Aerospatiale AS355F2 Ecureuil II, G-CAMB

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Aircraft Type and Registration:	Aerospatiale AS355F2 Ecureuil II, G-CAMB
No & Type of Engines:	2 Rolls-Royce Allison 250-C20F turboshaft engines
Year of Manufacture:	1989
Date & Time (UTC):	6 April 1999 at 1405 hrs
Location:	St Neots, Cambridgeshire
Type of Flight:	Police operations
Persons on Board:	Crew - 1 - Passengers - 2
Injuries:	Crew - None - Passengers - None
Nature of Damage:	Uncontained engine failure, shrapnel damage to fuselage skin and engine deck
Commander's Licence:	Airline Transport Pilot's Licence (Helicopters)
Commander's Age:	52 years
Commander's Flying Experience:	6,820 hours (of which 374 were on type) Last 90 days - 53 hours Last 28 days - 12 hours
Information Source:	AAIB Field Investigation

History of flight

The helicopter's speed was being reduced to come to the hover out of ground effect at about 700 feet agl. At about 60 kt the pilot heard a loud bang; the right hand engine oil pressure and generator captions illuminated and he shutdown the right engine and carried out a precautionary landing in a field.

The right engine had suffered an uncontained failure of the first stage turbine wheel. A large piece of detached wheel rim, comprising slightly less than one quarter of the wheel's circumference, was found in the baggage compartment. The released engine debris did not damage the other engine or any essential aircraft system. An energy absorption ring is available for fitting around the turbine section of the Model 250 engine (CEB 1255) but the modification was not embodied on G-CAMB.

Engine examination

The detached piece of wheel rim was sent, with the engine turbine module and Fuel Control Unit (FCU), to an overhaul agency in the UK. The module was stripped and examined for any evidence or defects that could be related to the turbine failure. The engine conditions which were considered as potentially related to turbine wheel cracking included, an oil fire from a leak in the No 8 bearing, asymmetric combustion, overtemperature operation and the development, into the wheel, of cracks which are routinely found in the wheel platform (the outer edge of the rim) between the blades.

Because of the damage sustained it was not possible to check fully for the possibility of an oil leak from the No 8 bearing, either through pressure testing or dimensional checks. The cap which covers the No 8 bearing and the associated labyrinth seal were both heavily coated with carbon, a sign of thermal degradation of oil in the bearing, but no anomalies in the fit or the assembly were seen. The fuel nozzle spray pattern was normal and the combustion can and damaged first stage nozzles showed no sign of significant flame distortion. A rig test of the (Bendix) FCU showed nothing that was abnormal for a unit returned from service. A number of parameters were outside overhaul limits but all were within allowable field adjustments and within, or only marginally outside, service limits. Nothing was seen in the behaviour or adjustment of the FCU that was considered to be related to engine overheating.

The rim of the failed wheel exhibited many fine cracks in its platform and it seemed likely that the rupture had developed from one of these. Thermal fatigue is the normal process of deterioration of the wheel, driven by flight cycle heating and cooling, and fine fatigue cracking in the platform is the result of this. Some of the platform cracks extended from the platform around on to the front edge of the rim and, on the separated segment, one crack was seen which extended about 0.080 in down the leading edge. The manufacturer's Distributor Information Letter No 190 (DIL 190) gives acceptability/rejection criteria for first stage wheel rim cracks in turbine modules which have been stripped for repair (DIL 201 also applies). If cracks are restricted to the platform the wheel may be returned to service to complete its normal service life. If cracks extend into the leading or trailing edges of the rim, then any wheel with a crack that extends beyond 0.065 in down the edge must be rejected. Wheels with platform cracks that show less leading edge development may be returned to service but must be re-inspected after 500 hrs or 500 cycles.

It was agreed that the relevant parts of the turbine would be returned to the manufacturer for investigation. Some non-destructive examination of the failed wheel was carried out by DERA, Farnborough before it was sent to the manufacturer. As a precautionary measure the turbine module from the left engine was also sent to the UK agent for inspection. The first stage wheel in this module was found to contain numerous cracks in its rim platform. These were all within the limits of DIL 190 but the inspector was concerned by the large number of cracks present. This wheel was also sent to the manufacturer who subsequently stated that the number of platform cracks was not significant. Only the extent of individual crack development from the platform on to the leading or trailing edges, if it exceeded the stated limits, would be cause for concern. The manufacturer also confirmed that this wheel showed no sign of damage other than the thermal fatigue and, specifically, no sign of overheating.

The manufacturer found no positive evidence that there had been an oil fire in the right engine and an examination of surface deposits by DERA produced a conclusion that there had not been an oil fire. The oil used is phosphate ester based, and a fire leaves traces of phosphorus diffused into the metal surfaces, as well as more obvious oily combustion products deposited on the surfaces. Cooling air holes in the nozzle diaphragm allow air from the engine core to impinge on the front face of the turbine rim. If there is an oil fire fed by a leak in the No 8 bearing, then the fire is fed on to the wheel face through these holes. The fire also increases erosion of the holes. Some erosion was present but examination of a metallographic section of a cooling hole (and also of a rim sample) showed no phosphorus diffusion.

Over-temperature testing and effects

The first stage wheel is a cast nickel cobalt component (Mar-M-246). The manufacturing heat treatments result in a crystal structure called "gamma prime". In the past, the manufacturer has carried out studies of the stress distribution in the wheel by three dimensional inelastic stress analyses and by direct assessment of the residual stress in test wheels by X-ray diffraction. These tests were carried out on new wheels for the -28 version of the Model 250 engine, which are identical to the -20 version but for blade geometry, and the results were made available to the AAIB. One wheel served as a datum and two others were exposed to differing levels of overtemperature during start cycles in a test engine. These tests showed that high start temperatures moved residual stresses within the rim from compressive towards tensile and the more severe overtemperature test resulted in a crack in the rim. Stresses in the wheel are affected by thermal gradients as well as mechanical loads. During the start cycle the wheel rim reaches a higher temperature than the diaphragm and hub and the associated thermal expansion creates compressive stresses within the rim. If the event is sufficiently severe, through a combination of temperature and time, the rim can suffer yielding in compression and the residual compressive stress normally present after manufacture can be reduced or replaced with residual tensile stress. Rim stress varies from compressive to tensile during normal operation and the effect of the change in residual stress is to increase the operating tensile stresses in the rim whether transient, steady state or cyclic.

A severe hot start, or other over-temperature event, producing a metal temperature above the solution temperature of the gamma prime phase (2100ûF, 1149ûC) will change the crystal structure of the material. The loss of the gamma prime crystal structure produces deterioration in the mechanical properties of the material. It has been found, however, that the gamma prime phase can reprecipitate (recover) after a period (30 to 50 hours) of normal operation. A more extreme instance of overheating can also produce oxidation of the blades and vanes**.** Development to rupture can progress from cracks created in the rim by a single overheat or from the already existing thermal fatigue cracks in the platform. With the change in residual stress and the increased levels of static (non-cyclic) tensile stress that result from an overtemperature event, it has been found that subsequent crack development, even at normal operating temperatures, is by a rapid creep-assisted process, though initially there may be a mixture of fatigue and creep. Fatigue is evident by its flat morphology and creep by its rough interdendritic nature.

Detailed fracture and turbine component examination

The fatigue initiation of the main fracture was multi-origin in nature, initiating from the surface, and was similar to the other platform cracks in the wheel. It did not appear, therefore, to have developed from a material defect and was typical of stress-driven, thermal fatigue. Semi-quantitative X-ray Energy Dispersive Analysis (XEDA) of the material showed that it closely conformed to the requirement for Mar-M-246 and it had the correct gamma prime microstructure. The initiating fatigue fracture had extended from the platform around to the leading edge. How far the fatigue extended down the leading edge was obscured by damage but it was considered to be close to the maximum allowable crack length of 0.065 in. The fatigue penetrated to a depth of 0.1 in and was heavily oxidised. To a depth of about 0.5 in the fracture mode was interdendritic, also oxidised, and then it became tensile overload.

All of the blades had been damaged and had lost much of their span. No heavy oxidation of the blade or vane surfaces was observed. The longest remaining blade (75% span) was sectioned for metallographic examination, as was a sample of rim material. Both showed gamma prime microstructure. This showed that any overheating that had occurred had not subjected the blades to more than 2100ûF/1149ûC or had taken place a sufficiently long time before (30 - 50 operating hours) to allow reprecipitation of gamma prime to take place. Rolls-Royce Allison stated that overtemperatures resulting in metal temperatures below this level could still cause changes in the residual stress in the rim and produce the interdendritic creep crack growth observed on the fracture surface. In an overtemperature event the blades normally experience higher temperatures than the rim and could show gamma prime loss when the rim had not been affected in this way. The gamma prime condition seen in the blade micro-section was finer than that seen in the rim. Such finer microstructure had been seen in a sample that had been heated above the solution temperature and then re-precipitated at the normal engine operating temperature. This, therefore, appeared consistent with an overtemperature having occurred and the blades suffering solutioning and reprecipitation.

Conclusion

The manufacturer stated that the pattern of interdendritic fracture development from the thermal fatigue initiation, was indicative of rapid creep assisted crack growth. The company was unaware of any way in which such fractures could form other than following exposure to high turbine temperatures, usually associated with engine start-up, in excess of the limits given in the Model 250 Operation and Maintenance Manual.

The operator reported that the pilots who flew G-CAMB did not consider that the engines showed any tendency to exceed starting temperature limits and in general did not exceed 850°C. The aircraft was fitted with two batteries and the extra capacity helps the starting process. The operator pointed out that G-CAMB was not being operated in a commercial or training environment. The operating philosophy placed great emphasis on safety and as a "no blame" culture was promoted he was confident that crewmembers would report any observed overtemperature events.

The pilot is required to monitor five parameters during engine start; gas generator rotation speed (N1), Turbine Outlet Temperature (TOT), power turbine rotation speed (N2), oil pressure and elapsed time. The TOT rises rapidly when fuel is introduced during the start cycle and the temperature profile can show two peaks before is stabilises at IDLE. There is a temperature band (810 to 927ûC) above the primary limit which may be entered for up to 10 seconds and a higher band (927 to 999ûC) which requires turbine inspection. If the ultimate limit of 999ûC is exceeded wheel replacement is mandatory. In some aircraft installations of the Model 250 a TOT gauge is available which records exceedances; a light on the gauge illuminates, and the light can only be switched off through a lock-switch, normally by maintenance personnel. No such gauge system is currently made available to operators of the AS355F2 Ecureuil II by the aircraft manufacturer. Given that an uncontained turbine burst can result from a hot start or other temperature exceedance the following recommendation is made:-

Safety recommendation No 2000-51

It is recommended that:-

Eurocopter make available to operators of the AS355F2 Ecureuil II helicopter a Turbine Outlet Temperature indicating system which will register and record temperature excursions above Rolls-Royce Allison Model 250 allowable limits.