Aircraft Type and Registration:	Piper PA-28-161 Cherokee Warrior II, G-BNXT
No & Type of Engines:	1 Lycoming O-320-D3G piston engine
Year of Manufacture:	1977
Date & Time (UTC):	18 October 1992 at 1300 hrs
Location:	Manston (Kent International) Airport, Kent
Type of Flight:	Private (training)
Persons on Board:	Crew - 2 Passengers - 2
Injuries:	Crew - None Passengers - None
Nature of Damage:	Battery destroyed by fire, extensive fire damage to seats and cabin furnishings, and heat damage to fuselage and wings spar structure
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	43 years
Commander's Flying Experience:	3,300 hours (of which 1,000 were on type) Last 90 days - 104 hours Last 28 days - 26 hours
Information Source:	Aircraft Accident Report Form submitted by the instructor and AAIB examination of the aircraft and battery

Circumstances

The engine on this aircraft normally started without difficulty but on this occasion it failed to start. After cranking for approximately 10 seconds the instructor, thinking that the student might have flooded the engine, told the student to continue with the internal checks whilst he tried to start the engine. After a further 30 seconds of unsuccessful cranking, the starter was rested for 2 minutes before further attempts were made.

However, when a third attempt was made to start the engine a burning smell was noticed, which appeared to emanate from the rear seat area, beneath which the battery was located. The aircraft was therefore evacuated and, when the rear seat squab was lifted, smoke and flames emerged. The airport fire service was summoned and in the meantime an attempt was made to extinguish the fire using two

BCF fire extinguishers, but this was unsuccessful. Shortly afterwards, the fire service arrived and extinguished the fire.

The fire destroyed the battery and damaged seats, interior fittings and parts of the fuselage and wing spar structure (see Figures 1, 3 & 4).

Cause of the fire

The lid of the battery box and the upper part of the battery had melted and partially burnt away, but there was no evidence to suggest that the fire had been caused by a fault within the battery itself. The heating and fire damage appeared to have been from outside the battery, with damage concentrated around the negative terminal post. The leaded part of the terminal post had melted, allowing the terminal attachment bolt and the battery cable to separate from the battery. It appeared that the upper part of the battery earth cable had been cut by the fire service and neither the separated terminal bolt nor the adjoining section of earth cable were recovered. The remaining section of the earth cable was still securely bolted to the structure. It had been severely overheated and its insulation had burnt away, except at the extreme bottom end of the cable, adjacent to the earthing attachment to the structure.

The known tendency for the rear seat springs on this aircraft type to press down onto the battery lid had been addressed on G-BNXT by the introduction of a sheet of plywood attached to the seat springs immediately above the battery. Consequently, even if the seat had been forced down onto the battery, a short circuit between a part of the seat and the battery was most unlikely to have occurred in this case. Furthermore, study of the fire damage to the aircraft and fittings revealed a pattern which was consistent with the damage to the battery itself, and showed beyond reasonable doubt that the primary source of the heat had been centred around the (missing) negative battery terminal. This aircraft type has a negative earth electrical system and consequently an earth short would not have produced any heat build up. Therefore, a resistive connection at the negative battery terminal appeared to be the only viable explanation for the fire. Such a resistive connection would have generated heat under conditions of high current flow, and would also have produced a voltage drop which would have reduced starter performance, even if only slightly.

It would appear that when difficulty was experienced in starting the engine, due to the reduced starter performance associated with the resistive connection, or to over-priming, or for some reason unconnected with the battery problem, the high current flow during the ensuing period of cranking on the starter motor had generated heat for long enough to ignite the cable insulation and/or the plastic battery box lid immediately adjacent to the terminal post. This then led to a more general fire involving the battery box, the upper part of the battery itself, and eventually the seat and interior fittings of the cabin.

Three potential resistive paths existed in the immediate area of the battery post:

i) the junction between the (aluminium) cable and the (aluminium) cable terminal,

ii) the junction between the cable terminal and the battery post,

iii) the junction between the battery post terminal stud and the lead base-material which forms the battery post proper.

From the evidence remaining, it was not possible to determine which of these possible sites had been the source of the heat in this particular case. However, poor connections between aluminium battery cables and their swaged cable terminal fittings have been implicated in previous fires, and a poor battery connection at the battery post, due to a loose terminal connection and/or a loose terminal stud in the battery post, is believed to have resulted in an electrical fire on a Piper PA 34 Seneca in 1987.

Aluminium Battery Cables

Piper Service Bulletin No 836

In August 1986, Piper issued SB 836 covering all Piper aircraft. This drew attention to the problems of corrosion at the connections between the aluminium cables and the aluminium cable-end terminal fittings at both the positive and negative connections to such batteries, and also at other connections subject to high current flows including the master relay and starter relay, and the starter motor and engine earth connections. It pointed out that *"If this condition exists and is left uncorrected, excessive heat build up could result in an electrical fire."* The Service Bulletin called for the examination of all affected aircraft at the next inspection, or within a period not exceeding 50 hours, and the replacement of all aluminium cables in the relevant areas with copper cables. The Bulletin was headed, *"PIPER CONSIDERS COMPLIANCE MANDATORY"*.

However, the FAA did not appear to view the matter with the same concern as Piper, and did not take any formal action.

In a letter to owners/operators dated August 1986, the UK CAA noted that the FAA considered the Piper stance "over protective". It felt that it had little evidence to support a mandatory classification for SB 836 in the UK, but said that in view of the past history of problems it could not ignore the Bulletin. It therefore recommended that all Piper aircraft affected by the Bulletin be inspected within 150 hours or six months, and any cables or fittings showing signs of overheating be replaced as soon as possible. It also recommended that the inspection be repeated annually, and embodied in the relevant maintenance schedules.

G-BNXT was fitted with aluminium cables throughout the affected areas. The service organisation was aware of the Service Bulletin but had followed the CAA advice to inspect annually rather than to undertake precautionary replacement of the aluminium cables.

Loose battery connections

In the case of the Seneca fire in 1987, which had also occurred on the ground, it was believed that arcing at a loose battery terminal had ignited battery gases (hydrogen), causing a fire. After the fire, the positive battery terminal was found to have become completely detached, the top of the battery was distorted by heat, and there was localised fire and overheat damage to the adjoining structure, including the fuselage skin. The CAA investigated the incident and during the course of that investigation a number of instances of loose terminal 'studs' were found on batteries, from a variety of manufacturers, which were in service.

The terminal studs on most general aviation lead-acid batteries take one of two similar forms: either a square-headed brass bolt; or a conventional steel hexagon-headed bolt, which is 'embedded' in the terminal post proper. (The 'bolt' is tinned during manufacture before the lead terminal post is cast around the head of the bolt, leaving the threaded portion protruding.) A wing-nut is used to secure the cable terminal to the battery post, and when fitted correctly the cable terminal is clamped directly down onto the pad of the battery post thereby providing a direct current path between the cable and battery post, rather than current passing via the stud.

As a result of the CAA's findings the FAA investigated, over an extended period, the potential problems associated with battery connections and loose terminal studs in particular, and in January 1990 FAA Airworthiness Alert No AC 43-16 was published. Subsequently, in November 1990, the CAA published Airworthiness Notice No 12, Appendix 44. After an introduction describing the background to the problem, each document gave (essentially similar) practical advice on how to correctly install and maintain battery connections. An extract from the FAA alert is reproduced below:

> "Most instances in which battery terminals "burn off" or melt, the failure is either due to a loose connection between the battery and cable, corrosion of the connection between the battery and cable, direct shorting of the battery terminals, or overheating of the battery cable caused by corrosion between the cable and ring terminal.

For best results, the following actions should be helpful:

1 Before installing any battery into the aircraft, insure it is the proper model for the installation. Batteries are approved as part of the airplane type design, or a supplement to the type design (STC).

2 Make it a point to look at the terminal and stud. If it's loose, not tinned or is deformed, reject it.

3 Clean the battery cable terminal ring of any corrosion, oxidation, or contamination. A clean surface finish will provide the best conductive path (a wire brush is the tool to use - not sandpaper which can leave contamination or grit which will add resistance to this circuit). During high rate charge or discharge, a small resistance can mean a lot of heat.

4 When attaching the battery cable terminal ring to the terminal stud, the ring should fit flat on the terminal. If there are any burrs or high spots on either, a once over lightly with a file should smooth things off.

WARNING: Any filing should be done on the bench with no cables connected to the battery. A file can make an effective short circuit and result in personal injury. There should be nothing between the battery cable terminal ring and the terminal. This includes any type of anti-corrosion chemical inhibitor.

5 Tighten the terminal post wingnut to the specification torque--no more. No pliers, vise grips or mini-breaker bars should be used to tighten the stud.

Finally, if you have a problem, report it through the Service Difficulty Report System."

Comment on the hazard

Although problems arising from resistive connections are most likely to occur during periods of heavy current drain from the battery, eg. when the starter is operating, and therefore problems are more likely to manifest themselves whilst on the ground than when airborne, there nevertheless remains a significant risk that fires could develop in the air - either as a result of a smouldering fire during start-up taking hold subsequently, or at a time when other demands are placed on the battery whilst in flight, *eg* during landing gear retraction. It is therefore considered that the risks of fires developing from resistive battery connections, whether at the connection between the cable and the cable end terminal, or between the cable terminal and the battery post, or as a consequence of loose battery terminal studs, should be re-assessed and that the attention of aircraft owners and maintainers should be drawn to the problem.

It is also considered that the CAA should re-assess its original response to the Piper Service Bulletin No 836, pertaining to aluminium cables, when the CAA considered the manufacturer's recommendations to replace aluminium battery cables with copper cables "over-protective", and recommended instead a one-time inspection for corrosion, followed by annual inspections. It is considered that once deterioration in the quality of an electrical connection has begun, the rate of deterioration is likely to increase and consequently the CAA's reliance upon an annual inspection may prove unrealistic as a means of protecting against such occurrences.

Although the battery cover was destroyed on this aircraft, it was noted that the battery box lid on a sister aircraft was designed to fit very closely over the top of the battery, particularly in the region where the cables entered the battery box and around the terminal areas, see Figure 2. The cover shown in this photograph appears to have been of a different type from that on G-BNXT, but this aspect raises the general question of whether battery box lids made of combustible materials should be designed so as to provide a tight fit around the battery terminal areas, when it is known that this area is a potential source of resistive heating.

Recommendations

In view of the findings arising from this incident, the following Safety Recommendations are made:

93-19 The CAA should draw the attention of owners and maintainers of general aviation aircraft to the potential problems associated with battery terminal connections, possibly through the medium of the General Aviation Safety and Information Leaflet (GASIL), or a similar publication. (Issued 23 March 1993)

93-20 The CAA should consider a review of the design of general aviation battery boxes in general, with particular reference to the fire potential arising from the close proximity of combustible cover materials to terminal posts and other potential sources of resistive heating.
(Issued 23 March 1993)

93-21 The CAA should take note of the manufacturer's concern in relation to aluminium battery cables in Piper aircraft and re-consider whether such aluminium conductors should be replaced with copper cables, as called for in Piper Service Bulletin 836, of 26 August 1986. (Issued 23 March 1993)

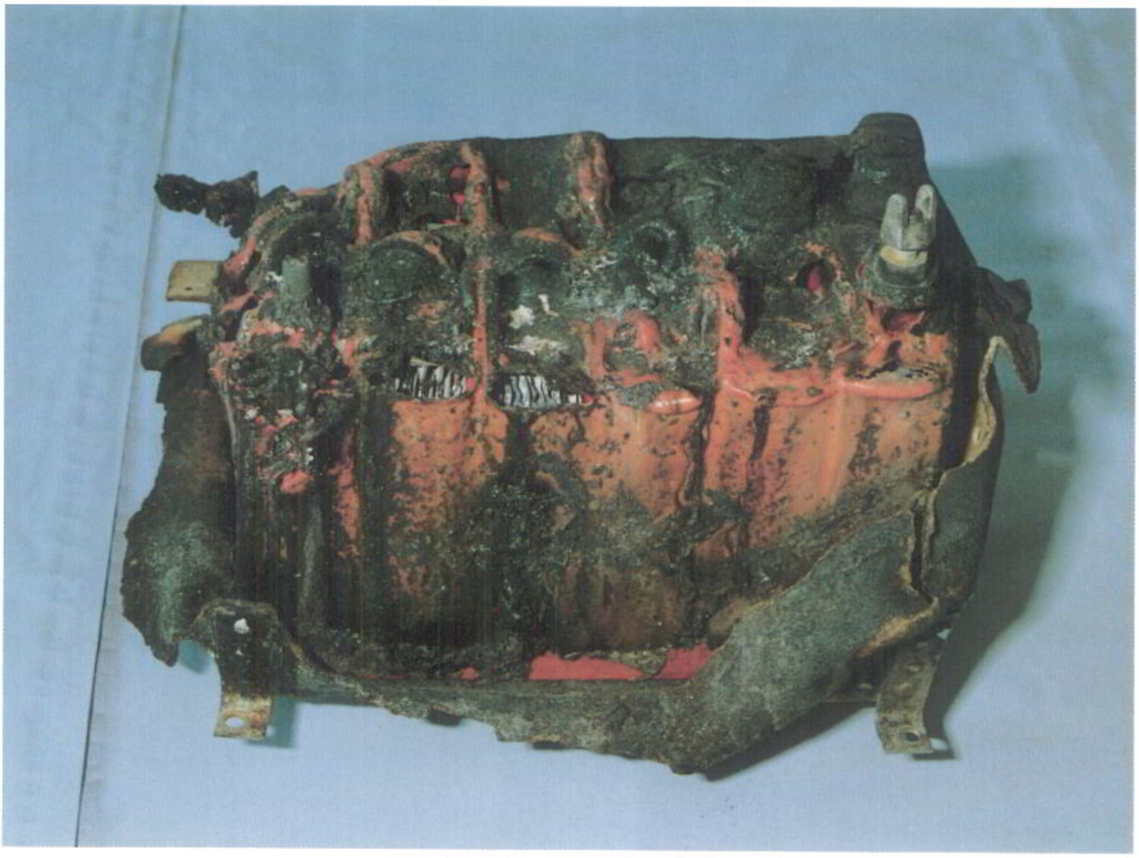

Figure 1
Battery and battery box remains from G-BNXT

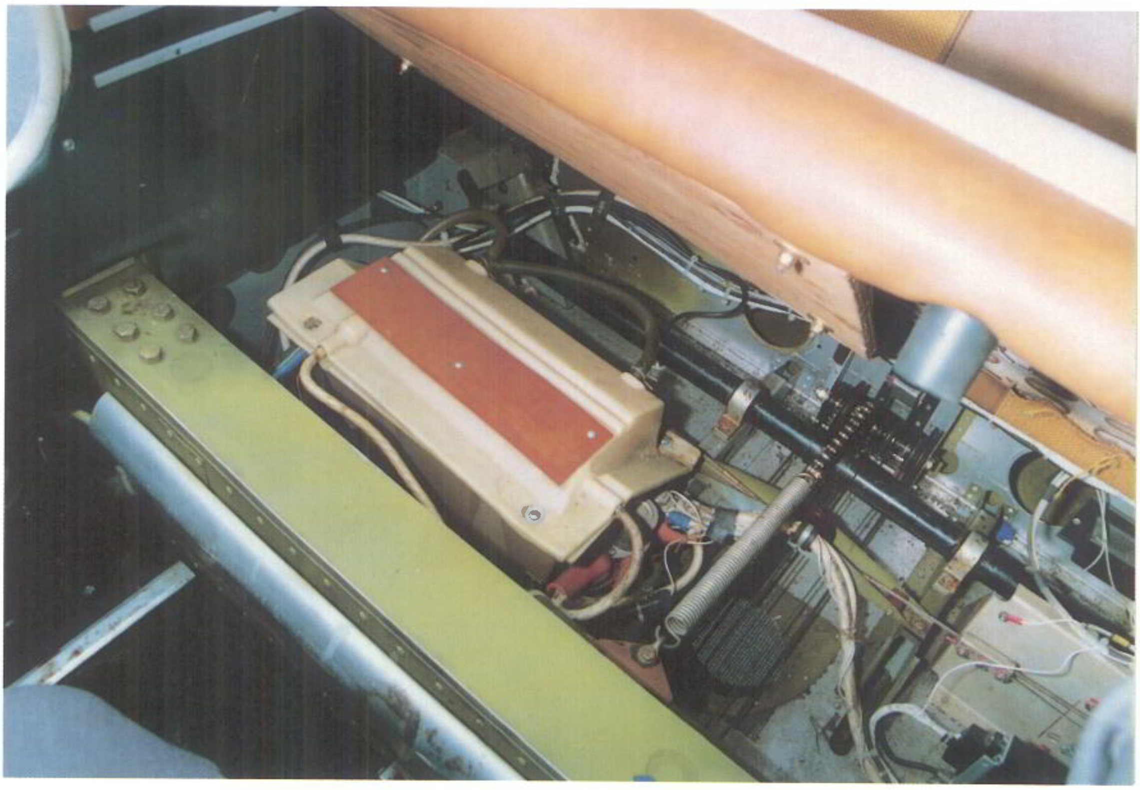

Figure 2
Typical PA 28 battery installation under rear seat
(Viewed rearwards and to starboard; note close-fit of cover in vicinity of terminals)

Figure 3
G-BNXT: Battery compartment after fire
(Showing remains of bottom part of battery box and earth cable. Viewed looking forward from baggage door on starboard side of fuselage)

Figure 4
G-BNXT: Underside of rear starboard passenger seat
Showing extensive fire damage including complete penetration of plywood board attached to underside of seat springs, to prevent springs contacting battery components.