Aircraft Type and Registration:	Pulsar, G-MCMS	
No & Type of Engines:	1 Rotax 582 piston engine	
Year of Manufacture:	1993	
Date & Time (UTC):	25 July 2004 at 1305 hrs	
Location:	Near Taynuilt, Scotland	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - 1 (Serious)	Passengers - N/A
Nature of Damage:	Damage to landing gear and fuselage belly	
Commander's Licence:	Private Pilot's Licence	
Commander's Age:	52 years	
Commander's Flying Experience:	408 hours (of which 50 were on type) Last 90 days - 24 hours Last 28 days - 4 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot and metallurgical examination of radiator failure	

History of the flight

The Pulsar, pictured at right, is a low-wing composite single-seat kitplane operated under a Permit to Fly. The aircraft was on a cross-country flight from Perth to Oban. Ten miles away from Oban the pilot called Oban Radio and requested the airfield information. He did not receive a reply but he heard the wind direction and speed being passed to another aircraft. While at 4,000 feet on the Oban QFE the pilot detected a slight burning smell. He advanced the throttle but the engine did not respond. The pilot immediately declared a MAYDAY, stating his position and the nature of his emergency to Oban Radio, but the Oban radio operator was unable to decipher the message. Due to a strong westerly wind the pilot decided that he would be unable to reach Oban. There were no suitable fields nearby for a forced landing so the pilot selected a field on flat ground beside a river and planned a circuit while repeating his MAYDAY transmission several times but with no response. At approximately 1,000 feet agl the engine seized. The aircraft reached the chosen field but the touchdown was hard and the field was rough with cows grazing at the eastern (near) end. The landing gear separated during the ground roll and the aircraft decelerated rapidly to a rest. The propeller had stopped in a horizontal position and so was undamaged. The pilot was able to vacate the aircraft by opening the canopy as normal and then telephoned '999' from his mobile phone for assistance. It was later determined that the pilot had suffered from a crushed vertebra.

Aircraft's engine cooling system

The aircraft's Rotax 582 engine is liquid cooled using two small radiators that are mounted within the forward cowling (see Figure 1). The primary hoses A and D between the engine and each radiator have an inside diameter of 1 inch. The cross-over hoses B and C between the radiators have an inside diameter of 5/8 inch. There are rectangular slots within the upper and lower cowlings to hold the radiators in place. The grey adhesive 'gaffer' tape that is visible on the port radiator in Figure 1 was, according to the owner, applied to ensure a snug fit within the upper cowling slot.

The aircraft's instrument panel was fitted with a water coolant temperature gauge but not with a temperature exceedance warning light or aural warning. Because the Rotax 582 is a two-stroke engine there were no oil temperature or oil pressure gauges. The Pulsar construction manual warns: '*if the water ever leaks out of the system in flight, you'll find yourself in a glider in probably less than a minute*.'

Engine examination

A Popular Flying Association (PFA) inspector examined the engine following the accident. He discovered that all the coolant had drained from the radiators. There was a small pool of coolant in the lower cowling and the port radiator's outboard hose coupling had detached from the radiator - circled area in Figure 1 and close-up in Figure 2. The failed coupling, the port radiator and the port radiator hoses were sent to the AAIB for a more detailed examination. An engine strip was subsequently performed by the PFA inspector which revealed severe over heating damage of piston number two.

Examination of radiator hoses

There was no evidence of any leaks within radiator hoses C or D. Hose D had a slight bend in it but it was a straight hose that had retained some of its bend from having been bent into position for a long period. The Pulsar construction manual states that hose D should be constructed from two pieces of straight hose that are then joined together with the 45° copper fitting supplied with the kit (the alternative is to use a curved moulded hose). This should ensure that no side load is imparted to the radiator coupling.

Examination of radiator and failed coupling

The port radiator and failed coupling were examined by an independent organisation with metallurgy and fracture expertise. The following is a summary of their findings. A visual examination of the brass radiator showed that the whole circumference of the detached area exhibited a fracture surface and that the corresponding coupling still had a section of the brass radiator attached to it (see Figures 3 and 4). This indicated that the failure occurred in the radiator material rather than in the brazed joint between the coupling and the radiator. A cross section of the failed coupling and the intact coupling on the other end of the radiator revealed their composition (see Figures 5 and 6). A brass connecting tube had been inserted into an opening within the radiator and then brazed with a silver based filler metal. A copper coupling had then been soldered to the brass connecting tube with a lead-tin based solder. The evidence of lead-tin solder on the inner surface of the brass connecting tube suggested that the copper coupling had been dip soldered. Lead-tin solder also coated the outer surface of the brass connecting tube and radiator joint. There were no differences in the construction of the failed and intact couplings although the connecting tube of the failed coupling appeared to be offset downwards at an angle of approximately 5°.

The majority of both the fracture surfaces on the radiator and on the coupling were masked by contaminants apart from a small area of the fracture in the upper left position of the radiator (see Figure 3) which was clean. The fracture surface of the detached section was examined under a Scanning Electron Microscope (SEM). The SEM examination did not reveal conclusive evidence of the failure mechanism but it was likely that the clean area of the fracture was the last section to detach and that it occurred due to overload. The lower half of the fracture (with reference to Figure 3) was more obscured by damage and surface contamination; however, small patches were observed which showed a transgranular fracture that appeared to have corroded. This evidence suggested that this part of the crack had been present for a longer period than the cleaner area hence the crack appeared to be progressive. The fracture surface in this area also showed some faint parallel markings that may be evidence of fatigue striations, although they were not clear enough to confirm this positively.

There was a build up of solder around the lower part of the fracture (see Figure 3) and there was solder contamination on the lower right area of the fracture – the area from which the crack is likely to have propagated. Lead-tin solder usually melts in the range of 180°C to 320°C depending on its exact composition. The solder contamination on the fracture surface may have been a result of local overheating during the engine failure which resulted in some of the solder melting and being drawn into the crack. However, the radiator was not in direct contact with the engine and therefore the engine bay itself would have had to reach a temperature of 180°C to 320°C. It is also possible that the solder contamination is evidence of a repair. Because it is likely that the crack growth was progressive, it is possible that a coolant leak was observed at some point before final failure occurred. The leak around the area of failure could have been mistaken for a poor joint and re-soldering may have been carried out to rectify the leak. Re-soldering would have filled the crack and temporarily stopped any leaks but a fatigue crack in the brass radiator would still have propagated under the influence of cyclic loading from engine vibration through the hose.

History of the aircraft

The aircraft was manufactured from a kit and first registered on 3 February 1993. In 2001 the original owner, who built the aircraft, sold it to its present owner who was the accident pilot. The AAIB tried to contact the original owner by phone and e-mail but received no response. The present owner was very helpful during the investigation. He stated that no repairs had been carried out on the radiator system during his period of ownership and that no record of a repair was detailed in the aircraft's logbook. He had also not changed any of the radiator hoses. The aircraft had sat unused for one and a half years until December 2003 when it was inspected and issued with a new Permit to Fly on 22 December 2003. Since then the aircraft had flown 35 hours leading up to the accident flight and it had logged a total of 261 hours. The pilot had not noticed a leak from the radiator coupling prior to the accident flight or any preceding flights, although any leak would have been somewhat obscured by the surrounding grey masking tape and black tape around the coupling.

Analysis

The engine failed because it overheated following a loss of radiator coolant. The radiator lost its coolant in flight through either a crack or complete detachment of the port radiator outboard coupling. An examination of the coupling fracture revealed that the brass radiator had failed rather than the solder or brazing material. The results from an SEM examination of the fracture surface were not conclusive but it appeared that a crack had initiated on the lower right part of the fracture surface (with reference to Figure 3) and then propagated circumferentially until it failed in overload at the upper left part of the fracture surface. The evidence of a heavy solder deposit and solder contamination on the lower fracture surface raised the possibility that an inadequate solder repair had been carried out, although this could not be confirmed from the aircraft records.

The hose connecting the engine to the failed coupling was a straight hose that had been bent into position whereas either a moulded hose or a two-piece hose with a 45º intermediate joining piece should have been used. The bent hose would have applied some side load to the coupling which, together with the cyclic loads imparted from engine vibration, may have induced fatigue crack growth in the coupling. The crossover hose from the other radiator could also have applied a side load to the coupling. Furthermore, the brass connecting tube of the failed coupling was offset downwards at an angle of approximately 5° which may also have contributed to the loading at the edge of the joint.

The PFA and Pulsar Aircraft Corporation were contacted regarding this accident and neither organisation was aware of any similar failures having caused accidents in the past. The accident pilot was aware of another pilot who had suffered from a leak at the radiator fitting although it was not clear whether this was as a result of a stress fracture in the brass or a leaking solder joint. The AAIB spoke to another Pulsar pilot who approximately five years ago experienced a leaking radiator fitting in flight. He became aware of the problem when coolant fluid started to spatter the windscreen but he was able to carry out a precautionary landing before the engine failed. In that case the pilot stated that he had used a curved moulded radiator hose, but again the exact failure mechanism was not known. The pilot of G-MCMS said he had recently discovered that some Pulsar owners used 'Ronyflex' hose which is a more flexible type of hose than that supplied with the kit, on the basis that this would reduce the cyclic loads imparted from the engine to the radiator. The PFA was not aware of the 'Ronyflex' hose type.

The current owner of the Pulsar Aircraft Corporation did not design the original Pulsar and therefore did not comment directly on this accident but referred the AAIB to an experienced Pulsar kit builder and pilot in the USA. This builder and pilot stated that the Rotax 582 engine was known for its high level of vibration and that vibration would be transmitted through the radiator hoses. In his opinion, the use of a straight hose induced stress which caused the failure of the radiator coupling on G-MCMS. He had not heard of 'Ronyflex' hose before and could not comment on its use. He also said that the radiator was supposed to be held rigidly by the upper and lower cowlings.

Conclusions

Regardless of the cause of the coupling failure, Pulsar owners would be well advised to ensure that their aircraft is fitted with the correct hoses as detailed in the engine manual or an alternative approved by the PFA. In light of this accident Pulsar owners should also be made aware of the importance of regularly checking the radiator couplings for leaks and cracks. The AAIB therefore made the following safety recommendation:

Safety Recommendation 2005-005

The Popular Flying Association should:

a. Ensure that Pulsar aircraft owners are aware of, fit and use only radiator hoses approved for use by the Association or the Pulsar aircraft kit manufacturer.

b. Encourage Pulsar owners to carry out regular checks of the integrity of the engine cooling system, especially in the regions of the radiator hose couplings.

Safety action

On 11 March 2005 the Popular Flying Association informed the AAIB that it accepted the Safety Recommendation. Its Engineering department is designing a modification which will reduce the vibration transmitted to the radiator via the hose and avoid any pre-stress in the hose connection. The modification will be issued to Pulsar owners shortly.

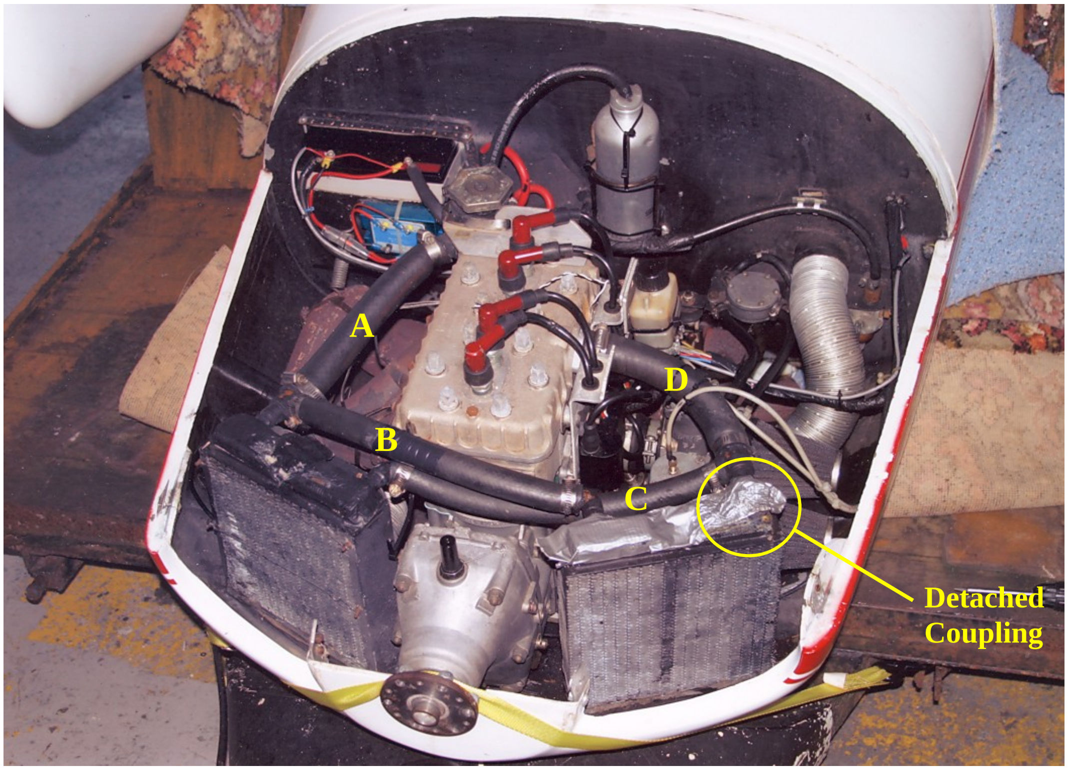

Figure 1 Engine and radiator layout inside G-MCMS post accident (photo courtesy P. Murray)

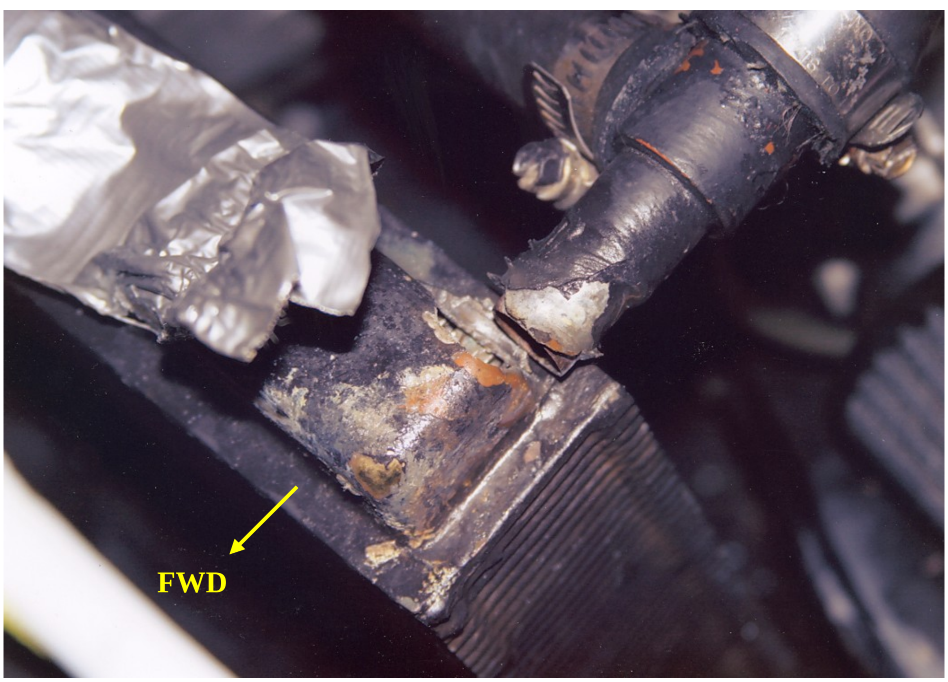

Figure 2 Detached coupling from outboard fitting of port radiator (photo courtesy P. Murray)

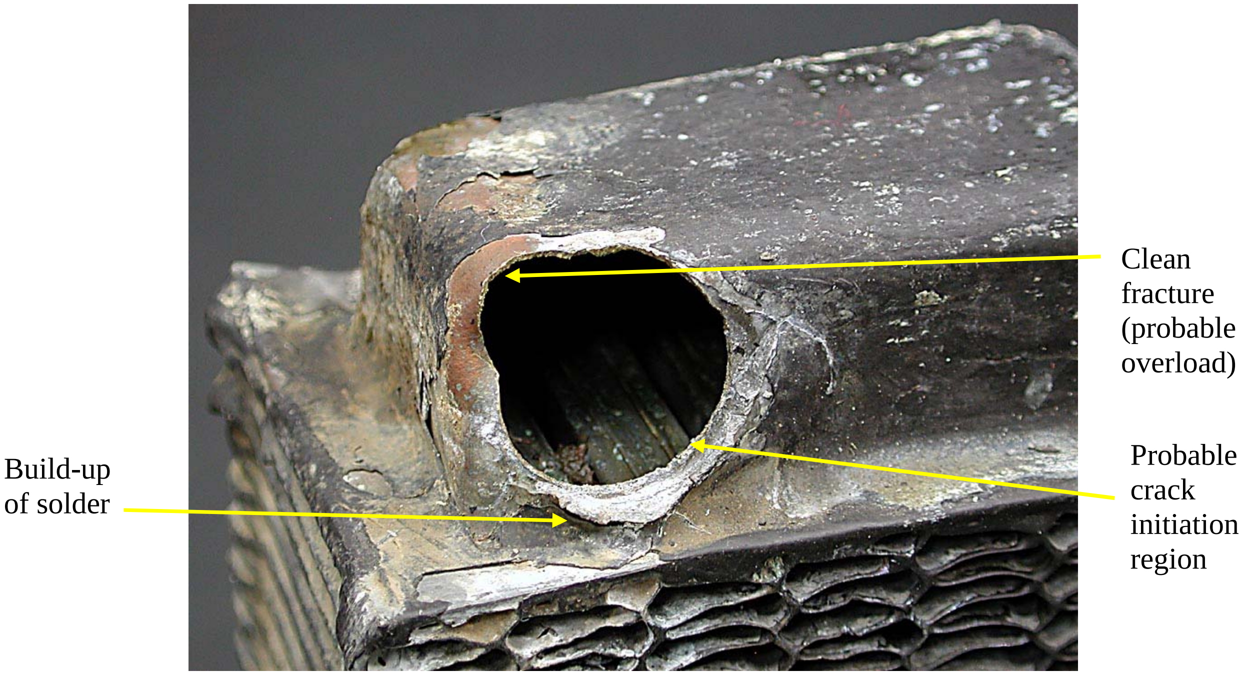

Figure 3 Detailed view of fracture surface on radiator (photo courtesy of QinetiQ)

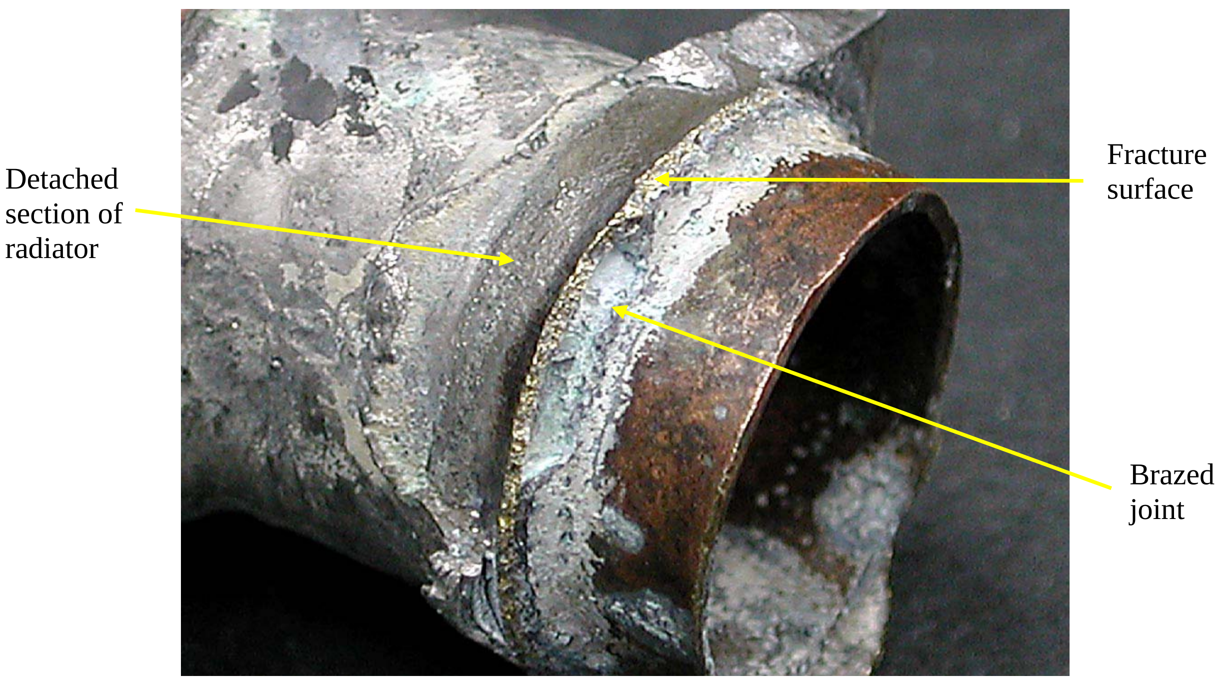

Figure 4 Detailed view of fracture on coupling (photo courtesy of QinetiQ)

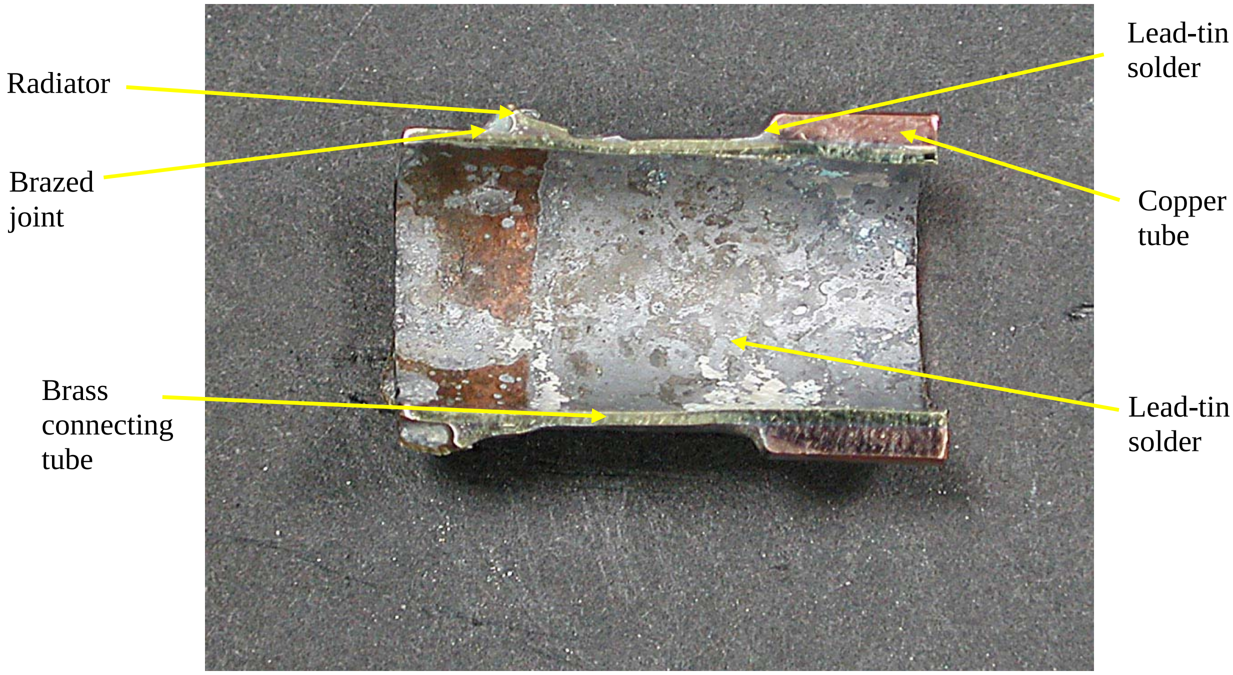

Figure 5 Cross-section through failed coupling (photo courtesy of QinetiQ)

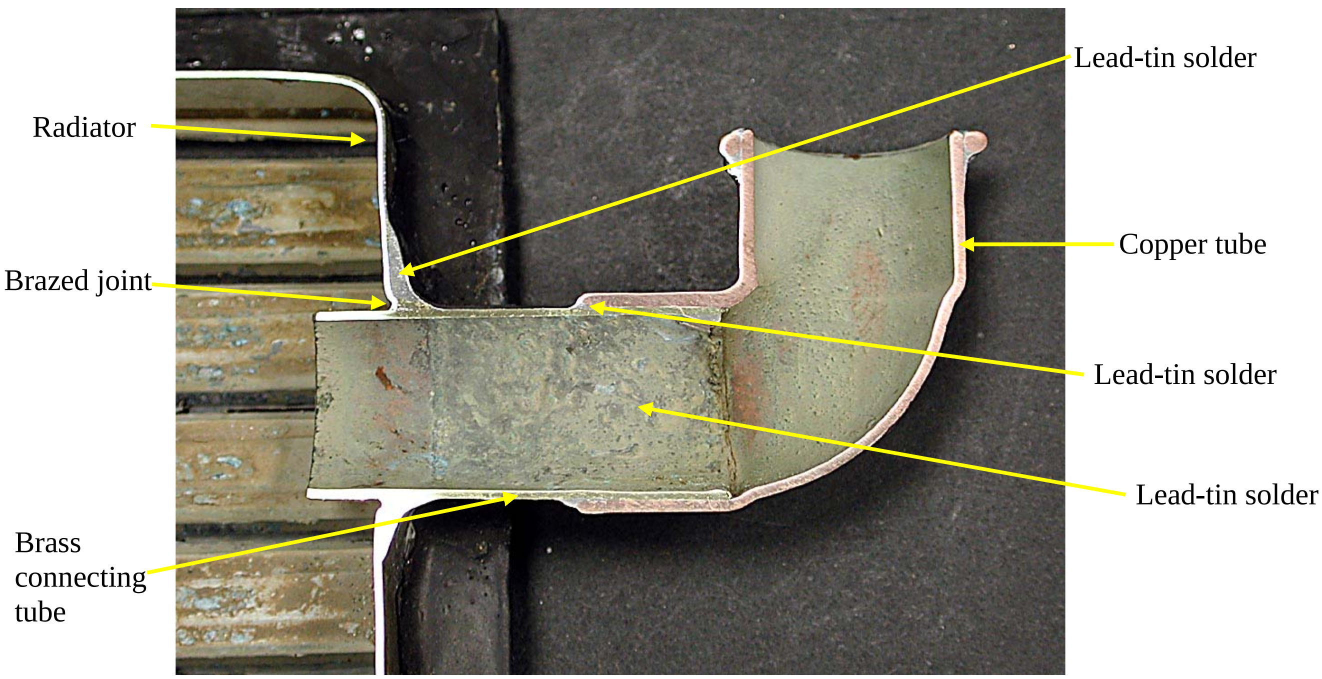

Figure 6 Cross-section through intact coupling on inboard end of port radiator (photo courtesy of QinetiQ)