DH115 Vampire T11, G-DHAV

AAIB Bulletin No: 12/2002	**Ref: EW/C2001/6/3**	**Category: 1.1**
Aircraft Type and Registration:	DH115 Vampire T11, G-DHAV	
No & Type of Engines:	1 Rolls Royce Goblin MK35B turbojet engine	
Year of Manufacture:	1955	
Date & Time (UTC):	2 June 2001 at 1702 hrs	
Location:	Biggin Hill airfield, Kent	
Type of Flight:	Private (Display)	
Persons on Board:	Crew - 2	Passengers - None
Injuries:	Crew - 2 (Fatal)	Passengers - N/A
Nature of Damage:	Aircraft destroyed	
Commander's Licence:	Private Pilots Licence with display authorisation	
Commander's Age:	66 Years	
Commander's Flying Experience:	4,398 hours (of which 185 were on type)	
	Last 90 days - 33 hours	
	Last 28 days - 3 hours	
Information Source:	AAIB Field Investigation	

History of the flight

On 2 June 2001 three aircraft, a Sea Vixen, a Venon and a Vampire, all belonging to a Bournemouth based company, planned to fly from their home base to participate in a flying display held at Biggin Hill. They intended to depart Bournemouth, fly in formation and land at Biggin Hill in the morning before the programmed display started. This was to give the ground crew, who travelled to Biggin Hill by road, time to prepare the aircraft for the display and for the pilots to attend the display briefing given by the airshow organisers.

The pilot of the Sea Vixen was to fly his aircraft solo for the transit flight and the forthcoming display. The Venom, fitted with only a single seat, was flown by the company chief pilot. The pilot of the Vampire, a very experienced ex-military and display pilot, was to be accompanied by a passenger who was to take air-to-air video of the aircraft in formation during their flight to Biggin Hill. For the display later that day he was to be accompanied, in the right seat, by a different safety pilot. Video footage, taken by the passenger during the transit flight, showed the Vampire pilot to be relaxed and very competent maintaining his formation position throughout.

The formation flight to Biggin Hill was routine until the aircraft split to carry out individual landings. The Sea Vixen and Vampire landed without incident. The Venom, however, landed with its wheels up and was damaged such that it could not participate in the display. The runway at Biggin Hill was blocked for approximately three hours whilst the Venom was removed. The Vampire pilot was on the scene throughout the Venoms recovery advising and assisting as necessary. He eventually left the area to attend the airshow briefing. Because of the accident to the Venon and its recovery from the runway it was decided that the Sea Vixen and Vampire would display at the end of that afternoons show and would carry out a short sequence as a pair followed by short individual displays. The pilots of both the aircraft discussed and briefed the changes. The safety pilot, who was to be in the right seat of the Vampire, was qualified on type but his presence was merely to assist with lookout as the view from the left seat was restricted. Civil Aviation Authority permission had been granted for the use of a safety pilot under these circumstances.

The plan was for the aircraft to take off separately several minutes before their allotted display time in order to join up as a pair behind the crowd. The two aircraft were then to run in along Runway 03, in front of the crowd, with the Vampire in right echelon. The pair were then to carry out a level 405° turn to the left with the Vampire changing to the line astern position. This manoeuvre was to end with the aircraft flying away from the crowd on a heading of approximately 345°. As the aircraft flew away from the display line the Sea Vixen was to carry out a wing-over to the right to return in the opposite direction down the display line. The Vampire was to carry out the same manoeuvre but delay its turn to achieve approximately 1,000 metres of separation from the Sea Vixen. The Sea Vixen would then fly behind the crowd leaving the display area free for the Vampire to carry out a solo display before departing to RAF Lyneham in Wiltshire where a further display and night stopover had been arranged. Both pilots had flown a similar display sequence a week earlier at Duxford near Cambridge but on that occasion the formation included the Venom aircraft.

The sequence, as described, was flown as planned except that the Vampire, which took off approximately 30 seconds after the Sea Vixen, had to delay its join up behind the crowd because of a transient problem with its landing gear. The weather recorded for Biggin Hill at about their time of departure gave the surface wind as northerly at 14 kt, visibility 20 km with scattered cloud at 3,000 feet, temperature of 13°C and a sea level pressure of 1016 mb.

The aircraft eventually joined as a pair, flew past the crowd and carried out their level turn to the left through 405°. The Sea Vixen then pulled up for its wing-over to the right reducing to a speed of approximately 220 kt at its apex before accelerating and pulling approximately 2.5g into the turn. The Vampire moved to the left of the line astern position to fly a wider radius turn followed by a right wing-over to achieve separation. As it reached its planned 80 degrees to enter its wingover however, it continued its roll to the right ending up inverted with the nose dropping into an ever-steepening descent. Almost immediately the aircraft rolled to the erect position and its angle of attack increased. The roll to the right continued and at 1802 hrs local time the aircraft impacted with the ground. Both pilots received fatal injuries in the impact. No radio transmissions were received from the pilot of the Vampire.

Radar information recorded by London and Heathrow radars showed the track flown by the formation during their display. A separate radar return from the Vampire, as it split from the Sea Vixen during the final manoeuvre, was not recorded because of its close proximity to the Sea Vixen and the short time interval between the aircraft separation and the Vampires impact with the ground.

Video evidence

After the accident numerous members of the public came forward with video recordings of the display. The recordings showed an extremely competent display sequence with the Vampire in close, stable, echelon and line astern positions relative to the Sea Vixen. Unfortunately most of the recordings concentrated on the Sea Vixen as the two aircraft separated and did not show the final seconds of the Vampires flight. One digital video recording, however, showed the final moments of the Vampire prior to impact. This recording was taken from a position close to the active runway threshold approximately 2 km from the crash site. By analysing the video, frame by frame, it was possible, using computer software, to construct a montage of the manoeuvre carried out by the Vampire as it descended (see Figure 1 *(jpg 79kb)*). From the montage it could be determined that the descent from approximately 1,500 feet to impact took 5 seconds. The aircraft initially descended with increasing right bank and at a descent angle of 18°. The aircraft was inverted in a 56° descent 2.6 seconds from the start of the sequence and had rolled to a wings level attitude, albeit still in the steep descent, 1.6 seconds later. Impact with the ground followed within a second of the wings-level attitude with the aircraft continuing to roll to the right. It was calculated that the aircraft was rolling at a rate of 112° per second from the inverted to the wings level attitude. Measurements taken from the still frame at the time the aircraft commenced its roll to the inverted attitude showed that the Vampire was approximately 550 feet behind the Sea Vixen. It was not possible to determine the ground track of the Vampire relative to the Sea Vixen.

Practical and theoretical studies (see below) have shown that when flying in certain regimes of disturbed air behind other larger and heavier aircraft the Vampire can be subjected to disturbances in roll that exceed the aircrafts aileron control authority.

Pathology

The speed of impact was in excess of 200 kt and the aircraft disintegrated with an immediate post impact fire. It was not possible, because of the nature of their injuries, to determine if there was any natural disease in either pilot, which may have caused or contributed to the cause of the accident. A limited toxicological examination was possible and this was entirely negative.

Aircraft History

G-DHAV was built by the De Havilland Aircraft Company in 1955 as a DH115 Vampire T11 and released into RAF service in 1956 as XH308. Following its retirement from the RAF in 1962 the aircraft was stored until 1967 when it was sold to the Swiss Flugwaffe and upgraded to the export Mk 55 standard. The aircraft was operated by the Flugwaffe as U-1234 until 1991 and was returned to the UK in 1995.

Examination of the wreckage

The aircraft crashed into a field of long grass outside the airfield boundary, some 850 metres to the north of the end of Runway 03/21. The aircraft was destroyed and parts of the wreckage were thrown more than 130 metres from the point of impact. The ground scars and the wreckage distribution showed that the aircraft was travelling in a direction of approximately 130°M at impact, 45° nose down and banked vertically to the right.

G-DHAV was equipped with two Martin-Baker Mk 3B ejection seats and was operated with these seats armed. A detailed examination of the seats was undertaken in collaboration with the seat

manufacturer, at the site and after the removal of the wreckage to the AAIB at Farnborough. At the site it was found that the ejection gun and drogue gun from the right-hand seat had not fired. The guns from the left-hand seat had fired but reconstruction of the seats showed that this occurred after the disruption of this area of the aircraft on impact. There was no indication that an ejection had been initiated before impact with the ground and reconstruction of the cockpit canopy and its frame showed that it had not been jettisoned.

There were clear marks of rotation within the Goblin engine but the amount of power could not be assessed. Examination and reconstruction showed the aircraft was structurally intact at impact, with flaps and landing gear retracted, and that all the mechanical failures within the flying control system were consistent with the crash loads.

Effect of wingtip vortices

Although the effect of wingtip vortices has not normally been a large problem in formation displays, there were a number of particular factors in this instance that suggested that the vortices shed from the Sea Vixen might have played a part in the accident. These factors included the large disparity in operating weights between the Sea Vixen and the Vampire and that both aircraft were banked in a turn, thus generating additional wing lift and vortex strength, at the time that the Vampire departed from its expected path. Most formation displays are conducted with the aircraft closely spaced along the line of flight. In this case, however, the two aircraft were separating and the strength of trailing vortices may be considered as developing gradually behind a wingtip (rolling up) to reach full strength some two to four wingspans behind the generating aircraft, then staying approximately at this intensity for at least 80 to 100 wingspans.

Because of the possibility of a wake vortex encounter the AAIB commissioned an aerodynamic study to determine the degree to which the trailing vortices from the wingtips of the Sea Vixen might have influenced the flight path of the Vampire. To judge the strength of the vortex field the horseshoe vortex approximation was used: this does not include modelling of vortex dissipation but it was considered that, at the typical spacing of 150 metres, little dissipation would have occurred.

The Sea Vixen was modelled as having a mass of 14,784 kg (Max AUW 18,858 kg) and flying at 270 kt in a 2.5g turn. The Vampire was given a mass of 4,400 kg (Max AUW 6,124 kg) at 220 kt in a 2.0g turn. Longitudinal displacement of 150 metres between the two aircraft was used and the Vampire was placed 6.7 metres to the left of the Sea Vixens centreline.

With these assumptions the modelling showed the vortex circulation of the Sea Vixen as being three to four times stronger than that of the Vampire. It also showed that the vortices could generate roll accelerations exceeding 70°/sec2 in the Vampire, probably greater than the roll authority available to the Vampire at that speed. The modelling also suggested that, if the Vampire stayed close to the vortex core, its roll rate could reach 200°/sec. This would be very unlikely, however, as the Vampires interaction with the vortex from the Sea Vixen would only be transient as the flight paths diverged.

In conclusion, the aerodynamic study suggested that a rapid roll to the right of 90° by the Vampire, as seen in this accident, would be a likely result of such a vortex wake interaction.

Further evidence of this is suggested in a study carried out by the Armament Department of the Royal Aircraft Establishment in 1954. The tests were to determine the position of the wake of a

target aircraft and its general effect on a tracking aircraft. Extracts from the test paper (Technical Note No Aero. 2283) are reproduced below:

The study considered the wake behind a jet aircraft as having the following components:

> *The jet (jet efflux)*
>
> This consists of a small diameter region having a longitudinal velocity combined with perhaps a relatively small rotation due to swirl. Considerable small scale disturbances would be expected to be present.
>
> *The body of other wakes*
>
> These are characterised by regions of turbulence and reducing total head behind drag producing components. In most cases the largest region would be behind the fuselage.
>
> *The vortex sheet and trailing vortices*
>
> The vortex sheet shed from the wing rapidly rolls up into a pair of trailing vortices. These trailing vortices may be represented by a double rotational motion of the classical form. Small scale disturbance is confined to the cores of these vortices.

Tests were planned in such a way as to investigate each of the above components separately, an attempt being made to measure the magnitude of these components as well as their rate of decay with distance behind the aircraft.

A Meteor Mk 4 aircraft (AUW approximately 6,900 kg) was used as the target with a Vampire Mk 4 as the trailing aircraft. Measurements showed that the jet velocity (jet efflux) fell to a negligible value by about 200 to 300 feet behind the jet exit.

The major disturbance behind the aircraft was due to the trailing vortices that decayed only slowly. Theory and flight test experience showed that the rolling moment imposed on the tracking aircraft constituted the most severe disturbance from these vortices, and that in some circumstances this rolling moment could be sufficiently large to overpower the aileron control of the tracking aircraft (see Figure 2 *(jpg 78kb)*). The Vampire was instrumented to measure aileron angle, aileron stick force and normal acceleration as the aircraft traversed from right to left across the centre of the wake vortex (see Figure 4 *(jpg 78kb)*). Comparing these with the theoretical curves (see Figure 3 *(jpg 78kb)*) it was seen that the general shape of the aileron angle to trim curves are similar except that the small peak predicted at about 35 feet from the centre of the wake does not occur so markedly on the flight record.

The flight tests showed that although the pilot could control the aircraft to just beyond the first maximum aileron angle reached, the changeover from maximum aileron angle one way to maximum the other was so rapid that he had difficulty in keeping the aircraft under control.

A further series of tests were carried out to measure the variation of the peak aileron angle with range, speed and altitude. The results showed that the vortices persisted for a considerable time and had decayed to only half of their initial strength by 8,000 feet behind the target. For the two speeds

(188 kt and 235 kt) at 30,000 to 35,000 feet altitude, the disturbances close behind the aircraft were so strong that although maximum stick travel was used, the wings could still not be kept level.

Analysis

The aircraft was one of a pair carrying out a formation display at the Biggin Hill Airshow. Having carried out their initial manoeuvres the pair, in line astern, led by the Sea Vixen, turned 45° away from the crowd and pulled up to carry out a right wing over to fly past the crowd in the opposite direction. During the pull up the pair separated and planned to fly individually past the crowd approximately 1,000 metres apart. It is probable that, as the Vampire reached approximately 80°of right bank, approximately 550 feet astern of the Sea Vixen and the pilot was applying back stick, the aircraft was briefly affected by the wake vortex generated by the Sea Vixen. Theoretical studies have shown that trailing vortices generated by a Sea Vixen can exceed the aileron roll authority of the Vampire. Practical tests, albeit carried out at higher altitudes and with a Meteor as the lead aircraft, have shown that vortices generated by an aircraft of a similar AUW to that of the Vampire can have significant effects up to 8,000 feet astern of that aircraft.

There was no evidence of any pre-impact failure within the aircraft structure or the flying controls that could have caused this accident. Incapacitation of the pilot or safety pilot could not be determined by post mortem examination but is highly unlikely as there is evidence of an attempted controlled recovery from the final descent. Interference with, or jamming of, the controls is again highly unlikely for the same reason. A short-lived external influence on the aircraft's flight path thus remains the most likely initiating event leading to the accident.

The Vampire, separated from the Sea Vixen by some 550 feet, rolled from 80° of bank to the inverted position, a manoeuvre probably unexpected by the pilot, and for a fraction of a second pitched nose down because of the continued application of back stick. Having found himself in an inverted attitude, pitched down by some 56° below the horizon, the pilot appears to have arrested the pitching moment, stabilised the aircraft, and immediately initiated a roll to the right by applying maximum aileron deflection to recover to the nearest horizon. This was achieved, albeit still with a low nose down attitude. As the aircraft rolled rapidly towards the wings level attitude the pilot would have been faced with the need to apply a maximum pitching moment to recover from the dive and at the same time arrest the rolling momentum by applying some degree of opposite aileron. During this recovery the video montage shows that the aircraft adopted a high angle of attack, and probably entered an accelerated flick stall to the right. The roll was not arrested and the aircraft continued to approximately 110° right bank before impacting with the ground at high speed. The total time elapsed from the initiating upset to impact was less than five seconds.