

Lockheed P-38J Lightning, N3145X

AAIB Bulletin No: 5/97 Ref: EW/C96/7/4 Category: 1.1

Aircraft Type and Registration:	Lockheed P-38J Lightning, N3145X
No & Type of Engines:	2 Allison V-1710 (1,425 hp) piston engines
Year of Manufacture:	1943 (Rebuilt 1992)
Date & Time (UTC):	14 July 1996 at 1451 hrs
Location:	Duxford Airfield, Cambridgeshire
Type of Flight:	Aerial Work (Flying Display)
Persons on Board:	Crew - 1 - Passengers - None
Injuries:	Crew - Fatal - Passengers - N/A
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	54 years
Commander's Flying Experience:	14,500 hours (of which 60 were on type) Last 90 days - 11 hours on type Last 28 days - 5 hours on type
Information Source:	AAIB Field Investigation

The aircraft was performing at the 'Flying Legends' Air Display at Duxford, which was being staged over the two days of the weekend of 13/14 July 1996. The display on 13 July was completed without incident. On 14 July, the aircraft had taken off at 1435 hrs as the lead aircraft in a formation comprising one Curtiss P-40B Tomahawk and one Bell P-63 King Cobra fighter aircraft. The display's 'slot' commenced at 1439 hrs and after several formation passes in front of the assembly of spectators, the trio split up in order to enable each aircraft to carry out a solo display. The P-38 was the final aircraft to perform its solo routine and was due to clear the display area by 1455 hrs. The aircraft commenced its run in from the east of the airfield, in a shallow dive to gain speed, then carried out a loop. This manoeuvre was followed by a 'Cuban Eight' manoeuvre, which involved two short periods of flight under negative 'g'. As the aircraft returned to normal positive 'g' flight after each of these periods, a slight trail of light coloured vapour was noted coming from under the main body of the aircraft (post-accident consideration of the aircraft systems concluded that this was most likely to have been vapour escaping from the fuel tank vent lines).

At the end of the 'Cuban Eight', the aircraft was passing from east to west (crowd left to right). It pulled up and to the left initially, levelled the wings, then performed a 270° roll to the left. The aircraft then came back to pass across the front of the crowd from west to east.

With the aircraft appearing to be at a normal entry height and speed, an aileron roll to the left was commenced as the aircraft crossed the western threshold of the hard surfaced Runway 06. The first 360° roll was completed apparently normally but the aircraft continued, without pause, into a second full roll. While the aircraft was inverted in this second roll, the nose pitched towards the ground and the aircraft began to lose height while the roll continued. By the time the aircraft became upright again, it had descended to a very low height above the runway. The aircraft continued to roll left and struck the runway with its left wing, with some 30° of left bank applied, about two thirds of the way along Runway 06.

The left outer wing ruptured and collapsed, followed by an impact of the left engine. At this time, a large fireball erupted as the aircraft began to cartwheel across the airfield, breaking up into multiple fragments as its trajectory took it diagonally away from the main spectator area towards a row of parked light aircraft on the south side of the airfield. Several of these aircraft were destroyed or severely damaged in the wreckage's path. One of the engines bounced further than the rest of the wreckage, crossing the airfield boundary and then the M11 Motorway which runs almost perpendicular to the end of the runway. A passing freight truck sustained some minor damage from pieces of wreckage but was able to continue travelling northwards along the motorway. The engine came to rest in a field just to the east side of the motorway, close to where several members of the public had been standing in order to watch the flying activities from outside the airfield boundary.

The airfield Fire and Rescue services were quickly at the scene and brought the numerous areas of fire under control in a short time. The pilot was found in the seat, with his four point harness still fastened, amongst the wreckage of the main fuselage pod. A post-mortem examination found that the pilot had been killed by a severe head injury. No physical condition was found which could have caused any incapacitation of the pilot and no traces of drugs nor alcohol were found to be present. It was assessed that the destruction of the cockpit was such that survival was impossible.

The pilots and passengers of the visiting light aircraft had been required, by the airport operator, to move to the spectator side of the runway in order to watch the air display. Fortunately, there were no injuries to any spectators.

The display routine followed by the P-38 formation was identical to that flown at the display on the day prior to the accident. The significant difference was that during the Saturday display, only a single 360° aileron roll had been carried out, but at the time of the accident two consecutive 360° rolls had occurred, with a continuation past the wings level at the end of the second roll.

Soon after the accident, the air display organisers made an announcement over the public address system for any spectators who had photographed, or taken video footage of, the final manoeuvre to hand in their films/tapes on loan for the purposes of this investigation. An excellent response was forthcoming, which resulted in AAIB having access to some 60 video tapes and 40 sets of photographs of the event.

The weather at the time was a surface wind from 270° at 6kt, variable in direction between 240° and 300°, visibility in excess of 10 km, scattered cloud base 3,000 feet, QNH 1026mb.

Video Analysis (Figure 1)

Photographs and video coverage of the aircraft's manoeuvres were analysed with a view to assessing not only the pre-impact flight path characteristics but also the pre-impact aircraft integrity and the operation of aircraft systems. A full flight path analysis was carried out using several video sequences which had been filmed from a variety of viewpoints.

A recording was available of the Saturday display, where one aileron roll to the left was performed. The time taken to complete the roll on this occasion was 3.4 seconds and it was noted that the aircraft had an upward trajectory throughout this manoeuvre.

The analysis of the accident coverage showed that the aircraft had performed two continuous aileron rolls, taking 4.4 seconds and 3.6 seconds respectively to complete. This had been started at a height of about 250 feet above the runway, at a speed of about 250 knots and with an initial nose-up pitch attitude. The roll, to the left, was initiated by a rapid roll control input to produce a considerable aileron deflection. This aileron deflection remained more or less constant until the aircraft had completed about 675° of roll. At that point, the ailerons were returned to the neutral position where they remained until the aircraft struck the ground.

During the first roll the aircraft climbed to an apogee of about 360 feet when inverted, descending to about 260 feet by the time it was erect again. At this point the aircraft pitch attitude was approximately horizontal or very slightly nose-down. There was no pause before the second roll was executed. During this roll, the nose dropped progressively and an increasing rate of descent built up. At the inverted position the aileron position was observed to be being maintained in the almost fully (left roll) deflected position and a considerable elevator displacement in the 'stick back' sense was made. Considerable left rudder control was also added at this time and the roll rate increased. About 45° of roll before the aircraft became erect, the rudder and aileron inputs were moved to neutral, but were not applied in opposition to the roll. The rate of roll was seen to increase slightly as the aircraft rolled through wings level (from about 110°/sec to 125°/sec), with a rate of descent of about 7,200 feet per minute, to the point of impact. Ground speed at impact was assessed as 230 kt. The final angle of descent was 14.5°, giving a speed along the flight path of 238 kt.

Impact was seen to occur on the left wing tip at an attitude of about 30° left roll with the fuselage level in pitch. The aileron and rudder positions were approximately neutral and the elevator was deflected up.

An analysis of the propeller speeds from video showed that they remained constant throughout the rolling manoeuvre. Both propellers were turning at about 1,300 RPM, the right slightly faster than the left. With the engine propeller reduction gearing ratio of 2:1, this accorded with the aircraft operating limitations which quoted the engine limits for use in aerobatic manoeuvres as 2,600 RPM/40 inches manifold pressure.

It was also noted on the video coverage that the coolant radiator exit flaps were not symmetric for each engine. Those for the left engine were noted to be fully open, while those for the right engine were in trail, for a large part of the final display sequence. Correct engine operation during the manoeuvres was assessed by other means and any possible effect of the asymmetry on the handling of the aircraft was not considered to be significant.

Engineering Investigation

The aircraft had struck Runway 06, straddling the centreline and about 450 metres short of the eastern end. The initial impact had been of the left wingtip on the runway and the sequence of marks

of the immediately subsequent impacts was consistent with the aircraft being on a heading of about 079°M (the runway heading is 062°M), in a substantially level pitch attitude and significantly banked to the left. Examination of the cuts made by both propellers in the runway surface indicated that both engines were developing considerable power and that the aircraft had a high rate of descent. Initial assessment of the propeller marks, without making allowances for rate of descent, indicated that the aircraft had struck the ground with engine speeds of the order of 2500 RPM associated with a ground speed of about 200 kt.

After the initial impact, the left outer wing, empennage and both tail booms separated from the remainder of the airframe which yawed sharply to the left before crossing the southern edge of the runway and cartwheeling across the grass. The main wreckage came to rest, inverted, in a wheat field, about 420 metres from the point of initial impact, just outside the southern boundary of the airfield. Both engines became detached from their mountings after impact; the right had been thrown 60 metres beyond where the main wreckage came to rest and the left 180 metres beyond, crossing the M11 Motorway. Although the aircraft had burst into flames very shortly after the initial impact, there was little evidence of substantial fuel spillage between the point of initial impact and where the main wreckage came to rest, there being only isolated areas of blackened grass. There was, however, evidence of a moderately severe ground fire around the main wreckage and a considerable area of the wheat field, generally to the south (right) of an extension of the line between the initial impact and the main wreckage, had been burnt.

The wreckage was removed to the AAIB facility at Farnborough for more detailed examination.

This revealed no evidence of any pre-impact structural distress of the airframe nor loss of attachment of control surfaces. There was no evidence of pre-impact loss of integrity of the control systems, all damage being consistent with the nature and degree of structural break-up after impact. The extent of the disruption to the control systems precluded eliminating the possibility of any transient obstruction of the systems. Assessment of the scrap marks on the left outer wing and aileron, made during the initial contact on the runway, showed that the aileron had been at a substantially neutral position at that moment. Damage on the left end rib of the elevator and on the closing rib at the left end of the tailplane cut-out indicated that the elevator had been deflected up at the time the left fin base struck the runway. The impact positions of both ailerons and elevator surfaces were confirmed by the video analysis.

The aileron boosters were examined. The position of the by-pass control piston of the left booster showed that, when it became disrupted at the time of impact, hydraulic pressure had been available. Damage to the input rod of its control valve indicated that there had been no aileron movement demand at that time and damage to the output rod of the actuating cylinder was consistent with its being at a neutral position. All damage to the left and right booster assemblies was consistent with the damage to the structure to which they were attached and there was no evidence of any pre-impact failures.

The blade pitch change mechanisms both propellers were examined; the initial dismantling being performed with the assistance of the operator's maintenance organisation. This revealed no evidence of malfunction nor damage inconsistent with that sustained as a result of impact. It was not possible, from examination of the pitch control gear quadrants from the blade roots, to establish exact blade pitch settings at impact. However, impact damage to the teeth of the quadrant gears indicated, on balance, that both propellers had been working within their governed pitch range and consequently at selected speed. It was not possible to determine the selected speed from the engine mounted governors.

Pilot's Flying Experience and Documentation

The pilot held an Airline Transport Pilot's Licence and was type-rated on Boeing 737 series, Boeing 757/767 and Piper PA-23/34/44 series aircraft. He was a Captain with a UK charter airline flying Boeing 757 and 767 aircraft and was the Chief Pilot for the operator of the P-38, responsible for the crewing and operation of a varied fleet of some 15 vintage 'warbird' aircraft types.

The pilot was also the Air Show Display Co-ordinator for the 'Flying Legends' display at Duxford, being responsible for the planning of the display items and for the choreography of the show finale, which also involved leading a mass flypast of some 40 historic aircraft. He gave the daily display briefing to the participating pilots and undertook some in-show replanning on the Sunday afternoon when the planned show sequence was interrupted by the arrival of a significant display item almost an hour ahead of the planned schedule. This undoubtedly added to the pilot's workload for the afternoon. Shortly after this, the pilot participated in the show in the lead aircraft of a pair of DH89A Dragon Rapides. After landing from this, there was then some 12 minutes before he then taxied out in the P38 for the start of that display item.

The pilot was operating the P-38, an aircraft registered in the USA, under the privileges of his FAA Commercial Pilot's Licence. Under normal circumstances, as the aircraft maximum take-off weight was in excess of 5,700 kg (12,500 lb), a specific aircraft type rating would be required. In this case, the pilot held a letter, issued by the FAA Flight Standards District Office in Oakland, California during 1988, which authorised him to operate as pilot-in-command in experimental category aircraft - *"All types and makes of high performance piston-powered aircraft."* The letter also noted that it did not, in itself, authorise the performance of aerobatics in airshows. A separate authorisation for this activity is required, but only in respect of participation at airshows within the USA.

The FAA indicated that the documentation held by the pilot did comply with the appropriate US Federal Aviation Regulations and the special operating limitations for the aircraft during this flight. However, the FAA did note that since the issue of the letter of authority, the procedures had since been changed to reflect current requirements, but the letter remained valid.

A Biennial Flight Review certification (to validate the FAA licence) was entered in the pilot's flying log book by an FAA Certified Flight Instructor on 16 July 1995.

The pilot held a CAA Display Authorisation (DA) covering many aircraft types including the P-38. He also held an appointment as a Display Authorisation Evaluator on behalf of the CAA.

The pilot's DA had a current validation and permitted the performance of flypasts down to 30 feet agl and aerobatic manoeuvres (in certain types) down to 100 feet agl. For the P-38, the minimum aerobatic height was specified as 200 feet agl. Formation flying was also permitted.

From the video evidence available, it was apparent that the pilot commenced the final rolling manoeuvre at a height which was in accordance with his DA.

On the Saturday, the day prior to the accident, the pilot flew a similar display profile but with only one aileron roll at crowd centre. Some minor transgressions of the pilot's DA limitations were noted by the attending CAA Air Display Inspector, notably in terms of the minimum aerobatic height during the aileron roll and for being marginally inside the minimum lateral separation distance appropriate for aerobatics. Both of these comments were made by the Inspector to the pilot after the

event and the pilot gave assurance that the Sunday display would fully conform to the DA limitations.

The pilot had conducted a display practice in the P-38 on 11 July and had flown in the public display on 13 July. In the 28 day period prior to the accident, the pilot had also flown each of the following types: Boeing 757, Spitfire V, Hellcat, Skyraider, Bearcat, Rapide, Aztec, Baron and Cub.

Aircraft History and Documentation

The aircraft was manufactured during 1943 at the Lockheed Aircraft Factory in Burbank, California and had the serial number 42-67543. It operated in service with the United States Army Air Force until being discharged in February 1945. It was found by its current owner in a derelict state in Texas in 1988. After purchase, it was taken to California and restored to flying condition. Test flying was carried out early in 1992 and the aircraft was imported into the UK during the summer of that year. Since then, the aircraft has operated under a CAA Exemption to the Air Navigation Order which permitted the aircraft to fly without a valid Certificate of Airworthiness for the purposes of Demonstration and Exhibition flying only, provided that the FAA Special Airworthiness Certificate and Operating Limitations dated 9 January 1992 were current.

The FAA Special Airworthiness Certificate was issued in January 1992 in the Experimental category, for the purposes of Exhibition flying and was current at the time of the accident. The aircraft was being operated in accordance with the Operating Limitations document. The aircraft's maintenance documents showed that it had been correctly maintained in accordance with the FAA requirements and had been properly certified by an FAA approved licensed engineer. The FAA Certificate of Registration was issued on 21 February 1992 to an owner with an address in Las Vegas, Nevada.

The aircraft was also subject to an exemption issued by the CAA in order to allow it to operate at speeds greater than 250 kt while below 10,000 feet. A current Aerial Work Operating Permit for the aircraft had also been issued by the Department of Transport.

The pilot had compiled a set of aircraft operating notes for the P-38, which indicated that, for aerobatics, the engine limits were 2,600 RPM and 40 inches manifold pressure (the maximum continuous power setting for the aircraft), the entry speed for rolling manoeuvres was 200 kt and that no negative 'g' manoeuvres were permitted because of possible hydraulic problems. It was ascertained that a previous occurrence of negative 'g' had caused a hydraulic aeration problem which prevented the landing gear down function, which required manual hand pump operation to recover. It was also indicated that the preferred rolling direction was to the left in order to prevent the unlocking of the nose landing gear door mechanism, which was known to have occurred during previous rolls to the right. These hydraulic problems were not known to have caused any adverse effects in the aileron booster systems.

Information from the aircraft's Maintenance Instruction Manual states that with aileron hydraulic boosters operating, the pilot's control input applies one sixth of the total aileron load. The implication of this is that, in the event of a failure of the hydraulic booster system, the aileron control forces felt by the pilot would be six times greater than normal for a given aileron deflection under the same flight conditions. From examination of the aileron booster system, it is considered that, in the event of a hydraulic failure while the ailerons were deflected during the rolling manoeuvre, the aileron deflection would have tended to reduce as a result of the aerodynamic forces.

Copies of the original 1944 Pilot's Flight Operating Instructions for this type of aircraft were also available. These contained the following relevant extracts:

"AILERON CONTROL HYDRAULIC BOOSTER - ...On these airplanes most of the aileron control force is provided by hydraulic boost; the remainder is applied by the pilot....Control cables which control the boost mechanism are mechanically connected to the control surfaces, allowing manual flight control in an emergency. The aileron boost shut-off valve is located on the right side of the cockpit near the pilot's control column. In addition to this valve an automatic by-pass valve is incorporated in the mechanism to allow free movement of the ailerons in case the hydraulic pressure should fail."

In the "Flight Restrictions" section, it was noted that "Snap Rolls" and continuous inverted flight were prohibited. The section also contained the cautionary note:

"Extreme care must be taken during acrobatic manoeuvres which require a downward vertical recovery. Acrobatics should not be attempted at altitudes below 10,000 feet."

Duxford Airfield Information

Duxford airfield has a main Runway 06/24 of asphalt/concrete construction, dimensions 1,503 metres long and 45 metres wide. Additionally, to the north of this, is a parallel grass runway, 890 metres long by 30 metres wide (Figure 1). For air display purposes, the display axes are defined by reference to either the grass or hard runways, dependant upon the speed of the participating aircraft.

For this display, participants were briefed that the display axis for aircraft performing at speeds up to 200 kt was the northern edge of the grass runway. The P-38 display speed was in excess of 200 kt, so it was using the northern edge of the hard surfaced runway as its display axis, in order to comply with the minimum distance requirements laid down in CAP 403.

When detailed measurements were checked during this investigation, it was found that there were some anomalies in the display axis distances at the western end of the airfield which did not meet the specified minima. This situation was advised to the airfield management at Duxford by AAIB and the necessary changes were implemented in time for the subsequent public air display in September 1996. These involved the relocation of the display line (for aircraft up to 200 kt) to the southern edge of the grass runway, and the movement of the crowd line northwards by 23 metres at the western end of the airfield.

The airfield General Flying Orders contain Annex B, Rules for Display and Demonstration Flying. The Orders contain the statement that *"Aerobatic manoeuvres should be flown such that they are capable of being completed by 500 feet AGL."* This requirement was also stated in the daily briefing notes produced by the airfield management.

Consideration of the final rolling manoeuvre

Evidence was obtained which showed that the aircraft had successfully completed a double rolling manoeuvre in the past, with a significant upward trajectory apparent throughout. However, the majority of other pilots, who also flew aircraft belonging to the same operator, indicated that a single aileron roll manoeuvre was by far the more common. This view was supported by Air Display Inspectors from the CAA.

The pilot used a metal knee-board which was usually strapped around his right leg. This was found with the strap fastener undone in the debris adjacent to the main wreckage. Checks carried out on a similar aircraft in the USA found that a similar knee-board could, if dislodged, become jammed in the flight controls in any of several places. The pilot also habitually carried (in his flying suit) a 'multi-tool' and a screwdriver set with detachable bits. These were also found adjacent to the main wreckage. There were no significant witness marks, either on the knee-board or on the tools, to suggest that they had become jammed in the flying control mechanisms. The pilot's torch and other personal effects were found in-situ in his flying suit.

Consideration of the flight profile (Figure 1) indicates that the start of the final manoeuvre occurred over the western end of the hard surfaced runway. At the end of the first roll, the aircraft was still in a location which was to the right (west) of the centre of the crowd. It is considered unlikely that the pilot would have intended to stop manoeuvring at this position as the display would then have appeared 'asymmetric' from the crowd's viewpoint.

It is known that the pilot was a very experienced display pilot and produced high quality, aesthetically pleasing displays. There is no evidence to explain why the aircraft entered the second part of the final manoeuvre in a less than optimum pitch attitude which developed into a significant downward trajectory. The possibility of a temporary restriction to the flying controls (especially the roll control), or some other form of distraction of the pilot, could not be dismissed.

Air Display Safety Review

In response to this and several other UK air display accidents which occurred during the 1996 display season, the CAA set up a Civil Air Display Review Group. The group identified some 18 areas for detailed investigation and comment, covering many aspects of display organisation and participation. The work of the group is currently ongoing but relevant recommendations should be implemented, either by means of amendments to CAP 403 or by other means, in time for the start of the 1997 display season. There is also an intention for the CAA to develop additional guidance material for display pilots in a similar fashion to the RAF Flying Display Notes.

In view of the Review Group activity already being undertaken, AAIB considered that no further Safety Recommendations were necessary in this case.