Messerschmitt BF109G-2, G-USTV

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Aircraft Type and Registration:	Messerschmitt BF109G-2, G-USTV
No & Type of Engines:	1 Daimler-Benz DB 605A piston engine
Year of Manufacture:	1942 (Rebuild completed 1991)
Date & Time (UTC):	12 October 1997 at 1600 hrs
Location:	Duxford Airfield, Cambridgeshire
Type of Flight:	Air Display
Persons on Board:	Crew - 1 - Passengers - None
Injuries:	Crew - None - Passengers - N/A
Nature of Damage:	Substantial
Commander's Licence:	Basic Commercial Pilot's Licence
Commander's Age:	54 years
Commander's Flying Experience:	4,612 hours (of which 18 were on type)
	Last 90 days - 23 hours (including 1 hour on type)
	Last 28 days - 22 hours (including 1 hour on type)
Information Source:	AAIB Field Investigation

Accident Flight Profile

The aircraft was performing in aflying display at the Imperial War Museum's Autumn Air Show atDuxford. The aircraft took off normally from the grass Runway24 and cleared the display area while a Spitfire aircraft performeda solo aerobatic display. It was then joined by GUSTV fora coordinated display sequence. The Spitfire then landed andG-USTV performed its planned solo aerobatic display. As the aircrafttravelled from east to west along the display line, it pulledup into its penultimate planned manoeuvre, a 'half cuban', duringwhich a plume of white vapour became apparent streaming from theaircraft. A second similar white trail was noted as the aircraftrecovered to the upright attitude and positive 'g' was appliedto pull out of the dive at the completion of the manoeuvre (Figure1). The Aerodrome Flight Information Service Officer (AFISO)advised the pilot by RTF that "there was white vapour trailingfrom the rear of the aircraft". The pilot acknowledged thisinformation. Power was then reduced and the aircraft carriedout a descending turn away from the crowd and into a short righthand circuit to the south of the airfield. It was positionedfor a landing on the grass Runway 06, which has a landing distanceavailable of 890 metres. The aircraft arrived over the airfieldboundary somewhat higher and faster than normal. A touchdownwas achieved on the main landing gear. The aircraft was travellingtoo fast for the brakes to be applied without the risk of nosingover and it was unable to stop within the remaining runway distance. The pilot therefore elected to lift off and climbed sufficientlyto cross the M11 motorway which lies almost perpendicularto the runway direction adjacent to the eastern boundary of theairfield. Fortunately the aircraft was high enough to avoid anycollision with vehicles on the motorway and the pilot managedto touchdown in a tail-down attitude in the field just to theeast side of the motorway. The field had an unprepared grasssurface and the aircraft initially rolled out normally. However,the field had been partly ploughed and once the aircraft ran ontothe ploughed section, it nosed over at slow speed and came torest inverted (Figure 2).

The pilot was unable to vacate theaircraft because the canopy was jammed closed with the aircraftinverted. Fuel was leaking around the cockpit area but fortunatelythere was no fire. Fire Service Rescue crews were on the scenequickly but the pilot requested that the aircraft be lifted ratherthan cut open in order to prevent further damage to the fuselagestructure or risk to himself. A crane was brought from the airfieldin order to lift the aircraft so that the pilot could be releasedfrom the cockpit.

Pilot's Debrief

The pilot holds a CAA Display Authorisationwhich includes flying in G-USTV and is a Display AuthorisationEvaluator. He had a total of 18 hours flying experience on G-USTVgained over a period of 6.5 years since the second flight of theaircraft after its restoration to flying condition. The pilothad flown between four and seven sorties in the aircraft duringeach of the summer display seasons in the intervening years. The accident flight was the pilot's fifth flight in the aircraftduring 1997, a total of 2 hours 20 minutes flying. Interspersedwith this, in addition to his military flying, the pilot had alsoflown about 70 types of historic and light aircraft types including,most recently, Spitfires, Sea Hurricane and Yak-50. He is alsoan experienced glider pilot.

The pilot indicated that he had operatedthe aircraft with the cooling radiator shutters in AUTO (notedin the Flight Reference Cards as "at 12 o'clock - set 'AUTO'throughout the accident flight. The coolant temperature, engineoil temperature and oil pressure were checked prior to the firstrun in for the display and were found to be normal, with boththe oil and coolant temperatures being about 80°C. The engineexhibited a brief period of harsh running as power was increasedat the commencement of the display, but the pilot had experiencedthis sort of behaviour on previous occasions and discounted itas being of no significance. The display was flown with the fuelboost pump on, the propeller pitch control set to automatic anda standard mean boost setting. The engine performance was normalduring the display until the aircraft was inverted during thehalf cuban manoeuvre. The pilot recalled that, at this time,the cockpit filled with a blue haze accompanied by the smell ofhot oil.

Power was reduced and the half rollto complete the manoeuvre was extended to a descending turn awayfrom the crowd and towards a downwind position for Runway 06. The pilot recalled that the propeller pitch indicator was cyclingrapidly back and forth. He recalled with less certainty thatthe coolant temperature was 80 to 85 degrees C, but could notrecall the oil pressure gauge reading. The oil temperature wasnot checked. On being throttled to idle, the engine ran veryroughly, but picked up if power was increased. The smell of hotoil did not recur.

The propeller pitch control was setto manual and the pitch hunting subsided as the engine was throttledback. The pilot was somewhat confused by conflicting indicationsof engine status, but was certain that an immediate landing wasessential. He made the decision to make a forced landing withthe gear down on the airfield grass runway with the throttle atidle, without reliance on further power application.

The pilot's judgement at the timewas that the most probable cause of the problem was an oil leak,with the consequent expectation of an imminent engine seizure,the possibility of a fire and the expectation of a very poor glideperformance in the event of an engine seizure. He was aware ofthe need to maintain a speed of at least 200 kph in order to ensuresufficient elevator authority for the landing flare in that event.

He also assessed that the crosswindcomponent would tend to drift the aircraft away from the airfield. In the event, the engine continued to operate and the consequenceof the allowances made was an extremely tight circuit patternand an arrival over the landing threshold with considerable excessenergy. To compound this situation, there was no headwind componentto reduce the landing distance required. The pilot estimatedthat the initial touchdown occurred at around 220 kph, with 30°flap selected.

After the fast touchdown, the pilotrealised that it would not be possible to apply the brakes andto stop within the remaining runway distance. Given his beliefthat a total engine failure was imminent, he did not attempt togo-around but concentrated on preserving energy and lifting theaircraft clear over the motorway embankment at the end of theairfield. He turned off the magnetos at this point and managedto complete the forced landing in the field on the east side ofthe motorway.

After the aircraft came to rest inverted,the pilot was aware of a strong smell of fuel. He switched offthe fuel selector and battery master switch. The left cockpitwindow was opened, which admitted more light and air into thecockpit. The pilot's harness was kept fastened while rescue wasawaited.

Aircraft Handling Information

The aircraft's Flight Reference Cards(FRC's) indicated that for Forced Landings, landing on unpreparedground with the landing gear down is not recommended. However,having overshot the landing strip the pilot had little choicebut to land beyond the airfield with the landing gear locked down. The procedure also contained the instruction to touchdown atas low a speed as possible with the wings level and flaps fullydown (40°). From previous flight test data, the stallingspeed of the aircraft in the landing configuration was around140 kph (75 kt), with wing rocking occurring some 6 kt above thisspeed. The operation of the auto-slat system was noted as beingsmooth and unobtrusive with no appreciable pitch changes. Thetime taken to wind the flaps manually from up to the fully downposition was about 22 seconds (commented upon as being a 'cumbersome'operation) and the time for the hydraulically operated landinggear lowering was 23 seconds. The aircraft limitations specifya maximum flaps extended speed of 250 kph.

The following paragraph covers theCircuit and Landing phase:

'Sufficient time must be allowedin the circuit for the undercarriage to lock down. Typicallythis can take 20-25 seconds or even longer if the speed is closeto the 250 kph limit. Owing to the low pressure hydraulic systemthe u/c movement is influenced by air loads on the gear and eachleg may travel both down and up again before finally locking down. 220 kph is recommended as a suitable speed for lowering the u/c. Lowering of the manual flaps is also time consuming and shouldbe done in concert with trimming aft. Prior to landing, the propellershould be set to 11:30 and the boost

pump turned on. The u/cdown button should be pulled out once the u/c has locked down. The final turn should be flown at 200 kph, tapering to 175 kphat the threshold. The view is acceptable provided a slightlycurving approach is flown. 175 kph will yield a short float. The aim should always be a 3 point landing and attention mustbe paid to touching down without drift and maintaining firm directionalcontrol throughout the landing roll.'

Advice sought from the engine specialistswithin the Messerschmitt Restoration Group (MRG) indicated thatthe propeller pitch change mechanism on this aircraft is slowin operation and is partly commanded by throttle lever angle ratherthan engine RPM. Consequently, rapid changes of lever angle mayresult in propeller pitch destabilisation and cycling. Roughrunning may also be experienced under certain combinations ofthrottle lever movement, airspeed and propeller pitch angle.

Meteorological Information

An aftercast from the Met Officeindicated that, at the time of the accident, the surface windwas from 330° at 10 kt, variable between 310° and 350°,visibility greater than 10 km, with scattered to broken cloudabove 3,000 feet. The temperature was +10°C.

With the prevailing surface windand runway orientation of 06/24, the aircraft was subjected toa landing crosswind component of 10 kt, which is the maximum demonstratedcrosswind component for landing on grass runways.

Video analysis

Video tape coverage of the aircraft'sdisplay was analysed. This showed that white vapour was trailingfrom the aircraft for a period of some five seconds during thepull up and some seven seconds during the recovery from the diveat the end of the manoeuvre. The white vapour appeared to becoming from the engine forward of the wing and dissipated rapidly. The manoeuvre took a total of about 32 seconds to complete, measuredfrom a camera positioned about 2/3 of the way along the spectatorline towards the western end of the airfield. The aircraft thenturned away from the airfield onto a downwind leg. For some 11seconds at the end of the downwind leg, the aircraft was bankedslightly towards the airfield. A turn was then made onto a rightbase leg, then this was widened out with a bank away from theairfield for some four seconds, followed by a three second periodof sideslip immediately before the aircraft was turned towardsthe runway. At this point the aircraft was already inside theairfield boundary. The initial brief touchdown occurred almosthalf way along the grass runway about 6 seconds after the aircraftwas aligned with the runway axis. The total circuit from abeamthe camera (after recovery from the final manoeuvre) to the firsttouchdown took 1 minute 46 seconds to complete. The aircraftspeed, once aligned with the runway but prior to the first touchdown,was about 250 kph.

Aircraft History

Built under licence by Erla MaschinenwerkGmbh of Leipzig in the autumn of 1942 this aircraft, a MesserschmittBf 109G-2, wk.no. 10639, was allocated to a unit on the EasternFront. This unit was transferred to Cyrenaica, via Italy, inlate October of that year to support Rommell and the Afrika Korps. Within two weeks the aircraft, identified as 'Black 6', sustainedsome damage in combat against American P-40's and subsequentlywas ferried for repair to Gambut airfield south-east of Tobruk. The speed of the Allied advance, however, forced the abandonmentof much equipment, including 'Black 6', and the damaged aircraftwas subsequently discovered by No 3 squadron

RAAF, who subsequentlyrepaired and flew the aircraft. Before it could be shipped backto Australia as a 'war trophy' an order was received to despatchthe aircraft, along with all available spares, to Lydda in Palestinefor its overall performance to be assessed by the Allies. Ittranspired that No 3 Squadron had captured the first of the newG (Gustav) series and that the type was proving troublesome againstall Allied types, including the then current Spitfire Mk V. Afterfurther testing at Great Bitter Lakes, 'Black 6' was shipped toEngland to join the ranks of No 1426 Enemy Aircraft Flight atCollyweston in Lincolnshire where, after a brief overhaul, itwas displayed to the press as RN228. Following the war the aircraftwas placed in storage and apart from occasional appearances forstatic display and an abortive attempt at restoration, it remainedthere until the current MRG began work on the project in 1973. 'Black 6' next flew again on 17 March 1991 from RAF Benson. 'Black 6' had been the only airworthy example of a genuine Germanbuilt Second World War Bf109 fitted with a Daimler Benz 605 engine,the type being built in greater numbers (in excess of 30,000 plus24 prototypes) than any other aircraft and credited with morevictories than any other fighter type in history.

Aircraft Operational Administration

The aircraft is owned by the Ministryof Defence but is on loan to the aircraft's operator and custodian,the Imperial War Museum Duxford. It is maintained on the civilregister by the MRG and was operating under a CAA Permit to Fly. The operation of the aircraft is carried out under the termsof the Imperial War Museum Organisational Control Manual (OCM)for the aircraft, which has been formulated in accordance withthe guidelines laid down in CAA document CAP 632, Arrangementsfor the Operation of ex-Military Aircraft on the UK Register witha Permit-to-Fly.

It was originally agreed betweenthe various parties that the aircraft would be flown at displaysfor a period of three years, before becoming a static exhibitat the RAF Museum. This period was subsequently extended to fiveyears, the accident occurring on the last planned flight of thisextension.

A total of four pilots (all militarypersonnel, but each also holding a civilian pilot's licence andCAA Display Authorisation) were nominated and approved pilotsfor G-USTV. While the OCM specified that each pilot would maintaina current civilian licence and current CAA Display Authorisation,it did not specify the method and content of any continuationtraining and the policy for handling in-flight emergencies. This was left to the discretion of the pilots involved. Thepilot involved in this accident indicated that he had not recentlypractised the simulated engine failure/glide approach procedureon this aircraft.

Initial Examination

After the accident the aircraft wasrecovered from the field to a hangar at Duxford by lifting it,still inverted, onto a trailer where it was initially examinedby the AAIB the following day. The aircraft's wings and tailplanewere essentially undamaged but serious structural damage had occurredto the fin, rudder, rear fuselage and propeller. It was apparentat this time that the cooling flaps for both radiators were closed,the propeller was at a coarse pitch setting and the flaps wereset symmetrically at 30°. (The flaps on this aircraft aremanually positioned by a multi-turn handwheel located on the leftsidewall of the cockpit, 40° being the maximum extension). There had been no fire. The airframe, particularly the fuselage,had been contaminated with earth, but there was no evidence ofcontamination by engine coolant (a 50/50 mix of ethylene glycoland water) or oil. A visual examination of the cockpit revealedlittle information of significance as most instruments had returnedto their 'at rest' positions. The engine had been shut down,the propeller pitch gauge indicated coarse pitch and the propellercontrol was set to 'manual'. The radiators cooling flaps rotaryvalve selector handle was found close to the automatic position,but not actually in the 'autom' detent.

Engine cooling system description

The powerplant in this aircraft wasa Daimler Benz 605A 12 cylinder inverted 'V' supercharged liquidcooled piston engine. Heat generated by this engine is dissipatedinto the slipstream from two radiators, one located beneath eachwing root towards the trailing edge. The cooling air flow iscontrolled by two hydraulic actuators which determine the positionof the intake lip and upper and lower radiator flaps associatedwith each radiator. These flaps are controlled by the rotaryselector valve, set by the pilot to one of four detented positions(Figure 3). Both radiator flaps move in association with thewing flaps. The valve settings are 'auf' (flaps fully open),'zu' (flaps fully closed), 'ruhe' (flaps hydraulically lockedat their current position) and 'autom'. It was found that itwas necessary to position the rotary selector handle from the'autom' legend by 16° in order to engage the detent. Thedifference between the 'as found' position and the 'detent' positionsof the selector can be seen at Figure 3. When the flaps are atthe closed position, and the wing flaps are retracted, the coolingflaps remain slightly apart, and maintain a minimum cooling flowthrough the radiators. The 'autom' setting provides for automaticmodulation of the flaps position under the influence of a thermostat. This is installed in the coolant outlet pipework from the engineand normally regulates the engine coolant temperature to around80°/85°C. At approximately 110°C, at low altitudes,the coolant may be expected to boil. The cooling system operatesat elevated pressure maintained by a pressure relief valve whichoperates at approximately 1 bar. Any outflow of coolantfrom this valve is piped so as to discharge immediately aheadof the exhaust stubs on the right side of the engine, where itimmediately vaporises, thereby indicating to the pilot in a directmanner that the engine has become too hot. Under these conditionsit is reported that vapour may enter the cockpit although thepilot was not aware of this. The design and orientation of thisrelief valve are such that positive g assists the valve to open. Engine temperature is indicated to the pilot on a dual functiongauge (Figure 4). This gauge normally indicates coolant temperature,unless the adjacent spring loaded button is pushed, whereuponoil temperature is displayed.

Detailed examination

After removal of the wings and tailplane,the fuselage was righted, and the engine removed. General visualexamination of the aircraft by the MRG in conjunction with theAAIB at this time revealed no evidence of any pre-accident defects,or any significant engine or hydraulic oil leaks, coolant leaks,broken pipe/hoses etc, or failures within the cooling flaps operatingmechanisms or water pump. All four radiator shutoff valves werefound still wirelocked in the open position. A significant quantityof coolant was drained from the system components and the engineoil reservoir was found to contain a normal level of oil. Thepropeller was seen to be windmilling before the final touchdownon the far side of the motorway and, following its removal, theengine could be turned freely using normal effort and withoutevidence of distress. The visual appearance of the exhaust stubsand spark plugs examined shortly after the accident was consistentwith normal combustion with no evidence to suggest that the enginehad been burning oil. Also, as a borescope inspection of thevalves and cylinders revealed no visible mechanical damage, itwas decided that detailed strip inspection of the engine was notappropriate. However, should evidence of any unserviceabilitybe discovered during any future engine re-build, this will bereported in a future edition of the AAIB Bulletin.

In order to establish the serviceabilityof the cooling system, the pressure relief valve, thermostat operatedhydraulic valve, and the rotary selector valve were all removedand subjected to functional testing.

The pressure relief valve was testedusing air rather than water, and shown to relieve at around 19/20psig. A strip examination of this unit revealed the diaphragmand valve seats to have been on good condition, with no evidenceof external leakage.

The thermostat/valve assembly wasconnected to a hydraulic supply and through appropriate portsto a slave actuator. When placed in a water bath whose temperaturecould be varied, the actuator began to retract at 75°C andwas fully retracted at 85°C on rising temperature. On lowering,it began to extend at around 80°C and was fully extendedat 65°C.

The detent mechanism associatedwith the rotary selector valve is integral with this unit, andwas found to operate positively and smoothly between all fourpositions, which are set at 90° to each other. (When installedin the aircraft, however, the feel of the detent was less positivedue to backlash in various joints between the handle and valve). On test it was established that hydraulic fluid ported correctlybetween the input and output connections, in accordance with thesystem diagrams in the maintenance manual, at all four detentedpositions. Tests were also carried out with the valve misaligned. This revealed that fluid flow through the valve was shut offif the input shaft was rotated 45° either side of the 'auf'or 'zu' detents, but the same effect could be achieved by a 20°rotation either side of the 'autom' detent. Between 15°and 20° misalignment, flow was severely restricted.

Additionally, the engine coolanttemperature indicating system was tested and found to be accurate.

Analysis

In view of the findings of the detailedexamination and the lack of positive evidence of a mechanicalproblem, a strip examination of the engine was not completed. Analysis of the video recordings of the aircraft's display suggestedthat the intermittent white exhaust trail occurred due to coolantdischarge. The video recordings also indicate that the radiatorcooling flaps were at the closed position from just after start-upto when the aircraft was lined up on the runway, but that theyappeared to be open during the take-off and initial climb. However,as far as could be seen throughout most of the display these coolingflaps appeared to be near to the closed position, there beingno doubt that both were fully closed during the attempted landing,almost two minutes after the cessation of the coolant discharge. Figure 1 compares the (reportedly) more typical open positionof the cooling flaps during a previous display with their positiontowards the end of the subject display. In the absence of coolingsystem leaks it was considered possible that the pressure reliefvalve had opened, under the influence of positive g, when theengine coolant temperature had been rising above normal towardsthe end of the display.

Functional testing carried out onthe primary engine cooling control components, and a more generalexamination of the system, failed to reveal any significant defectsindicating that technical malfunction was unlikely to have beenthe cause of the overheating. Thus, if the selector valve hadbeen set in the 'autom' detent throughout the flight, normal controlof the cooling system would have been expected. However, if the'as found' position of the cooling flaps rotary selector valvehandle were its true position throughout the display (ie, alignedmore closely with the 'autom' legend than when in the detent),and not been inadvertently knocked into that position during theaccident or subsequent escape by the pilot, then the followingsequence of events is indicated.

With the selector valve nominallyat 'autom', but not in the detent (and hence the valve being displacedby about 16°), fluid flow between the rotary valve to thethermostat would have been severely restricted during this flightas demonstrated by tests on the valve. If this were the casethen it might be expected that the cooling flaps would have remainedshut on the ground until the engine warmed to its normal operatingtemperature following which, under the influence of the thermostat,they would open, albeit at a slower rate than normal. In a completelytight hydraulic system, with no internal leakage across pistonand valve seals, normal pressure would eventually be developedat the actuators and the flaps would adopt the desired positionagainst air loads. However, with a restriction through the rotaryvalve any such leakage would reduce the effective pressure inthe actuators, and hence the flaps position against air loads,the level of reduction depending on the ratio between the ratesof leakage and restricted flow through the rotary valve.

However, any overheating of the coolingsystem during the final manoeuvre would not explain the smellof "hot oil and blue haze" in the cockpit, as a resultof which the pilot elected to make a forced landing.

At the time of writing a decisionof the future of this aircraft had yet to be made. Should 'Black6' be returned to an airworthy condition then it will be possibleto test the engine and the cooling flaps operating system, asa complete system. Should any relevant defects arise at thattime, they will be reported upon in a future edition of the AAIBBulletin.