



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: September 30, 2008

In reply refer to: A-08-77 and -78

Mr. Patrick Goudou
Executive Director
European Aviation Safety Agency
Postfach 10 12 53
D-50452 Koeln, Germany

The National Transportation Safety Board is an independent Federal agency charged by the U.S. Congress with investigating transportation accidents, determining their probable cause, and making recommendations to prevent similar accidents from occurring. We are providing the following information to urge your organization to take action on the safety recommendations in this letter. The Safety Board is vitally interested in these recommendations because they are designed to prevent accidents and save lives.

These recommendations address inadequacies in the splined connection between the hydraulic pump and the pulley assembly of Eurocopter AS-350 and EC-130 helicopters. The recommendations are derived from the Safety Board's investigation of six accidents involving these assemblies and are consistent with the evidence we found and the analysis we performed. As a result of this investigation, the Safety Board has issued four safety recommendations, two of which are addressed to the European Aviation Safety Agency (EASA). Information supporting these recommendations is discussed below. The Safety Board would appreciate a response from you within 90 days addressing the actions you have taken or intend to take to implement our recommendations.

Findings from the investigations of six events since 2002, including two fatal accidents, have raised Safety Board concern regarding the safe operation of Eurocopter AS-350 series helicopters. The Safety Board Materials Laboratory examined parts of the helicopters involved in these events, specifically the hydraulic pump assembly and pulley assembly that provide all the hydraulic power for the main rotor controls and the tail rotor controls. Staff found that the splined connection that couples the hydraulic pump to its pulley assembly displayed excessive wear that in some cases caused it to fail with subsequent loss of hydraulic power. Loss of hydraulic power hinders helicopter control and increases the possibility of a serious accident. A similar system is installed on Eurocopter EC-130 model helicopters.

The hydraulic pump assembly is driven by a pulley assembly that contains a coupling sleeve, as shown in the figure. The coupling sleeve, with internal splines at its forward end, extends forward through the center of the pulley assembly to engage with the external splines on the hydraulic pump drive shaft. A lubricant (specified in the maintenance manual as NATO grease G-355) is contained within the coupling sleeve by a plug inserted in the aft end of the sleeve and, at the forward end, by contact with an O-ring located in a groove forward of the drive shaft splines.¹ The pump and the coupling sleeve are replaced “on condition” (that is, when a problem is found during routine maintenance or during operation).

The helicopter can be flown without hydraulic power (that is, in manual mode) but doing so increases the physical demands on the pilot and can cause a serious accident if the pilot has not maintained familiarity with operation of the helicopter in manual mode or if an uncommanded reversion to manual mode occurs suddenly, especially during a critical maneuver.

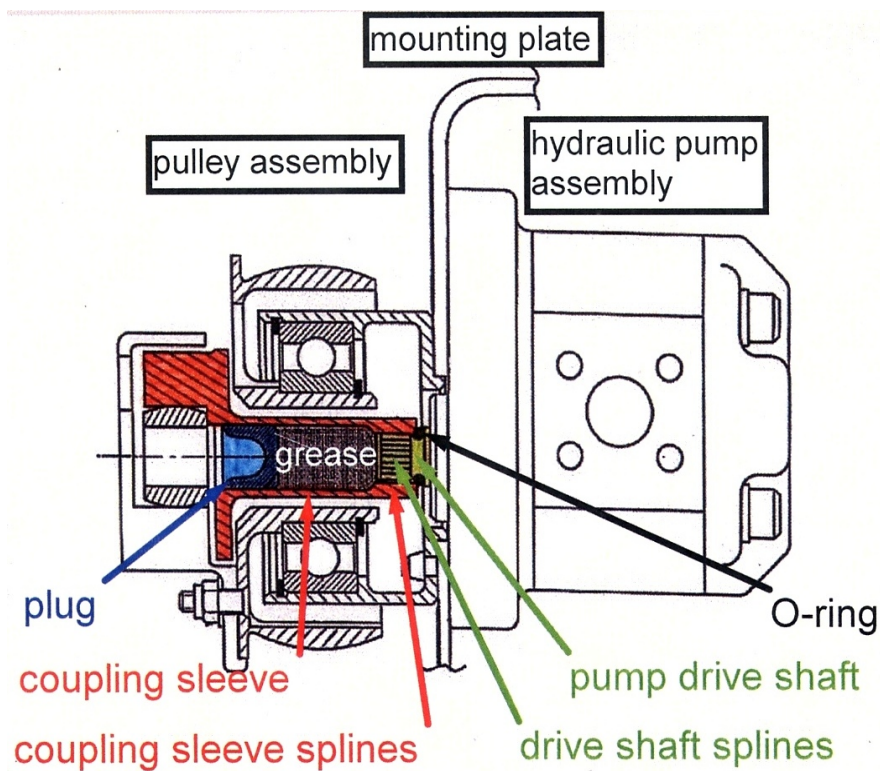


Figure. Diagram of hydraulic pump and pulley assemblies in Eurocopter AS-350 series helicopters.

¹ The O-ring was required by Eurocopter Service Bulletin 29.00.04, dated January 27, 2004, to retain grease and to “prevent early wear of the splines.” The bulletin also reduced the lubrication interval from 500 hours to 100 hours.

Accidents and Incidents Involving the Eurocopter AS-350

This letter describes Safety Board examinations of AS-350 pump and pulley assemblies from the six events described below, as well as three comparison assemblies. During these investigations, the Board reviewed the Master Servicing Recommendations in effect at the time of the events²; Eurocopter Service Bulletin (SB) 29.00.04, dated January 7, 2004; Eurocopter Service Letter (SL) 1808-29-06, released on September 22, 2006; and AS-350 publication revisions issued immediately before and after the events.

On March 9, 2007, a Eurocopter AS-350, registration N91GT, experienced a loss of hydraulic control and the pilot performed a run-on landing.³ The investigation has revealed that the incident was initiated by a failure of the bearing in the pulley assembly that drives the hydraulic pump. The detailed examination revealed that the pump drive shaft splines were worn by approximately 25 percent⁴ and that the coupling sleeve splines were completely worn away, likely as a result of the bearing failure. This finding is contrary to a statement in the manufacturer's 2006 SL that drive shaft splines were expected to wear faster than the coupling sleeve splines.

Safety Board staff performed hardness testing of the pump drive shaft splines and the coupling sleeve splines⁵ and found that the measured hardness was significantly below the requirements specified in the engineering drawings. Further, the examination revealed that the outer surface of the coupling sleeve, in the vicinity of the splines, had also been hardened during manufacture, contrary to engineering drawing requirements. Lubrication levels were found to be minimal although "abundant" was specified in the maintenance manual work card. Total pump operating hours for this helicopter were not available; however, the operator's records indicated that the last 100-hour visual inspection was done 75.7 hours before the incident, and the last 1,000-hour wear check was done 621.9 hours before the incident. Eurocopter's Master Servicing Recommendations in effect at the time of this event required a visual inspection and lubrication of the hydraulic pump drive shaft splines every 100 hours and a wear check of the splined connection every 1,000 hours, in accordance with the relevant work cards in the maintenance manual.⁶

² Eurocopter Master Servicing Recommendations indicate required maintenance actions, the intervals for those actions, and the pertinent maintenance manual work cards that contain the details needed to carry out those actions appropriately.

³ A run-on landing is a precautionary landing that a pilot would elect in situations that might include a hydraulic power failure where, due to the loss of power to the controls, the aircraft lands with some forward velocity and slides to a halt.

⁴ In this letter, percentage of reduction refers to a reduction in the original thickness of the spline.

⁵ Hardness testing was performed in the root of the splines, a location where the case hardening is normally pristine, as it is not contacted by any portion of the mating spline and is normally intact even when the body of the spline has been worn away.

⁶ Eurocopter allows an extension of up to 10 percent in servicing intervals; for example, a 100-hour servicing can be performed between 100 hours and 110 hours, and a 1,000-hour servicing can be performed between 1,000 hours and 1,100 hours.

On March 8, 2007, a Eurocopter AS-350, registration N354NT, reported a hydraulic failure and collided with terrain, resulting in four fatalities and three serious injuries.⁷ On-scene investigators found the left lateral main servo disconnected. Since the hydraulic pump and pulley assembly is part of the same hydraulic system as the servo, and given problems already being investigated in other Eurocopter AS-350s, described below, the hydraulic pump and pulley assembly was removed as a unit and sent to the Safety Board for examination. Disassembly revealed that the drive shaft O-ring had not been installed. Although the drive shaft splines and the coupling sleeve splines were relatively intact, Safety Board hardness testing revealed that the measured hardness at the specified minimum depth for the drive shaft splines was significantly below the requirements specified in the engineering drawings. Although the examination also revealed viable grease on the splines, the grease in the coupling sleeve cavity was dried and was no longer capable of lubricating the splines. Analysis revealed that the viable grease and the dried grease were similar but that neither was specified in the maintenance manual. Total pump operating hours for this helicopter were not available, but a review of the servicing records revealed that a required 100-hour visual inspection and lubrication of the pump drive shaft splines had been performed 58.1 hours before the accident.

On July 17, 2006, a Eurocopter AS-350, registration N606TV, experienced a hydraulic failure, and the pilot performed a run-on landing.⁸ Safety Board examination of the hydraulic pump drive shaft revealed that approximately 20 percent of the splines had been worn away, and that their hardness was below the requirements specified in the engineering drawings. Examination of the coupling sleeve revealed that the splines were completely worn away and that their hardness was also below engineering drawing requirements. The examination also revealed that the drive shaft O-ring and the coupling sleeve plug had not been installed and that lubrication levels were minimal. Reportedly, the helicopter had been imported from France within the last year and the 100-hour visual inspection and lubrication of the pump drive shaft had been performed 14 days prior to the incident. Pump operating hours were not available.

During the course of the investigation into the July 17, 2006, event, the Safety Board learned of a similar incident being investigated by the Transportation Safety Board (TSB) of Canada. The TSB provided the pump and coupling sleeve from that helicopter, registration C-FYUN, for comparison. The hydraulic pump assembly and the pulley assembly, which were not considered contributory to the incident that the TSB was investigating, had reportedly operated for 2,192 hours since new. Although the drive shaft splines and the coupling sleeve splines were found to be relatively intact, their hardness was also found to be below the requirements specified in the engineering drawings. Lubrication levels were minimal.

On May 29, 2006, a Eurocopter AS-350, registration C-GGLM, experienced a hydraulic failure and attempted a run-on landing, which resulted in the helicopter rolling over and incurring significant damage.⁹ Safety Board examination of the hydraulic pump drive shaft revealed that

⁷ Preliminary information about this accident, NYC07MA073, is available on the Safety Board's website at <http://www.nts.gov/ntsb/query.asp>.

⁸ More information about this event, NYC06IA176, can be found on the Safety Board's website at <http://www.nts.gov/ntsb/query.asp>.

⁹ More information about this event, NYC06LA121, can be found on the Safety Board's website at <http://www.nts.gov/ntsb/query.asp>.

approximately 30 percent of the splines had been worn away, and their hardness was significantly below the requirements specified in the engineering drawings. Examination of the coupling sleeve revealed that approximately 50 percent of the splines had been worn away and that their hardness was also significantly below engineering drawing requirements. The examination also showed that lubrication levels were minimal. Reportedly, the helicopter had been rebuilt in 2005 and had only flown 140 hours since that time. However, because the hydraulic pump is replaced only when it fails, staff could not determine if it had been replaced during the overhaul.

On September 20, 2003, a Eurocopter AS-350, registration N270SH, impacted the side of the Grand Canyon, resulting in seven fatalities and the loss of the aircraft.¹⁰ Although the hydraulic pump and its related components were not factors in the accident, Safety Board examination of the hydraulic pump drive shaft revealed that approximately 10 percent of the splines had been worn away and that their hardness was significantly below engineering drawing requirements. Examination of the coupling sleeve revealed that approximately 60 percent of the splines had been worn away, and their hardness was also below the requirements specified in the engineering drawings. The examination also showed that lubrication levels were minimal. Maintenance documents revealed that the last visual inspection and lubrication of the hydraulic pump drive shaft had been performed only 10.3 hours before the accident and was not due for another 490 hours.¹¹ The last 1,000-hour wear check had been performed 1,057.5 hours before the accident and was due within the next 42.5 hours.

On September 11, 2002, a Eurocopter AS-350, N357NT, experienced a loss of hydraulic control that resulted in a hard landing and substantial damage to the aircraft.¹² Safety Board examination of the hydraulic pump drive shaft revealed that approximately 30 percent of the splines had been worn away and their hardness was significantly below the requirements specified in the engineering drawings. Examination of the coupling sleeve revealed that the splines had been completely worn away and that their hardness was below engineering drawing requirements. The examination also showed that lubrication levels were minimal. Maintenance documents revealed that the hydraulic pump had been installed 15 days before the incident and had operated for 74.6 hours.

During the investigation of the September 11, 2002, event, another operator reported a hydraulic failure and shipped this hydraulic pump and its coupling sleeve to the Safety Board for examination. Examination revealed that the hydraulic pump drive shaft splines from this helicopter were also worn approximately 30 percent. The splines in the coupling sleeve were completely worn away and their hardness was found to be below the requirements specified in the engineering drawings. Examination of the coupling sleeve revealed that it contained a minimal amount of grease and displayed no indications that a plug had been installed. Maintenance documentation revealed that the pump had operated for 123.5 hours.

¹⁰ More information about this event, LAX03MA292, can be found on the Safety Board's website, <<http://www.nts.gov/publictn/2007/AAB0703.pdf>>.

¹¹ This event and the 2002 event that follows pre-date SB 29.00.04, dated January 7, 2004, which reduced the inspection and lubrication interval from 500 hours to 100 hours.

¹² More information about this event, LAX02FA281, can be found on the Safety Board's website at <<http://www.nts.gov/nts/query.asp>>.

At the Safety Board's request, Eurocopter supplied a new hydraulic pump and a new coupling sleeve for further comparison. Hardness testing of the splines in the new coupling sleeve revealed that they too were below the requirements specified in the engineering drawings.

In summary, Safety Board examinations of the splined connections from nine AS-350 hydraulic pump/coupling sleeve assemblies (six event helicopters and three comparison assemblies) revealed the following:

- In the six events, neither the drive shaft splines nor the coupling sleeve splines met the hardness requirements in their respective drawings and, in some cases, were deficient by significant amounts. Similarly, spline hardness in the comparison assemblies removed from operating helicopters was found to be below engineering drawing requirements. In a new coupling sleeve supplied by the manufacturer, the spline hardness was also found to be below the requirements specified in the engineering drawing.
- In four cases, the coupling sleeve splines were completely worn away, and in the other two cases, coupling sleeve splines showed excessive wear.
- Inadequate lubrication was found in all coupling sleeves, except for one that had been cleaned prior to being acquired by the Safety Board and one that was filled with old, incorrect grease.
- In one case, the coupling sleeve plug had not been installed and in another case, the drive shaft O-ring had not been installed.

The Safety Board is concerned because inadequate hardness and inadequate lubrication accelerates the wear in the splined connection, increasing the likelihood of in-flight failure. Potentially catastrophic wear on coupling sleeve splines could occur before the next wear check, which is required by the Master Servicing Recommendations every 1,000 hours. At the time these events occurred, Eurocopter manuals for AS-350 and EC-130 model helicopters did not specify the need to include the coupling sleeve splines as part of the visual inspection and lubrication of the hydraulic pump drive shaft splines. SL 1808-29-06 required that the coupling sleeve splines be added to the visual inspection and reduced the visual inspection interval from 500 to 100 hours.

Safety Issues

Each of the examinations described in this letter, including that of a new hydraulic pump and pulley assembly, revealed that the hydraulic pump drive shafts and/or coupling sleeves were not airworthy because the hardness of the splines was below the requirements specified in the engineering drawings.¹³ The lower hardness values of the mating splines accelerated the rate of

¹³ Eurocopter representatives attended several examinations of the spline connections conducted in the Safety Board's Materials Laboratory in connection with the events described in this letter and were made aware of the worn condition of the coupling sleeve splines, as well as the hardness testing results. At that time, Eurocopter stated its belief that the problem of wear in the splined connection was a lubrication (maintenance) issue only.

wear, in several cases enough that the loss of spline material was sufficient, within a servicing period, to sever the connection between the coupling sleeve and the hydraulic pump and produce a hydraulic system failure. Further, variations in the hardness of the splines, and the discovery that the manufacturer had performed the hardening process in an area of the sleeve where it was not required by engineering drawing requirements, indicate an issue with the manufacturer's quality control. Therefore, the Safety Board recommends that the EASA require Eurocopter to identify AS-350 and EC-130 helicopter hydraulic pump drive shafts and coupling sleeves with splines that do not meet design specifications and take appropriate action to ensure that these parts (that is, replacement parts and parts to be installed in new helicopters) are expeditiously removed from the supply chain.

On the basis of its examinations of the hydraulic pump system components cited in this letter, the Safety Board is concerned that in-service splined connections are experiencing accelerated wear, or are already significantly worn, and this wear might not be detected before the next scheduled wear check (conducted every 1,000 hours) or visual inspection and lubrication (conducted every 100 hours). The problem of accelerated wear is likely to be exacerbated if the splines are not lubricated properly and if the O-ring and plug are not in place.

In May 2008, Eurocopter distributed a revision to its maintenance manual incorporating the requirement from SB 29.00.04 to include the coupling sleeve splines in the 100-hour visual inspection of the drive shaft splines. This revision is an important addition to the maintenance manual because previously, the only inspection required for the splined connection was the wear check of the hydraulic pump drive shaft splines every 1,000 hours.¹⁴ In each of the Safety Board examinations cited in this letter, the coupling sleeve splines displayed most of the wear, contrary to the statement in SL 1808-29-06 that pump drive shaft splines generally wear out before the coupling sleeve splines.

Although the Safety Board is encouraged by Eurocopter's action in regard to the inspection of the coupling sleeve splines, it remains concerned that the more extensive wear check will be conducted only at 1,000-hour intervals. The wear check requires the removal of the drive belt from the pulley and is performed by measuring the rotational displacement of the pulley assembly on the pump assembly, which provides an indication of total spline wear.¹⁵ The maximum allowable rotational displacement is 4 mm, which, according to the pertinent maintenance work card, corresponds to a wear depth in the splines of 0.013 inch, well past the specified hardened layer (0.004 to 0.008 inch) on the coupling sleeve splines. The Safety Board is concerned that once the wear progresses through the casehardened layer on the coupling sleeve splines, the wear rate could accelerate with the potential for hydraulic failure that could contribute to a serious or fatal accident. Although the Board is not aware of data on the wear rate once the hardened layer on the coupling sleeve splines is worn through, its examinations of spline connections have shown that splines that are not lubricated correctly wear out before the 1,000-hour wear check can occur. Given the evidence of inadequate lubrication and the amount

¹⁴ These inspections were specified in maintenance manual work card 29.10.10.601, paragraph 3, for the AS-350 model helicopters and work card 29-11-00, paragraph 4-1, for the EC-130 model helicopters.

¹⁵ The allowable wear limits for the wear check are contained in work card 29.10.10.601, paragraph 3, for AS-350 models and work card 29-11-00, paragraph 4-1, for EC-130 models.

of coupling sleeve spline wear found during the examinations cited in this letter, the Safety Board believes that every 100 hours would be a reasonable interval for properly lubricating the splines, monitoring their wear, and detecting excessive wear before the coupling sleeve splines are completely worn away. Therefore, the Safety Board recommends that the EASA require operators of Eurocopter AS-350 and EC-130 helicopters to perform a wear check, visual inspection, and lubrication of the hydraulic power assembly splines and coupling sleeve splines in accordance with the latest version of the maintenance manual at the earliest opportunity, and, thereafter, require operators to repeat the wear check, visual inspection, and lubrication of the splined connection at 100-hour intervals, and remove unairworthy parts from service.

Therefore, the National Transportation Safety Board recommends that the European Aviation Safety Agency:

Require Eurocopter to identify AS-350 and EC-130 helicopter hydraulic pump drive shafts and coupling sleeves with splines that do not meet design specifications and take appropriate action to ensure that these parts (that is, replacement parts and parts to be installed in new helicopters) are expeditiously removed from the supply chain. (A-08-77)

Require operators of Eurocopter AS-350 and EC-130 helicopters to perform a wear check, visual inspection, and lubrication of the hydraulic power assembly splines and coupling sleeve splines in accordance with the latest version of the maintenance manual at the earliest opportunity, and, thereafter, require operators to repeat the wear check, visual inspection, and lubrication of the splined connection at 100-hour intervals, and remove unairworthy parts from service. (A-08-78)

In response to the recommendations in this letter, please refer to Safety Recommendations A-08-77 and -78. If you would like to submit your response electronically rather than in hard copy, you may send it to the following e-mail address: correspondence@ntsb.gov. If your response includes attachments that exceed 5 megabytes, please e-mail us at the same address for instructions on how to use our Tumbleweed secure mailbox procedures. To avoid confusion, please use only one method of submission (that is, do not submit both an electronic copy and a hard copy of the same response letter). The Safety Board has also issued recommendations to the Federal Aviation Administration.

Acting Chairman ROSENKER and Members HERSMAN, HIGGINS, SUMWALT, and CHEALANDER concurred in these recommendations.

[Original Signed]

By: Mark V. Rosenker
Acting Chairman