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| **Aircraft Type and Registration:** | Piper PA-32-301 Saratoga, G-TOGA |
| **No & Type of Engines:** | 1 Lycoming IO-540-K1G5 piston engine |
| **Year of Manufacture:** | 1980 |
| **Date & Time (UTC):** | 29 August 1993 at 1745 hrs |
| **Location:** | Belmont, Lancashire |
| **Type of Flight:** | Private |
| **Persons on Board:** | Crew - 1 Passengers - 4 |
| **Injuries:** | Crew - None Passengers - 2 Minor |
| **Nature of Damage:** | Engine torn out, fuselage and wings structure distorted and fractured |
| **Commander's Licence:** | Private Pilot's Licence with IMC Rating |
| **Commander's Age:** | 46 years |
| **Commander's Flying Experience:** | 235 hours (of which 6 were on type)<br>Last 90 days - 22 hours<br>Last 28 days - 10 hours |
| **Information Source:** | Aircraft Accident Report Form submitted by the pilot and AAIB phone enquiries, engine examination and test |

The aircraft was flying between Henstridge and Blackpool. Following a transit of the Manchester Low Level route at 1,500 feet amsl, a climb to 3,000 feet amsl was commenced, in cloud. On passing 2,500 feet the pilot noticed a vibration and about half a minute later the engine began to lose power. The pilot immediately selected the left fuel tank, switched on the electric fuel pump and selected alternate air, all to no avail. The aircraft was then found to be in a descending turn. The pilot levelled the wings and eased out of the dive, stabilising the aircraft at about 700 ft/min descent rate, before attempting to start the engine with the starter. This was unsucessful and the pilot concentrated on maintaining a stabilised glide. The aircraft broke out of the cloud with little height above the terrain and after a brief flare impacted on a roadside near the base of Winter Hill. The latter peaks at 1,496 feet amsl and carries transmission masts rising to 2,452 feet amsl.

The aircraft came to rest erect with the engine mounts broken and the fuselage and both wings severely distorted and partially fractured. There was no fire. Two of the passengers suffered injury, described as minor.

The fuel system selections and tank contents at the time of the power loss could not be established with certainty. The engine was obtained by the AAIB and found to have suffered surprisingly little damage; after replacement of a fractured adapter for the oil filter it was judged capable of test running. However, initial examination revealed that the plunger driving the engine driven fuel pump (EDFP) had been installed inverted and had worn significantly. Test bed running with the worn plunger installed inverted found that the engine ran throughout the range with a normal power output, but that the outlet pressure from the EDFP was below the requirement of 22 to 26 psi at full power. On several runs the pressure was initially 18 to 19 psi, but after a few minutes fluctuated and decreased to 10 psi and remained at this level. Further runs were conducted with a known serviceable EDFP with the original or a serviceable plunger fitted, and G-TOGA's EDFP was run on another engine. The fuel injector unit was rig tested and found to achieve the required performance.

The EDFP supplies pressurised fuel to the injector unit by means of a flexible diaphragm assembly operated by an engine driven lever and springs. A circular eccentric cam in the engine accessory gearbox acts on the lever, via a plunger, to drive the diaphragm up and suck fuel into the pumping chamber via a non-return valve (Fig 1); further rotation of the cam allows the diaphragm to be driven downwards by helical compression springs and thus expel fuel from the chamber to the outlet chamber via a second non-return valve (Fig 2). A further helical compression spring acts on the diaphragm end of the lever to preload it downwards. The cam acts on the lever via a 3.59 inch long steel plunger located in a cylindrical bore in the accessory gearbox housing cover. The plunger is 0.31 inch in diameter with an integral 0.43 inch diameter domed head that is intended to bear on the cam. The face of the cam has a slight axial taper, believed to be intended to cause the plunger to rotate as it reciprocates in order to facilitate lubrication. The upper chamber of the pump is open to the gearbox interior and thus contains oil and oil mist; it is sealed by a second flexible diaphragm stacked above the fuel diaphragm. The inter-diaphragm chamber, which receives any oil or fuel leaking across the diaphragms, is drained overboard. The base of the fuel pumping chamber is formed by a static flexible diaphragm which is clamped between the pump body and an end cap that includes a central web, thus forming two chambers beneath the suction and pressure fuel chambers. The bottom chamber beneath the pressure fuel chamber is closed, but that beneath the suction side is vented to the inter-diaphragm chamber by small diameter drillings in the pump end cap and case.

Inverted installation of the plunger can be carried out via the cut-out for the fuel pump in the gearbox cover; however, correct installation requires cover removal. The point at which the plunger had been wrongly installed was not established. Engine performance parameters recorded by the aircraft maintainer between July 1990 and August 1992 at each 50 Hour Check did not show any appreciable change in engine operating conditions over this period.

Removal of G-TOGA's engine accessory gearbox cover revealed signs of distress to the EDFP cam, with the surface in an area around the peak portion smeared from contact with the plunger, although measurement showed that the cam diameter had been reduced by only approximately 0.001 inch. However, the end of the plunger that had been in contact with the cam had worn away by almost 0.1 inch in comparison with a serviceable component. The evidence was consistent with the wear having occurred because of poor lubrication at the contact point, possibly due to lack of rotation of the inverted plunger. With a plunger of the correct length installed inverted the head remained clear of the end face of the plunger bore even when the plunger was at the upward limit of its travel, bearing on the base of the cam, and the travel of the pump lever was unaffected by the inversion. The total cam lift was measured as 0.425 inch, but the first 0.075 inch downward movement of the plunger as the cam was rotated from the base position was lost motion, taken up before the diaphragm assembly lifted from its seat and started the pumping stroke; the effective pumping stroke was thus 0.350 inch. With the shortened plunger found on G-TOGA installed inverted the head bottomed on the end face of the cover when the plunger was bearing within approximately ±55° of the base of the cam (Fig 3) and the pumping stroke was reduced to 0.250 inch.

EDFP disassembly revealed a long circumferential slit in the oil diaphragm just inside the annulus where the diaphragm was clamped between sections of the pump body, consistent with the effects of prolonged flexing at this point. The bottom chamber beneath the suction side was found to be almost full of oil; this was consistent with oil leaking past the damaged diaphragm having passed down the vent path from the inter-diaphragm chamber rather than overboard.

The results of the test bed engine running demonstrated that the reduced pump stroke resulting from the wear of the wrongly installed plunger caused a significant reduction in EDFP outlet pressure, sufficient to account for some of the shortfall from the requirements found with G-TOGA's engine. The cause(s) of the additional deficit and of the variation in the outlet pressure was not positively established. Markings suggested that the plunger may have bounced on the cam as the latter rotated beyond the position at which the play in the mechanism produced by the plunger wear was eliminated. It was therefore possible that dynamic effects on the mechanism resulting from unseating of the shortened plunger from the cam or effects on the pumping action of the oil in the bottom chamber may have been factors. It was found that the engine was operating with an abnormally low fuel flow; at maximum power with the mixture control set at full rich the fuel flow was in the threshold range at which this type of engine would typically stop running due to a lean cut. Although this did not occur with G-TOGA's engine on test, only a small degree of leaning from full rich caused it consistently to lean cut.

## ENGINE DRIVEN FUEL PUMP

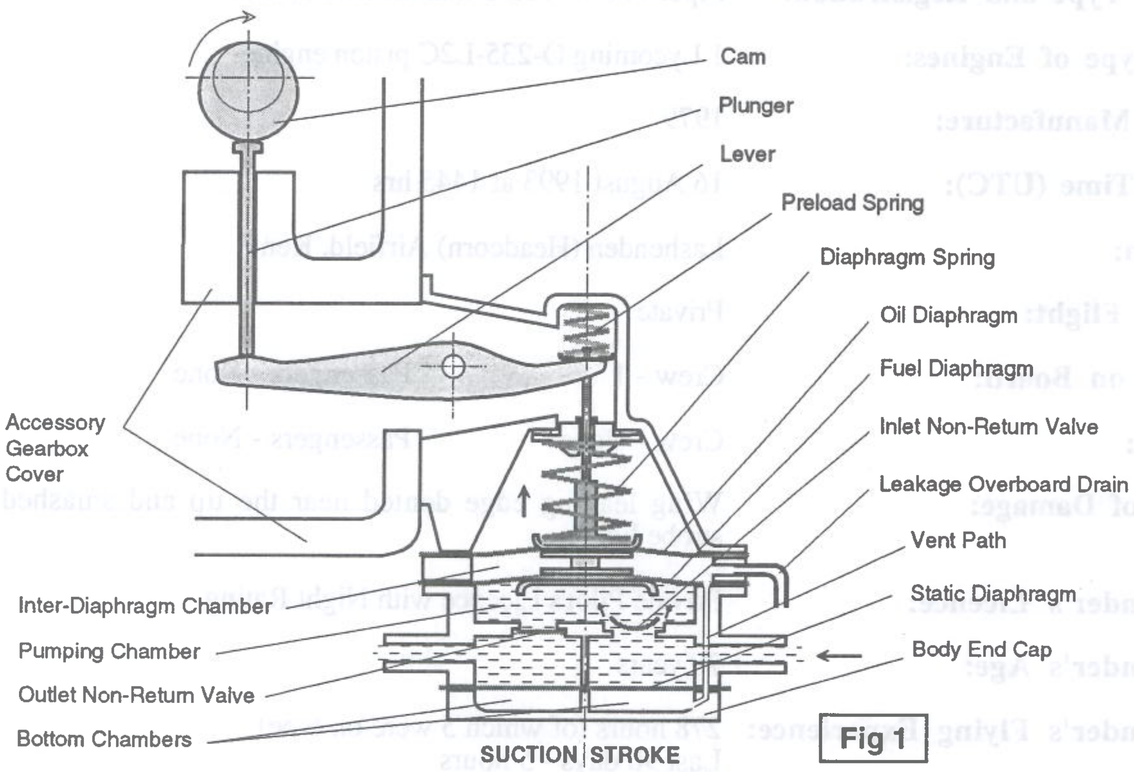


Fig 1

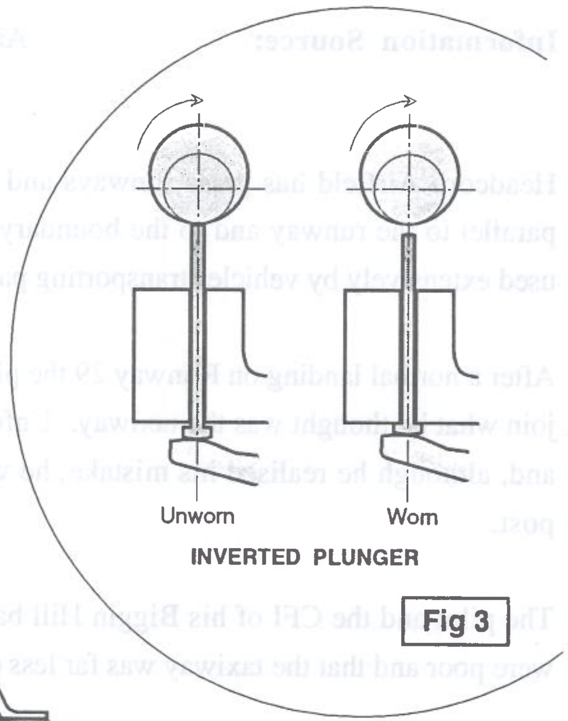


Fig 3

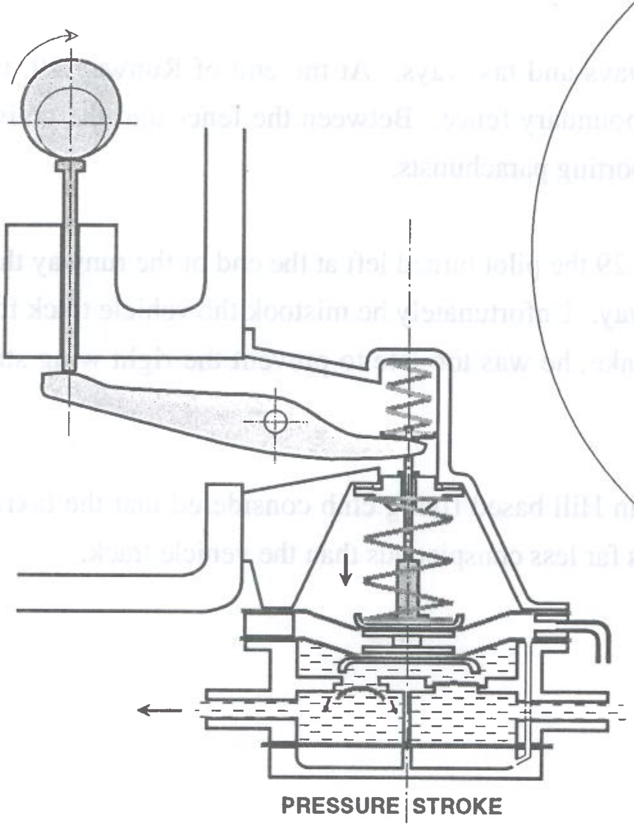


Fig 2