ACCIDENT

Aircraft Type and Registration:	Grob G115E Tutor, G-BYWH
No & Type of Engines:	1 Lycoming AEIO-360-B1F piston engine
Year of Manufacture:	2000
Date & Time (UTC):	12 September 2009 at 1440 hrs
Location:	RAF Leeming, North Yorkshire
Type of Flight:	Military
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to the landing gear rib and lower wing skin
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	46 years
Commander's Flying Experience:	5,500 hours (of which 600 were on type) Last 90 days - 85 hours Last 28 days - 35 hours
Information Source:	AAIB Field Investigation and RAF Unit Inquiry

Synopsis

During the rollout from a three aircraft 'stream' landing, the pilot and passenger of the rear aircraft had to apply full brake pressure to avoid a collision with the aircraft in front. Although the aircraft did not collide, the resulting loads experienced by the wing structure supporting the landing gear, caused it to fail in overload. Subsequent analysis of the failed structure identified possible manufacturing issues, which may have contributed to the failure. The accident was also subject to an RAF Unit Inquiry. Five safety recommendations have been made.

History of the flight

A formation flypast by three Tutor aircraft from the Northumbrian University Air Squadron (NUAS) was planned as part of RAF Leeming's station families' day flying programme. The normal morning meteorological brief took place at 0730 hrs, after which the pilot and passenger of the accident aircraft separately operated passenger experience flights in other Tutor aircraft, until a flypast formation at 1000 hrs. A light tailwind of 2-3 kt was forecast for Runway 16 for the duration of the families' day event. The aircraft commanders, from the three aircraft involved, attended the formation brief, which reiterated aspects of the formation flypast that had been briefed and rehearsed three days previously. The rehearsed profile consisted of a formation takeoff, to reposition for several 500 ft formation flypasts, culminating in a 'Visual Run In And Break' (VRIAB) and 'stream' landing on Runway 16. The brief highlighted that the formation would land beyond the raised arrestor cable; however, no mention was made of where the formation would exit the runway. The commander of G-BYWH was in the No 3 position in the formation; he had taken part in the rehearsal flight, but had deliberately overshot the landing to continue with a student training sortie. During the day's proposed flying programme, there was also a Royal Flight scheduled at RAF Leeming. The crews planned a flexible time slot for the Tutor flypast based around a Royal Flight noise embargo. The lead pilot conducted a standard formation 'outbrief' and authorised the flight.

The formation crews then checked in and awaited a radio call to initiate the flypast profile. The Ground controller passed the clearance to start and the Tower controller advised an amended noise embargo start time "in twenty minutes." The formation moved off the dispersal area at 1425 hrs. The new embargo time of 1445 hrs meant the formation flypast, recovery and close down had to be completed within the available 20 min slot. The formation leader decided that this was achievable and continued with the takeoff.

The formation display was uneventful and the aircraft completed a final 360° orbit before departing away from the crowd line to reposition in 'echelon right' formation for the VRIAB. The VRIAB was conducted level and at 2 second intervals, with the lead aircraft flying at approximately 110 kt. The break was successfully completed with the aircraft equally spaced throughout the downwind and final turn segments of the approach, maintaining a standard 1,000 ft minimum separation for the planned 'stream' landing on Runway 16. The commander of G-BYWH reported that, during the final stage of the flight, he was preoccupied with maintaining accurate formation spacing to ensure the display looked correct and also by the possibility of wake turbulence in the latter stages of the approach. He therefore elected to fly a slightly higher and faster approach than normal, aiming for an approach speed of 80 kt rather than the usual 70 kt. ATC informed the formation that the surface wind was from 330° at 10 kt, which was stronger than expected, though this information was either not heard or not assimilated by any of the pilots.

The lead aircraft landed on the runway centreline, just beyond the arrestor cable on Runway 16, at what the pilot described as normal touchdown airspeed (approximately 65 kt). Using a combination of aircraft attitude and then a gentle application of the brakes, he reduced the aircraft's ground speed and moved to the pre-briefed 'slow lane' on the left side of the runway. The pilot of the No 2 aircraft experienced a small amount of wake turbulence on short finals, which required a corrective input of right aileron. As a consequence, he touched down further along the runway and to the right of the centreline. The pilot estimated that he landed 2-3 kt faster than the normal landing airspeed and with at least 1,000 ft separation from the lead aircraft. Again the pilot used a combination of aircraft attitude and then gentle brake application to slow the aircraft.

The pilot of G-BYWH, in an effort to avoid the effects of wake turbulence, maintained the faster than normal approach speed and a slightly steeper than normal approach to lose the additional height. As a result of this, and due to the position of the No 2 aircraft and the turbulence experienced prior to touchdown, the pilot felt that the safety margin would be reduced if he followed the brief to land on the centreline, and so he elected to land to the left. The pilot and passenger reported that they touched down just beyond the arrestor cable. Neither could recall the touchdown airspeed, but both suggested it may have been slightly faster than normal, though not excessively so. They also considered that they had a minimum of 1,000 ft separation from the other aircraft at this stage. In order not to lose sight of the No 2 aircraft, the pilot of the No 3 aircraft (G-BYWH) selected a lower than normal nose attitude for landing and commenced braking immediately after touchdown.

By this time, the pilot of the lead aircraft assessed that he had slowed sufficiently to turn off the runway onto a taxiway. At the same time, the pilot of the No 2 aircraft initiated a move across the centreline of the runway to the 'slow lane' on the left. The faster touchdown ground speed of G-BYWH and reduced drag of its landing attitude resulted in a rapid rate of closure with the No 2 aircraft. Both the pilot and the passenger of G-BYWH now assessed there was a risk of collision with the aircraft manoeuvring in front of them and both occupants simultaneously applied the brakes as hard as possible. The aircraft started to skid and the crew reported significant nosewheel shimmy and mainwheel 'brake judder'. The pilot of G-BYWH made two radio calls to the pilot of the No 2 aircraft to stay on the right of the runway. In response, both the lead aircraft and the No 2 started to move to the right, with the lead aircraft re-entering the runway. This removed the initial risk of collision between the rear two aircraft, but resulted in the lead now blocking the path of the third aircraft. After the initial application of full braking, the crew of G-BYWH recalled hearing two loud 'cracks' and reported that he felt an increase in the 'brake judder' from the main gear, with an associated loss of stopping performance. G-BYWH eventually came to a halt alongside the other two aircraft, with approximately 2 ft wingtip separation.

Whilst repositioning the formation, the pilot of G-BYWH believed he had a burst tyre and made a radio call requesting a visual inspection from the No 2 pilot, who confirmed that all tyres were still intact. The three aircraft taxied back to the NUAS dispersal and were shut down. G-BYWH was inspected by the site engineer, who noticed that the aircraft attitude was abnormal and that both landing gear access panels were damaged. When the aircraft was taken into the hangar for a more detailed inspection with the landing gear access panels removed and significant damage to the lower wing skin was discovered.

Pilot information

The three aircraft commanders were either serving or volunteer reserve RAF Officers each with over 3,000 hrs experience and were Qualified Flying Instructors (QFI). The first two aircraft flew with NUAS Officer Cadets as passengers. The passenger in the accident aircraft was a qualified and experienced instructor on the aircraft type, but had not been involved in the briefing, planning or rehearsal process and had only volunteered to sit in the spare seat when the opportunity was offered.

Landing performance

The landing distance available from the raised arrestor cable on Runway 16 was 6,220 ft and the distance to the taxiway turnoff selected by the lead aircraft was 1,950 ft. The aircraft Flight Manual landing distance chart assumes idle throttle, flaps set at LAND, a dry paved runway and use of maximum braking. This gave a calculated landing distance required for calm conditions and a normal touchdown speed of 1,500 ft. However, the reported conditions at the time of the accident gave a tail wind of 10 kt, resulting in a calculated landing distance of 2,200 ft. As the No 2 and No 3 aircraft (G-BYWH) reportedly landed at a slightly higher than normal touchdown speed, in accordance with RAF wake turbulence procedures, the landing distance required was likely to have been in excess of this figure.

The lead pilot, who planned the flight, did not calculate the landing distance required. Instead he relied on his experience and the significant landing distance available, to assess the amount of runway required for the 'stream' landing aircraft to decelerate and exit the runway.

Landing technique

A 'stream' landing is when the aircraft land normally one behind the other along the runway centreline, maintaining a minimum 1,000 ft separation. A nominal 'fast' and 'slow' side of the runway are agreed beforehand depending on which side the taxiway turnoff is located. Once each aircraft has slowed to a safe taxi speed they move to the 'slow' side of the runway. This allows any aircraft, which encounters a problem in slowing down, to move to the 'fast' side of the runway and have a clear escape lane. According to RAF procedure, should a pilot consider the separation distance from the aircraft in front to be insufficient prior to or at the point of touchdown, they are to perform an 'overshoot'.

The actual touchdown ground speed of the accident aircraft could not be accurately established, given the lack of GPS data available and neither occupant being able to recall the airspeed. Members of the RAF Unit Inquiry flew the flight profile described by the pilot and concluded it would result in a faster than normal ground speed at touchdown. However, they also considered it would have been within the typical operating range experienced by the aircraft. The manufacturer's manuals do not specify a landing speed or rate of descent limit for the landing gear.

The Grob G115E Flight Manual states that the recommended technique for maximum braking performance on short dry runways is 'cadence' braking. The technique is described as follows:

> *'As soon as the nose-wheel is on the runway use three to four seconds of moderate braking to establish the braking system effectiveness. As the brakes "bite", pull the control column back towards the rear stop. Then pause the braking for 2 seconds and then reapply. Continue the 2 second 'off' and 2 second 'on' braking cycle until the ground speed is under control.'*

Although the manual advises against steady pedal pressure to give the best deceleration performance and prevent disc heating, there are no specific warnings or limitations in the manual to suggest that this action could result in overload of the wing structure.

Pre-flight planning

NUAS were invited to participate in the families' day flying schedule to replicate a flypast flown by them during the 2008 families' day. The RAF considers a flypast to be a routine benign event, where an aircraft transits past a crowd-line as part of a special occasion. Their procedures define a flypast as involving:

> *'Aircraft flying, either singly or in formation, past a reviewing stand or any specific point along a pre-planned route without manoeuvring, other than when necessary for safe and accurate navigation.'*

This type of flight is not intended to include any additional pressures compared to routine flying, although it is often flown in formation. Risk mitigation at the planning stage for these flights is therefore similar to that required for normal formation flying, although special approval for the flight is still required. Display flying is different from normal flying due to the number and type of manoeuvres flown within a pre-defined airspace, often at low-level and with timing pressures.

Although the officers who authorised the flight considered it was a routine flypast, with standard manoeuvres and no aerobatic content, it did contain timing and airspace restrictions, an unusual downwind takeoff, three formation changes and an unusual, downwind 'stream' landing. As such, the RAF's investigation concluded that the pilots encountered the following:

> *'…unusual takeoff procedures; formation handling and Crew Resource Management (CRM); a higher than normal workload for the lead [pilot]; higher than normal timing and spacing pressures; crowd-line pressures; unusual landing procedures and crowd-pleasing pressures. The investigation considered that the planned sortie therefore involved elements of display flying and therefore carried an increased risk, compared to a routine flypast...'*

Approval for the flight was provided from two sources. The lead pilot's position within NUAS gave him self-authorisation privileges but a senior officer in the station command structure also gave approval after watching the rehearsal flight. NUAS is part of 22 Group, which is a training organisation within the RAF, whereas the senior officer was part of 1 Group, which conducts operational flying. His approval was given based on the physical performance during the rehearsal flight and not on a specific check of the planning and preparation or confirmation of permission having been obtained from 22 Group Headquarters.

Despite being able to authorise the flight himself, the lead pilot was expected to seek permission for the flypast from his chain of command within 22 Group. He delegated this task to another member of his team, who misunderstood the requirement. Both individuals assumed that the requested task had been completed satisfactorily and the matter was not discussed further. As a consequence, 22 Group Headquarters were not aware of the flypast or the semi-display nature of the planned content. The Commanding Officer of 22 Group advised that had permission been requested, approval would either have been refused or additional risk mitigation in the form of more extensive planning and rehearsal of the flypast would have been required.

Runway ground marks

Significant tyre marks could be identified on the runway left by the accident aircraft, showing that both wheels had 'locked up' for a distance of approximately 1,280 ft. The marks were a mix of solid tyre tracks and short skip marks.

Aircraft information

The Grob G115E Tutor is a small, lightweight aircraft used by the RAF for elementary flight training (Figure 1). The accident aircraft was a Civilian Owned Military Operated (COMO) aircraft and on the UK civilian register as G-BYWH. The Grob G115 type was certified to Federal Aviation Admistration (FAA) Federal Aviation Regulations (FAR) 23 standards, with an EASA type certificate issued for the Grob G115E in 2002, following on from German Luftfahrt-Bundesamt (LBA) approval of the type. It is constructed predominantly from carbon fibre, has a tapered low wing, fixed horizontal and vertical stabilisers and conventional flight control surfaces. The aircraft is fitted with a panel mounted GPS unit, with a track memory feature. However, no recorded data was found when the unit was downloaded after the accident.

Figure 1
Photograph of an RAF operated Grob 115E Tutor aircraft

The aircraft has a fixed, tricycle landing gear with simple, hydraulically operated, single disc brakes on each mainwheel and no anti-skid system. The main landing gear leg is a single piece of sprung steel attached to the wing in two places by bolting to steel brackets, which are in turn bolted to a composite gear rib (Figure 2) and the root rib. The gear rib is a carbon structure which angles inboard, with a web bonded around its circumference. The rib/web is bonded by adhesive to the upper and lower wing skins and the main spar and root rib at each end. The wing is a sealed structure, but has a small access port around the main gear attachment fitting, which is covered by an access panel in normal operation.

Aircraft inspection

Both the mainwheel tyres were in good condition, with the exception of flat spots and areas of melting consistent with the reported wheel lock-up under heavy braking. The main landing gear legs, wheels and brakes showed no evidence of damage. Visual inspection of the wing structure in situ was limited to the outer skins, and small sections of the inner side of the gear rib and outer side of the root rib visible via the access port. This inspection identified significant cracking of the lower skin and cracks between the gear rib and the wing spar on both wings. There was also damage evident on both the access port cover panels around the rear of the cut-out for the gear leg.

The aircraft was returned to the manufacturer's facility in Germany for the damaged sections to be removed and assessed under the supervision of the German Federal Bureau of Aircraft Accident Investigation (BFU). The damaged sections were then returned to the UK for analysis by composite material specialists.

Detailed examination confirmed similar and almost symmetrical damage to both wings. The access port cover panels had fractures through the carbon fibre from

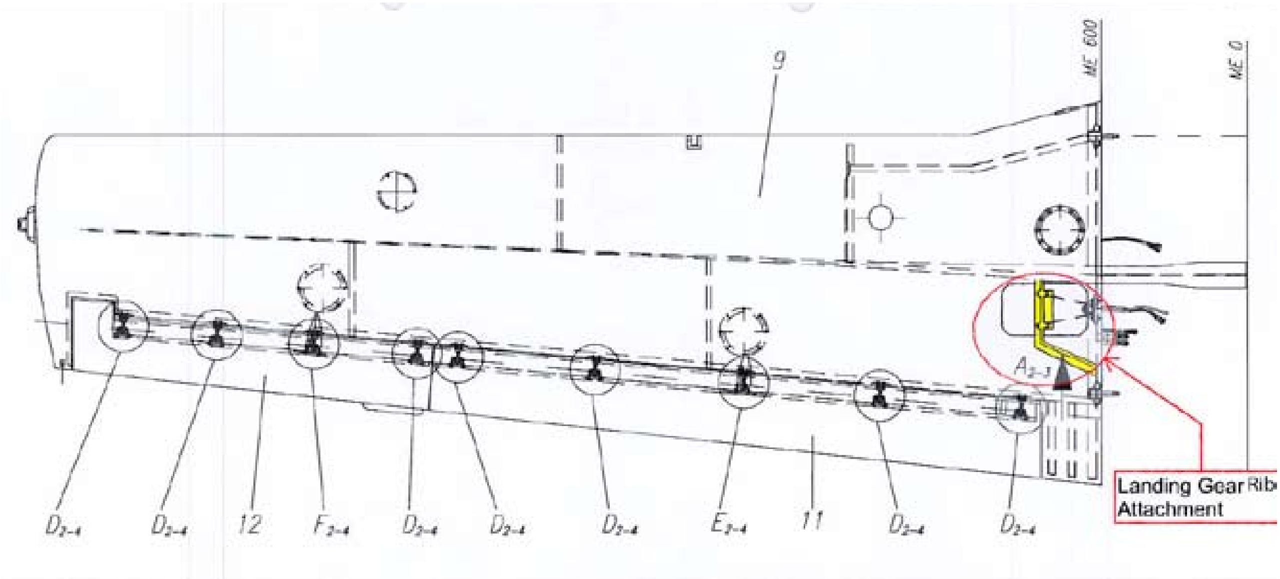

Figure 2

Diagram of Grob G115E wing structure.

the rear of the gear leg cut out of 50 mm for the left panel and 20 mm for the right panel. The orientation of the fibres and the cracking of the surface coating indicated that the panels had been pushed outwards by the gear legs. This was matched by witness marks on the paint of the gear legs. The lower wing skin was significantly cracked in the recess which formed the access port. Detailed inspection of the carbon fibres along the edges of these cracks indicated that the wing skin had been pushed upwards relative to its normal position.

Inspection of the disassembled sections of the gear rib showed that the rib/web had separated from the front spar and also along the top and bottom wing skins. It was not possible to determine exactly how far down the rib length the failure extended, as this was not confirmed prior to the deliberate removal of the rib from the wing skins during the disassembly process. However, an assessment of the additional areas of damage suggests that this separation must have extended along the rib. The bond failure on the left wing rib was predominantly adhesion[1], but with approximately 8% of the bond surface failing cohesively. The right wing rib exhibited an almost 100% adhesion failure, with the adhesive layer remaining on the wing spar surface of the joint.

The adhesive which had bonded the rib/spar and rib/skin joints was an unusual white translucent colour, with only small areas of pale yellow coloured adhesive at the edges of the joints. Inspection under a microscope identified that the white colour was due to a high level of porosity within the adhesive (Figure 3). Ductile fibrils were also identified in the areas of the adhesive that had failed cohesively, suggesting a ductile rather than brittle failure. A brittle failure would normally be anticipated from the epoxy resin system specified for these joints in the manufacturer's design specification. Fourier Transform Infra Red (FTIR) spectroscopy was

Footnote

1 Adhesion bond failures occur at the interface between the adhesive and the structure being bonded, with residual adhesive remaining on one surface only. Cohesion bond failures occur within the adhesive layer, such that adhesive remains on both the structure surfaces.

used to analyse the composition of samples of both the yellow and white coloured adhesive. Both were consistent with an epoxy resin system. Chemical analysis of the samples, with comparison to exemplar samples at various stages in the cure cycle, confirmed that there were variations in the degree to which the adhesive had cured. Differential Scanning Calorimeter (DSC) tests were completed on the white adhesive to determine if the ductility was due to incomplete cure of the adhesive. Due to the porosity of the sample these tests proved inconclusive.

Also noted in the adhesive joints were large void areas. An example observed in the joint between the rib and the rib web measured 30 mm by 50 mm. The thickness of the layer of adhesive forming the bondline was noted to exceed the manufacturer's design specification (and industry production standard) of 0.5 to 2.0 mm in many areas. A large section of the web joint had failed in an interlaminar manner. The resulting fracture surface exhibited features consistent with a shear failure, with relative movement between the rib and the web in the vertical and longitudinal planes (rib moving forward and down/web moving up and back). The ductile properties of the adhesive masked the fracture features on the other surfaces, preventing further analysis.

The rib web had also failed in the corner of the gear rib where it angled inwards towards the root rib. Both ribs had fractured diagonally across the rib web and

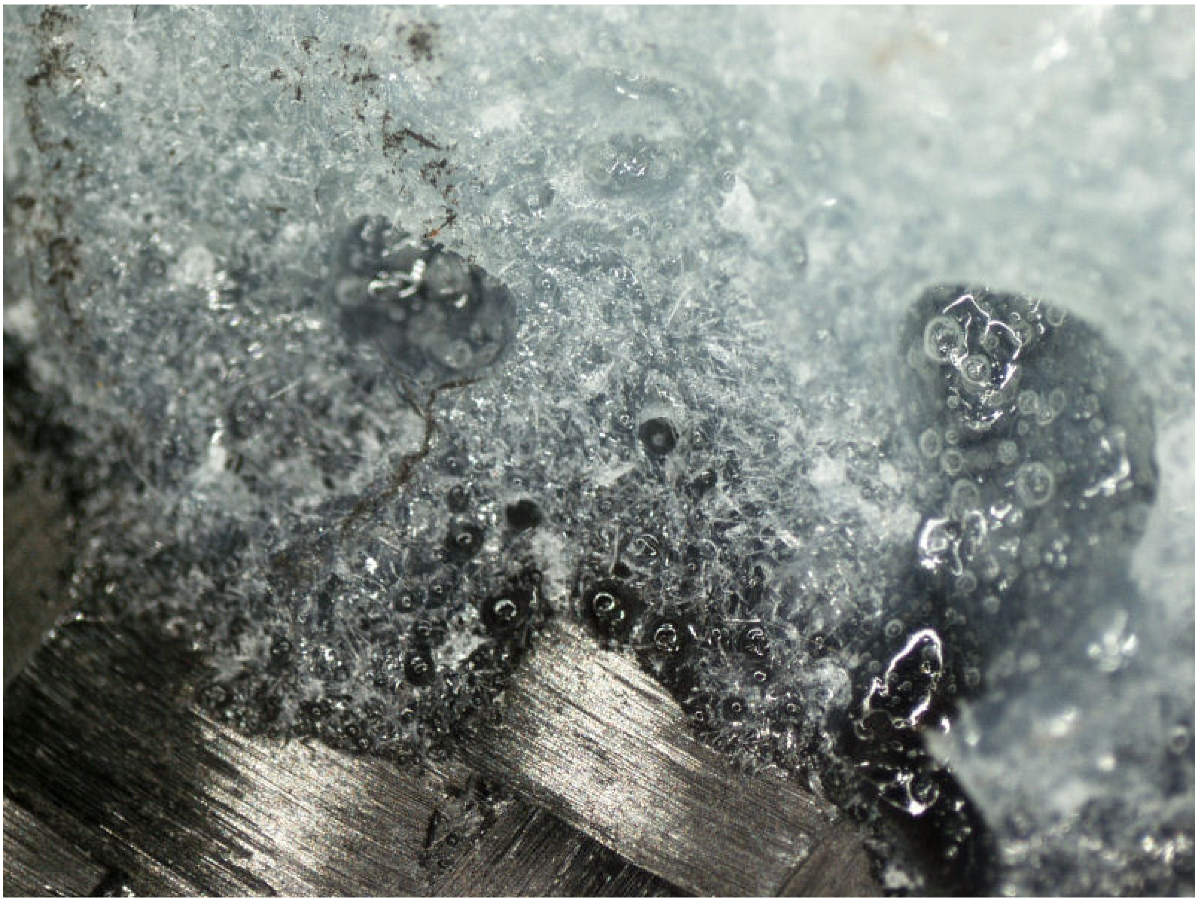

Figure 3

Magnified image of the white adhesive showing porosity down into the rib structure. The carbon fibres along the crack showed that the failure was tensile, with the front section of the rib being pulled outboard away from the wing root effectively 'straightening out' the angle. The rearward part of the metal gear leg attachment back plate was bent away from the composite rib by 1.5 mm on the left rib and 3 mm on the right rib, with associated separation of the composite straps used to secure it. This was also indicative of the forward section of the ribs having flexed outboard. The back face of the gear leg attachment plate showed fretting marks around the bolt-holes which were reflected by wear marks on the rib face, indicative of relative movement between the plate and the rib structure.

Manufacturing issues

During the detailed component inspection, a number of features were identified which indicated that the assembly process had not followed accepted industry best practice. In many cases these features were outside the manufacturer's design specification limits. These included:

- Significant interlaminar pores/voids within thick laminate sections
- Inconsistent fibre alignment and surface 'wrinkling' on composite sections
- Foreign object inclusion within a thick laminate section
- High levels of adhesive porosity
- Significant pores/voids within the adhesive at joints
- Excessive application of adhesive at joints, with resin flow-off not being removed and adhesive being used to secure non-structural items
- Excessive and inconsistent adhesive bondline thicknesses
- Fibre breakout at machined holes in the carbon fibre structures resulting in galvanic corrosion of metallic fasteners and delamination of the composite
- Low quality welding of metallic parts resulting in cracking and corrosion at the joints

Manufacturer's investigation findings

The manufacturer assessed the structural failures during the disassembly process, prior to the components being sent back to the UK. They issued an interim report confirming that the damaged areas had not been subject to a previous repair and were not the result of pre-existing damage. They stated that the structure had been certified against FAA FAR Part 23, which did not include any dynamic load test requirements and the majority of the compliance demonstration was based on similarity to previous Grob 115 models. They also advised that there had been no previous failures of this nature on any Grob 115 model in over 600,000 flying hours. Based on discussions with their Chief Test Pilot they considered the most plausible explanation for the damage was:

> *'Dynamic loads in the form of heavy vibrations'*

They expand this further by stating:

> *'Unfortunate combinations of tyre grip level, gear load at touchdown and speed may result in severe vibration of the landing gear rod. To avoid eventual vibration rising to a destructive level and for other good reasons, it is common sense to brake an aircraft sequentially instead of maintaining full brake pressure.'*

They also stated that as the failure was caused as a result of an 'emergency condition' and as such no further action was planned.

Previous occurrences

Review of operator and CAA records showed that a Mandatory Occurrence Report (MOR) was raised by the same operator following the discovery of almost identical damage to another aircraft in their fleet in 2004 during an Approved Maintenance Schedule (AMS) periodic inspection of the mounting bracket. At the time, the damage was attributed to an unreported heavy landing incident, though no evidence or analysis was put forward to support this conclusion.

Certification requirements

Requirements exist in both FAA FAR 23 and EASA Certification Standards (CS) 23 regarding the ability of aircraft structure to withstand limit load and ultimate load. These state:

'23.301 Loads

(a) Strength requirements are specified in terms of limit loads (the maximum loads to be expected in service) and ultimate loads (limit loads multiplied by prescribed factors of safety). Unless otherwise provided, prescribed loads are limit loads.

23.305 Strength and deformation

(a) The structure must be able to support limit loads without detrimental, permanent deformation. At any load up to limit loads, the deformation may not interfere with safe operation.

(b) The structure must be able to support ultimate loads without failure for at least three seconds, except local failures or structural instabilities between limit and ultimate load are acceptable only if the structure can sustain the required ultimate load for at least three seconds. However, when proof of strength is shown by dynamic tests simulating actual load conditions, the three second limit does not apply.

23.307 Proof of structure

(a) Compliance with the strength and deformation requirements of CS[FAR] 23.305 must be shown for each critical load condition. Structural analysis may be used only if the structure conforms to those for which experience has shown this method to be reliable. In other cases, substantiating load tests must be made. Dynamic tests, including structural flight tests, are acceptable if the design load conditions have been simulated.

(b) Certain parts of the structure must be tested as specified in Subpart D of CS[FAR]-23.'

The requirements/assumptions for braked roll load calculations are provided by CS[FAR] 23.493. The standard safety factor between limit and ultimate load is 1.5.

Subpart D does not specifically require dynamic testing of the braked roll condition to validate the theoretical loads analysis. However, CS[FAR] 23.601 does state:

> *'The suitability of each questionable design detail and part having an important bearing on safety in operations, must be established by tests.'*

There are two further regulations within subpart D which are also relevant. CS[FAR] 23.603 states:

> *'(a) The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must –*
>
> *(1) Be established by experience or tests;*
>
> *(2) Meet approved specifications that ensure their having the strength and other properties assumed in the design data; and*
>
> *(3) Take into account the effects of environmental conditions, such as temperature and humidity, expected in service.*
>
> *(b) Workmanship must be of a high standard.'*

CS[FAR] 23.605 (a) states:

> *'The methods of fabrication used must produce consistently sound structures. If a fabrication process (such as gluing, spot welding, or heat treating) requires close control to reach this objective, the process must be performed under an approved process specification.'*

Operational analysis

The RAF Unit Inquiry reported a number of operational factors which were assessed to have contributed to the accident. These and others have been considered in this investigation.

The issues surrounding the approval of the content of the flypast meant that an opportunity to avoid or reduce the risks involved was lost. The limited preparation and rehearsal of the flypast may have been significant with regard to the deviations from standard procedures which occurred during the landing. The nature of the manoeuvres flown during the display, including those leading into the landing and rollout were not entirely routine and although well within the capabilities of the pilots involved, required higher level and more specific planning and preparation. Additional distraction and specific task focus was also encountered by the pilots as they felt pressure to ensure the display looked good for the spectators.

Both the No 2 and No 3 (G-BYWH) aircraft's pilots independently elected to fly at higher airspeeds than usual in the approach, as advised by the RAF procedure for suspected wake turbulence. However, when combined with the stronger than forecast tailwind, which was passed to the pilots by ATC but reportedly not heard or assimilated by them, it resulted in higher than normal groundspeeds. Their focus on maintaining a high standard of display formation spacing, combined with the missed radio call may have prevented the formation from considering the option of increasing aircraft separation during final approach, to reduce the likelihood of encountering wake turbulence or to take account of the tailwind and deliberately higher airspeed. Had this option been taken, it may have maintained the margin that was required to safely continue with the 'stream' landing.

The No 2 pilot landing to the right of the centreline resulted in the No 3 pilot electing to land to the left of the centreline on what should have been the 'slow' side of the runway. The briefed 1,000 ft minimum separation should have allowed the aircraft to land safely behind each other regardless of position on the runway, providing the aircraft were travelling at similar speeds and decelerated at the same rate. The pilot of G-BYWH stated that he considered it necessary to land on the opposite side of the runway to avoid wake turbulence. It is possible, however, that he had already anticipated a reduction in separation distance due to the speed differential between the aircraft, even if the minimum distance existed as he crossed the threshold. The normal safeguard of having an escape lane on the 'fast' side of the runway had also been lost by the positioning of the No 2 aircraft. The accident pilot stated that a perceived need to ensure the display looked good for the crowd contributed to his decision not to perform an 'overshoot' while the opportunity was available. It is possible, though not specifically stated by the pilot, that timing pressures resulting from the Royal Flight noise embargo may also have been a contributory factor.

The lead aircraft was not aware of what was occurring with the two aircraft behind. The taxiway turn-off he selected was safely achievable based on his own aircraft's ground speed. However, had the stopping distances been calculated prior to the flight, this may have emphasised the reduced margin available in the event of the landing not going to plan. The timing of the crossing manoeuvre by the No 2 pilot may also have been influenced by an anticipation of the need to follow the lead aircraft's turn to maintain the formation. Planning for an extended rollout may have helped to avoid the compressed landing distance available, which the pilot of the No 3 aircraft (G-BYWH) encountered. Including a target turnoff in the original brief may also have added to the pilots' situational awareness in anticipating a risk of collision before it reached a critical stage.

The higher groundspeed and lower drag attitude of the No 3 aircraft meant that the separation distance from the No 2 aircraft rapidly reduced following touchdown. Once the possibility of collision had become a critical concern, the pilot of G-BYWH made a non-standard radio call to the No 2 pilot to remain on the right of the runway. This was misinterpreted by the lead pilot who re-entered the runway and became a further obstacle to the accident aircraft's escape route.

These factors in combination resulted in both the pilot and passenger of G-BYWH sharply applying full and continuous operation of the brakes in an effort to avoid a collision.

Engineering analysis

When the brakes were applied during the avoiding action, both the wheels locked causing the aircraft to skid. The momentum of the aircraft effectively acting through the aircraft's centre of gravity and the effect of the locked brakes at the level of the wheels/tyres, produced moments around the gear leg attachment points in both the vertical and horizontal planes (Figure 4). These were transmitted into shear loads on the adhesive bonds locating the gear ribs. The adhesive bonds failed and the ribs separated from the spar and wing skins around a section of their circumference, with the ribs flexing outwards and downwards. This caused the rib and web to crack at the point where it kinks to meet the root rib. It also caused associated flexing and cracking of the lower wing skin, as it became a secondary path for the loads. Loss of the rigid location of the landing gear meant the deceleration loads could no longer be transferred to the primary aircraft structure, compromising stopping distance and the ability of the pilot to control the aircraft.

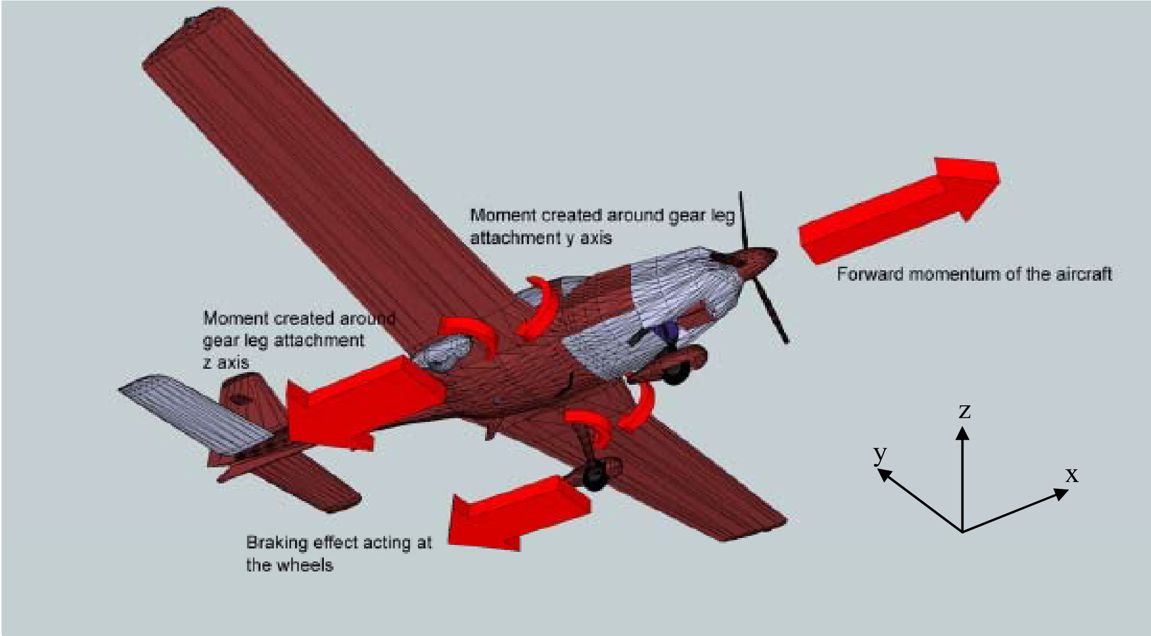

Figure 4

Illustration of loads acting on the aircraft

The adhesive in the failed joints had high levels of porosity. Industry studies have shown that the presence of porosity within epoxy-based materials causes a significant reduction in the mechanical properties of the material. Studies showed that shear strength reduction by a factor of ten was observed between a non-porous and porous epoxy material[2]. The thickness of the adhesive layer forming the bonds meant the presence of porosity was also likely to have had a greater influence on the mechanical properties of the bond, than would have been the case for thinner adhesive layers.[3]

A degree of porosity within epoxy-based resins is unavoidable, as the curing reaction produces hydrogen that becomes trapped as bubbles within the resin. However, there are a number of manufacturing issues which can cause excessive porosity and may have contributed to the high adhesive porosity identified on the accident aircraft. These are:

- Excessive use of hardening agent which accelerates the curing reaction and thus the production of hydrogen
- Incomplete or incorrect mixing of the resin and hardening agent resulting in localised concentrations of resin or hardener (resin rich or resin poor areas)
- Excessive thickness of the resin/hardener layer applied allowing migration and coalescence of hydrogen bubbles into larger pores
- A mixing process that incorporates air from the atmosphere into the resin/hardener mix such as stirring partially cured adhesive

Footnote

[2] Alonso MV, Auad ML and Nutt S – Short-fiber-reinforced epoxy foams. Composites A: Appl Sci and Manu, 2006.

[3] Harte A-M, Fleck NA and Ashby MF - Sandwich panel design using aluminium alloy foam. Adv Eng Mater, 2000,

It is likely that the porous nature of the adhesive created a weak bond which may have contributed to the failure of the joints between the ribs and the spar and skins. The thickness of the layers of adhesive and the presence of significant voids/pores may also have contributed to the weakness of the joints. In some areas the adhesive layer was found to be three times thicker than the manufacturers own design specification and 20 times thicker than the limit suggested by industry studies beyond which it becomes detrimental to the shear strength of the bond. Both these features can result from insufficient pressure holding the structure together during the curing process, excessive layer thickness can also result from the use of adhesive to fill gaps created by large tolerances in component dimensions.

A number of other features were noted which were also indicative of design and manufacturing processes that were not in line with industry recommended practice and demonstrated a lack of effective quality control. Although these were not directly linked to the failure, they have been shown by industry studies to be detrimental to component structural strength and can lead to premature failure of aircraft structure. As the issues relate to both design assumptions and manufacturing processes, the following Safety Recommendation is made:

Safety Recommendation 2010-078

It is recommended that the European Aviation Safety Agency in cooperation with the Luftfahrt-Bundesamt (LBA) conduct an audit of Grob Aircraft AG's design and quality standards, manufacturing processes and facilities to ensure that they meet current regulatory standards.

To determine if the findings from the examination of G-BYWH are present on other Grob G115E aircraft, the following Safety Recommendation is made:

Safety Recommendation 2010-079

It is recommended that the European Aviation Safety Agency require Grob Aircraft AG to introduce an inspection of all G115E aircraft to ensure their structural integrity complies with regulatory airworthiness standards and that design assumptions relating to fabrication techniques and material properties used during aircraft certification remain valid.

In the absence of any test data for the dynamic structural loads encountered under heavy braking on the Grob G115E aircraft, it has not been possible to demonstrate that the failure of the gear rib structure was solely the result of a weak adhesive bond. The design of the joint between the rib and the spar/skins was more typical of metallic rather than composite design standard practice and as such was not optimised to withstand the loads experienced, even if the adhesive bonds had been sound. The response of the manufacturer to the accident relies on the current certification requirements not specifically calling for demonstration of the capacity of the structure to withstand dynamic braking loads. As such they have stated that the aircraft still meets its airworthiness certification basis. They also point out that this was an emergency scenario and therefore not representative of normal operation, drawing attention to the fact that the Flight Manual instructs that a cadence braking technique should be used.

Although the aircraft was travelling at a slightly higher groundspeed than usual at touchdown, it was unlikely to have been excessive or outside the range where the aircraft could be expected to operate safely. The application of the brakes was not in accordance with the Flight Manual guidance, but was a foreseeable response to the circumstances, as was the lock-up of the wheels. The braking system does not have an 'emergency mode' and the Flight Manual draws no distinctions between emergency and normal braking technique, nor could this be considered an emergency landing. Furthermore the aircraft Flight Manual does not quote a specific limitation against full and continuous application of the brakes. As such, the braking technique employed by the pilots during the accident, even though the wheels locked as a consequence, should be considered part of the anticipated operating envelope of the system.

Reliance on cadence braking when attempting to avoid a collision is unrealistic, as demonstrated by this accident, and particularly in light of the aircraft's primary role as an elementary flight trainer. The aircraft must be capable of withstanding the loads that are generated by the rapid and continuous application of full brake pressure, either by ensuring the structure is strong enough to withstand them or by reducing the effect of brake application, such that the resulting loads remain within the structural strength limitations of the aircraft. The following Safety Recommendation is made:

Safety Recommendation 2010-080

It is recommended that the European Aviation Safety Agency in conjunction with the Federal Aviation Administration review the Grob G115E aircraft design to ensure that rapid, full and continuous application of the brakes at groundspeeds within the normal operating envelope, does not result in failure of the aircraft's structure.

With regard to the certification requirements, the following Safety Recommendations are made:

Safety Recommendation 2010-081

It is recommended that the European Aviation Safety Agency consider the introduction of a specific requirement, for CS 23 certified aircraft, to ensure that theoretical maximum landing gear dynamic loads under braking, calculated during the design process, are validated by dynamic testing and the capacity of the aircraft structure to withstand them is demonstrated as part of the certification process.

Safety Recommendation 2010-082

It is recommended that the Federal Aviation Administration consider the introduction of a specific requirement, for FAR 23 certified aircraft, to ensure that theoretical maximum landing gear dynamic loads under braking, calculated during the design process, are validated by dynamic testing and the capacity of the aircraft structure to withstand them is demonstrated as part of the certification process.