AS332L Super Puma, G-PUMB

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Aircraft Type and Registration:	AS332L Super Puma, G-PUMB
No & Type of Engines:	2 Turbomeca Makila 1A turbine engines
Year of Manufacture:	1983
Date & Time (UTC):	20 July 1998 at 0808 hrs
Location:	Aberdeen Airport
Type of Flight:	Air Test
Persons on Board:	Crew - 2 - Passengers - None
Injuries:	Crew - None - Passengers - N/A
Nature of Damage:	Engine oversped, power turbine output shaft destroyed
Commander's Licence:	Airline Transport Pilot's Licence (H)
Commander's Age:	54 years
Commander's Flying Experience:	11,800 hours (of which 1,539 were on type)
	Last 90 days - 184 hours
	Last 28 days - 81 hours
Information Source:	AAIB Field Investigation

History of flight

The crew were tasked with an air test after engineering work on the helicopter. A Check at Maximum Contingency Power Rating was required. The Flight Manual defined the "Test Purpose and Requirements" as follows:

> *"From level flight approx: 100 kt check maximum Ng (gas generator speed) by reducing fuel flow control lever of the other engine to fast reduction detent then slowly increasing the pitch to bring the rotor speed to between 250 and 245 RPM - Reduce pitch after 10 seconds at the maximum Ng."*

The maximum Ng achieved would then be recorded.

The helicopter took off from Runway 16 at 0803 hrs; the surface wind was 140°/6 kt. Because the weather was less than ideal, the commander elected to do the test in the visual circuit at 800 feet agl, just below the cloud base which was scattered at about 900 feet. He was the handling pilot and the first officer recorded the results.

In level flight at 100 kt, the commander reduced the No 1 engine fuel lever to the Fast Reduction Idle detent. The pitch was increased slowly to achieve between 250 and 245 RPM and it was noted that the maximum Ng was 33,600 RPM. There was a loud bang followed by vibration, and the

helicopter started to descend. The commander immediately reduced the collective pitch to minimum and restored power on No 1 engine. He noticed that the No 2 engine was running down. The first officer was told to make a Pan call, which he did, and the helicopter landed safely on Runway 32 at 0808 hrs. The aircraft was shut down on the runway.

The aircraft was returned to the hangar for engineering investigation during which it was found that the six bolts which should have secured the splined sleeve to the aft end of the power turbine output (Bendix) shaft of the right (No 2) engine had not been fitted. (See Figures a, b & c) Subsequent metallurgical investigations showed that the surface temperature of the metal, in the area where the splined sleeve was a close fit inside the Bendix shaft, had risen above 700°C, causing discolouration and forming small friction welds between the sleeve and the shaft. The aircraft had just been subjected to a scheduled 500 hr engine inspection and this had been combined with an 'out-of-phase' 1200 hr inspection of the Bendix shafts on both engines.

Flying staff instruction

On 26 August 1998, the company issued Flying Staff Instruction GEN/207 - GUIDANCE ON THE CONDUCT OF INFLIGHT ENGINE POWER CHECKS. As well as guidance on weather, area of operation and preflight briefing it contained the following section:

"GENERAL PROCEDURE - MULTI CREW

a. Handling pilot establishes safe single-engine flight conditions and remains hands on all controls throughout the procedure.

b. The crew identify and confirm the engine not under test and the non-handling pilot retards its power lever to t he specified setting whilst monitoring the engine under test.

c. The non-handling pilot will observe the engine test parameters whilst maintaining his hand-hold on the retarded power lever. On completion of the test, he will restore the retarded power lever to flight status and record his observations.

d. In the event of failure of the engine under test, the handling pilot will reduce the collective pitch to minimum immediately and, simultaneously, the non-handling pilot will restore the remaining engine power lever to the flight position, calling "POWER AVAILABLE" when the power lever is in the flight position.

The operator's maintenance shift pattern

The operator ran a three shift system for line maintenance work. There was a permanent night shift, always staffed by the same personnel, which started at 2100 hrs and finished at 0700 hrs; an early shift, which started at 0630 hrs and finished at 1530 hrs, and a late shift, which started at 1500 hrs and finished at midnight. There were nominally three groups of personnel working the early and late shifts and they rotated between the shifts in the pattern; 3 days late shift, 3 days early shift and 3 days rest.

On what was known as 'changeover day', the late shift personnel formed the following day's early shift. However, to allow an adequate rest period between shifts, some went off late shift at 2100 hrs, coming on to early shift at 0630; the remainder worked until midnight but did not return to work until 0930 hrs on the following day. Normally, on changeover day, the late shift supervisor handed over to the night shift supervisor at 2100 hrs so that he could return at 0630 the following morning and thus ensure a continuous supervisory presence.

The size of a Line Maintenance shift was nominally about ten, including supervisors, licensed and unlicensed engineers and supplementary staff. However, with deployments to outstations, training courses and personnel on leave or sick, the average attendance was usually about six.

History of maintenance input before this flight

The 500 hr inspection of the engines on this type was defined by this operator to be a Line Maintenance task. The aircraft was brought into the line maintenance hangar during the morning of Saturday 18 July and the engines were removed by early shift personnel. As removed, the engines had the Power Turbine output shafts (Bendix Shaft) and the engine to transmission 'Coupling Tubes' still connected to them and it was in this condition that the late shift personnel first encountered them.

Two engineers, one licensed and authorised as an inspection signatory, and the other unlicensed, were allocated to conduct the engine and Bendix shaft inspections. As it was a shift changeover day, the unlicensed man was planned to leave work at 2100 hrs and return at 0630 hrs on Sunday; the licensed man was scheduled to work until midnight and return at 0930 hrs on Sunday. Although the unlicensed man had no authority to sign for the completion of any work, he had worked with this licensed man over a considerable period and his standards of workmanship and approach to aircraft maintenance were trusted by the licensed man.

Having ascertained from the work-pack what was required, each engineer undertook the work on one engine, the unlicensed man working on the No 2 (right) engine. By 2100 hrs both men had completed their respective engine's 500 hr inspection work and had reached the point when the exhaust ducts, coupling tubes and Bendix shafts had to be removed from each engine to enable the Bendix shaft inspections to be done. As the unlicensed man was due to go off shift then, a third engineer, who although licensed on three other aircraft types had only limited approval on the AS 332L, was allocated to continue the work on G-PUMB. Since the unlicensed man was due to return to working on the aircraft the following morning, he did a personal handover of the work to this third man. As one item of this handover, the unlicensed man asked that the Bendix shaft be left ready for inspection the following morning.

After the unlicensed man had left, the licensed man and the third man started to remove the exhaust ducts, coupling tubes and Bendix shafts from both engines. The licensed man found that he was unable to remove the Bendix shaft from the No 1 engine because the supplied tooling proved difficult to use. The third man then assisted him and the shaft was eventually removed so that the inspection of the shaft could be performed. The licensed engineer then completed the inspection tasks required and, before the end of the shift at midnight, rebuilt the No 1 engine assembly ready for refitting to the aircraft the next day.

The third man, having assisted in the removal of the Bendix shaft from the No 1 engine, started to remove the shaft from the No 2 engine with the reasonable intention of completing its shaft inspection and re-assembly. During this process, however, he cut his hand, due to the awkwardness of the tooling, and had to go to the first aid point for attention. After spending some time doing this, he finished removing the Bendix shaft from the No 2 engine and but found that he was unable to extract the splined sleeve from the aft end of the shaft (see figures) after he had removed the attaching bolts. This was not unusual as deposits can build up between the shaft and the sleeve making the separation of the two difficult. Therefore, during the time before the end of the shift, he identified and marked all the re-useable nuts and bolts. He also drew the required new ones from stores and left the new and re-useable nuts and bolts on the workbench by the engine; the nuts and bolts which were not to be reused were placed in a waste tray on the workbench. He also left the splined coupling end of the shaft soaking in white spirit to facilitate the removal of the sleeve by

the unlicensed man when he came back on shift in the morning. He also drew out, from the workshop, the tooling required to refit the shaft and torque tube and placed that on the workbench also.

At the end of the late shift the licensed man and the third man gave the required verbal report of the progress state of the job to the shift supervisor who compiled the formal handover paperwork.

The night shift was not tasked with continuing work on this aircraft between midnight, when the licensed engineer and the third man went off shift, and 0630 hrs, when the unlicensed engineer returned. Unusually, the late shift supervisor had stayed to the end of the shift, rather than handing over to the night shift supervisor at 2100 hrs, and came on at 0930 hrs the following day. This resulted in there being no supervision, and consequently no handover information, available to the unlicensed man for the first three hours of the early shift.

When the unlicensed man returned to work the following morning (Sunday 19 July) he found the engine and Bendix shaft in exactly the state which he had anticipated. He, therefore, removed the splined sleeve, which had been loosened by its overnight soaking, and cleaned and inspected the shaft as was required. Having completed the inspection he then, unusually, placed the splined sleeve back in the end of the shaft (without its attaching nuts and bolts) before going to the workshop to find the tooling to refit the shaft and connecting torque tube to the engine. His normal practice had been to fit the shaft to the engine first, before attaching the sleeve to the shaft, because it was difficult to apply the correct torque to the attaching bolts if the shaft was not firmly supported.

Because he had not expected to find the tooling lying beside the engine, it took a little time for him to locate it. However, having done so he fitted the Bendix shaft to the engine, concentrating on a safety locking device at its forward end. He then refitted the coupling tube, the exhaust duct and a wiring harness. Believing that he had now rebuilt the engine he went up onto the engine deck, on top of the aircraft, to prepare the engine mountings for the re-installation of both engines.

At about 0940 hrs he started to lift the No 2 engine to position it for re-installation. He had lifted it to a position above the engine deck when the licensed engineer arrived on shift and started to help him. At the time the licensed man arrived, the splined sleeve in the end of the drive shaft was still visible but about 14 feet above floor level and within the open end of the coupling tube. The two men then installed the No 2 engine, during which process they had to monitor the engagement of the transmission splines into the splined coupling on the Bendix shaft. Neither man noticed that the splined sleeve attachment bolts were not fitted. They then installed the No 1 engine, performed the engine rigging checks and then prepared and equipped the aircraft for ground running before a post-maintenance test flight. The licensed man also completed the maintenance documentation at this point.

At about 1400 hrs the aircraft was taken out for ground runs, with the two engineers still assisting. The No 1 engine was run first and the tests indicated that it was completely satisfactory. The No 2 engine was then started and, although apparently normal in other respects, the overspeed warning light kept flickering intermittently. The engine was shut down and avionics technicians performed a check on the overspeed warning system wiring plugs which showed them to be apparently satisfactory. It had also been noticed, during this set of test runs, that the aircraft had made a 'kick' to the left. The licensed man reported this to the shift supervisor who told him that the aircraft had had a lateral control problem before the engine inspection; this had been described in the Technical Log as an intermittent 'jerk' when operating the rudder pedals.

Further engine runs were carried out and the No 2 engine overspeed light was still seen to be flickering. It was, therefore, decided to remove the engine again to replace the wiring loom. However, by this time it was the end of the early shift and the work to do the loom change was done by the late shift. Subsequently, when the engine was being re-installed, the splines were again monitored during the engagement of the drive to the transmission, but again the absence of the splined sleeve attachment bolts was not noticed. The aircraft was left ready for further ground running by the early shift, for acceptance for a test flight.

On the Monday (20 July) morning, the unlicensed man was tasked as the line engineer to assist with the pre-flight vibration checks on the No 2 engine. These proved satisfactory and it was observed that the flickering of the overspeed light had been cured. The aircraft was then dispatched for the test flight during which the incident occurred.

Discussion

At the time that this incident occurred, the operator was in the process of reviewing and revising its maintenance control procedures as a result of an earlier minor incident arising from an uncompleted maintenance procedure. (G-PUMK, reported in AAIB Bulletin 7/98) The operator notified the AAIB of this incident to G-PUMB immediately it had occurred.

It became clear during the investigation that a number of issues had some influence on why the coupling bolts had not been fitted and their absence not detected. The crucial points in the maintenance sequence which led to this omission appeared to be:-

a The departure of the unlicensed man from the late shift before any work to remove the splined coupling had been done.

b His return on early shift, the following morning, after a shorter than usual overnight break, to find what he thought was the expected situation.

c The deviation of the late shift supervisor from normal shift changeover practice.

d The consequent unavailability, to the unlicensed man, of handover information to clarify the exact status of the job and the preparations, made by the third man, to progress it.

e The unsupervised progress of the job during the first 3 hours of the early shift, which precluded intermediate inspections because the authorised inspector was not on shift.

f The lack of identification, on worksheets, of vital inspection stages during progress of the maintenance.

The relatively small size of the shift gave rise to situations where unlicensed engineering staff might be working remote from supervision, particularly during the process of shift changeovers. The unlicensed engineer involved in this incident was in this situation and was placed in the position where he was working effectively alone for three hours during the early part of the Monday morning shift. It was during this time that he had deviated from what had been his normal practice for refitting the splined coupling and had experienced the distraction of having difficulty finding the tooling for refitting the shaft.

It was known that there would be no personal hand-on of the job from the third man to the unlicensed man and there was no intention on either man's part to write or expect a handover note as the established procedure for passing handover information was through the shift supervisors. The two men had parted at 2100 on Saturday evening with the unlicensed man having an expectation of how far the job would have progressed, but the third man, quite reasonably, having the intention to proceed as far as he could. Thus, with no available handover information to tell the unlicensed man the extent to which the third man had progressed the job and done preparatory work and provisioning, he was left thinking, mistakenly, that he understood the position fully when alone, very early in the morning, and after only a short break for rest and sleep

The deviation from normal practice, in the way the supervisor changed from late to early shift, defeated the established company procedure for handover information to be transmitted.

Another factor which came to light during the investigation was the placement, on the workbench, of the bolts for the shaft reassembly and fitting. There was a mismatch between what the third man believed he had left overnight against what the unlicensed man recollected finding in the morning. The presence of bolts on the workbench should have acted as a prompt that there were some bolts unfitted. However, the unlicensed man could not remember seeing any such bolts and no trace of them was found during the investigation. There was no evidence to suggest that the bolts were disturbed during the night shift and their disappearance has not been resolved. It is probable, however, that if a handover note had been written it would have highlighted the existence of the bolts and, whether they had been present or absent, they would have been brought to the unlicensed man's attention. The fact that the unlicensed man did not have to undo any bolts before removing the splined coupling from the shaft that morning may have constituted the absence of another potential reminder that bolts were needed to attach the coupling to the shaft.

There was found to be some uncertainty on the part of the licensed man as to what he was certifying when his signature was placed against work executed by the unlicensed man whilst working under his charge. Furthermore, all the engineers involved appeared to have a different perception of what a licensed man's signature indicated as against what the company Quality Control believed it meant. It was also observed that the worksheets for the various tasks were not entirely consistent in format and whilst the intention of part of these inconsistencies was to point up differences in the way the tasks were supposed to be viewed on the part of the certificating engineer, this had not been appreciated by them.

A factor which was in play in this instance, as it is in all leanly manned aircraft maintenance organisations, is the dilemma in which the engineers find themselves when deciding how often they should break from the task to check and sign off the work on the worksheets. The worksheets themselves do not point out the critical points of progress at which vital items disappear from inspectability. Although such points are readily identifiable with forethought or hindsight, history would indicate that these points get missed amongst the real time pressures and distractions of maintenance working.

This incident again highlights the vulnerability of maintenance tasks to errors of omission when the task is interrupted by handovers between personnel, especially where the handover is not face-to-face. They are particularly vulnerable when staff perceive a conflict between the necessity for getting on with the maintenance task and the requirement to write up the paperwork (both pro-formas and informal notes), not only as a record, but also as a prompt for themselves and others.

As a result of this and the earlier maintenance related incident, the operator has reviewed and made major changes to the shift system with the object of improving both safety and efficiency. It was recognised that the early shift was at work when the aircraft were all out flying and, as a result the

engineers were relatively lightly loaded. The early shift manning was, therefore, reduced to about half its previous size and the staff made available were used to increase the size of the late shift. 'Changeover day' has now ceased to exist and a system of rolling part shift change, in the cycle from 'late' to 'early' to rest days, has been instituted. The changes were implemented about 3 months after this subject incident and are in current practice.

The operator has also conducted a thorough review of the maintenance procedures on all aircraft types operated by them and have identified 'vital points' in their procedures. These have been highlighted in the maintenance program and on the worksheets; the worksheets themselves have been more standardised in appearance and made more unequivocal in their certification requirements. It is intended to maintain a continuous review of what constitutes a 'vital point' and the worksheets.

They have also taken steps to clarify the responsibilities of the various categories of engineering staff involved in the maintenance process and to ensure that the certifying staff know their individual responsibilities. A programme of Maintenance Resource Management training has been instituted.