Aerospatiale AS332L Super Puma, G-TIGT, 4 January 1996

AAIB Bulletin No: 6/96 Ref: EW/C96/1/2Category: 2.1

Aircraft Type and Registration: Aerospatiale AS332L Super Puma, G-TIGT

No & Type of Engines:2 Turbomeca Makila 1A turboshaft engines

Year of Manufacture:1983

Date & Time (UTC):4 January 1996 at 1720 hrs

Location: Aberdeen Airport

Type of Flight: Public Transport

Persons on Board: Crew - 2 Passengers - None

Injuries: Crew - None Passengers - N/A

Nature of Damage: Main rotor destroyed; tail boom assembly detached and fuselagedamage on left hand side

Commander's Licence: Airline Transport Pilot's Licence

Commander's Age:51 years

Commander's Flying Experience:11,800 hours (of which 7,200 were on type)

Last 90 days - 117 hours

Last 28 days - 43 hours

Information Source: AAIB Field Investigation

History of flight

Both pilots reported for duty at 1000 hrson the day of the accident each having had at least two days rest. The helicopter G-TIGT was airborne at that time and they tookcontrol from another crew at about 1125 hrs with the rotors running. The crew then completed multiple sectors to and from installationsin the Scott Field involving some five and a half hours flighttime. The helicopter remained fully serviceable with rotors runningthroughout that period and it landed in darkness at 1708 hrson Runway 19. The commander then taxied the aircraft on its wheelsto the company apron; the taxiway routing required several turnsand the commander noticed nothing unusual about the helicopter'sresponse to his control inputs. In accordance with company standardpractice, the passengers and cargo were off-loaded on the apronwith the rotors running. The commander then taxied the helicopteron a north-easterly heading towards the spot where it would eventuallybe shutdown. A weather warning issued by the airport forecastsouth-south-easterly winds of mean speed 15-20 kt with gusts of30-35 kt at times and so it was decided to park the helicopterfacing into wind. Obstructions on the apron dictated that thefinal turn onto a southerly heading had to be a tight turn and,initially, the pilot eased the helicopter to the left before reversingthe turn to the right. As he did so, the co-pilot (seated onthe left side) looked to his left and behind the helicopter toensure that the tail rotor remained clear of parked ground equipmentwhilst the commander turned off the landing lights and appliedright pedal to execute a right turn under the guidance of a marshaller. During the turn the helicopter began to roll to the left; thecommander applied full right cyclic control but this was ineffectivein containing the roll and the helicopter fell onto its left side. As it fell the main rotor blades struck the apron surface anddisintegrated. Both pilots then took appropriate action to shutdown the engines and electrical systems before vacating throughthe commander's door.

The marshaller who was in front of but tothe right of the helicopter saw the nosewheel begin to castoras the machine started to turn towards him, but as it did so hesaw the right main wheel lift clear off the ground. The helicoptercontinued to roll over and so he turned around and ran to escapethe path of debris from the main rotors. The only other personnear the helicopter was driving a tractor behind it and to itsright and well clear of the debris path. He felt a gust of windon his cheek at about the time the helicopter started to rollover and he too saw the right main wheel lift clear of the ground. He had seen this happen several times before to Super Pumas turningtightly but previously they had always recovered from the roll. Other ground handlers had also seen similar events but therewas no evidence that such observations had ever been reportedto the Operations Department.

As the main rotor blades struck the tarmac,their plane of rotation was towards the airport's main Terminal. Several minor pieces of metallic debris reached the Terminalwhich was 350 metres from the accident site. The largest piecepenetrated a window at the front of the Terminal with a very loudbang and struck an office wall on the ground floor. Another piecepenetrated the cladding on the exterior wall above the upper floorand was trapped by the suspended ceiling where it did little damage. Two windows in a nearby office building and the side window ofa parked car were also struck and smashed. Only one piece ofdebris struck a person, an airport employee who was walking infront of the Terminal. A small piece of metal struck him on theshoulder but did not injure him. One parked aircraft close tothe helicopter also received minor damage to its landing light.

Wreckage analysis

The aircraft was removed from the apron byagreement with the AAIB co-ordinator before the arrival of theAAIB team. Examination of the helicopter showed that it had tippedon to its left side, coming to rest about 10 or 15 degrees nosedown and rolled rather more than 90 degrees to the left, so asto rest on the left side of the nose and the left sponson. Thiswas subsequently confirmed from photographs and FDR data. Duringthis process the main rotor blades had been progressively destroyed. The balance weights at the blade tips had been released and throwntowards the main Terminal; the less dense fragments of the compositeblades had travelled shorter distances. One of the main rotorblades had struck the tailboom adjacent to the tail rotor transmissiontunnel but the strike was low energy and had occurred after theblade had already lost its tip. The horizontal stabiliser hadtouched the ground lightly during the roll-over, however considerableinertial loading on the tail in the opposite direction had causedall the rivets to fail in shear immediately behind frame 9000,the build joint at the major change of fuselage section just behindthe passenger cabin. The tail boom aft of frame 9000 did notseparate but was secured only by non-structural items. The tailrotor had been struck very lightly by pieces of composite bladematerial but was otherwise undamaged although a small heavy object,possibly a tip weight, had passed through the tail rotor discand penetrated the fin, exiting on the stabiliser side.

With the helicopter on its wheels in a hangarthe structure was assessed for damage. Damage had occurred tothe forward fuselage where frames on the left side had been crushedin the roll-over. There was also damage to the rotor head mountingstructure in the roof, and at frame 9000. All the structuraldamage was deemed repairable, although requiring the airframeto be returned to the manufacturer for re-jigging. Other damagewas mainly to the main rotor head which had been badly distorted,however it was possible to see that no part of the transmissionor flying control system had fractured completely or become detached. The engines, main gearbox and transmission components had allbeen shock loaded.

Flight Recorders

The aircraft was fitted with a Penny and GilesCombined Voice and Flight Data Recorder (CVFDR) together withan Health and Usage Monitoring System (HUMS). The data from theHUMS was removed from the aircraft and replayed by the Operatorbut proved of no use to the investigation. The CVFDR was returnedto AAIB where it was replayed successfully using standard methods.

The recorder contained the last hour of aircraftaudio comprising recordings of the two crew 'hot' microphone channelsand that of the cockpit area microphone. The recorder also containeda recording of the last five hours of aircraft data which includedthe last seven flight sectors.

The recording had terminated during the latterstages of the accident due to the operation of the tailboom mountedinertia switch. The switch was designed to cut aircraft powerin the event of an accident.

The recorded data showed that the aircraftmade an uneventful landing at Aberdeen and proceeded to taxi towardsthe Bristow Helicopters apron.

The aircraft made several right and left taxyingturns before it came to a halt on 'Hotspot 3' to discharge passengers.Once all passengers had disembarked the aircraft commenced taxyingtowards parking spot 1. In doing so, it made an initial rightturn, followed by a left and finally a sharp right to attemptto park on the spot into wind. It was during the final rightturn that the aircraft lifted its right main gear and turned overonto its left side. A summary of the turns showing change ofbearing, turn rate, collective position, lateral cyclic positionand yaw pedal position are shown in Table 1. The figures forlateral cyclic and yaw pedal are given as percentage movementof full travel (0% is fully left and 100% is full right).

TABLE 1 - Summary of Turns

	Bearing	Turn Rate (Deg/sec)	Collective (Deg)	Lat. Cyclic Position	Yaw Pedal Position
Right Turn	193_ to 227_	3.4	8.7	65.2%	66.9%
Right Turn	234_ to 325_	6.5	7.1	95.8%	86.0%
Left Turn	328_ to 270_	7.7	7.5	24.4%	7.3%
Right Turn	252_ to 014_	11.1	6.6	75.0%	90.9%

Right Turn	025_ to 063_	3.6	7.4	66.4%	75.6%
Left Turn	063_ to 050_	2.6	6.4	31.2%	18.2%
Right Turn	051_ to 121_	11.6	6.5	54.5%	100%

During the final right turn the voice recording revealed thatthe handling pilot became aware of the onset of the accident oncethe aircraft had achieved 6.7° of roll. He immediately appliedfull right cyclic and then reduced the amount of right yaw pedalbut the aircraft continued to roll left. Once the main rotorsstruck the ground, rotor speed decayed to below 50% and the lowNR aural warning was heard on the voice recording. This warningstopped once the main blades had broken off the rotor head andthe shaft was allowed to rotate more freely.

The voice and data recording terminated with the aircraft on itsleft side at a roll angle of 94 degrees and on a bearing of 090degrees.

Helicopter controls

The Super Puma's flight controls are all hydraulically powered. Each actuator has two cylinders in tandem supplied by duplicatedhydraulic systems. Three-axis autostabilisation is provided bythe automatic pilot system but it is normally disengaged for taxying. There is also a collective yaw coupling mixer which varies thetail rotor blade incidence with collective pitch setting to counteractchanges in main rotor torque. As collective pitch increases,tail rotor pitch increases by one degree per degree of collectivepitch. With the collective lever fully down, maximum tail rotorpitch is 23.4° and with it fully raised the maximum pitchincreases to 36.4°. Left yaw pedal decreases tail rotorpitch and right pedal increases it to oppose the tendency of thefuselage to yaw to the left due to main rotor torque. The wheelbrakes are operated by toe pedals mounted on the yaw pedal assembly,but on GTIGT they were only available to the right-handseat pilot. The brakes operate on the main wheels only.

Component Tests

The flying controls were examined in detail and could be functionedexcept that hydraulic power could not be applied. All the flyingcontrols to the main and tail rotors were found to be connectedand to operate correctly. The three hydraulic actuators on themain rotor head, the tail rotor pitch hydraulic actuator and theautopilot hydraulic block were removed and sent to the manufacturerfor testing, which was carried out with the AAIB in attendance. The actuators were tested to the manufacturer's specificationfor newly overhauled components using the approved facilitiesand were found to function correctly and within specification,except that the left and right main rotor head actuators werefound to be slightly slower than specification. In view of theminor magnitude of this discrepancy and the data obtained fromthe FDR it is unlikely that the actuators lagged behind the controldemands.

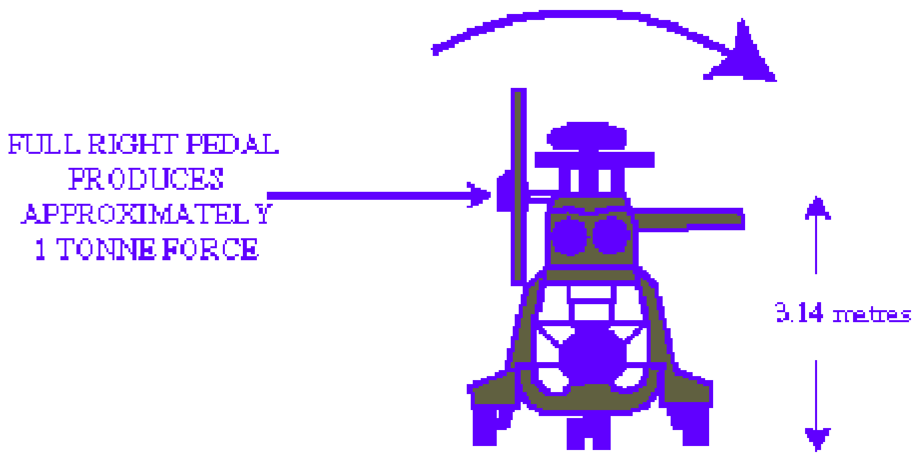
Landing gear

Because the aircraft was turning tightly when the accident occurred,considerable attention was paid to the condition of the landinggear. The Super Puma has a conventional tricycle undercarriagewith single main wheels and a double nosewheel. The track ofthe main landing gear is 3 metres and the centre of gravity isabout 2 metres forward of the main wheels. The main wheels arecarried on trailing arms with hydraulic oleos at the rear. Thenose oleo is a fully castoring strut with a self-centring camat the top of its stroke and a steering lock mechanism which canbe selected from a lever on the cockpit floor. When engaged ared placard swings down externally into view so that a marshaller,for example, can see that the lock is engaged.

Tests showed that the nose oleo extension, castoring and self-centringfunctions were normal. The main oleo extensions were found tobe normal and the brakes were effective, with the oleos strokingnormally during the application of brakes. A strip examinationof the brakes revealed no anomalies. The tyres were pressurechecked, the left main tyre was low at 80 psig, the right wascorrect at 100 psig. The nose gear tyres were both approx.90 psig. There is no minimum limit in the maintenance manual,however the tyres are replenished daily and 80 psig was not feltto be abnormally low. This condition would have introduced avery small, negligible, roll to the left. The steering lock wasfound to be serviceable and not liable to jam or engage when notselected. It was clear both from the photographs of the helicopteron its side after the accident, and from the witness statements,that the steering lock had not been selected, as the externalplacard was retracted. The castoring action had been checkedand seemed satisfactory, however the nose oleo was subsequentlyremoved and fitted to another helicopter, when taxi trials confirmedthat this oleo was at least as free to castor as the rest of thefleet. The surface on which the helicopter was taxying was lessthan perfect, however examination of the lateral and horizontal"g" traces from the FDR showed that no observable abnormalforces were introduced by the undercarriage or apron surface. There was a slope of about 4 percent on the surface, howeverthis fell to the right and would have opposed the overturningforces.

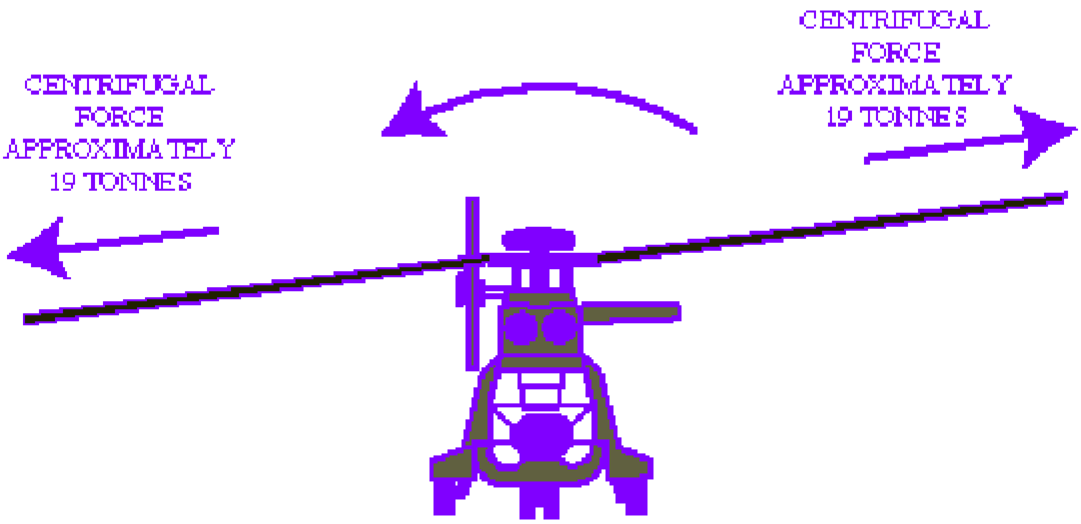
Rolling moments

When the collective lever is fully lowered for taxying, lift fromthe main rotor is negligible. The major forces which producefuselage rolling moments are weight, crosswind, tail rotor forceand main rotor hinge moment. Forces arising from cornering, groundslope and fuel slosh may also be present but generally their effectis small. On the ground the helicopter's rolling axis tends tobe along a line drawn between a mainwheel and the nosewheel. The effect of weight is always to provide a stabilising momentprovided that the centre of gravity remains inboard of this axis. On the other hand, the tail rotor force in a right turn tendsto roll the helicopter to the left. The rotor hub is nominally3.14 metres above the ground and full right pedal creates a forceto the left of approximately one tonne as shown below. In someconditions the rolling moment generated is sufficient to overbalancethe helicopter. This phenomenon is known as 'static rollover'.



Although the effect of weight is stabilising when the helicopterstarts to roll, once the centre of gravity (cg) moves outsidethe rolling axis, the effect of weight is de-stabilising and therollover becomes self-sustaining. The boundary (expressed asa roll angle) between stabilising and de-stabilising moments varieswith weight and the position, particularly the vertical position,of the cg. The Super Puma's fuel is carried under the floor andthe cg is highest when there is no payload and little fuel remaining. This condition, which is often encountered at the end of a flightwhen taxying from a hot spot to a parking spot, is when the helicopteris most vulnerable to static rollover.

The risk of static rollover can be minimised by using in-turncyclic roll inputs to counterbalance the destabilising moments. Left or right cyclic input causes the main rotor disc to tiltand the centrifugal forces from the blades act upon the rotorhinges to produce a strong moment which tries to align the hubwith the blades. This force is transmitted to the fuselage bythe rotor mast which results in a rolling moment in the same directionas the cyclic input as shown below.



Manufacturer's analysis

The helicopter manufacturer carried out an analysis of overturningforces based on the data obtained from the FDR and also the knownconditions at the time. The recorded data for cyclic and collectivepitch, tail rotor pitch, accelerations due to "g", roll,pitch and heading were smoothed and plotted. Roll pitch and yawrates, and speeds were derived and plotted. By integration thetrack over the ground was determined. From this the manufacturerconcluded that the helicopter was moving slowly and the lateralaccelerations generated in the turn were not major influences. The results of this part of the analysis were cross-checked byputting the recorded control inputs into a simulation and plottingthe resulting parameters such as roll pitch and heading againstthe same parameters recorded from the accident. A high degreeof correlation was seen to exist.

For the conditions of the accident, a plot was produced of yawpedal position versus cyclic stick roll position from the timethat the aircraft departed from Hotspot 3. The plot shown atFigure 1 below showed two areas outside the normal ground stabilityenvelope in which one or other of the main wheels would rise offthe ground. No collective demand was assumed in producing thisplot. The plot clearly showed that whilst either wheel couldbe made to rise from the ground, it was relatively easy to makethe right gear do so. With no cyclic roll input to counterbalancethe tail rotor moment, 90% right pedal or more would initiatea rollover.

FIGURE 1 - Cyclic and Yaw Pedal Taxi Limits

NOTE: The data in the above plot shows the ground taxying stabilityboundaries of cyclic/yaw control inputs only for the specificconditions of the aircraft at the time of the accident.

By superimposing the FDR data traces for cyclic roll and tailrotor pitch it was possible to see that the control demands hadmoved outside the ground stability envelope for about one secondat about the time the rollover began. Subsequent applicationof full into-turn cyclic had occurred without any reduction oftail rotor pitch demand, thereby minimising the correcting forces. Additional information available from four flights made by theoperator in 1987 showed that, during the ground taxying phase,there were a number of instances where combinations of tail rotorpitch and lateral cyclic control demands were being made whichwere close to the ground stability envelope. The AAIB carriedout some independent check calculations of overturning and rightingmoments which also suggested that the tail rotor thrust was byfar the most significant force, with lateral "g" providinga small additional overturning moment. With the likely forcesfrom roll cyclic demand introduced into the AAIB's own analysis,the results indicated a large positive stability margin wouldhave existed had right cyclic been used.

Taxying procedures

The taxying procedure in the manufacturer's flight manual wasas follows (verbatim):

- Automatic Pilot . . . . Off

- Parking Brake . . . . Released

- Nose wheel . . . . Unlocked

- Start off : full collective leverup to 9/10° ; if necessary, move cyclic stick slightly forwardwith respect to the neutral position. Then, as requested, re-centerthe cyclic stick and reduce the collective pitch.

- Turns : operate the yaw pedals progressively,then, to make the turn sharper, use the differential wheel brakingsystem. For spot turns, with a heavy gross weight, do not initiaterotation of the fuselage before taking the weight off the nosewheel, using the collective lever.

- Stopping : bring the cyclic stickto the neutral position and the collective lever to the full lowpitch position, then apply the wheel brakes progressively.

Do not apply the parking brake beforecomplete stopping of the aircraft.

CAUTION: 1/ THE AIRCRAFT WILL TEND TO BANK OUTSIDE A TURN, ESPECIALLYWHEN REACHING THE CROSS WIND POSITION. NEUTRALIZE THIS TENDENCYUSING THE CYCLIC STICK.

2/ AVOID WIDE MOVEMENTS OF THE CYCLICSTICK ROUND THE NEUTRAL POSITION (NOT MORE THAN 20%), PARTICULARLYWHEN THE COLLECTIVE LEVER IS IN FULL LOW POSITION, TO PREVENTTHE BLADES FROM HAMMERING AGAINST THE DROOP RESTRAINERS, WHICHCAUSES HEAVY STRESSES.

Safety recommendations

It was recommended that:

96-25 Eurocopter should revise the wording of the section of theAS332L Flight Manual covering taxying procedures and agree thiswording with the CAA. This revision should include guidance onthe optimum use collective pitch, unambiguous statement of thelimitations on the use of lateral cyclic, and include a warningof the possibility, under certain conditions, of static rolloverif large deflections of yaw pedal are applied.

96-26 Eurocopter should provide AS332L operators with additionalinformation for inclusion in training manuals on the factors affectingthe potential for rollover whilst ground taxying together withthe appropriate preventative measures.

96-27 The CAA should include in the Helicopter Operational RecordingProject, which uses AS332L Super Puma data, exceedence triggersthat highlight critical combinations of yaw pedal and lateralcyclic which are near the boundary of that required to induceroll-over while ground taxying.