedge it apart in order to release the enclosed section of shank without inflicting damage or destroying existing evidence on the cylindrical faces of the latter.

It was observed during this process that the contact faces between the shoe and the threaded insert and those between the shoe and the bolt shank, together with the outer half of the thread, were heavily coated in a red-brown powdery deposit, similar to that observed on the initially exposed end face of the threaded insert. The deposit was almost certainly the dust produced by wear of the teflon lined faces of the teetering bearings. Similar deposits formed a layer between the bolt shank and the inside diameter of the threaded insert.

The exposed shank was examined and compared with that of a similar bolt removed from service in another aircraft in the operator's fleet. Contact with both the shoe and threaded insert was observed to have resulted in fretting damage on the shank of the failed bolt. Evidence was observed that the failed bolt had been rotating in the hub/insert/shoe. This evidence included fretting marks and a sharp-edged band of wear, corresponding to a relative rotation of about 60° resulting from contact with the edge(s) of the screwdriver slot in the end of the threaded insert.

Examination of the bolt head revealed evidence of five impact marks. Hardness testing was carried out on the shank and head. The tests confirmed that the material hardness was in the expected range. Measurement of the bolt shank diameter indicated that it was not measurably different from that of the sample removed from the similar aircraft. Reliable measurement of the internal diameter of the threaded insert could not, however, be guaranteed since the latter component had to be slit to enable the parts to be separated. It was therefore not possible to establish whether an unusually small clearance between these components accounted for the tightness of the bolt in the insert that was identified earlier during the investigation.

Maintenance documentation

Reference to the maintenance schedule of the aircraft revealed that a requirement exists for the pre-load in the teetering bearing to be ascertained at regular intervals. Should it become insufficient, it is necessary to remove the bolt and hence the tail-rotor, inspect the bearing surfaces, re-assemble the bearing and re-fit the rotor, setting up the correct pre-load in the conical bearings by the selection of suitable shim washers. The documentation of this aircraft indicates that the most recent maintenance action on the tail rotor assembly occurred at 632 airframe hours and the technician responsible for this work has reported that during re-installation, the securing nut was torque-tightened in accordance with the manufacturer's Maintenance Manual, (known as the HMI).

An alternative method of tightening the nut, involving achieving a measured stretch in the bolt, was also available at that time. Since then, however, the torque-tightening procedure for the nut has been removed from the HMI and the measured stretch method of securing the bolt became the only accepted procedure. When the torque tightening procedure was removed, a requirement to check the torque of the bolt 25 hours after installation was introduced into the section detailing the method of re-assembling the hub and fork assembly (Model 269C-1 HMI Appendix C Part IV Section 6). This requirement, although absent from the re-assembly instructions at the time the re-assembly work was carried out, was detailed separately in the SPECIAL INSPECTIONS section of the HMI (HMI Appendix B, Table B3). This Appendix cross-referred to the requirements for the 300 HOUR CHECK for details of the implementation method. (The SPECIAL INSPECTIONS section was subsequently revised to include the implementation information relating to the bolt that was previously only available in the 300 HOUR CHECK document.)

The company which carried out the maintenance work pointed out that the absence of any reference to the 25 hour torque check in the re-assembly instructions for the C-1 model is atypical of other maintenance procedures detailed in the HMIs for all Schweizer 269 models. For example, on the 300C version of the aircraft the requirement is specified in the fork bolt/bearing re-assembly instructions. Therefore, it was reasonable to assume that the absence of any reference to this inspection in the re-assembly instructions in the HMI of the 269C-1 model indicated that no such requirement existed on this (later) version of the aircraft.

Although the operator used only C-1 versions of the aircraft, the previous experience of the technician who carried out the work on G-ODNH was predominantly with the earlier versions. The absence of any reference to the subsequent 25 hour check in the fitting instructions, as they were detailed in the HMI for the C-1 aircraft, contributed to his belief that it was not, or was no longer, a requirement on the C-1 version. Consequently this subsequent check was not carried out.

Some maintenance companies with responsibilities for large fleets of mixed versions of the type routinely carry out this torque check 25 hours after re-assembly on all their aircraft.

Discussion

There is little doubt that failure of the fork bolt was the initial event and that all other failures were consequential. The torsional shear fatigue failure could not be explained by any realistic phenomenon, given the geometry of the hub assembly and the condition of the associated components. Seizure of the conical teetering bearing closest to the fracture would produce a suitable loading condition to account for a torsional shear fatigue mechanism. This cause could, however, be ruled out since:

1. The teflon bearing face was in good condition except where it had been scoured away by contact with part of the pitch change mechanism after the bolt had failed and released the inner race, thus exposing the teflon face. No evidence of seizure was present.

2. Such a torsional loading would be centred at the bolt axis, whereas the torsional evidence observed was consistent with relative rotation about an axis well displaced from the axis of the bolt.

The red/brown deposit noted above was almost certainly the dust produced by wear of the teflon lined faces of the teetering bearings. A number of Hughes/Schweizer helicopters with similar tail rotor hub designs were noted as having accumulated external deposits of such dust in the region of the bearings after periods of service. The fact that such deposits were noted on both the exposed end face of the threaded insert and the contact faces between the threaded insert and the shoe, however, indicates that those faces were exposed in service. This fact, together with evidence that considerable rotation of the bolt had taken place, indicates that the assembly must have operated for a period without the normal tension present throughout the bolt length.

The tightness of the bolt shank in its housing found during sectioning of the hub could have been caused by an unfavourable combination of manufacturing tolerances. The bolt was not, however, measurably different in diameter from another sample bolt measured. It was not possible to measure accurately the internal diameter of the threaded insert or the shoe due to the necessarily destructive method used to separate them. There was, however, the unusual physical evidence present to suggest that quantities of the red/brown dust were trapped between the bolt shank and the various components through which it passed. In particular, the bolt was firmly seized in the threaded insert even after the hub had been sectioned and only the bolt shank and insert remained united.

Further evidence of at least five impact marks on the hard material of the bolt head indicate that significant force had been required at some time to drive the bolt into position. It would therefore appear that the tightness noted during dismantling was present during assembly, requiring the bolt to be driven into position with unusually high force. It is thus possible that the correct torque value was applied to the nut at installation, when, as a result of the high friction of the bolt in one or more of the various elements through which it passed it was, in fact, not fully seated as torque was initially applied. The recessed nature of the head of the correctly installed bolt would make difficult the required confirmation that the head was seated.

It is possible, therefore, that the bolt was able to migrate longitudinally through a small distance once the component was in service, thereby relieving the contact pressure between the nut and associated shim washers and permitting the bolt to rotate an unknown amount.

The observations regarding the fracture mechanism cannot be explained conclusively. It is, however, possible that repeated shear loading applied at differing angles to the bolt, as the latter progressively rotated, would produce a fatigue effect which mimicked the appearance of torsional fatigue.

The tightness which is assumed to have resulted in the difficulty in fitting the bolt may have been the result of residual teflon dust not being completely removed from the bore of the hub, the shoe or the threaded insert on the last occasion the bolt was re-fitted.

It seems reasonable to assume that the bolt failed as a result of a fatigue mechanism which, although not fully explained, nonetheless resulted from operation with a bolt which was not carrying the correct end-load consistently throughout its length. The installation irregularity responsible for this condition was most probably excessive friction of the bolt within the bore, shoe or threaded insert in the hub, experienced at the time of assembly, resulting in the bolt failing to seat fully, notwithstanding the presumed application of the specified torque figure, a procedure detailed in the HMI at that time.

The confusing location of the requirement for the 25-hour torque check following re-assembly, mentioned only in the SPECIAL INSPECTIONS appendix of the HMI applying to the C-1 model, was unfortunate. The absence of any reference to this stated requirement, at that time, from the HMI section detailing re-assembly instructions, was even more unfortunate and, to some extent, explains how the requirement was overlooked. Had such a check been carried out, there is a strong possibility that any freedom of the bolt would have been detected and rectified.

An alternative theory was advanced, that the aircraft had suffered an unrecorded tail-rotor blade strike, inflicting unusual loading on the hub whilst not doing visible damage to either blade. The absence of any evidence to this effect, in particular the absence of measurable distortion detected in the hub, during measurements carried out prior to its cutting, does not support this theory.

Failure of the tailboom attachment

The simple overload failures of the tail-boom attachment lugs indicate that they were not the consequence of the high vibration level brought about by the unbalanced rotation of the tail rotor during the descent. The pilot's report, the lack of reported ground markings and the absence of evidence of a heavy landing on the skids and other parts of the aircraft all suggest that failure did not occur as a result of ground impact. Neither the timing nor the mechanism of their failure are clear.

Two possibilities could, however, account for this failure. These are as follows;

1. The cyclic forces generated by the rotation of the tail rotor, after the bolt failure, created greater stresses in the boom attachment lugs once the aircraft was on the ground than they did during the descent. This was because the forces were reacted by the solid foundation of the aircraft resting on its skids rather than the reaction created by the moment of inertia in pitch of the helicopter structure, head, power unit and all other items forward of the lugs whilst the aircraft remained airborne.

2. The tail rotor RPM briefly coincided with the natural frequency of the tail-boom as the speed of the former decayed once the aircraft was on the ground. This amplified the effect of

the unbalanced rotational forces to a level sufficiently high to cause overload failure of the lugs.

Other information

A later design of hub mounting is available which has been incorporated in some new production aircraft and may be fitted retrospectively to existing machines. This design utilises an elastomeric bearing which is not subject to in-service wear and therefore requires infrequent replacement.

Conclusions

The tail rotor fork bolt failed in fatigue after a period of operation with no pre-load present in the bolt/nut assembly. The lack of pre-load was probably a consequence of failure to establish the correct tension in the bolt at the time of last assembly. Failure to establish the correct tension may have resulted from a tight fit of the bolt within the threaded insert, disguising the fact that the bolt head was not correctly seated as torque was applied.

Contamination of the bore of the threaded insert with teflon dust may have caused the tight fit of the bolt within the threaded insert. Torque tightening was an installation procedure detailed in the manufacturer's maintenance manual at the time the hub was refitted. Establishment of a measured bolt-stretch dimension was also a procedure detailed in the manual. The torque tightening procedure was used for the last installation but is no longer an installation method detailed in the manual.

Implementation of a torque check of the tail rotor retaining nut is required 25 hours after installation of the fork bolt on all versions of the Schweizer 269 helicopter. This requirement applied to the C-1 version, the type of aircraft in question, at the relevant time but was not highlighted amongst the re-assembly instructions. Use of the bolt-stretch method of fitting (the only method now detailed) may have resulted in any incorrect seating of the bolt being identified at installation. Finally, implementation of the 25-hour torque check, if carried out, might have alerted maintenance staff to any incorrect tightening of the bolt.

Given the atypical layout of the information within the HMI when the work was done, the oversight was, to some extent, understandable. The HMI has since been changed.