ACCIDENT

Aircraft Type and Registration:	Hawker Sea Fury T Mk 20, G-RNHF
No & Type of Engines:	1 Bristol Centaurus XVIII piston engine
Year of Manufacture:	1949 (Serial no: ES3615)
Date & Time (UTC):	31 July 2014 at 1601 hrs
Location:	RNAS Culdrose, Cornwall
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Engine internal disruption, right wingtip, flap and minor fuselage abrasion damage
Commander's Licence:	Military
Commander's Age:	44 years
Commander's Flying Experience:	3,545 hours (of which 232 were on type) Last 90 days - 54 hours Last 28 days - 35 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft was performing in a public air display at Culdrose when the pilot became aware of a significant engine vibration and then a corresponding loss of thrust. Despite the loss of engine power the pilot was able to land the aircraft on the runway but the landing gear collapsed on touchdown, causing it to veer off the runway. The aircraft came to a stop on the grass approximately 1,500 ft from the initial touchdown point. The pilot vacated the aircraft unaided and without injury. The accident was a result of the loss of engine power caused by severe mechanical disruption within the 'front row' crankcase of the engine. The breakup may have been caused by the failure of an articulated connecting rod wrist pin bearing, possibly due to overheating, the cause of which is not yet known. Forensic investigation is continuing, to establish the exact cause.

History of the flight

The aircraft launched to carry out a public air display at RNAS Culdrose. The pilot noted at takeoff that all the engine temperatures and pressures were normal and remained so during the first few manoeuvres of the display. However, as the aircraft descended from 2,000 feet at 200 KIAS for the next stage of the display, the pilot became aware of a significant engine vibration and brought the power back to a "more gentle" cruise position and declared a PAN. The instrument panel was vibrating but no abnormal indications were evident and the pilot could not accurately read the engine oil pressure. At about this time witnesses saw white smoke coming from the engine exhaust stubs. The pilot immediately aborted the manoeuvre and used the aircraft inertia to zoom-climb back to 2,000 feet at 130 KIAS and then positioned the aircraft abeam for a landing on Runway 30. As he approached the runway he lowered the landing gear and lowered the nose to maintain 130 KIAS. At this point he opened the throttle to maintain the runway sight line but it became clear that the engine was producing no usable power. The glide angle was unsuitable so the pilot selected rpm to AUTO to coarsen the propeller and he raised the landing gear to reduce drag and improve the glide angle. He considered abandoning the aircraft but decided against it as the actions already taken, along with selection of flap, had improved the situation and gave a probable touchdown point just inside the airfield boundary.

The pilot initially aligned the aircraft to the left of the runway and then, as the aircraft flared over the grass, manoeuvred towards the runway for landing. He noted that there seemed to be sufficient hydraulic pressure being developed by the still-turning engine and re-selected the landing gear down, to minimise damage to the aircraft. After holding off for as long as possible he landed the aircraft with a gentle touchdown, on the left landing gear followed by the right. At this point the right landing gear folded, the wing dropped and the propeller blades struck the runway. The aircraft veered to the right and shortly before leaving the runway the left landing gear also collapsed. The aircraft eventually came to a stop on the grass, approximately 1,500 feet from the initial touchdown point. The pilot then made the aircraft safe and exited without further incident. The aircraft had sustained damage to all five propeller blades, the spinner and to the underside of the fuselage, landing gear and wing (Figure 1). Both sides of the fuselage and tailplane were almost completely covered by a film of oil. Despite the loss of power and the propeller impact with the ground, the engine had no external signs of damage.

Figure 1

Sea Fury T Mk 20 G-RNHF

Bristol Centaurus Mk18 engine description

The Centaurus engine was designed and built by the Bristol Aeroplane Company in the early 1940s for use in a variety of single and multi-engine aircraft types. It was derived from the Bristol Perseus and Hercules engines used before and during World War II. The Centaurus was, and remains, one of the most powerful piston aero-engines to enter service and was very successful in the Hawker Sea Fury. The engine is an eighteen-cylinder double-row sleeve valve supercharged radial, with a 53 litre capacity and capable of producing 2,500 horsepower. In the Sea Fury it is fitted with a five-bladed Rotol propeller. This combination gives the aircraft a service ceiling of 35,800 ft and a top speed of 460 mph at 18,000 ft. G-RNHF is a T Mk 20 which is the two-seat trainer variant of the Sea Fury aircraft.

Fuel, ignition and lubricating systems

Fuel is metered via an injection carburettor and ignition is by twin magnetos and two spark plugs per cylinder. The engine has a direct-pressure filtered ‘dry sump’ lubrication system and oil is fed under pressure to the main crankshaft white metal bearing and, via drillings, to each wrist pin. The wrist pin bearings are made of phosphor bronze, an alloy of copper, tin and a small proportion of phosphor. The pistons, gudgeon pins, cylinders and sleeve valves are lubricated by splash and oil jets.

Valve gear

The engine uses sleeve valves rather than conventional poppet valves. The advantages of sleeve valves are a high volumetric efficiency and better thermodynamics and gas flow during combustion. They also overcome the problems of ‘valve bounce’, spring resonance and inertia; the energy required to operate sleeve valves remains constant throughout the rpm range. The disadvantages are that sleeve valves require a complex gear drive and synchronising mechanism and can have lubricating, sealing and cooling problems, along with high oil usage.

In the Centaurus the sleeve valves in each cylinder row are driven by front and rear spur reduction gear trains. There are three gear sets per row, driven by the crankshaft, and each set has three outputs to the sleeve cranks. The cranks are attached to the sleeves by knuckle joints and as the cranks rotate, the sleeves are driven up and down the cylinders. The arrangement of the cranks causes the sleeves to twist through a few degrees as they pass up and down the cylinder.

Engine history

This engine, serial number 37726, was one of four originally exported to Iraq by the Bristol Aeroplane Company in the late 1940s. In 2010 the engine returned to the UK still in its original crate and was stripped to confirm fits and clearances. An internal inspection confirmed it as only ever having been test run and the overhaul required one sleeve replacement, due to corrosion, along with rubber parts for age-related deterioration. The engine was fitted to G-RNHF and by the date of the accident had accumulated 220 hrs of its 500 hr overhaul life.

Engineering investigation

After the accident, the aircraft was recovered to a hangar at RNAS Culdrose and the damage assessed. The damage to the fuselage, wing and flaps was minor and attributable to the aircraft veering from the runway and sliding along the grass. The propeller blade damage was consistent with striking the ground at low power. The evidence suggested that a major but contained component failure had occurred within the engine, although there were no outward signs of distress. There were approximately 10 gallons of lubricating oil removed from the tank and oil and filter debris samples were sent for analysis. The engine was removed and transferred to the aircraft maintenance facility at North Weald. After a boroscope examination the cylinder heads were removed, which revealed that the No16 (front-row) piston and articulated connecting rod ('con-rod') were missing. Figure 2 shows the distressed wrist pins through the No16 cylinder. There was also substantial mechanical damage to the other visible con-rods, of which some were detached from the master con-rod.

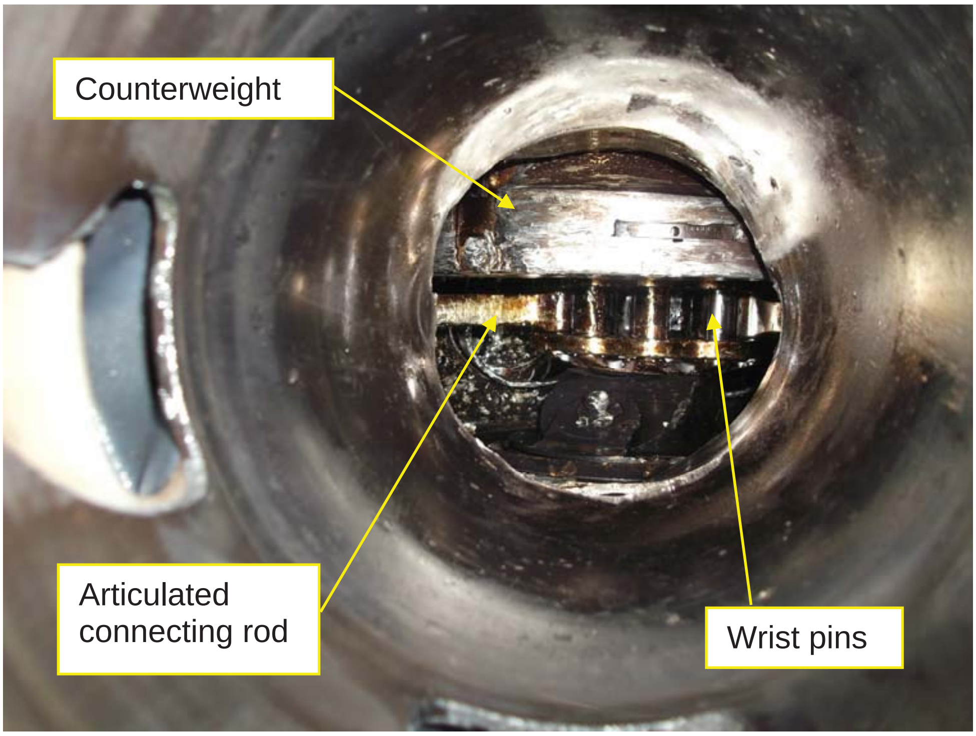

Figure 2

Master con-rod wrist pins viewed through the No16 cylinder

Further conventional disassembly was not possible due to distortion of the cylinders and sleeve valves. In order the gain access to the front row crankcase the gear carrier plate was chain drilled and removed. Figure 3 shows the crankcase component damage and debris.

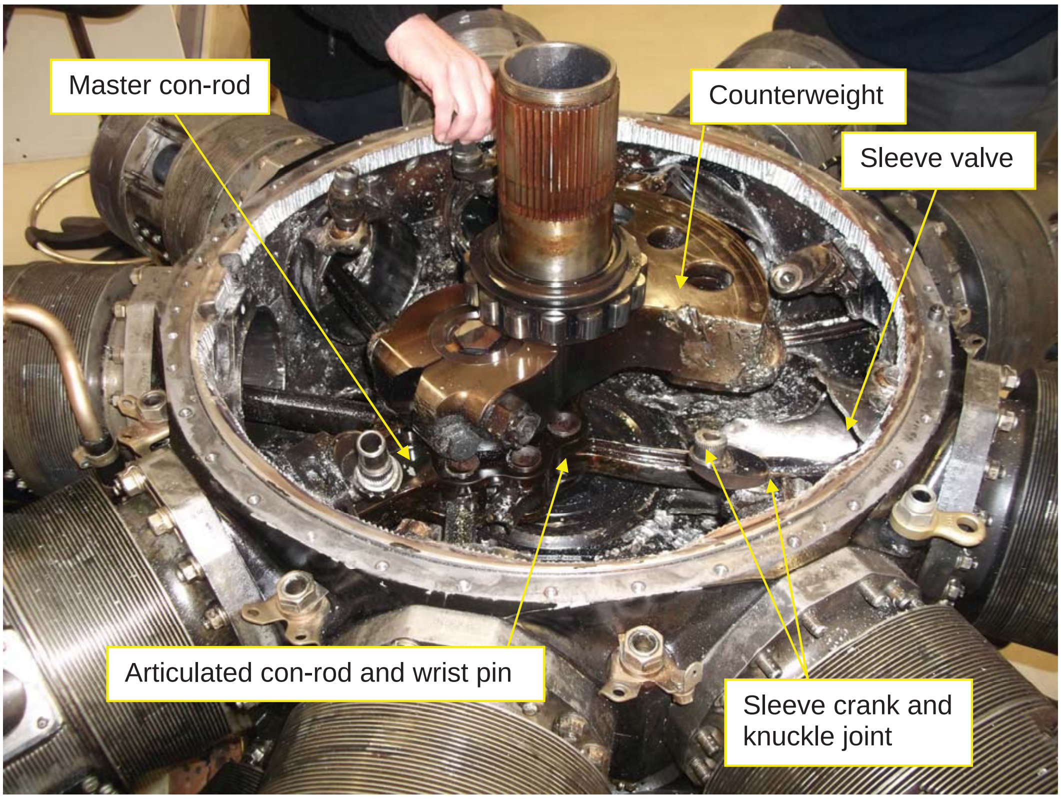

Figure 3

Front row crankcase component damage

The majority of the components within the crankcase were severely damaged. All the sleeve driveshafts showed signs of torsional overload and some of the driveshafts had failed. The majority of the knuckle joints, which attach the drive crank to the sleeve, were damaged and in some cases had detached. Several of the sleeves had been severely damaged, in particular where they had extended out of their respective cylinders into the path of the crankshaft counterweight. Multiple impact marks were also present as a result of increasing amounts of churned-up debris. The front row sleeve valve gear trains were generally intact and meshed, except for one of the valve crank drive and idler gears which had damage indicative of gear tooth overload.

Closer examination of the debris removed from the crankcase identified forged steel con-rod and aluminium piston material. The remains of No16 piston were found loose and had the appearance of a pulverised and flattened sphere. The con-rod material, particularly from the wrist pin ends, showed signs of extreme heating and appeared to have been splattered with molten copper. Examination of the wrist pins and their associated holes in the master con-rod showed similar evidence and one of the broken con-rod wrist pin ends exhibited the characteristics of plastic deformation leading to failure. Lubricating oil was present throughout the crankcase but showed evidence of overheating and had lacquered various surfaces. It was also observed that the gear carrier diaphragm outer surface was discoloured with hot oil lacquering. Normally this surface would be a bright silver grey.

The rear row of cylinders, con-rods, sleeve valves and pistons were generally undamaged, although some metallic debris had found its way through ports in the diaphragm which separates the front and rear row. The supercharger, plugs, magnetos and accessories were also found undamaged.

The results of the oil analysis showed that, although various metallic chemical elements were present, their levels were only slightly above those found in normal running and were consistent with previous routine sample analysis of this engine. However, the filter was heavily contaminated with metallic debris and twelve different types of metal were identified including white metal, bronze, aluminium and various types of carbon steel.

Analysis

Witness video evidence showed the aircraft carrying out the various phases of the display normally. However, during one of the manoeuvres white smoke emerged from the exhaust stubs on both sides of the aircraft. The propeller remained turning, at a reduced rpm, until eventual impact with the ground. The pilot was of the opinion that, although the engine was not producing significant power, one row of cylinders continued to operate. The evidence confirms that it was the rear row of cylinders that continued to operate. The performance, temperatures, pressures and settings of the engine seemed normal. This led the pilot to believe that, in the early stages of the incident, he just had a rough running engine. It was only after he attempted to change his power setting that he realised that all was not well and that the engine could not be relied upon. Despite the engine problem the pilot was able to make a forced landing and cause little further damage to the aircraft.

There are two possibilities as to the nature of the initiating event within the engine. The lack of any physical warning immediately prior to the engine failure suggests that the situation may have developed slowly, without adversely effecting other systems or components. Alternatively, it is possible that the initiating event occurred very quickly, leaving no time for secondary indications. The evidence of heat on remote components, such as the gear carrier diaphragm, indicates that it was a slow development.

The localised heat evidence on the master con-rod suggests that one or more adjacent wrist pin and con-rod bearings overheated, leading to material failure and resulting in a piston, and the remains of its con-rod, stopping in its sleeve. The clearance of the crankshaft counterweight is such that anything in its path would be struck with massive force. It appears that the No16 con-rod was caught and dragged out of its cylinder and this resulted in it being knocked around the inside of crankcase, causing further damage. The counterweight and knuckle joint clearance is very small, so damage caused by high-energy loose debris impact would quickly lead to sleeve valve de-synchronisation.

Some of the sleeve valves were found at or below lowest points of travel in the path of the counterweight, with substantial swaging and tearing of their lower ends, enough to jam them within the cylinders. This disruption is likely to have caused the gear slip and the torsional damage found on the cranks, which led to the complete loss of synchronisation and further damage to the sleeves.

Conclusion

The engine failure was a result of the breakup of mechanical components within the front row of the crankcase. The evidence suggests the failure sequence included the failure of one of the articulated con-rods, in the vicinity of its wrist pin bearing, and that this was caused by severe heating. The cause of the overheating is yet unknown. Forensic investigation is continuing, to establish the exact cause of the engine failure.

BULLETIN ADDENDUM

At the time the original report was published in July 2015, evidence suggested the breakup was as a result of an overheated articulated connecting rod (con rod) wrist pin bearing. After the report was published, forensic work continued to try to establish the exact cause of the engine failure and the AAIB undertook to publish the relevant findings when available.
These findings have now been published as an addendum in the September 2017

ACCIDENT REPORT ADDENDUM

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Synopsis

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Introduction

The accident report, EW/G2014/07/32, was published in AAIB Bulletin 7/2015 and at the time evidence suggested the breakup was as a result of an overheated articulated connecting rod (con-rod) wrist pin bearing. After this report was published, forensic work continued to try to establish the exact cause of the engine failure and the AAIB undertook to publish the relevant findings when available.

Despite the extensive destruction of most of the components within the front section of the engine, forensic analysis has been able to determine that severe overheating had occurred in the crankpin sleeve bearing in the front bank of cylinders. This led to a chain of events within the engine which became increasingly destructive to the wrist pin bearings, connecting rods, pistons and sleeve valve gear. This destruction was exacerbated by the rear bank of cylinders continuing to run until the accumulated damage within the front bank of the engine stopped the engine producing useable power, although it continued rotating as the aircraft landed until its landing gear collapsed. The extreme damage to the components of the front bank of cylinders left insufficient evidence to determine conclusively the initial cause of the engine failure.

System description

The Bristol Centaurus engine is an eighteen-cylinder double-row sleeve valve supercharged radial, with a 53 litre capacity, capable of producing 2,500 horsepower. Figure 1 and Figure 2 show the arrangement of the master con-rod, articulated rods, crankpin and floating retainer assembly.

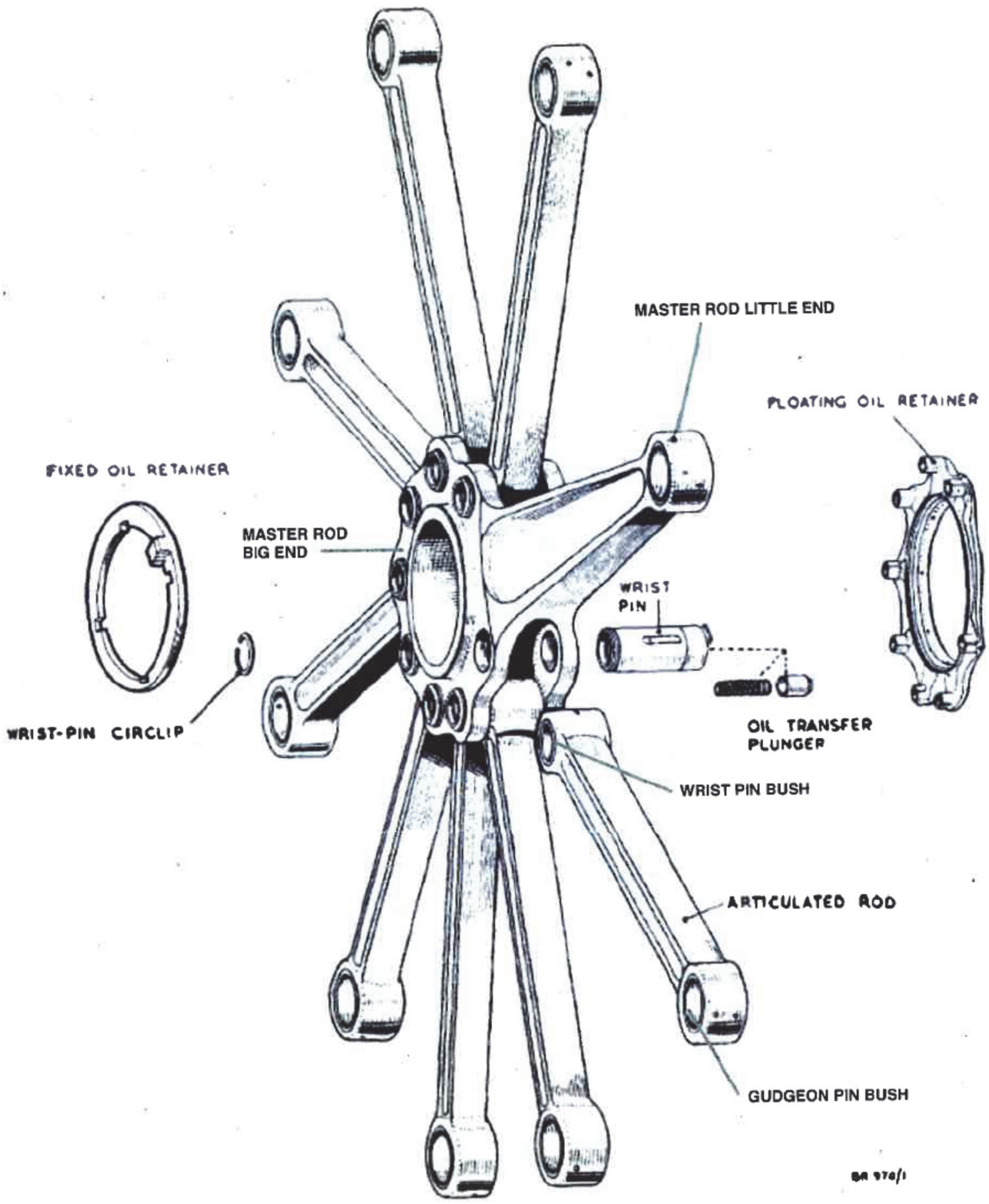

Figure 1

Master and articulated connecting rods with the floating oil retainer

Lubrication system

In this engine, oil pressure is generated by the main oil pump at a nominal 100 psi and distributed into four separate sub-sections around the engine. A main oil feed passes through a tube inside the supercharger into the rear end of the crankshaft. It then travels forward along the crankshaft, finally exiting through feedlines to lubricate the reduction gearbox. Along the way, oil is forced through various ports and jets to lubricate bearings, pistons and cylinders. High-pressure oil also feeds the 'centrifugers', which remove any sludge and aeration before it is used to operate the supercharger control valve and drive system. Another high-pressure feed is supplied to the governor before entering the propeller constant-speed unit. Oil pressure is then reduced by a reduction valve to lubricate the sleeve valve drive system and a small supply of low-pressure oil lubricates the magnetos.

Return oil from the spray jets and oil that has passed through the bearing, collects at the bottom of the engine where it is scavenged by front and rear pumps. Oil is trapped in some locations and used as splash lubrication for start-up.

The oil system in G-RNHF contained a sufficient quantity of lubricating oil and samples taken at the time showed that the oil had suffered some adulteration during the engine failure, but this is not considered causal or contributory to the engine failure.

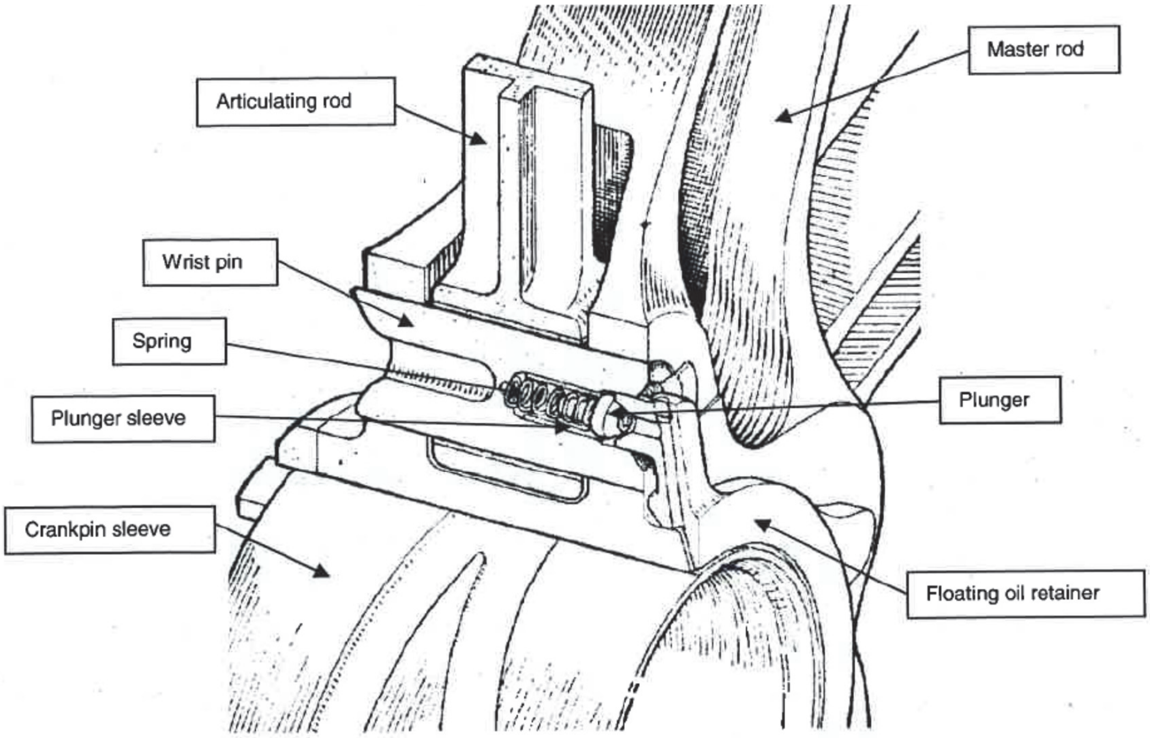

Figure 2

Crankpin sleeve and wrist pin assembly

Crankpin assembly

The crankpin carries all of the loads into the crankshaft from the master and articulated connecting rods via a white metal crankpin sleeve bearing. This bearing is pressure lubricated via ports within the crankshaft. From there oil is collected by an oil retainer, known as the floating oil retainer, which distributes oil to the centre of the wrist pins to lubricate the phosphor bronze wrist pin bearing surfaces. Oil pressure is maintained within the wrist pin by a spring loaded plunger which seals the gap between the wrist pin and floating oil retainer.

Sequence of events

Forensic analysis was carried out in the materials laboratories of 1710 Naval Air Squadron (1710 NAS) within the Royal Navy. The following sequence of events have been identified and are summarised from their report:

> ‘a. *For reasons unclear the forward crankpin sleeve bearing overheated, cracked up and liberated flakes of white metal.*
>
> b. *Breakup of the bearing resulted in greater overheating, melting the white metal bearing surface.*
>
> c. *Liquid tin from the bearing penetrated along the grain boundaries of the forward master rod, causing embrittlement at the grain boundaries.*
>
> d. *The embrittled grain boundaries cracked and some fragments of the master rod around the bore become separated. This process continued as the liquid tin penetrated more deeply.*
>
> e. *Loose fragments of master rod material from around the bore gouged the bore surface and the sleeve, overcoming the interference fit and causing it to spin with the master rod, finally cutting off any possible oil flow to the connecting rod assembly.*
>
> f. *Continued embrittlement, high temperature and high stress caused the master rod to burst locally at its thinnest and highest temperature points, behind the wrist pins #16 and #18.*
>
> g. *Erupted material interfered with articulating rods #16 and #18 and frictionally heated them, causing them to overheat, soften and fail.*
>
> h. *The unrestrained piston and articulating rod #16 came out of their cylinder into the engine core and were impacted by the counterweight.*
>
> i. *Continued impacts fractured and propelled the piston, gudgeon pin and articulating rod around the engine core, impacting and damaging other components.*
>
> j. *At some point the gudgeon pin became momentarily trapped and was impacted, shattering it.*
>
> k. *Debris fragments became trapped in the sleeve driving mechanism, jamming them and causing them to fail.*
>
> l. *Throughout the above, the heat generated around the forward crank pin propagated back into the rear bank crankpin, overheating the crank pin sleeve bearing causing it to start breaking up.’*

This sequence was arrested when the landing gear collapsed and the propeller struck the ground and stopped as the aircraft slid along the grass alongside the runway.

Possible contributory factors

Although the exact feature which caused the crankpin sleeve bearing to overheat is unknown, there are a number of areas of interest which may have been contributory factors. These factors have been extracted from the 1710 NAS laboratory report and are set out below:

'a. Pieces of a fibrous cellulose material were found within the engine from an unknown source. One was causing a partial blockage of the rear crankweb oil jet, which could not have caused the failure, but in combination with the piece found loose in the crankcase indicates that there was debris in the system. The source could not be confirmed. The material may have come from a degraded fibre gasket somewhere in the system, or possibly from an original gasket that was replaced during earlier maintenance. Alternatively it could have come from a source outside the engine and entered at some point during its life. It is possible that some of this debris may have entered the forward crankpin bearing and disrupted the lubricating oil film, leading to overheating. Cellulose debris may have passed through that bearing and blocked the oil supply to a wrist pin, heating the pin and transmitting heat into the master rod, overheating the crankpin bearing. Whichever specific mechanism, overheating of the crankpin bearing resulting from contamination of the system with fibrous cellulose debris is considered a possibility.

b. The crankshaft oil retainer gland was found to be severely embrittled. This may have been due to heat transmitted along the crankshaft or may have been due to its extreme[1] age. If it was embrittled prior to the accident it may have stopped working as an effective seal and caused a pressure loss inside the crankshaft. This pressure loss may have disrupted the oil film in the crankpin bearing and allowed it to overheat. The pressure distribution around the engine is not understood in enough detail to determine if a leak of this type would have been detectable to the pilot. This scenario is considered to be a possibility.

c. It is possible that hard debris, from an external source or a part of the engine or oil system not found, was able to enter the forward crankpin bearing and either cause abrasive wear and overheat it or block local oilways, allowing a wrist pin to overheat. If this was the case then the debris was displaced during the failure sequence and not subsequently recovered. This scenario cannot be conclusively ruled out.

d. It is possible that an out of balance loading on the forward connecting rod assembly transmitted an excessive loading to the forward crankpin bearing, causing it to overheat. No evidence was observed to indicate that the assembly was intrinsically out of balance.'

Footnote

[1] It is possible that this seal was originally fitted to the engine when it was built prior to delivery to Iraq in the late 1940s. There is no evidence to suggest this seal was replaced when the engine was brought back into service in 2010.

Discussion

The Centaurus engine is fitted with roller main bearings and conventional close tolerance white metal bearings on the crankpins. White metal, in this case known as Babbitt metal, is an alloy of copper, tin, lead and antinomy alloyed to give a low-friction but hard-wearing surface. The low friction and heat conduction properties of the material is further enhanced by the oil lubrication system whereby a hydrodynamic oil film forms under pressure on the bearing surface. Although the bearing will operate without too much difficulty during momentary reduced lubrication, sustained loss or constant reduced lubrication will result in bearing damage. The damage will initially manifest itself in scuffing and scoring in the bearing surface and is often referred to as 'running' a bearing. Heat is generated in this process and in most circumstances will degrade any oil present, reducing lubrication further. Eventually the heat generated will be so great that bearing damage occurs, as observed in this engine.

Unlike in-line engines, where the big end bearing only carries a single piston load with an impulse once per revolution, a radial engine crankpin bearing carries multiple impulse loads per revolution from the articulated con-rods via wrist pins into the master con-rod. Should a crankpin bearing become distressed, the multiple impulse effect can accelerate the situation and therefore degrade more rapidly than with an in-line engine. If the crankpin bearing is overheated and starts to fail, the wrist pins by their design and location, will also be susceptible to any excess heat from the nearby crankpin bearing.

The evidence, in this case, shows an overheated crankpin bearing and this may be as a result of a seriously degraded or complete loss of lubrication. The condition of the other major engine components, such as the rear bank and supercharger, suggests a localised problem. It is possible that unidentified debris interrupted oil to the bearing. Of interest was the embrittlement of the crankshaft oil retainer gland. Loss of the sealing capabilities of this gland could result in a sustained weakening of the hydrodynamic oil film which may lead to the 'running' of the bearing over a very short period.

In either case the temperature generated would eventually cause any remaining oil present to boil or burn off the vital surfaces in an ever-worsening cycle.

Conclusion

The evidence suggests a localised lubrication problem led to a severe overheating of the crankpin bearing. An extensive forensic examination of the engine has been carried out and it has not been possible to identify the exact initiator that led to this situation. However, it has been possible to identify the precise sequence of metallurgical effects on key components as the bearing overheated and failed, which resulted in the highly destructive chain of events within the front crankcase.

Safety action

Various marks of the Centaurus engine are still in use in a small number of aircraft but findings in this case could equally apply to other radial and in-line aero-engine types. Based on this, the CAA has undertaken to publish a

Safety Notice aimed at the historic aircraft community, to draw attention to the issues and difficulties of maintaining airworthiness of aging aircraft engines and their associated components.