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SPORT AVIATION / BALLOONS

ADDENDA and CORRECTIONS

None

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SERIOUS INCIDENT

Aircraft Type and Registration:	Boeing 757-28A, G-STRY
No & Type of Engines:	2 Rolls-Royce RB211-535E4 turbofan engines
Year of Manufacture:	1996
Date & Time (UTC):	25 August 2010 at 0025 hrs
Location:	En route over Mauritania
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 7 Passengers - 96
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	34 years
Commander's Flying Experience:	8,662 hours (of which 2,820 were on type) Last 90 days - 181 hours Last 28 days - 79 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft was in the cruise at FL370 when the flight crew noticed an increase in both engine vibration levels. They selected the Engine Anti-Icing (EAI) ON but the vibration levels continued to increase gradually. The crew decided to carry out an ice shedding procedure, which was described in their operations manual (OM). As thrust was reduced on the left engine its vibration increased rapidly to the maximum level shown on the EICAS. The crew attempted to restore the thrust but the engine did not respond normally to the thrust lever movement. A descent was made to a lower level and a diversion to Nouakchott was initiated. The engine recovered at some time during the descent and a normal two-engine approach and landing was made.

The left engine is considered to have entered a surge or stall condition following the action of retarding the thrust lever and then increasing thrust. There was no damage evident within the engine and the vibration condition was attributed by the engine manufacturer to an asymmetric ice build-up under the spinner fairing. The manufacturer's Fan Ice Removal procedure as described in the OM was found to be inappropriate for the prevailing conditions.

Three Safety Recommendations are made.

History of the flight

The aircraft was operating a scheduled service from Freetown Airport, Sierra Leone, to London Heathrow

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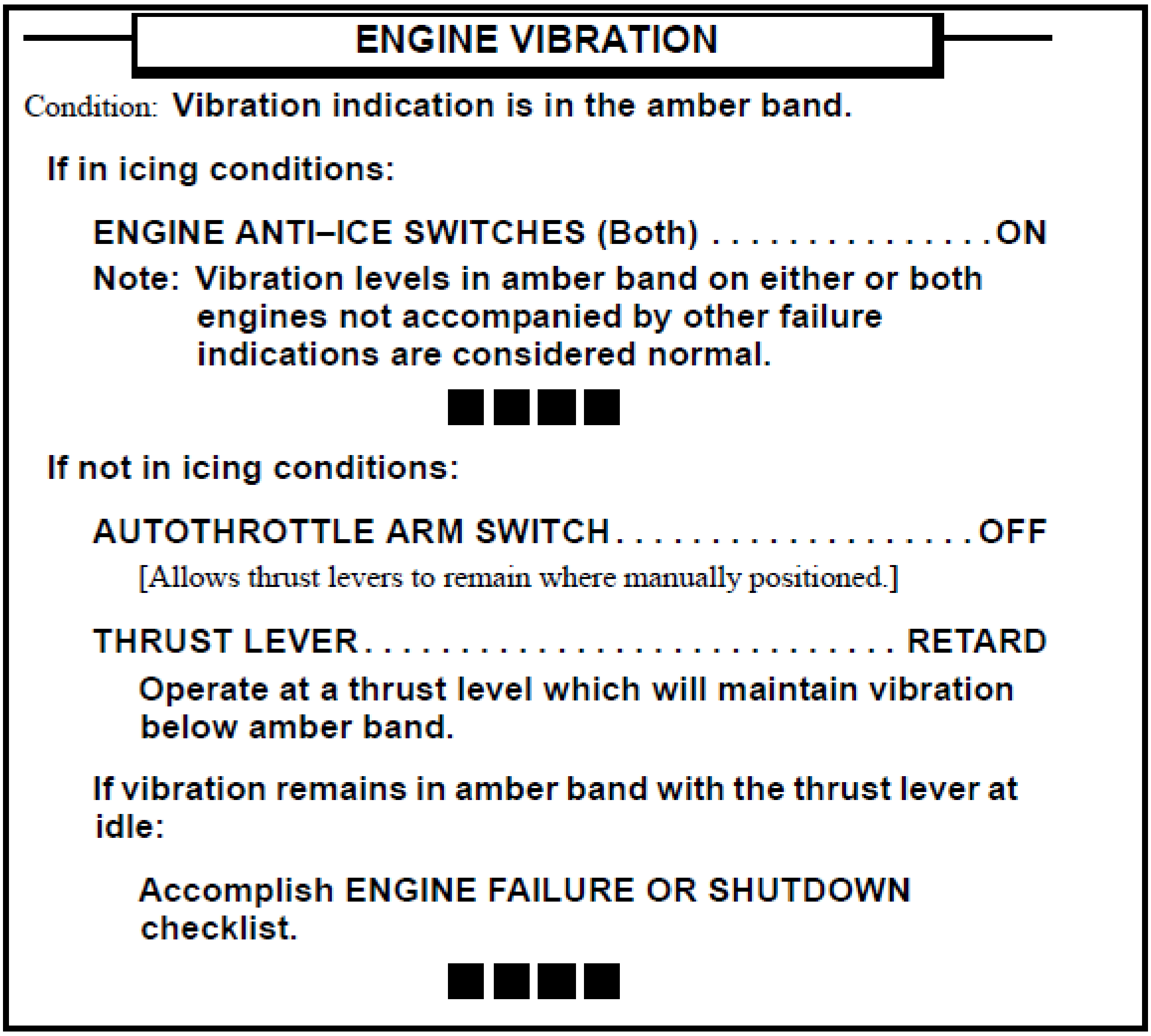
Airport. The aircraft took off at 2343 hrs and climbed directly to FL370. En-route there were some significant areas of convective weather activity, which the crew identified on their weather radar and altered course to avoid.

One hour and forty minutes into the flight the crew noticed a sustained increase in both engine vibration levels to approximately 2.3 units. Looking for a possible reason, the commander shone a torch onto his windscreen wiper and noticed a thin layer of ice present. The Static Air Temperature (SAT) was -47°C. The crew selected the EAI ON. The vibration continued and increased to between 3 and 3.5 units over a ten minute period. The Quick Reference Handbook (QRH) non-normal checklist for engine vibration was consulted and the crew decided that, as icing conditions were present, no further action was required. Note: normally in icing conditions in the climb or cruise, with SAT below -40°C, the EAI is not required.

The vibration could now be felt through the airframe by both the flight crew and the cabin crew. The commander decided to perform the manufacturer's



ENGINE VIBRATION

Condition: **Vibration indication is in the amber band.**

If in icing conditions:

ENGINE ANTI–ICE SWITCHES (Both) . . . . ON

Note: Vibration levels in amber band on either or both engines not accompanied by other failure indications are considered normal.

■■■■

If not in icing conditions:

AUTOTHROTTLE ARM SWITCH. . . . . OFF

[Allows thrust levers to remain where manually positioned.]

THRUST LEVER. . . . . RETARD

Operate at a thrust level which will maintain vibration below amber band.

If vibration remains in amber band with the thrust lever at idle:

Accomplish ENGINE FAILURE OR SHUTDOWN checklist.

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Figure 1

QRH Engine Vibration non-normal checklist

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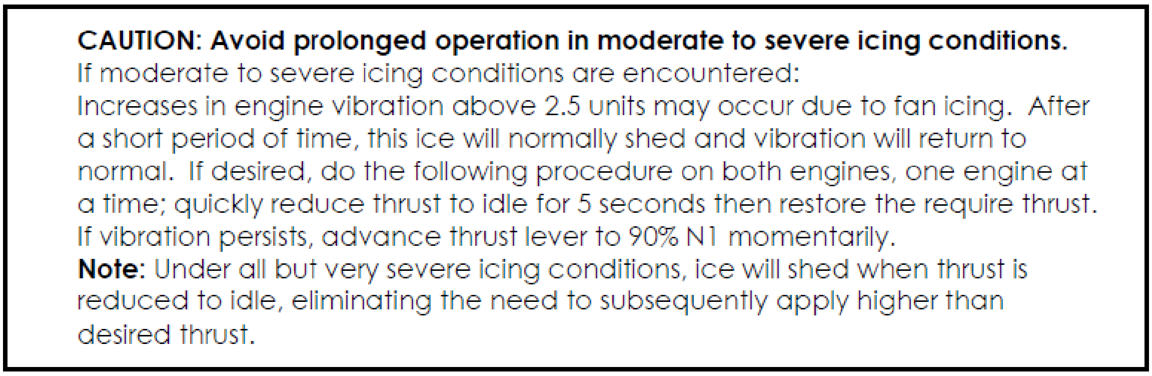

CAUTION: Avoid prolonged operation in moderate to severe icing conditions.
If moderate to severe icing conditions are encountered:
Increases in engine vibration above 2.5 units may occur due to fan icing. After a short period of time, this ice will normally shed and vibration will return to normal. If desired, do the following procedure on both engines, one engine at a time; quickly reduce thrust to idle for 5 seconds then restore the require thrust. If vibration persists, advance thrust lever to 90% N1 momentarily.
Note: Under all but very severe icing conditions, ice will shed when thrust is reduced to idle, eliminating the need to subsequently apply higher than desired thrust.

Figure 2

Fan Ice Removal procedure

Fan Ice Removal procedure detailed in their OM, in an attempt to reduce the vibration (see Figure 2).

The autothrottle was disconnected and the thrust lever was retarded on the left engine. As the thrust reduced, the crew observed an immediate increase in vibration on the left engine, which they recollected as 5 to 6 units. Thrust was reapplied but the engine power did not correspond to the thrust lever movement and the EGT increased to an observed peak of 803°C. The crew reduced the thrust again to 1.2 EPR, to prevent an EGT exceedence, whereupon the vibration stabilised at around 2.5 units. The right engine, while still indicating a vibration level of 3 units, was operating as expected. A MAYDAY was declared and the aircraft descended to FL250 and altered course towards Nouakchott. The right engine was kept at a medium power level during the descent. Several more attempts to increase power on the left engine were made, again resulting in increased vibration and high EGT. The crew decided not to shut down the left engine in case a similar problem should occur with the right engine. Later on, during the descent the left engine started to respond normally to thrust lever movement.

At 0229 hrs a normal two-engine landing was made at Nouakchott. Subsequent examination of both engines on the ground, both externally and internally, did not reveal any damage.

Meteorological information

For their pre-flight planning, the crew had available an Africa High Level Significant Weather Forecast chart. This showed several areas of isolated cumulonimbus cloud along the route, with tops reaching up to FL500. The upper level winds for the first two hours of flight were generally from an easterly direction.

En route, the crew were able to monitor the conditions ahead of track using the aircraft weather radar. They made several deviations to the east of the flight planned track to avoid flying into areas of strong convective activity. In the process of the investigation a colour enhanced infrared satellite image, timed at 0100 hrs, with the track of the aircraft superimposed upon it, was constructed. This image showed the height of cloud, based on a colour coded scale, with the white areas being the highest level. The commander subsequently sketched the approximate position of the weather activity he had observed on the weather radar onto this image (see Figure 3).

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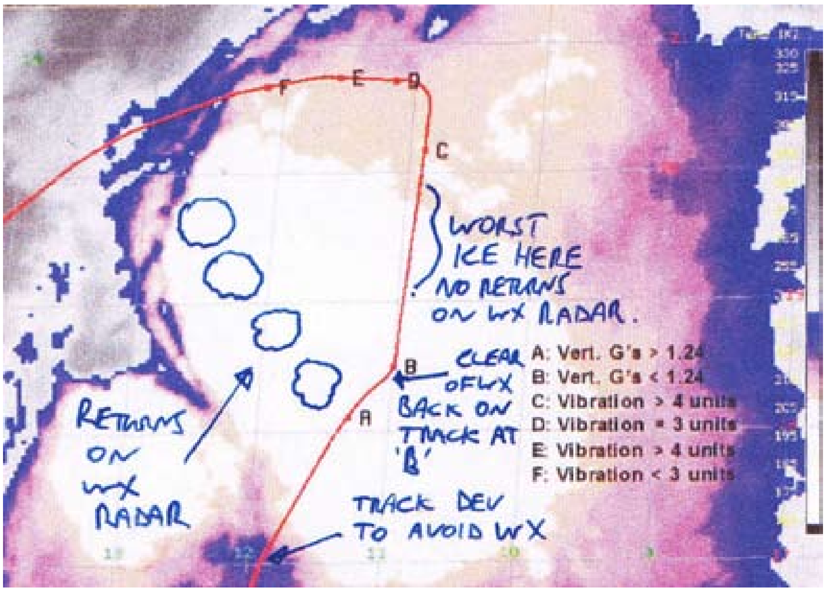

Figure 3

Infrared satellite image with sketch of en-route weather (for scale, each vertical graticule is 60 nm ie the distance from A to C is approximately 120 nm)

An analysis of the weather radar identified two Mesoscale Convective Systems[1] (MCS) along the route flown by the aircraft. The total distance the aircraft flew within one of the two systems was more than 500 nm, over a two hour period.

Flight recorders

The aircraft was equipped with a Flight Data Recorder (FDR), a Quick Access Recorder (QAR) and a 30-minute Cockpit Voice Recorder (CVR). Whilst at Nouakchott Airport, the operator had made preparations to remove the FDR. However, following confirmation from its engineering department that the QAR system would record the same data as the FDR, the operator secured the QAR data and decided not to replace the FDR. The QAR data was successfully replayed by the operator following the aircraft's return to the UK. The operator advised that it did not remove the CVR, as it understood that the period containing the peak engine vibrations would have been overwritten prior to landing. At the time of the incident, the operator did not have a formal procedure for the preservation of the FDR or CVR. The operator has since addressed this.

Salient parameters from the QAR included the selection of EAI, thrust lever position, engine EPR, EGT and vibration. For each engine vibration parameter only the shaft (N_1, N_2 or N_3) with the highest vibration level was recorded at any one time. The thrust lever and engine EPR parameters were recorded once every second, and engine EGT and vibration once every 64 seconds. Figure 4 provides a plot of the flight, with shaded areas A to G identifying periods flown whilst in the two MCSs. Figure 5 is a satellite image containing the two MCS areas, planned waypoints and flight track; the flight track

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Footnote

[1] Mesoscale Convective Systems (MCS) are thunderstorm regions which may be round or linear in shape, with a horizontal extent of 100 km (54 nm) or more. MCS form when clouds occurring in response to convective instability amalgamate into a single cloud system with a very large upper cirriform cloud structure.

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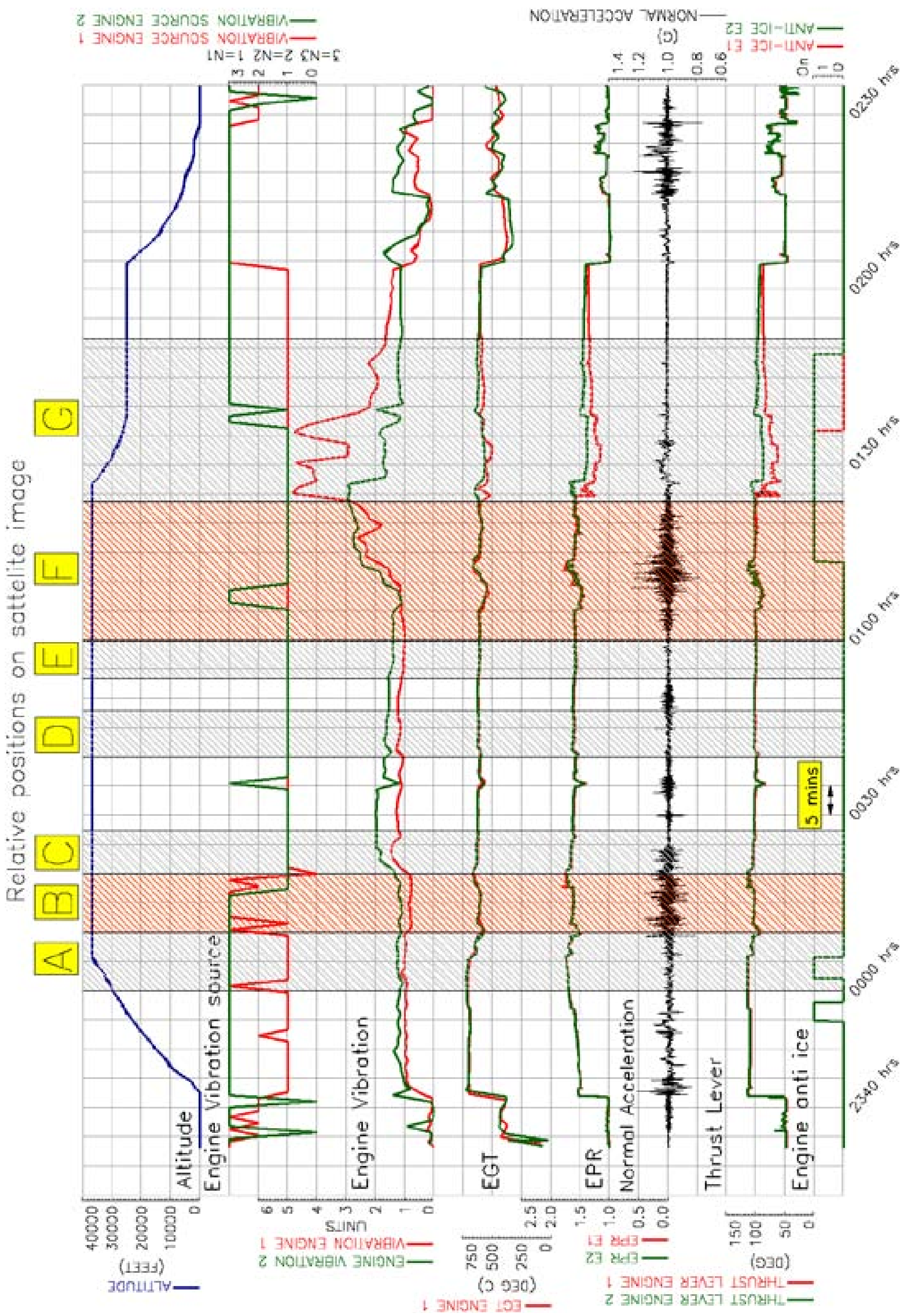

Figure 4

Flight from Lungi Airport (Sierra Leone) to Nouakchott Airport (Islamic Republic of Mauritania)

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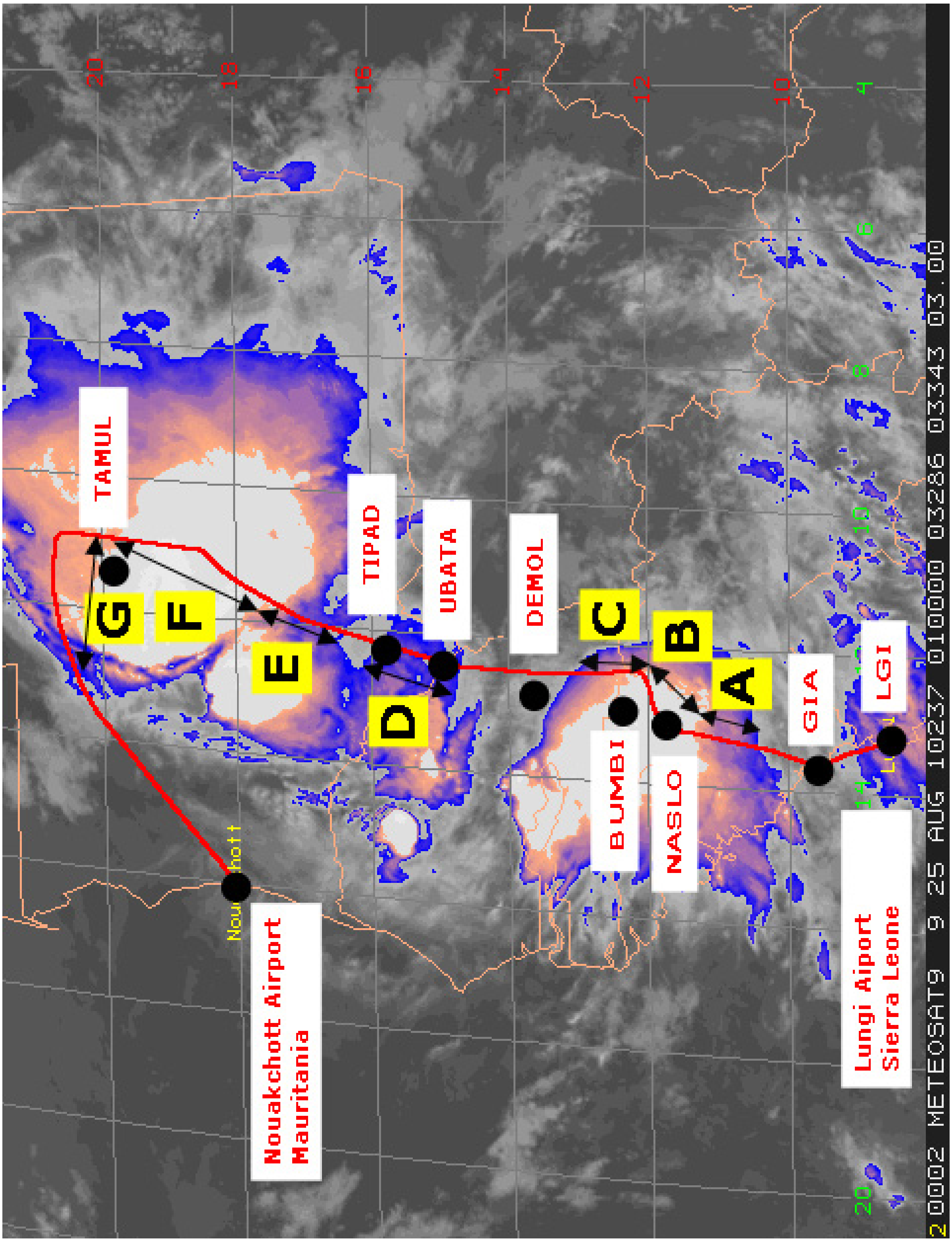

Figure 5

Satellite image of MCS areas over Africa and G-STRY flight track and waypoints
(Points A to G refer to the relative aircraft positions detailed in Figure 4)

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is annotated with sections A to G for cross reference with those detailed in Figure 4. Figure 6 is a plot of the left engine response to manual thrust lever commands whilst in the cruise.

The takeoff was uneventful, with the aircraft initially tracking northwards along the west coast of Guinea, to waypoint GIA, before routing inland to waypoint NASLO. During the climb, EAI was selected ON between FL227 and FL270 and then again between FL320 and FL365. As the aircraft climbed through FL290, it entered the first MCS (see Figures 4 and 5). The first MCS was approximately 230 nm in length and 170 nm wide. At 0006 hrs, the aircraft levelled off to cruise at FL370. The SAT had gradually reduced from 25°C, at takeoff, to -48°C. Four minutes later, the aircraft entered the area with the highest cloud tops within the MCS (see Figures 4 and 5 – area B) and there was an increase in normal acceleration activity, indicative of moderate turbulence. Shortly after, as the aircraft approached waypoint NASLO, the flight crew altered track approximately 35 nm to the east, routing away from the core of the MCS.

After the takeoff at 2343 hrs, the engine vibration levels remained at about 0.9 units for the left engine and 1.2 units for the right, with N_1 shaft vibration predominantly recorded for the left engine and N_3 for the right. However, at 0020 hrs, just at the aircraft was resuming its northerly track to waypoint UBATA, the N_1 shaft vibration level on both engines started to increase. The aircraft was still in turbulent air at the time and the EPR on both engines was just reducing from 1.75 to 1.65. At 0028 hrs the aircraft exited the MCS. The left engine N_1 shaft vibration had now stabilised at just less than 1.2 units, and the right engine N_1 shaft vibration at 2 units. The aircraft had flown for about 200 nm whilst in the MCS.

At 0035 hrs, whilst experiencing light turbulence, the autothrottle gradually reduced the EPR settings on both engines from 1.6 to 1.4. At this time, the left engine peak vibration source changed from the N_1 shaft to the N_3 shaft and reduced from 2 to 1.2 units. The EPR on both engines was then progressively increased to 1.6, following which the right engine peak vibration source returned to the N_1 shaft, at a level of 1.7 units. There was no change in left engine vibration during this period, with the N_1 shaft at 1.2 units.

At 0041 hrs, as the aircraft approached waypoint UBATA (situated near to the border between Senegal and the Islamic Republic of Mauritania), it entered the southern tip of the second MCS. The MCS extended to the north by approximately 480 nm and was between 170 nm and 350 nm wide. Twenty minutes later, the aircraft entered the area of the MCS having the highest clouds (see Figures 4 and 5 – area F) and there was an increase in turbulence. Several minutes later, the EPR on both engines was progressively reduced, from 1.6 to 1.4. This was accompanied by a reduction in right engine vibration, with the N_3 shaft becoming the source of maximum vibration at 1.1 units. During the next four minutes, as the autothrottle attempted to stabilise the airspeed, the EPR on both engines was progressively increased to 1.7. As EPR increased, the right engine maximum vibration source changed to the N_1 shaft and there was an increasing trend in both left and right engine N_1 shaft vibration levels. As the left engine reached 2 units and the right 2.5 units, the flight crew selected both EAI systems to ON. Both engine N_1 shaft vibration levels continued to increase, before stabilising at about 2.6 units. The trend over the next five minutes was a slight reduction in the left engine N_1 shaft vibration, before both engine N_1 shaft vibration levels further increased to 3 units. The aircraft was just leaving the highest cloud level within the MCS at this time (see Figures 4 and 5 – area G).

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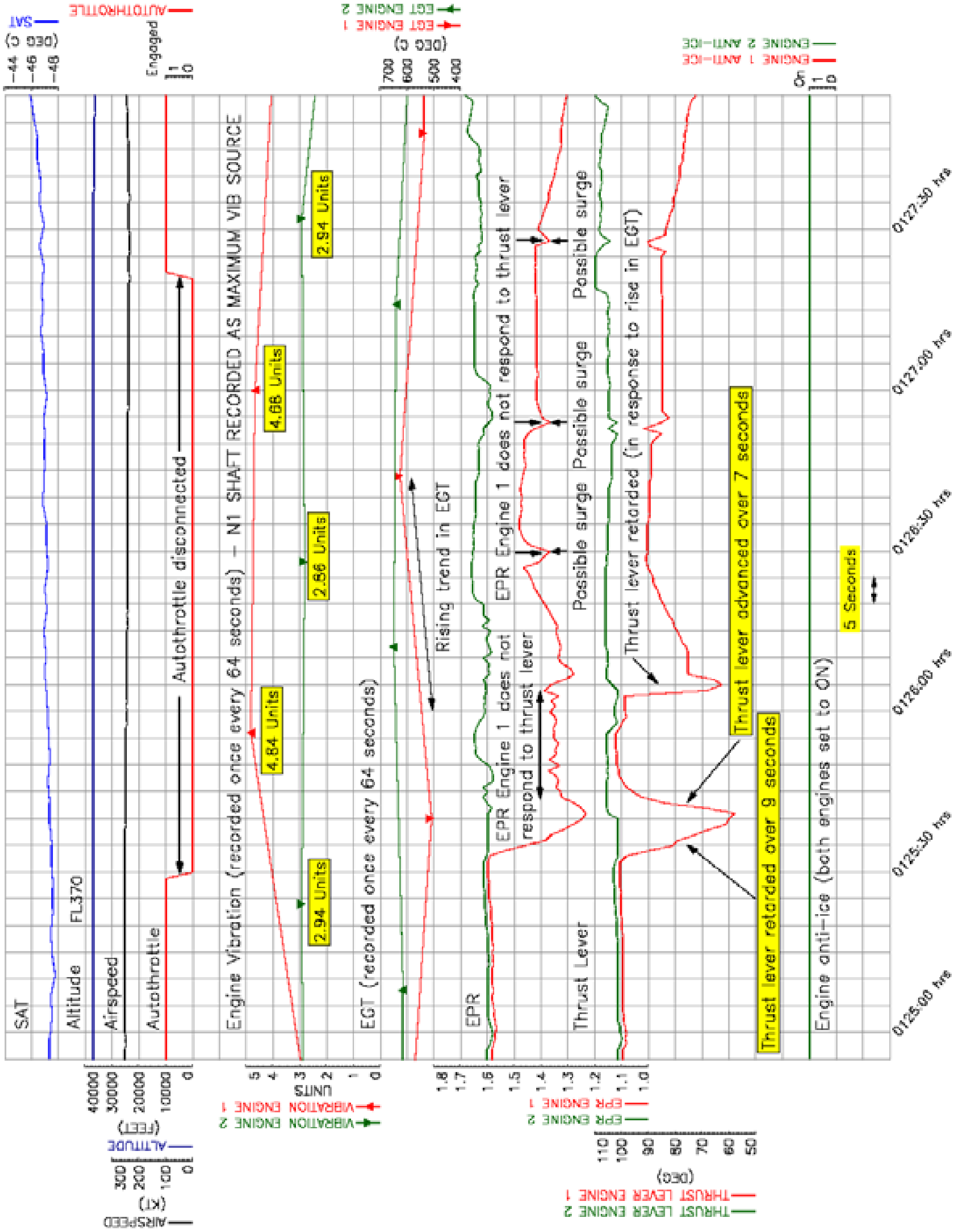

Figure 6

Recorded data during period of manual thrust reduction whilst in the cruise

A few minutes later, at 0125 hrs, the autothrottle was disconnected by the flight crew and over a nine second period, the left engine thrust lever was manually retarded to an intermediate position above idle, with the EPR reducing to 1.2 (see Figure 6). The left thrust lever was then advanced, without delay, to its previous cruise position over a seven second period. The left engine initially responded, before stabilising at about 1.3 EPR, which was below that being commanded. The right engine N_1 shaft vibration had remained stable at about 3 units; however, the left engine N_1 shaft vibration increased to 4.8 units. This was accompanied by a recorded rise in left engine EGT, to a maximum of 630°C[2]. The left thrust lever was quickly retarded and then gradually advanced over a further 30 second period. The left engine EPR initially tracked the increasing thrust command but the EPR then rapidly reduced before increasing again. During the following minute the left thrust lever was advanced and retarded twice. On both occasions, the left engine EPR failed to respond correctly (see Figure 6). Shortly before the last of these two thrust lever movements, the autothrottle was re-engaged as the flight crew initiated a descent to FL250 and altered track to the south-west, towards Nouakchott Airport. Since entering the cruise, the SAT had remained predominantly stable at about -48°C. As the aircraft descended, the SAT gradually increased.

As thrust was reduced for the descent, there was a slight stagger in the position of the left and right thrust levers, with the right leading the left. The right engine thrust was reduced to 1.4 EPR and its N_1 shaft vibration level subsequently reduced from 3 to 1.7 units. The left engine stabilised at a lower EPR of about 1.2, although its N_1 shaft vibration remained at about 4 units. Over the next eight minutes, the left engine N_1 shaft vibration level varied between 3 and 4 units, with the right engine N_1 shaft vibration remaining predominantly stable at about 1.7 units. As the aircraft descended through FL265, the left EAI was selected to OFF. It was at about this time that a reducing trend in the left engine N_1 shaft vibration began. By the time the aircraft levelled at FL250, the left engine N_1 shaft vibration level had reduced to about 2.2 units. At this time, the right engine peak vibration was 1.2 units and the source had changed from the N_1 to the N_3 shaft. A few minutes later, the right EAI was selected to OFF.

At approximately 0152 hrs, the aircraft exited the second MCS, having flown in it for approximately 2 hours, over a distance of 460 nm. The left engine N_1 shaft vibration level was now at about 1.6 units. The thrust lever stagger had also slowly started to reduce. As the thrust levers were retarded for the start of the final descent, the left engine dominant vibration changed from the N_1 to the N_3 shaft, with vibration level reducing to less than 1 unit, where it remained.

During the descent and approach, with the thrust levers re-aligned, both engines operated at similar EPR values. During the final approach, there was an increase in both engine N_3 shaft vibration levels, with the right engine increasing to a maximum of 1.4 units – the aircraft was also experiencing turbulence at this time. The subsequent landing and taxi were uneventful.

Preservation of flight recordings (FDR and CVR)

Although the operator had no formal procedure in place to preserve the FDR or CVR data, it had taken steps to preserve a record of the FDR by securing the QAR data. On this occasion, the QAR was successfully replayed; however, it should be noted that neither ICAO Standards and Recommended Practices nor EU-OPS regulations,

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Footnote

[2] The flight crew reported a maximum left engine EGT of 803°C. This was not captured on the FDR due to the recording rate of EGT, which was once every 64 seconds.

concerning the preservation of the FDR following an incident or accident, refer to the QAR being used as an alternative means of compliance. The operator had also considered the removal of the CVR but, aware that the period containing the peak engine vibrations would have been overwritten prior to landing, they elected not to preserve it. Although the event period itself may have been overwritten, AAIB experience is that CVR's may still provide useful information if preserved in a timely manner after landing, with the possibility that post-event discussions in the cockpit may have been recorded.

With reference to UK CAA publication CAP 382 (*The Mandatory Occurrence Reporting Scheme*), the incident was subject to mandatory reporting since an engine had failed to respond correctly to thrust lever commands. The operator subsequently reported the incident to the AAIB on 27 August 2010 and provided a safety report to the CAA.

EU-OPS 1.160, '*Preservation, production and use of flight recorder recordings*', requires the following of an operator:

> *'(a) Preservation of recordings:*
>
> *(2) Unless prior permission has been granted by the Authority, following an incident that is subject to mandatory reporting, the operator of an aeroplane on which a flight recorder is carried shall, to the extent possible, preserve the original recorded data pertaining to that incident, as retained by the recorder for a period of 60 days unless otherwise directed by the investigating authority.'*

In June 2010, AAIB Safety Recommendation 2010-012, concerning the unintentional overwriting of CVR records, was made to the UK CAA. On 24 August 2010, the UK CAA issued Airworthiness Communication (AIRCOM) 2010/10. In addition to identifying operator requirements for the preservation of recordings, as laid down in ICAO Annex 6, Part I, 11.6 and EU-OPS 1.160, AIRCOM 2010/10 also made the following recommendations to operators.

> *'4.1 Operators and continuing airworthiness management organisations should ensure that robust procedures are in place and prescribed in the relevant Operations Manuals and Expositions to ensure that CVR/FDR recordings that may assist in the investigation of an accident or incident are appropriately preserved. This should include raising awareness of Flight Crew and Maintenance staff to minimise the possibility of loss of any recorded data on both the CVR and FDR.*
>
> *4.2 When appropriate, the relevant circuit breakers should be pulled and collared/tagged and an entry made in the aircraft technical log to make clear to any airline personnel that an investigation is progressing. Furthermore, confirmation from the investigating authority/ operator is required to be obtained before systems are reactivated and power is restored.*
>
> *4.3 Operators who contract their maintenance or ground handling to a third party should ensure that the contracted organisation is made aware of all their relevant procedures.'*

Aircraft and engine information

The EAI system is operated by individual switches for each engine. When selected ON, the leading edge of the engine cowl is anti-iced by engine bleed air and the engine ignition is activated. The spinner utilises a flexible rubber tip which, in conjunction with the rotational forces imparted on the spinner during engine operation, limits the build-up of ice on the spinner to acceptable levels.

The aircraft has two central EICAS screens. Primary engine indications are shown on the upper EICAS screen, which is always displayed, and secondary engine indications are shown on the lower screen, which is selectable or will display automatically if an amber band or red line limit is reached.

The aircraft has an airborne vibration monitoring system that monitors engine vibration levels. The sensors measure vibration in a radial direction on each engine (ie out of balance forces) and the vibration indications are displayed on the secondary engine display on the lower left side of the lower EICAS screen (see Figure 7). The amber alert level is at 2.5 units. The maximum continuous EGT is 795°C, at the start of amber caution area, and the maximum takeoff limit is 850°C, at the red line.

The Quick Reference Handbook (QRH) contains non-normal checklists for *'Engine Vibration'* and *'Engine Limit or Surge or Stall'*.

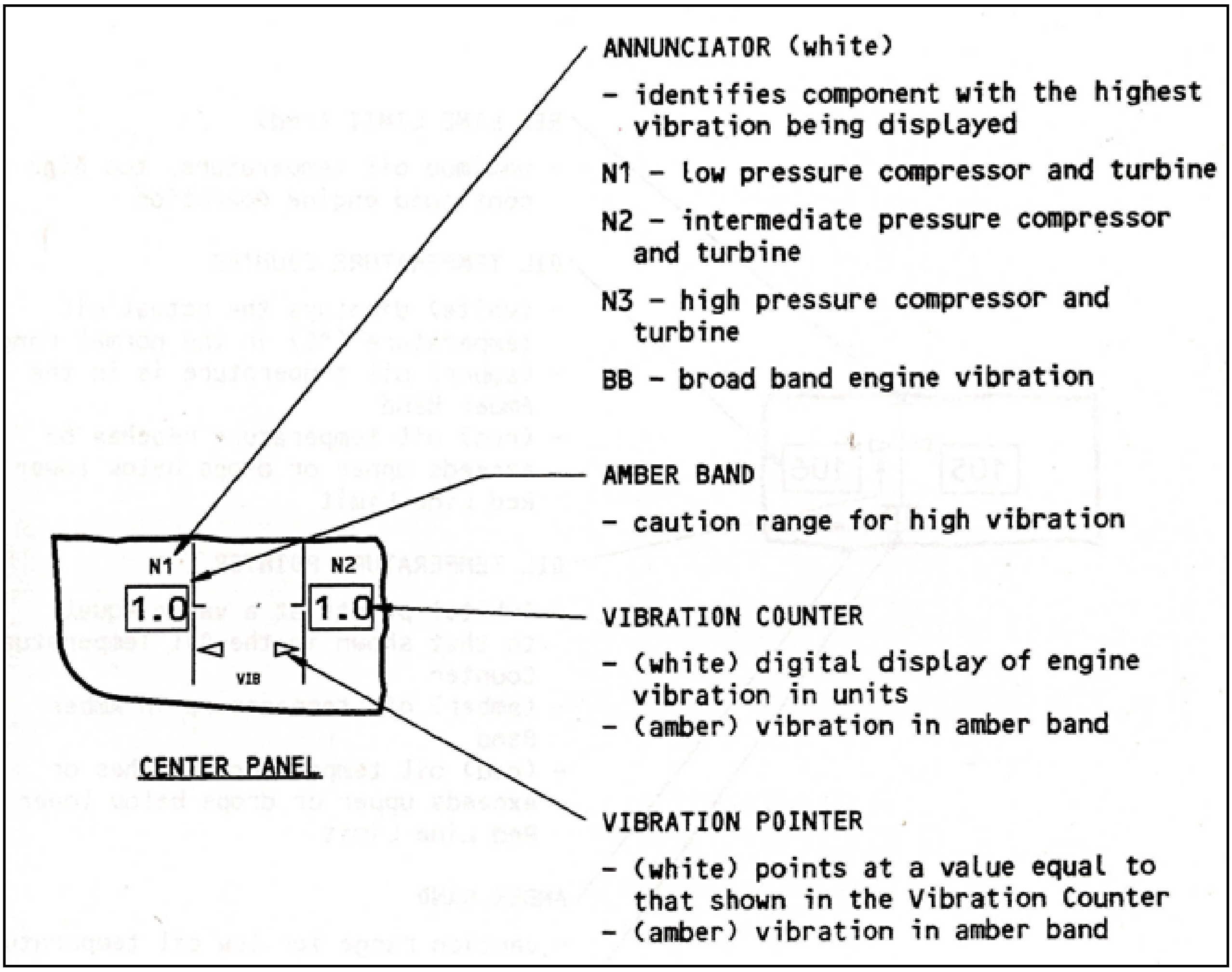

Figure 7

EICAS Engine vibration display

The issue of moisture ingress into the cavity between the spinner and the spinner fairing, resulting in asymmetric ice build-up and subsequent engine vibration, has been recognised by the engine manufacturer. The manufacturer originally introduced SB72-AD132 in September 2001 to address this issue. The key element of the Service Bulletin (SB) is an 'Omega' seal that is bonded to the spinner and provides a seal between the spinner and the spinner fairing, preventing the ingress of moisture into the cavity. This modification is now instructed by SB72-AF034 revision 1, released in August 2006 and all parts of the SB are to be accomplished by March 2015.

The spinners on the incident aircraft were checked and neither featured modified spinners to SB72-AD132 or SB72-AF034 standard.

Engine manufacturer's assessment

The presence of visible icing on the wiper indicated the aircraft was operating in icing conditions, whilst the recorded vibration monitoring parameters indicated that the low pressure shaft was the source of the vibration.

The engine manufacturer was aware of several low pressure shaft vibration events on this engine type which have been attributed to ice. All these events have occurred on aircraft which have either not had SB72-AD132 or SB72-AF034 embodied or have exhibited damage to the spinner/spinner fairing or Omega seal.

The possibility of core engine icing was considered an unlikely factor by the engine manufacturer. This was based on the higher temperatures in the front stages for this 3-spool engine and the lack of previous events in such conditions for this engine type. The engine manufacturer noted that, in cold high altitude conditions, the clouds consist of dry ice crystals that do not stick to the fan blades or the spinner. Thus, they considered the most likely source of the vibration was ice collecting under the spinner fairing.

The Fan Ice Removal procedure is to reduce the thrust to idle rapidly (which untwists the blades and sheds ice), followed by a short delay of around 5 seconds to allow the engine to stabilise thermally, and then to restore the required thrust. If ice in the spinner and spinner fairing region was the source of the vibration, then this procedure was not likely to be successful in removing the source of the vibration. Furthermore, on this occasion the thrust was reduced to a setting higher than idle, the thrust reduction was over a nine second period and the engine did not stabilise prior to the thrust being increased.

In summary, the engine manufacturer believes that the most likely source of vibration was an accumulation of ice crystals behind the spinner fairing and that a surge or stall condition occurred as a result of the rapid increase in thrust demanded by the thrust lever movement, without a short period at idle to allow the engine to stabilise. The accumulation of ice behind the spinner fairing is believed to be addressed by the SBs.

Airframe manufacturer's assessment

The aircraft manufacturer stated that the fan ice shedding procedure found in the Flight Crew Operating Manual and the Engine Operating Instructions was intended to shed ice from the fan. The prevailing conditions were not likely to form ice on the fan so this procedure was unlikely to be successful. However, the flight crew having no way of knowing this information continued with the procedure.

The procedure, as carried out by the crew, produced the unexpected result of increasing the vibration. It is the airframe manufacturer's opinion that the resulting

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surge or stall behaviour could have been a result of the procedure not being carried out correctly, or the presence of ice in the engine, decreasing margins.

Analysis

The aircraft climbed through an area of convective cloud, where conditions favourable for the formation of ice were likely to exist, to its cruising level of FL370. It subsequently passed through extensive areas, as much as 500 nm along track, where high altitude ice crystal concentrations could be expected. While ice crystals would not normally be expected to adhere to engine or airframe components, it is possible that they could stick to any pre-existing ice. Physical evidence of icing is often difficult to establish and this incident was no exception. Furthermore, the modest range of recorded parameters and low sampling rates made it difficult to reach robust conclusions. Subsequent examination of both engines on the ground, both externally and internally, did not reveal any damage that could be attributed to the root cause of either the vibration or the surge or stall condition. Therefore, the most likely cause of the vibration is considered to be a build-up of ice, although the exact mechanism of ice accumulation is not certain.

The engine manufacturer's opinion that the source of the vibration was probably icing under the spinner fairing seems plausible, given the N_1 as the source of the vibration, the presence of visible icing and that the conditions at the time were not favourable for icing on the fan blades. Whether the ice accumulated there during the climb through convective cloud, or subsequently, as a result of prolonged exposure to ice crystals, could not be determined.

The weather information available to the flight crew at the planning stage did not indicate that any large areas of convective activity were to be expected along the route. An analysis of the satellite image covering the time of the flight shows that two Mesoscale Convective Systems (MCS) had formed across the track of the aircraft. When en route, the crew observed some significant areas of thunderstorms and altered course to the east, upwind, to avoid the most intense areas.

The crew noticed that the engine vibration had increased to a sustained level of approximately 2.3 units and there was a small amount of ice on the wiper arm. This led them to select the EAI ON, which was in accordance with the QRH checklist. However, the engine manufacturer advised that EAI would be ineffective in these circumstances because only the engine cowl is anti-iced.

The increased vibration led the crew to refer to the QRH checklist. The checklist suggested that no further action was required if icing conditions were present, which the crew decided was the case because of the visible ice on the wiper arm. As the vibration increased above the alert level of 2.5 units, the crew tried to find a solution to prevent a further increase. There was a fan ice removal procedure published in their OM which they decided to carry out. However, on retarding the left thrust lever, the immediate effect was to increase the vibration significantly and the procedure was not completed.[3] The thrust did not reach idle and, without the required five second delay, it was rapidly increased towards the previous level. As the thrust increased, a surge or stall condition developed and the engine did not respond to the thrust lever movement. The crew noticed the EGT rising towards the limit and observed a peak of 803°C.

Footnote

[3] Vibration may increase as a result of out of balance forces during ice shedding.

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However, this was not recorded on the QAR because of the 64 second sampling rate for this parameter.

The crew operated the engine at a reduced power setting of around 1.2 EPR and respected the maximum EGT limit. A diversion was initiated. Several attempts were made to increase the power again on the left engine but, at first, these were unsuccessful. The crew decided not to shut down the left engine in case the other engine should become similarly affected; during the descent, the right engine was operated at an intermediate setting. At some point during the descent the surge/stall condition on the left engine was resolved, probably as a consequence of the warmer external air temperature.

The root cause of the left engine surge or stall condition was considered by the engine manufacturer to have been the result of the deceleration and sudden re-acceleration of the engine.

The crew had attempted to carry out the ice shedding procedure but omitted what the engine manufacturer considered were critical elements. These were, a rapid reduction of thrust to idle, stabilisation at idle for five seconds and a steady reapplication of thrust. The reason the procedure was interrupted was probably that the crew did not expect the sudden increase in vibration that occurred when left engine thrust was reduced. In view of this, the engine manufacturer carried out a review of their published Engine Operating Instructions (EOI) and concluded that they should be improved to give better clarity to flight crews in the recognition of ice crystals and reaction to vibration in icing conditions. They also proposed that the ice shedding procedure should not be used when at climb or cruise thrust in high altitude ice crystal clouds above FL250 and the most appropriate action was to descend into warmer conditions.

Safety action

In November 2010 the engine manufacturer sent the aircraft manufacturer's Flight Operations Department a proposed revision to the engine operating instructions for the RB 211-535-E4-B, with respect to the Fan Ice Removal Procedure. The proposed revision has been reviewed by the aircraft manufacturer and the following response has been received by the AAIB:

> *The proposed changes have been agreed to by the airframe manufacturer. Procedures addressing ice crystal icing in addition to changes to the Fan Ice Removal procedure will be embodied in the QRH and FCOM in the 2011 revision.*

Therefore, on the basis of this assurance, the AAIB does not intend to make a Safety Recommendation on this aspect of the incident.

CVR and FDR recordings

During the investigation, it was found that the operator had no formal procedures for the preservation of either the CVR or FDR. This had not been identified during previous audits of the operator by the UK CAA. Further, on 3 October 2010 a different UK operator failed to preserve the CVR following a landing accident involving another aircraft, registration G-OOBK. That operator's procedures did include the preservation requirements detailed in EU-OPS 1.160 and EU-OPS 1.085 (commander's responsibilities) but its procedures proved ineffective in stopping the CVR from being overwritten. Two further operators' procedures were reviewed and found to contain similar content to that of G-OOBK's operator. Therefore, the following Safety Recommendation is made:

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Safety Recommendation 2011-020

It is recommended that the Civil Aviation Authority ensures that United Kingdom operators have procedures for preventing the loss of Cockpit Voice Recorder and Flight Data Recorder recordings, following an occurrence subject to mandatory reporting, in accordance with the legislative requirements of EU-OPS 1.160 and EU-OPS 1.085.

FDR documentation requirements

Information for the conversion of the FDR digital record to engineering units was provided in the aircraft manufacturer's document D226A101-3 Revision J - issued 1 April 2003. The document was confirmed as being the latest revision. During the course of the investigation, it was found that the 757-2 data frame, which was applicable to G-STRY, incorrectly defined the conversion of the left and right engine vibration parameters. The output resolution of the parameters was confirmed as being 0.02 units, and not 0.01 as stated in D226A101-3, with the input bits being 21 to 28 and not 20 to 28. Applying the incorrect conversion resulted in both parameters being converted to half the actual vibration units displayed on EICAS. Although it cannot be established, the error may have led to the incorrect analysis of previous engine vibration events, for aircraft utilising the 757-2 data frame. The accuracy of FDR conversion documentation is fundamental.

Therefore, the following Safety Recommendations are made:

Safety Recommendation 2011-021

It is recommended that Boeing advises all operators utilising the Flight Data Recording 757-2 Data Frame of the need to correct the conversion of the left and right engine vibration parameters.

And

Safety Recommendation 2011-022

It is recommended that Boeing provides updated documentation that corrects the Flight Data Recording 757-2 Data Frame conversion information for the left and right engine vibration parameters.

Comment

The aircraft experienced a prolonged exposure to an area where ice crystal concentrations may have been present. Although ice crystals may not have been the cause of this event it is an atmospheric condition that is not yet well understood. This has been recognised and a data collection programme is presently underway in the USA to increase the understanding of high water content ice crystal conditions. These are conditions where strong convective weather activity lifts high concentrations of ice crystals to high altitude. The crystals can partly melt and stick to internal engine surfaces causing power loss and/or surge/stall to occur. Data indicates that there have been at least 100 events of jet engine power loss due to core-icing during the last 30 years. The data gathered should enable certification authorities to define new parameters for developing and certifying engines. It may also lead to better forecasting of the presence of such areas, which are not detectable by existing aircraft weather radars. The knowledge of these conditions, and their effect upon various aircraft systems, is at present limited. Proposed guidance to flight crew is restricted to avoiding such weather or flying clear if encountered.

In March 2011 the EASA published two Notices of Proposed Amendment (NPAs), 2011-03 and 2011-04, entitled '*Large Aeroplane Certification Specifications in Supercooled Large Drop, Mixed phase, and Ice Crystal Icing Conditions*' and '*Turbine Engine Certification*

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Specifications in Icing Conditions' respectively. The background to these NPAs is described:

> *'It has been evidenced that the icing environment used for certification of large aeroplanes and turbine engines needs to be expanded in order to improve the level of safety when operating in icing conditions.*
>
> *Several accidents and incidents occurred in severe icing conditions including supercooled large drop (SLD) icing conditions. Please refer to NPA 2011-03 for details on the history of these events.*
>
> *Other incidents involved turbine engine power losses or flameouts in ice crystal and mixed phase icing conditions. From 1988–2003, there were over 100 documented cases of ice crystal and mixed phase engine power loss events. Some of these events (11) resulted in total power loss from engine flameouts. During the same period there were 54 aircraft level events of SLD icing engine damage where 56 % occurred on multiple engines on an aircraft and two events resulted in air-turnback.*
>
> *These particular severe icing conditions are not included in the current certification icing environment for aircraft and engines.'*

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SERIOUS INCIDENT

Aircraft Type and Registration:	Bombardier DHC-8-102, SX-BIO	
No & Type of Engines:	2 x Pratt & Whitney Canada PW120A turboprop engines	
Year of Manufacture:	1992	
Date & Time (UTC):	24 April 2010 at 0733 hrs	
Location:	Bristol International Airport	
Type of Flight:	Private	
Persons on Board:	Crew - 2	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	None	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	38 years	
Commander's Flying Experience:	6,300 hours (of which 1,700 were on type) Last 90 days - 3 hours Last 28 days - 3 hours	
Information Source:	AAIB Field Investigation	

Synopsis

After a base maintenance check at Exeter the aircraft was flown uneventfully to East Midlands to be repainted. During the return flight to Exeter the right engine suffered a significant oil leak and lost oil pressure, so the flight crew shut it down. Subsequently, the crew noticed the left engine also leaking oil, with a fluctuating oil pressure, so they initiated a diversion to Bristol, where they landed safely. The oil leaks were traced to damaged O-ring seals within the oil cooler fittings on both engines. Both oil coolers had been removed and refitted during the base maintenance check at Exeter. It was probably during re-installation that the O-ring seals were damaged. A number of factors led to this damage and to missed oil leak checks. Six Safety Recommendations are made.

History of the flight

The aircraft had been flown from Greece to Exeter to undergo a maintenance check. On 16 April 2010 the aircraft was flown from Exeter to East Midlands, where it was to be repainted. The crew that operated the aircraft observed nothing unusual on the flight but on its arrival at East Midlands, the engineer who met the aircraft observed some oil spots on the ground beneath both engine nacelles.

On 24 April 2010 the aircraft was to be flown back to Exeter. The crew for this flight were collected from their hotel at 0500 hrs and driven to the airport. The weather conditions were good and the crew were taken to the aircraft where they performed their pre-flight inspection. The engineer requested that the crew perform a ground

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run on both engines so that he could check the engine oil levels; he had intended to do this himself the previous day but had not been able to locate an appropriate ground power unit. The ground run was completed without event and the engineer added one quart of oil to the right engine, which brought both engines' oil levels up to the 'full minus 2' (F-2) mark, a normal refill level for these engines.

The start-up, taxi and departure were all described by the crew as normal. However, photographs taken by an aviation enthusiast at 0654 hrs show some signs of oil leaking from both engines as the aircraft taxied out (Figures 1 and 2).

Approximately 10 minutes into the flight, at FL100, flying on an ATC radar heading, the commander noticed the master warning light illuminate momentarily. A closer inspection of the aircraft's instruments revealed that the right engine oil pressure was fluctuating and decreasing. The co-pilot went into the cabin and observed what appeared to be a major oil leak coming from the right engine, with oil flowing down the right side of the aircraft fuselage. The oil pressure continued to fluctuate and fall, so the crew carried out the checklist drill for low engine oil pressure, which involved initially feathering the engine. When the oil pressure fell below a certain value, they shut the engine down.

The crew declared a PAN and requested direct vectors to Exeter. After approximately 5 minutes of flight, the crew, who were monitoring the remaining engine closely, saw the left engine oil pressure begin to fluctuate. The co-pilot again entered the cabin and, this time, observed

Figure 1

Oil leak visible on right main gear leg during taxi at East Midlands on 24 April 2010

(photograph courtesy Dave Sturges/ AirTeamImages.com)

Figure 2

Oil leak visible on left main gear leg during taxi at East Midlands on 24 April 2010

(photograph courtesy Dave Sturges/ AirTeamImages.com)

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an oil leak from the left engine. The commander made the decision to divert to the nearest suitable airfield and, with ATC assistance, diverted to Bristol, which was 25 nm ahead of the aircraft. ATC asked the crew if they wished to upgrade their emergency, which the crew confirmed they did, but ATC were not made aware of the problem with the operating engine until after the aircraft had landed safely.

Aircraft examination

The aircraft was examined four hours after it landed at Bristol International Airport. Both the left and right main landing gear legs were coated in clean oil (Figures 3 and 4), as were the lower surfaces of both engine nacelles and main gear doors. The right side of the fuselage adjacent to the right engine was coated in oil streaks, whereas the left side was clean. The underside of the left and right oil coolers, which are located forward of the main gear doors (Figure 4), were heavily coated in oil but there was no oil on the nacelle undersides forward of the oil cooler positions.

The engine cowlings were removed to identify the source of the oil leaks. The left engine oil cooler is shown in Figure 5 with the lower forward cowling lowered. There was oil along the lower forward surface of the oil cooler and along the lower forward cowling hinge line. Oil was also seen slowly weeping from around the knurled nut where the inlet pipe connects to the oil cooler. When the inlet pipe was disconnected and the oil cooler removed, it was revealed that two O-ring seals were fitted inside the groove of the pipe; the smaller O-ring was split and the larger O-ring contained a cut (Figures 6 and 7). The larger O-ring was of the correct size and type for the installation, but the smaller O-ring should not have been fitted. One O-ring, of the correct size, was fitted to the outlet pipe of the oil cooler and this O-ring was undamaged.

Figure 3

Left engine nacelle and landing gear leg after landing at Bristol

Figure 4

Right engine nacelle and landing gear leg after landing at Bristol

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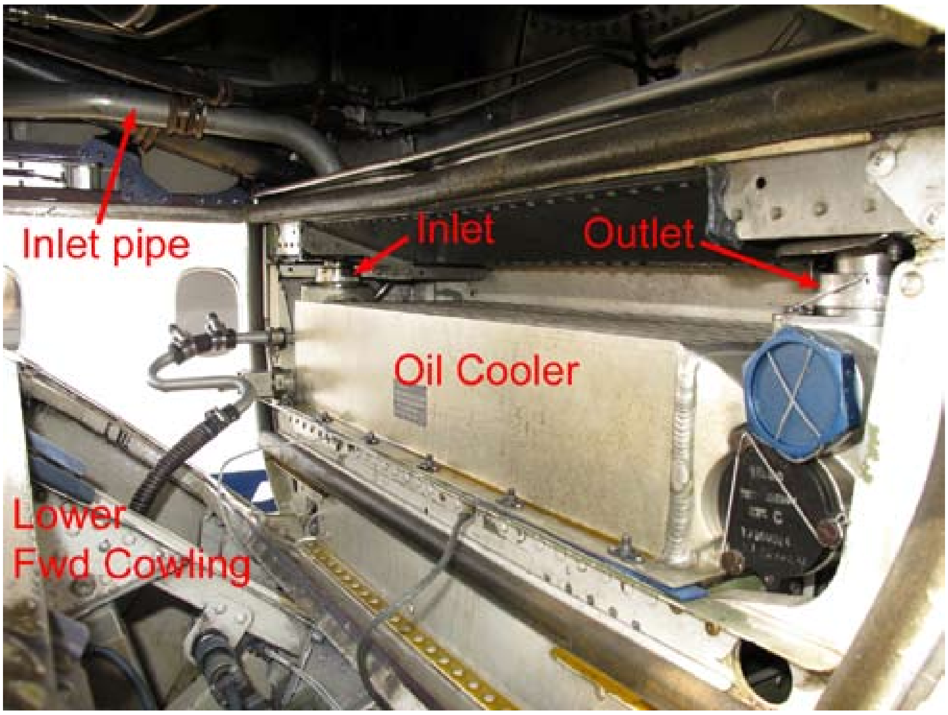

Figure 5

Left engine oil cooler with lower forward cowling lowered.
Slow oil seepage from oil cooler inlet nut

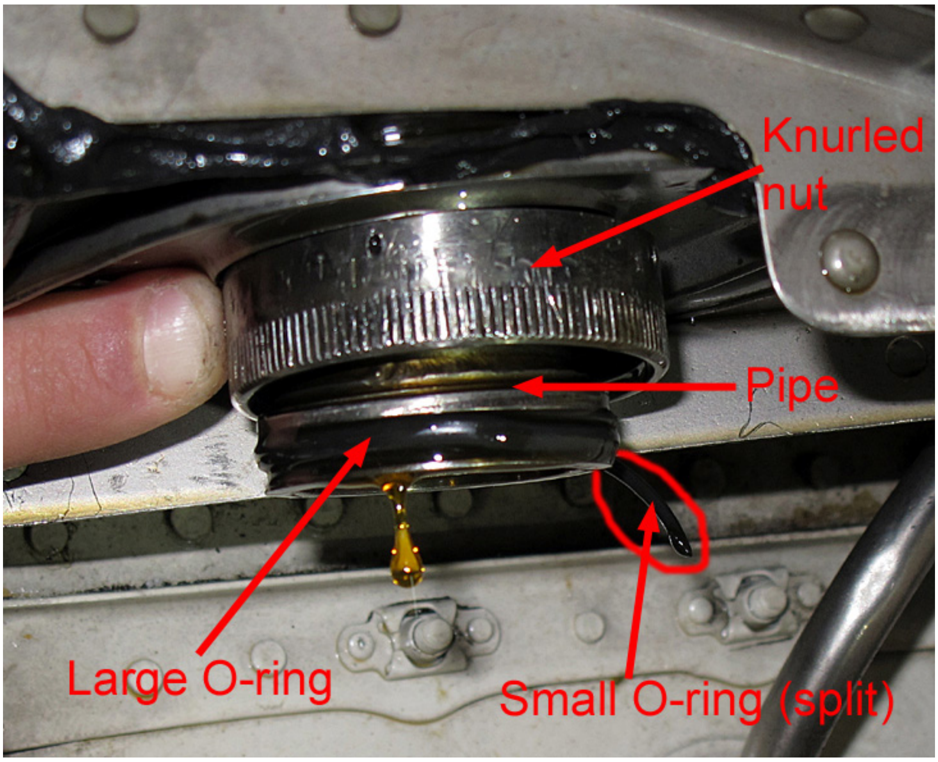

Figure 6

Left engine oil cooler inlet (inboard) pipe connector, showing large O-ring seal and small O-ring seal, which had split, part of which can be seen hanging down (highlighted in red)

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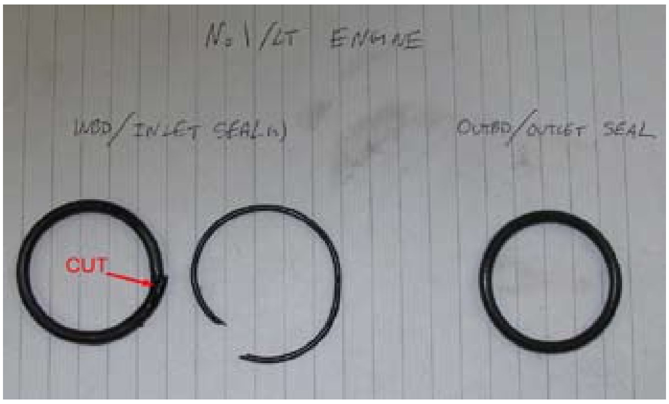

Figure 7

Left engine oil cooler inlet and outlet seals;
large inlet seal contained a cut; small inlet seal was split

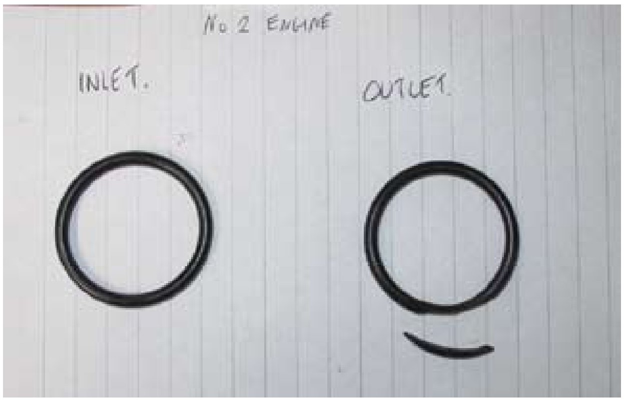

Figure 8

Right engine oil cooler inlet and outlet seals;
outlet seal had been cut; severed piece shown below it

When the right engine lower forward cowling was lowered, oil was seen along the lower forward cowling hinge line and around the oil cooler outlet pipe, but it was not noticeably weeping. This oil cooler was also removed and its inlet and outlet pipes examined. The O-ring seal on the outlet pipe had been cut and was missing a large section from its outer circumference (Figure 8). The missing section of O-ring seal was found in a side cavity beneath the oil cooler outlet. The O-ring seal on the inlet pipe was undamaged.

The circlips, which retained each knurled nut on the pipe, contained grooves where the nut had squeezed the circlip hard against the lip of the pipe (Figure 9). The knurled nuts also had score marks on their outer circumference consistent with having been tightened with a pair of grips. This was evidence that the knurled nuts on both pipes from both oil coolers had at some point been over-tightened. The maintenance manual calls for the nuts to be tightened 'by hand'.

Following the right engine oil cooler removal, it was noticed that the inlet and outlet pipes were not aligned perpendicular to the oil cooler but were canted outwards (Figure 10). This orientation of the pipes would have made it more difficult to insert the pipes into the oil cooler during installation, because some force would have been needed to align the pipes. After this incident, before the oil coolers were re-installed, the oil pipes were disconnected at their forward end to enable the pipes to be rotated to the vertical; this facilitated the insertion of the pipes into the oil cooler fittings.

A total of 13.5 litres of oil was drained from the left engine and 11.5 litres were drained from the right engine. The oil capacity of each engine was 19 litres (20 US quarts). The engine oil levels were at 'F-2' ('Full minus 2 quarts' which is equal to 17 litres), as recorded in the technical log, when the aircraft departed East Midlands Airport. Therefore, the left engine lost 3.5 litres of oil and the right engine lost 5.5 litres of oil during the flight to Bristol.

The left and right oil coolers were pressure leak tested and no leaks were found. Following rectification work, which involved installing refurbished oil coolers and new O-ring seals, no further leaks were detected. The aircraft has since completed numerous flights with no reported oil leaks.

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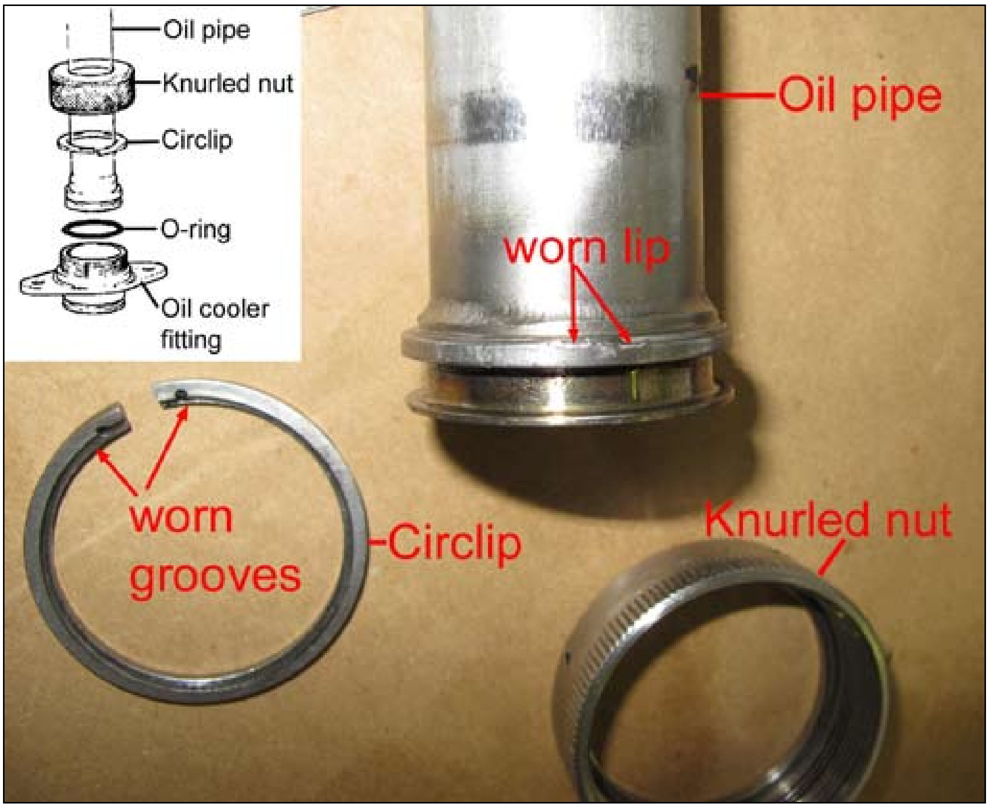

Figure 9

Worn grooves on circlip retaining knurled nut
(left oil cooler inlet pipe shown; similar wear found on the other three circlips)

Figure 10

View looking aft beneath the right engine where the oil cooler had been installed.
Note that the oil cooler inlet and outlet pipes are not orientated at 90° but are canted outwards

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Maintenance history

The aircraft was based in Greece and had not flown between July 2009 and March 2010, as the previous operator of the aircraft had ceased trading. In early 2010 two new engines were fitted to the aircraft and on 18 March 2010 the aircraft was flown from Athens to Exeter Airport for a C-check[1] by a local Part-145 approved maintenance organisation (AMO). During the C-check both oil coolers were removed and refitted. On 16 April 2010 the aircraft was flown to East Midlands Airport to be re-painted and this flight took 49 minutes. One week later, on 24 April 2010, during the aircraft's return flight to Exeter, the incident and diversion to Bristol occurred. The aircraft had accumulated 29,998 hours and 38,752 cycles at the time of the incident.

A detailed investigation into the maintenance activities at both Exeter and East Midlands Airports was carried out, involving interviews of numerous technicians, engineers and managers at the AMO, in order to try and establish how the O-ring seals had become damaged and how leak checks had not detected the problem.

Oil cooler removal and re-installation

During the C-check it had been noticed that the bushings in the right and left main landing gear door pivot brackets were worn and needed to be repaired. These brackets are located in the upper forward section of the main landing gear bays, directly aft of the oil coolers. The aircraft manufacturer's Repair Drawing (RD) calls for the original bushing to be removed, the hole 'cleaned up' and then a special flanged bushing to be manufactured and installed in an interference hole. A new lined bushing is then installed into the repair bushing. The instructions in the RD do not specify if the repair can be accomplished in situ or if the bracket needs to be removed from the aircraft. A licensed aircraft engineer (LAE), a 'supervisor' grade at the AMO, initiated the work for the bushing repair tasks, but he was not sure if the bushing could be repaired in situ so he sought the advice of a workshop engineer. However, the workshop had closed for the day. In order to expedite the work, the LAE decided to have the bushings and brackets removed. He tasked two 'technician' grade unlicensed engineers to start removing the oil coolers, as he considered this was necessary to gain sufficient access to remove the brackets. One of these technicians had not completed his removal task when he went off shift, so the removal of both oil coolers was completed by the other technician, who will be referred to as Tech A. It was subsequently determined that the repair work could be done in situ, so the oil cooler removals had been unnecessary, and Tech A was then tasked with re-installing both oil coolers.

Tech A stated that he re-installed both oil coolers in accordance with the aircraft maintenance manual (AMM) instructions, section 79-20-11. He also commented that it was not an easy job as the oil cooler fits in a small space and the oil pipes were difficult to manoeuvre into position. He needed two hands to install each pipe and used a torch, held in his mouth, to illuminate the pipe and oil cooler fitting. He replaced the O-ring on each pipe with a new one, and the paperwork confirmed that four new O-rings, of the correct part number, had been used during the installation of the two oil coolers. He did not recall seeing a second smaller O-ring fitted to the left engine inlet pipe but was sure that he had not installed one. He hand-tightened the nuts first and then used a pair of soft grips to tighten the nuts further. He stated

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Footnote

[1] The C-check is a heavy base maintenance check that can take several days to complete.

that he had been asked to complete both oil cooler installations before the end of his shift, which added some time pressure, but he did not consider it unusual pressure. He completed the left oil cooler installation first, and finished the right oil cooler installation at his shift-end time, 1800 hrs (1900 hrs BST).

A 'defect job card' for the left bushing repair and a separate card for the right bushing repair had been generated electronically and printed out by an LAE. The task requirements were then left blank for individuals to complete and sign off. Tech A wrote down the separate requirements for tasks to:

> *'remove oil cooler for access'*

and:

> *'refit oil cooler on completion of access requirements'*

and signed them off. These were later counter-signed by an LAE who inspected the oil cooler installations, although it was not possible to inspect the O-ring seals after they were installed. The AMM procedure for the oil cooler installation (AMM 79-20-11) calls for an engine ground run to be carried out to check for oil leaks. Tech A omitted to add the leak check task to the 'defect job card' and his supervising engineer did not notice the omission. Each task on the 'defect job card' was written by the individual who performed it, rather than all tasks being pre-planned. For example, the task written after 'refit oil cooler' was 'carry out NDT inspection of bracket post rework' and the task after that was 'carry out bush repair in situ'. Both of these tasks were written by the different people performing the task, and were out of sequence.

Post-maintenance engine ground runs at Exeter

On completion of the C-check some engine ground runs were required, to test systems and check for oil leaks. However, a leak check of the oil cooler fittings was not specifically called for. An LAE, a 'senior supervisor' grade at the AMO, was responsible for carrying out the engine ground runs and was also responsible for the overall supervision of SX-BIO's C-check. This LAE, who will be referred to as Sup A, carried out the engine ground runs towards the end of the day on 15 April 2010. He also signed off many of the tasks carried out during the check, including the oil cooler re-installation tasks.

The first engine ground run was at low power and lasted 5 minutes. The engine side cowlings were opened and no leaks were seen. The engine oil levels were checked on the sight glass; they were below the 'F-2' mark, so some oil was added to each engine to bring the levels up to the 'F-2' mark. The lower forward engine cowling, which provides access to the oil cooler, was not opened on either engine. The engines were then re-started and Sup A taxied the aircraft to a location at the airport where high power engine runs could be conducted. During this ground run the power was increased to 94% N_H[2] and 88% torque. Towards the end of the engine run, about 40 minutes after engine start, a mechanic in the rear of the aircraft noticed oil leaking down the left main landing gear leg and notified Sup A. There were no indications in the flight deck of a problem, so Sup A taxied the aircraft back to the maintenance hangar to investigate the oil leak. The left engine lower forward cowling was lowered, revealing a significant amount of oil in and around the oil cooler area. It was noticed that at the inboard/inlet oil cooler fitting there was one

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Footnote

[2] N_H is the rotational speed of the high pressure turbine.

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thread visible beneath the knurled nut. This reminded Sup A that the oil coolers had both been removed and re-installed. The wire locking was cut and the nut was tightened with a pair of grips. The technician who did this recalled adding one full turn to the nut. The wire locking was also cut from the outboard/outlet nut and this nut was tightened, although it only moved by a fraction of a turn. It was reported that up to 5 quarts of oil were required to top up the left engine. Most witnesses said that no oil leaks were observed from the right engine, although there were conflicting reports on whether the lower forward cowling on the right engine was opened and whether the oil cooler nuts on the right engine were tightened. One technician reported that there were traces of oil near the drain holes of the right engine, but no leaks. The oil level on the right engine was found to be high so one quart was siphoned out, although there were differing reports on whether this resulted in the level reducing to 'F-2' or 'F-1'.

Following the rectification work, a third engine run, at low power, was carried out just outside the maintenance hangar. Both engines were run up to 76% N_H and 24% torque with the propellers un-feathered. The left engine was shut down after 5 minutes of operation, while the right engine continued to run for a further 10 minutes, in order to complete some pitot-static checks. Following this engine run there were no further oil leaks reported, although according to one technician only the side cowlings were opened and not the lower forward cowling. However, according to one engineer the left lower forward cowling was lowered and he inspected the oil cooler fittings, which were dry.

Maintenance at East Midlands Airport

On 16 April 2010, the day after the engine ground runs, the aircraft departed Exeter and flew to East Midlands airport to be repainted. The flight crew did not note any engine anomalies during the flight. On arrival at East Midlands the aircraft was met by an engineer who worked for the Exeter AMO; he was 'supervisor' grade and was responsible for overseeing the repaint which was being carried out by a separate company. This engineer, who will be referred to as Sup B, noticed some oil spots on the ground beneath the nacelles of both engines and took some photographs (Figures 11 and 12); these were taken about 15 minutes after the aircraft parked on stand.

Figure 11

Oil spots on ground beneath left engine nacelle after arrival at East Midlands on 16 April 2010

Figure 12

Oil spots on ground beneath right engine nacelle after arrival at East Midlands on 16 April 2010

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The aircraft was moved into a hangar and painting preparations were begun the next day, 17 April. On 18 April Sup B informed the production manager at Exeter that he had found oil leaks from both engines, but that he had not been able to open the engine cowlings to investigate the leaks due to the paint stripping work. During the ensuing days, access to the engines was limited by scaffolding but Sup B was able to access the aft section (zone 2) of the left engine and tightened an elbow joint that might have been weeping oil. Sup B reported that throughout the painting work small amounts of oil were seeping from the metalwork butt joints of both engine nacelle lower cowls – these butt joints are located on either side of the oil cooler. On 20 April Sup B took some photographs of this oil seepage. Figure 13 shows visible oil from the right engine – a similar amount of oil was visible from the left engine nacelle butt joints. On 21 and 22 April the butt joints were covered so he was unable to inspect them. On 23 April, the day before the aircraft was due to depart back to Exeter, Sup B was given full access to the engines and noticed that there was still a bit of oil seeping from the right engine butt joint but none from the left. That day, Sup A arrived from Exeter to perform the duplicate flight control inspections that were required because the flight controls had been disturbed by Sup B for balancing (required post-painting). Sup-B discussed the oil seepage with Sup A and Sup A informed him about the oil leaks they had experienced during the engine runs at Exeter and advised that the oil seepage was probably residual oil from the previous leaks. Sup A gave Sup B the impression that they had experienced oil leaks from both engines at Exeter and that these had been rectified. Sup B planned to carry

Figure 13

Oil seepage from butt joint beneath right engine oil cooler
(photograph taken on 20 April 2010 during painting at East Midlands)

out a low power engine ground run on the afternoon of 23 April to check oil levels and as a final oil leak check. However, the APU was unserviceable and a 28 volt ground power unit (GPU) was not available, so the engines could not be started. Arrangements were made for a GPU to be available the following morning prior to the aircraft's flight back to Exeter. Sup B noted that the left engine oil level was at 'F-2' and the right engine oil level at 'F-3'. However, since the engines had not been run for 8 days, these were not necessarily reliable indications.

On the morning of 24 April Sup B took some photographs of the right side of the aircraft at 0555 hrs (0655 hrs BST), about 1 hour before the aircraft's departure. The right main landing gear leg was clearly visible in the photographs and there were no traces of oil on it, or oil spots on the ground beneath the right engine. Sup B then met the flight crew and asked them to carry out a low power engine run so that he could complete a final oil level check and oil leak check. The engines were run for about 2 minutes, at flight idle with the propellers feathered (28% max torque and 74% max N_H[3]). After the engine run the indicated oil levels remained as before, so Sup B added 1 quart to the right engine to bring it up to the 'F-2' level. He did not see any oil leaks. His inspection included opening the engine side cowls but not the lower forward engine cowls[4]. The aircraft taxied out for departure at about 0653 hrs (0753 hrs BST), and at 0654 hrs and 0658 hrs respectively the photographs shown in Figures 1 and 2 were taken by an aviation enthusiast; these clearly show oil leaking down both the left and right main gear struts.

Previous oil cooler replacements on SX-BIO

Prior to the aircraft's C-check at Exeter the right oil cooler had previously been replaced on 6 November 2005 and the left oil cooler had previously been replaced on 3 July 2009 by another AMO when the aircraft had accumulated 29,938 hours (60 flying hours before the incident on 16 April 2010). Tech A was confident that he had not installed the smaller O-ring seal on the inlet pipe to the left oil cooler but admitted that it was possible that it was already on the pipe and he had overlooked it. If that was the case then it was likely that the smaller O-ring seal had been installed on 3 July 2009 when the left oil cooler was last disturbed. The operator of SX-BIO tried to obtain information on who performed this installation, but was unable to do so because the previous operator, who had maintained the aircraft at that time, had ceased trading.

Repair procedures

The procedures for most repairs on the DHC-8-100 are contained in the aircraft manufacturer's Structural Repair Manual (SRM). Other less common repairs are detailed in individual Repair Drawings (RDs) which are also produced by the aircraft manufacturer. The manufacturer's RDs usually contain a diagram of the repair with a short instruction on how to perform the repair itself. This was the case for the pivot bracket bushing repair in the forward section of the main landing gear bay. The RD for the pivot bracket bushing repair was a stand-alone document, but at the AMO a number of frequently used RDs were collated together in a series of RD folders that were accessible to the engineers working the aircraft. The LAE who raised

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Footnote

[3] Only 48 seconds of the 2-minute engine run were captured on the Flight Data Recorder (FDR). The FDR on this aircraft starts recording when the anti-collision light is turned on or 'weight-off-wheels' is detected. It is therefore likely that the anti-collision light was turned on after engine start. However, Sup B reported that the power lever was not moved beyond flight idle and the propeller remained feathered.

[4] Lowering the forward engine cowling requires at least two people, and preferably three whereas, opening the side cowls is a simple one-person task.

the 'defect job card' for the bushing repair had pulled a copy of the appropriate RD from the RD folder and had attached it to the 'defect job card'. The LAE who then actioned the 'defect job card' saw the RD but, having never undertaken this repair before, did not know what the access requirements were and judged that the oil coolers would need to be removed. The aircraft manufacturer initially stated that their RDs were a rough outline containing only detailed instructions for specific parts, and that if more detailed instructions were required, then these would normally be completed by the engineering section of the operator or maintenance organisation. The aircraft manufacturer later stated that if access to a repair required significant equipment removal, then this would be called for in an RD, with the relevant AMM reference. They also stated that the lack of an access requirement listing in this RD should have indicated to the engineer that no removals were necessary. However, one engineer at the AMO said that he was aware of a previous oil cooler removal for the same defect at another maintenance organisation in which the bracket needed to be removed and repaired in a jig due to the severity of the bushing wear.

The Head of Base Maintenance at the AMO said that normally when a repair was needed that was not covered in the SRM, the engineering planning department would contact the aircraft manufacturer to obtain an RD and the planning department would then provide instructions to the engineers on what was needed to carry out the repair. In this case the engineer already had a copy of the RD so the planning department was not involved in the repair process.

The regulations that apply to the AMO are in Annex II (Part 145) of European Commission Regulation (EC) No 2042/2003. Regulation Part 145.A.45 on 'Maintenance Data' requires organisations to establish procedures to capture any incomplete or ambiguous maintenance instructions contained in the maintenance data, and Part 145.A.45 states that the AMO can modify these instructions if they result in equivalent or improved maintenance standards. The AMO did not have a process in place for being able to provide their own instructions to supplement RDs that had been accumulated in the RD folders or to capture lessons learnt from previous repairs.

Safety Critical Maintenance Tasks

On 23 February 1995 a Boeing 737-400 (G-OBMM) lost almost all its oil from both engines in flight. The aircraft diverted and landed safely, but the AAIB investigation revealed that following a borescope inspection of both engines by the same person, both HP rotor drive covers had not been refitted, and this resulted in the loss of oil from both engines (AAIB Formal Report 3/96). Among other safety recommendations the AAIB report recommended that:

> 'The CAA, with the JAA, consider issuing advice to aircraft maintenance organisations that, where practical, work which can effect the airworthiness of an engine should not be conducted on all of the powerplant installations of an aircraft at one point in time by the same personnel' (**Safety Recommendation 96-31**).

These types of task are now referred to as 'safety critical tasks' and some of the following regulations and guidance on safety critical tasks were, in part, a result of this Safety Recommendation.

Regulation Part 145.A.65 states that:

> *'The organisation shall establish procedures agreed by the competent authority taking into*

> *account human factors and human performance to ensure good maintenance practices…'.*

It states further that:

> *'With regard to aircraft line and base maintenance, the organisation shall establish procedures to minimise the risk of multiple errors and capture errors on critical systems, and to ensure that no person is required to carry out and inspect in relation to a maintenance task involving some element of disassembly/reassembly of several components of the same type fitted to more than one system on the same aircraft during a particular maintenance check. However, when only one person is available to carry out these tasks then the organisation's work card or worksheet shall include an additional stage for re-inspection of the work by this person after completion of all the same tasks.'*

In essence, the regulation requires maintenance organisations to have procedures to ensure that the same person is not carrying out the same safety critical task on two similar systems, for example on both engines of a twin-engined aircraft. However, it does allow an exception to this case if a re-inspection is carried out. In the case of the oil cooler installations, a re-inspection would not have detected that the O-ring seals were damaged. In Part 11 of CAP 562 ('*Civil Aircraft Information and Procedures*') the CAA has published Leaflet 11-21, entitled '*Safety Critical Maintenance Tasks*', to explain how it expects maintenance organisations to handle safety critical tasks. It states that:

> *'The CAA wishes to highlight the potential safety benefit where companies choose to apply aspects of Extended Range Twin Operations (ETOPS) maintenance philosophy to multi-system aircraft in order to avoid the possibility of simultaneous incorrect maintenance on two or more safety critical systems,…, engines and their systems being a case in point.'*

The Leaflet states that:

> *'arrangements should be made to stagger scheduled maintenance tasks'*

that are deemed safety critical and affect the same system. Where this is not practical:

> *'the use of separate work teams together with the accomplishment of appropriate functional checks to verify system serviceability should ensure a similar level of system integrity.'*

The AMO at Exeter had implemented the intent of Leaflet 11-21 in its company procedures. It had created a '*Critical Task Checklist*' for each aircraft type that it maintained. The checklist for the DHC-8-100 stated:

> *'This task has been assessed as a possible risk for multiple errors on critical systems, when carried out at the same time as a similar task by the same personnel. Therefore, any similar tasks must be separated by at least one flight, or carried out by different personnel, or if this cannot be achieved, a re-inspection of the work after completion of all similar tasks should be completed and worksheets annotated accordingly.'*

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Among the tasks included in the critical task checklist were '*Engine Oil Filter Change*', '*Engine Oil Chip Detector Remove/ Refit*' and '*Oil Filler Cap Removal/ Refit*'. 'Engine oil cooler removal/ refit' was not on the list. There were also no tasks on the list involving disturbances of the fuel system. This list was created in October 2009, after a CAA audit in January 2009 flagged up the absence of such a list. The list was published on the company's internal internet (intranet), and the LAEs were made aware of the list during their recurrent training. Technicians and Fitters were not given the same training as the LAEs and some were not aware of the safety critical task list.

All the engineers and managers at the AMO who were interviewed during the investigation agreed that the 'oil cooler removal/ refit' task should have been flagged up as a safety critical task and that the same person should not have been tasked to refit both oil coolers. The LAE who assigned Tech A to install both oil coolers said it had not occurred to him that the task was safety critical. He said that, in hindsight, he would have identified the task as safety critical, but suggested that the list of safety critical tasks be included in each work pack as a reminder, and not just on the intranet.

The AMO has a planning department which generates a work pack for each planned maintenance input and this contained all the job cards for the required tasks. The planning department was responsible for identifying any tasks that were safety critical and annotating them as such. In the case of SX-BIO's maintenance, a 'third party' work pack was supplied by the operator of SX-BIO. The job cards in this work pack did not have 'safety critical tasks' identified on them. However, the oil cooler removal/ refit task on SX-BIO was not a planned task and therefore was not in the work pack. The oil coolers were removed because of a defect found on the main landing gear pivot door brackets, and were, therefore, part of a 'defect job card', which was raised by an LAE. The LAE who raised the 'defect job card' did not think that the oil cooler removal was necessary, but this view was not passed on to the LAE who initiated the work on the 'defect job card'. In relation to defects, the AMO's procedure on safety critical tasks (PRO TS25) states the following:

> *'Any engineer or other person raising a process sheet, task card, work request - scheduled or unscheduled (including defects) or tech log entry, in any format, should refer to the published list of critical tasks and annotate the document produced if the task involved is listed.'*

The LAE initiating the work on the 'defect job card' should have referred to the critical task list; however, the bracket repair task was not listed nor was the oil cooler removal/ refit task.

Oil cooler installation procedure

The procedure in the AMM (Revision 'Dec 20/2004') for installing the oil cooler states that the oil cooler should be positioned in the lower nacelle and its attachments aligned with the corresponding holes without inserting the bolts into the holes. It then states that the oil pipes should be connected to the oil cooler fittings and that the nuts should be run down without tightening. After securing the cooler to the nacelle with bolts and washers, it states:

> *'Complete tightening of tube assemblies (5) and (6).*
> *Pre Mod 8/0642 Torque union nuts to 1520 to 1680 pound-inches*
> *Mod 8/0642 Tighten tube assembly nuts to oil cooler fitting (20) by hand and wire lock.'*

SX-BIO had mod 8/0642 embodied which changed the assembly and nut type, and only hand tightening of the nuts was required. The following sequence of photographs in Figure 14 helps to illustrate the installation.

When the knurled nut is fully wound down, as in (4) in Figure 14, the oil pipe is free to move and can be rotated and moved up and down. The O-ring is the only barrier against oil leakage from the cooler. If the nut cannot be tightened and fully wound down by hand then this is an indication that the pipe has not been installed correctly and/or the O-ring may have been damaged. The O-ring provides the seal and no additional clamping force is provided by over-tightening the nut.

Above the oil cooler, the oil pipe passes through a pair of fire seal retainers and a clamp which serves to secure the pipe to the nacelle structure. The pipe then passes through a pair of retainers in the firewall and is attached to a flexible hose (Figure 15). The AMM procedure for the oil cooler removal requires the fire seal retainers to be disconnected, but it makes no reference to the clamp, firewall retainers nor flexible hose. According to the engineer and technician who undertook to re-install the oil coolers following the incident, in order to be able to rotate the oil pipe to the vertical position and easily manoeuvre it into the oil cooler fitting, they needed to loosen the clamp and disconnect the pipe from the flexible hose. They reported that the flexible hose was not sufficiently flexible to permit the pipe to be rotated to, and stay in, the vertical position, without disconnecting it from the pipe. Figure 10 shows that the oil pipes were not in the vertical position on the right engine installation.

Figure 14

From left to right: (1) oil cooler fitting; (2) oil pipe partially inserted – O-ring seal visible; (3) oil pipe fully inserted; (4) knurled nut fully wound down, hand tight

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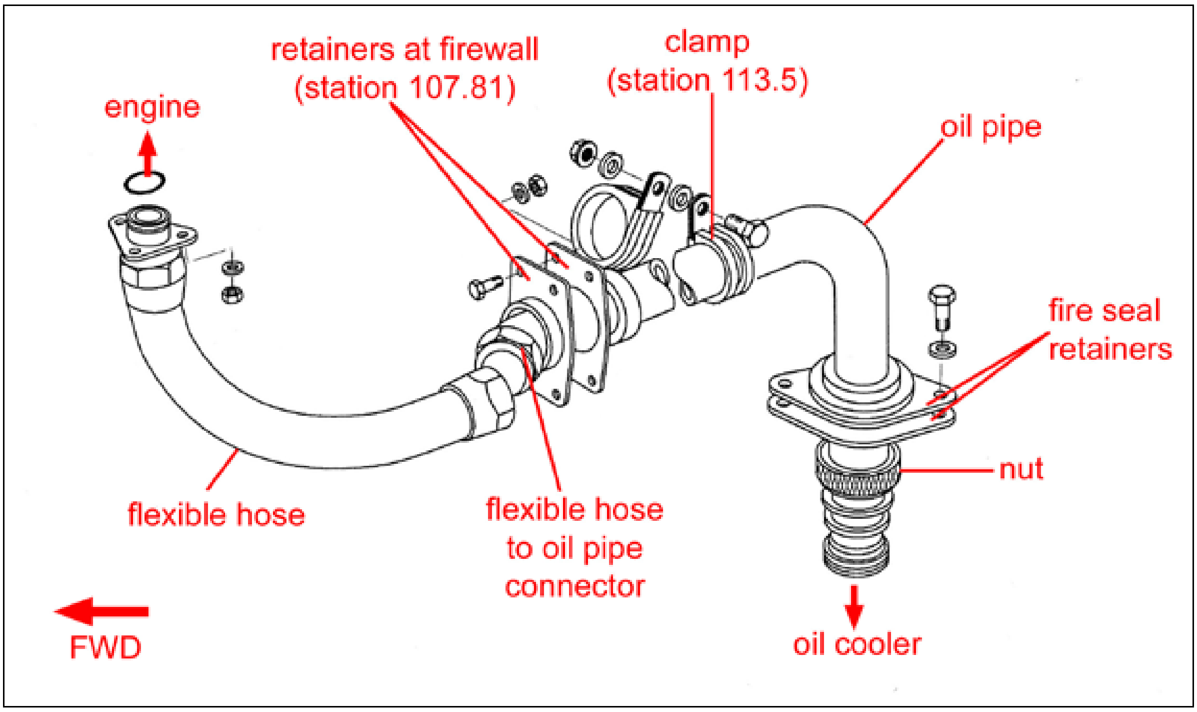

Figure 15

Oil cooler oil pipe installation on the DHC-8-100

The upper section of the oil cooler fitting (image (1) in Figure 14) has a thin wall, 1.64 mm thick, and on its inner edge it has a 30 degree chamfer which further reduces the wall thickness at its top edge, making this edge feel moderately sharp to the touch. Trying to force the pipe into the oil cooler fitting when it is not perfectly aligned could result in the sharp edge of the fitting pressing up against the O-ring seal on the pipe.

Oil leak check procedure

At the end of the oil cooler removal/installation task in the AMM (79-20-11) it states:

> *'Ground run engine (refer to Chapter 71). Check oil temperature stabilizes at approximately 80 degrees C. Check for oil leaks.'*

However, as identified earlier, this requirement was not included in the 'defect job card'. Chapter 71 contains a detailed procedure for ground running the engine, but it does not make any specific reference to an engine run procedure for oil leak checks. After starting the engine it says to unfeather the propeller, check that N_H stabilizes at 75% (power lever at FLT IDLE) and that the oil pressure is between 55 and 65 psi (green arc on gauge). A note in the AMM states that:

> *'Normal Oil Pressure is 55 to 65 psid at Nh speeds above 66% at oil temperatures between 71 Degrees and 115 Deg C.'*

The condition lever is then advanced to MAX, to perform a check of engine parameters. The engine shutdown procedure is to retard the power lever to FLT IDLE, retard the condition lever to MIN, and then to START & FEATHER for 30 seconds, to prepare the engine for the oil level check. The engine is then shut down. There is no minimum duration specified for the engine

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ground run in Chapter 71, and there is no requirement to move the power lever beyond FLT IDLE. The aircraft manufacturer stated that once the engine oil is up to normal operating temperature (45°C to 90°C), there will be minor fluctuations in oil pressure in transient conditions, but the oil pressure will be constant at stable power settings regardless of the power the engine is generating. The 80°C temperature listed in the oil cooler removal/ refit procedure is the temperature at which the thermostatic valve inside the oil cooler opens to divert oil into the matrix. This temperature would need to be reached to check for leaks from the cooler matrix, but not for checking leaks from the oil cooler fittings (as oil passes through the inlet and outlet fittings regardless of the position of the thermostatic valve). Once the engine run is completed, the lower forward cowling needs to be opened to check for leaks from the oil cooler fittings.

Working hours

The shift patterns for the engineers, technicians and fitters working on the aircraft at Exeter were '4 days on' followed by '4 days off', working 12 hours per day (including a half hour lunch break) from 0700 to 1900 hrs. Overtime was permitted. In the two weeks before Sup A started work on SX-BIO's C-check at Exeter he was working abroad. During the 10 days prior to his return to the UK he averaged 15.7 hours work per day with one day off in the middle (this time included 2 hours commuting between the hotel and airport). Sup A considered that he did not suffer from fatigue during this period despite the long working hours. After returning to the UK, Sup A had 2 days off and then he worked on SX-BIO for 6 days on, 2 days off, 6 days on, 1 day off, 4 days on, 3 days off, followed by 5 days on, averaging 12 hours per day (60 hours per week). Sup A said that during SX-BIO's leak checks, which were at the end of the aircraft's C-check, he felt tired and had a lot on his mind trying to get the aircraft ready for its scheduled painting slot. However, he said it was not an unusual level of tiredness and he did not consider himself fatigued.

According to '*The Working Time Regulations 1998*' and '*The Working Time (Amendment) Regulations 2003*'[5], an employer should ensure that a worker does not work in excess of an average of 48 hours per week over a 17-week period. In the 1998 regulations the air industry was excluded from this rule, but in 2003 this air industry exclusion was removed. However, the 48-hour limit does not apply if a worker has agreed with his employer, in writing, that it should not apply in his case. 97% of engineers at the AMO, including Sup A, had signed an 'opt-out' agreement so that the 48-hour limit would not apply to them. In the 17-week period leading up to the end of SX-BIO's C-check, Sup A had worked an average of 57 hours/week[6].

The WTRs also state that a worker is entitled to a rest period of 11 consecutive hours in each 24-hour period, and at least two rest periods of 24 hours each in each 14-day period (ie at least 2 days off during every 2-week period). These rest periods still apply even if the individual has signed an 'opt out' agreement. On most of the days when Sup A was working abroad he was averaging just 8.3 hours rest between shifts, significantly less than the 11 hours rest entitled under the WTR.

The AMO stated that their policy was that staff should not work more than 6 days on before a full day off, or 12 days on before 2 days off, in accordance with the WTR, although this was not a written policy. This

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Footnote

[5] The UK legislation enacted as a result of the EU Working Time Directive (2003/88/EC).

[6] 57 hours/week calculated using the WTR formula where 'annual leave hours' are included in the total average.

policy was not monitored by the AMO and relied on individuals reviewing their working hours with their managers. The AMO did not have a policy on minimum rest periods.

There are no regulations that limit the maximum hours that an individual can be asked to work in any 24-hour period, assuming it is followed by 11 hours rest. The AMO did not have a policy on the maximum hours that an engineer could work in any 24-hour period and relied on the fact that every engineer and manager had undergone human factors and human performance training and it was expected that engineers would tell their managers if they were becoming fatigued.

The Part 145 regulations do not explicitly require the AMO to monitor the working hours and the fatigue levels of their engineers. However, it does require that the planning of maintenance tasks take into account human performance limitations (145.A.47). As previously stated, Part 145.A.65(b) also requires that the AMO establishes procedures that take into account human performance to ensure good maintenance practices. Part 145.A.30(e) also requires that personnel are trained in human factors and human performance issues, and the Guidance Material for 145.A.30(e) states that this should include fatigue.

Maintenance personnel

Sup A, a 'senior supervisor' at the AMO, had worked for the organisation for 10 years. He was a 'B1' category LAE and had a type rating on the DHC-8-100. His responsibilities included being in charge of a team and deputising for management out of normal working hours. He had been the lead engineer responsible for SX-BIO's maintenance check.

Sup B, a 'supervisor' at the AMO, had worked for the organisation for almost 7 years. He was a 'B1' category LAE and had a type rating on the DHC-8-100. As a 'supervisor', he was occasionally expected to control aircraft hangar inputs and/or line shifts.

Tech A, a 'technician 2' at the AMO, had worked for the organisation for 10 years, with 7 years at Exeter. He was not an LAE and had no company approvals, but to become a 'technician 2' he would have had to demonstrate an ability to raise and complete paperwork (including 'defect job cards'), use technical manuals, possess reasonable problem-solving and troubleshooting ability, and be able to lead small groups on tasks. He had been promoted from 'fitter' grade to 'technician 2' grade in September 2008.

Analysis

The oil leaks from both engines, during the incident flight, were caused by damaged O-ring seals at the oil cooler fittings. The right engine oil leak originated from the outlet fitting of the right oil cooler, as a result of the O-ring seal on the outlet pipe being cut and losing a section during installation. The left engine oil leak originated from the inlet fitting of the left oil cooler, as a result of a cut in the main O-ring seal and a split in a smaller O-ring seal which should not have been fitted. The source of these two oil leaks was confirmed when the seals were replaced with new ones and the aircraft departed with no further reports of leaks.

Oil was already weeping slowly from both oil coolers when the aircraft arrived at East Midlands Airport and continued to do so during the ensuing week, manifesting itself in oil drops underneath the nacelle butt joints on either side of the oil coolers. However, the leaks appeared to have stopped or slowed just before the aircraft was cleared to depart. The leaks then worsened during the aircraft's taxi out, and continued

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to leak at a higher rate during the incident flight. The right engine lost about 5.5 litres of oil before it was shut down and the left engine lost about 3.5 litres of oil. The oil cooler fittings had not leaked at this rate during the aircraft's flight from Exeter to East Midlands and yet there was no evidence that the oil coolers had been disturbed while the aircraft was at East Midlands. It was therefore probable that either engine vibration, or the loads imposed during the landing at East Midlands, slightly shifted the position of the oil pipes such that the effect of the cuts in the O-ring seals was exacerbated. Shortly after landing, the engines were shut down and the oil pressure dropped, which would have caused any oil leak to slow. It is probable that during the 2-minute low power engine run, to check oil levels and as a final oil leak check before the aircraft departed East Midlands, the oil leak from the oil coolers would have been apparent had the lower forward cowlings been lowered and the oil coolers inspected. Two minutes was probably insufficient time for the oil to seep through and around the oil cooler and deposit itself on the main landing gear legs. However, once the aircraft started taxiing for departure, sufficient oil had made it through and a visible coating of oil on both landing gear legs was apparent. There were a number of contributory factors to this incident and these will be analysed in turn.

Repair of the main gear door pivot bracket bushings

The first contributing factor was the raising of a 'defect job card' to repair the left and right main gear door pivot bracket bushings with an attached RD which did not detail the access requirements for the repair. Had there been repair instructions which made it clear that the repair could be accomplished in situ, then the oil coolers would not have been removed and the incident to SX-BIO would not have occurred. The aircraft manufacturer stated that RDs were not meant to be detailed and it was for the maintenance organisation to write detailed instructions if necessary. The AMO did not have a process for creating repair instructions to accompany RDs, and they did not have a searchable database of common repair jobs that could be accessed by engineers. The planning department was involved when a new repair, that the AMO had not previously performed, needed to be carried out, but they were not necessarily involved when engineers obtained the RDs from the RD folder. The engineer who pulled the RD for the bushing repair knew that the repair could be done in situ but the engineer who picked up the repair task did not know this. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2011-014

It is recommended that Flybe Aviation Services revise their practices and procedures to ensure that their repair instructions are adequately detailed and specify the necessary access and removal requirements.

Removal and refit of the oil coolers was not identified as a safety critical task

When it was decided that both oil coolers needed to be removed from the aircraft, these tasks should have been identified as safety critical. If a person makes an error while disturbing the oil system on one engine, and then repeats the error on the other engine, the safety of flight of a twin-engined aircraft can be compromised. This was the case in the incident to the Boeing 737-400 (G-OBMM) that lost almost all its oil from both engines due to the rotor driver covers not being refitted following borescope inspections on both engines by the same person.

The AMO agreed that the oil cooler re-installation tasks should have been identified as safety critical tasks and should have been carried out by different people. The

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AMO had a process in place for identifying safety critical tasks and had a safety critical task checklist for the DHC-8-100. However, not all staff were aware of this process and the oil cooler removal/refit task and other critical tasks were missing from the safety critical task checklist. To address these issues, the AMO provided a 'Safety Awareness Presentation' to all staff in May 2010, which, amongst other things, highlighted the importance of identifying safety critical tasks. They also launched a Poster Awareness Campaign, which included one poster stating '*Think Safety – Are YOU aware of Safety Critical Tasks on the aircraft you are working on?*' A reminder of the importance of identifying safety critical tasks will also feature in the company's engineer annual continuation training. The safety critical task checklist for the DHC-8-100 has also been amended to include the removal/refit of the oil cooler. A new process has also been developed for identifying safety critical tasks on third party work cards.

Incorrect re-installation of the oil coolers

Both oil coolers were re-installed incorrectly and this resulted in the O-ring seals being damaged. The contributory factors to the incorrect re-installation were:

1. The technician had not performed the task before.
2. The technician did not ask for or receive any assistance (the job was possible for one person but it would have been easier with two).
3. There was some time pressure to complete the task by the end of his shift.
4. The working space under the nacelle was small and poorly illuminated.
5. The oil pipes were not aligned vertically and would have been difficult to orientate to the vertical position as they were still attached to the flexible hoses at their forward ends (the AMM procedure did not call for them to be disconnected at their forward ends).
6. The oil cooler fitting had a sharp edge which could cut an o-ring if the oil pipe was forced into the fitting with improper alignment.

After the oil pipes were installed it should have been possible to wind the knurled nut fully down with hand pressure alone. However, the technician said that he used a pair of soft grips to tighten the nuts. The fact that the nut on the inlet fitting of the left oil cooler was found not to be fully wound down after the first series of engine ground runs (one thread was visible), indicates that the nut had probably been difficult to tighten. This should have been an indication to the technician that the pipe was not installed correctly. There was clear evidence on the nuts and the circlips inside the nuts that they had been over-tightened on more than one occasion, and this could have been due to a miss-understanding of the purpose of the nuts. They do not provide any clamping force on the O-ring seal.

In order to address a number of these issues the aircraft manufacturer has incorporated some amendments to the AMM (Revision Jan 15/2011). A note has been added to the oil cooler installation task, at the step for connecting the oil pipes ('*tube assemblies*') to the oil cooler fittings, stating:

> *'If required, loosen or remove the tube assemblies from the flexible oil hoses to provide the freedom of motion for the installation of the oil cooler.'*

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Detaching these pipes at their forward ends (firewall station 107.81 in Figure 15) will make manoeuvring the pipes into the fittings easier and, therefore, should make it less likely that the seals will be damaged.

A further note has been added to the AMM (Revision Jan 15/2011) which states:

> *'If there is any difficulty in tightening the fittings, remove the pipes and check the O-ring for a defect.'*

The aircraft manufacturer had also intended to add a step stating:

> *'Make sure that the union nut on each tube assembly (5) and (6) bottoms out against the oil cooler fittings (20)'*

but this was missed out of the Jan 15/2011 revision. The manufacturer has stated that it will be added to the next revision.

It is considered that the aircraft manufacturer should also highlight the fact that correct installation of the engine oil coolers requires the knurled nuts, which secure the inlet and outlet pipes to the engine oil coolers, only to be hand-tightened. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2011-015

It is recommended that Bombardier Inc. amend the Aircraft Maintenance Manual for the DHC-8-100 series aircraft to emphasise the correct procedure for securing the inlet and outlet pipes to the engine oil coolers, including the method for tightening the associated knurled nuts.

Task breakdown on 'defect job cards'

The final step of the oil cooler installation procedure in the AMM called for an engine ground run and leak check of the coolers. This step was not written on the 'defect job card' and, therefore, at the end of the maintenance check when the engine ground runs were carried out, the engineer involved did not know that an inspection of the oil coolers was required. In the event, the leak from the left engine was obvious and the left oil cooler was visually inspected. However, had the leak not been so obvious then the left oil cooler may not have been inspected. It was not clear if the right oil cooler had been inspected. The omission of the leak check task from the job card was therefore a significant omission. The tasks on the job card (which was a 'defect job card' for the bushing repair) were written by a number of individuals, rather than all tasks being pre-planned. For example, the task after 'refit oil cooler' was 'carry out NDT inspection of bracket post rework' and the task after that was 'carry out bush repair in situ'. Both of these tasks were written by the different people performing the task, and were out of sequence. Tech A should have written down the 'oil cooler leak check' task after the 'refit oil cooler task', but he was only concerned with writing down his own specific tasks which only involved removing and installing the oil cooler. His supervising engineer did not notice the omission. Had a single person planned the entire job and written all the tasks required, then perhaps the leak check task would not have been missed.

The AMO has stated that it has since started a new programme of 'Documentation training' for its licensed engineers and unlicensed technicians and fitters. However, to ensure that this issue is fully addressed the following Safety Recommendation is made:

Safety Recommendation 2011-016

It is recommended that Flybe Aviation Services review their defect rectification processes to ensure that important safety checks, such as oil leak checks, are not omitted.

Engine oil leak checks at Exeter

Although there was no plan to specifically check the oil coolers for leaks, engine ground runs were required to be carried out to test systems and check for other oil leaks. During the first ground run which lasted about 5 minutes no oil leaks were observed. However, the lower forward cowlings were not removed so the oil cooler fittings were not inspected. During the second engine ground run, at higher power, the oil leak from the left engine became apparent after about 40 minutes when oil was noticed leaking down the left main landing gear leg. This leak was attributed to the nut on the left oil cooler inlet fitting not being fully wound down. This was rectified and a third engine ground run, at low power, was carried out and, reportedly, there were no more leaks. There were differing accounts as to whether the left lower forward cowling was removed after this engine run, and there were also differing accounts on what work, if any, was done on the right engine to check the right oil cooler. The engineer in charge of the engine ground runs (Sup A) had thought that all the oil cooler fittings on both sides had been tightened but no one could recall having tightened the right oil cooler fittings. One technician reported that there were traces of oil near the drain holes of the right engine, but no leaks. It was possible that these traces were due to a slight leak from the right oil cooler outlet fitting. The interviews of the relevant personnel were carried out two weeks after the events described, so poor memory recall of the events could explain the differing accounts. In summary, it was not possible to establish if the right oil cooler fittings had been inspected.

The fact that the aircraft then completed an uneventful 49 minute flight to East Midlands, with no loss of oil pressure or significant oil quantity loss, indicated that the leaks which remained, if any, were very slow.

Maintenance work at East Midlands – oil leaks not rectified

The engineer at East Midlands (Sup B) who supervised the repaint provided the investigation with photographic evidence that there was slow oil seepage from both the left and right engine nacelles beneath the oil coolers (Figure 13). The need to start preparing the aircraft for paint stripping prevented Sup B from initially investigating these leaks and he was subsequently hampered by scaffolding surrounding the engine nacelles. The day when full access to the engines was finally provided coincided with the day that Sup A arrived to perform the duplicate control inspections. Sup A's dismissal of the reported oil seepage as being residual from the previous leaks at Exeter had the effect of alleviating Sup B's concerns about the seepage he had seen. Therefore, Sub B did not lower the forward cowlings and inspect the oil coolers. An additional factor may have been that the task of lowering the forward cowling requires at least two people, and preferably three. Opening the side cowls is a simple one handed task but this does not provide access to the oil coolers. On the morning before the aircraft departed East Midlands, Sup B requested that the pilots perform an engine run to check the oil levels and as a final leak check. No leaks were seen but, again, the lower forward cowlings were not lowered, so another opportunity to detect the source of the leaks was missed.

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Had the engines been run for longer, then the leaks would probably have become apparent before the aircraft started to taxi. However, there is no minimum time period specified for operating the engine when conducting leak checks. According to the aircraft manufacturer once the oil is up to normal operating temperature the oil pressure will remain relatively constant. The engine was run for 2 minutes so it is probable that the oil was close to its operating temperature. However, that was not sufficient time for the oil leak to reach a point at which it became visible externally. Therefore, the only reliable method of detecting the leak would have been to open the lower forward cowling. It is important that the source of any oil leak, even if seemingly very minor, is correctly identified and rectified. Therefore the following Safety Recommendation is made:

Safety Recommendation 2011-017

It is recommended that Flybe Aviation Services remind all staff of the importance of investigating the source of every engine oil leak.

Working hours and fatigue risk management

In the 17-week period leading up to the end of SX-BIO's C-check, Sup A had worked an average of 57 hours/week which was 9 hours/week in excess of the Working Time Regulations (WTR). Furthermore, during the 10 days prior to SX-BIO's arrival at Exeter, Sup A had averaged 15.7 hours work per day, resulting in the 11-hour rest entitlement in the WTR being significantly curtailed. Sup A said that he did not consider himself fatigued during this period. However, he also said that during SX-BIO's leak checks he felt tired and had a lot on his mind, trying to get the aircraft ready for its scheduled painting slot, although it was not an unusual level of tiredness. There was no single factor in this serious incident that could be directly attributed to fatigue. However, the fact that an engineer had been tasked to work a 10 day period, with just one day off in the middle, averaging 15.7 hours per day, is a potential safety concern, particularly since it was not being monitored by the AMO. Insufficient sleep and rest can lead to fatigue and increase the probability of maintenance errors[7].

The AMO stated that following this incident they are now carefully monitoring working time to ensure that staff do not work more than 6 days on before a full day off, or 12 days on before 2 days off, and they are amending their staff handbook to reflect this. The revised draft staff handbook also includes a provision for 11 hours of uninterrupted rest per day, in accordance with the WTR. However, it includes a caveat that staff can be asked to start work again before their 11 hours of rest have elapsed and this extra time will be paid at the overtime rate. The WTR does not permit payment in lieu of the rest entitlement, although it does permit exceptions to the rest entitlement where '*activities involve the need for continuity of service*' or when a shift worker changes shifts. The AMO has no policy on the maximum hours that an engineer can work in any 24-hour period and relies on the fact that every engineer and manager has undergone human factors/performance training and that engineers will communicate to their managers if they are becoming at risk of fatigue. Some individuals who have undergone this training will probably be very responsible and will request time off when they feel that they need it. However, for some individuals this may not be the case, particularly when they have a strong desire to complete the job they have started and when there is a financial incentive to work longer hours. There is also evidence that people are not very

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Footnote

[7] '*Human Factors Guide For Aviation Maintenance*', U.S. Department of Transportation, Federal Aviation Administration, (ISBN 0-16-042643-X).

good at detecting their reduction in performance levels as they become fatigued[8]. Therefore, the responsibility for managing fatigue should belong to the AMO and not just the individual.

The Canadian aviation regulator, Transport Canada, has published two Notices of Proposed Amendment (NPA) 2004-047 and 2004-049. These NPAs propose requirements for an AMO to manage fatigue-related risks through their Safety Management System. To support these proposed regulations, Transport Canada has published guidelines for a Fatigue Risk Management System (FRMS)[9]. This system provides a method for quantifying fatigue risk on a numerical scale (see Appendix 1) using knowledge of working hours and rest periods. It does not rely on knowledge of sleep times which is difficult information for an AMO to acquire.

The US Federal Aviation Administration (FAA) has set up a maintenance fatigue working group that is currently reviewing the need for regulatory limits on working hours for maintenance engineers. The European Aviation Safety Agency (EASA) have stated that their remit does not include the regulation of working hours; they have no legal power to mandate maximum hours limits or minimum rest periods for maintenance engineers. However, EASA stated that fatigue risk management is an issue which they will be looking at as part of their introduction of a regulatory requirement for a Safety Management System.

Part 145 states that the AMO needs to take human performance limitations into account when planning maintenance tasks and, although not specifically stated, this should include taking maintenance engineer fatigue into account. However, the advisory material (AMC) and guidance material (GM) to Part 145 do not explain how this should be accomplished. Transport Canada have provided some advice on how to accomplish this. Therefore, the following Safety Recommendation is made:

Safety Recommendation 2011-018

It is recommended that the European Aviation Safety Agency expand the advisory or guidance material in Annex II (Part 145) of European Commission Regulation (EC) No. 2042/2003 on how approved maintenance organisations should manage and monitor the risk of maintenance engineer fatigue as part of their requirement to take human performance limitations into account.

Oversight of the AMO by the Civil Aviation Authority (CAA)

The CAA is required to conduct annual audits of the AMO to ensure that the AMO complies with the requirements of Part 145. At the time of writing, the last audit was carried out in June 2010. In order to ensure that the safety lessons from this investigation have been adopted by the AMO, the following Safety Recommendation is made:

Safety Recommendation 2011-019

It is recommended that the Civil Aviation Authority include the following areas in their Part 145 audits of Flybe Aviation Services: practices and procedures for detailing repair instructions, identification of safety critical tasks, planning of defect rectification and management of maintenance engineer fatigue.

Footnote

[8] '*Aircrew Fatigue, Sleep Need and Circadian Rhythmicity*' by Melissa M. Mallis, Siobhan Banks and David F. Dinges, Chapter 13 in '*Human Factors in Aviation*' Second Edition, edited by Eduardo Salas and Dan Maurino (ISBN 978-0-12-374518-7).

[9] These guidelines can be found at http://www.tc.gc.ca/eng/civilaviation/standards/sms-frms-menu-634.htm.

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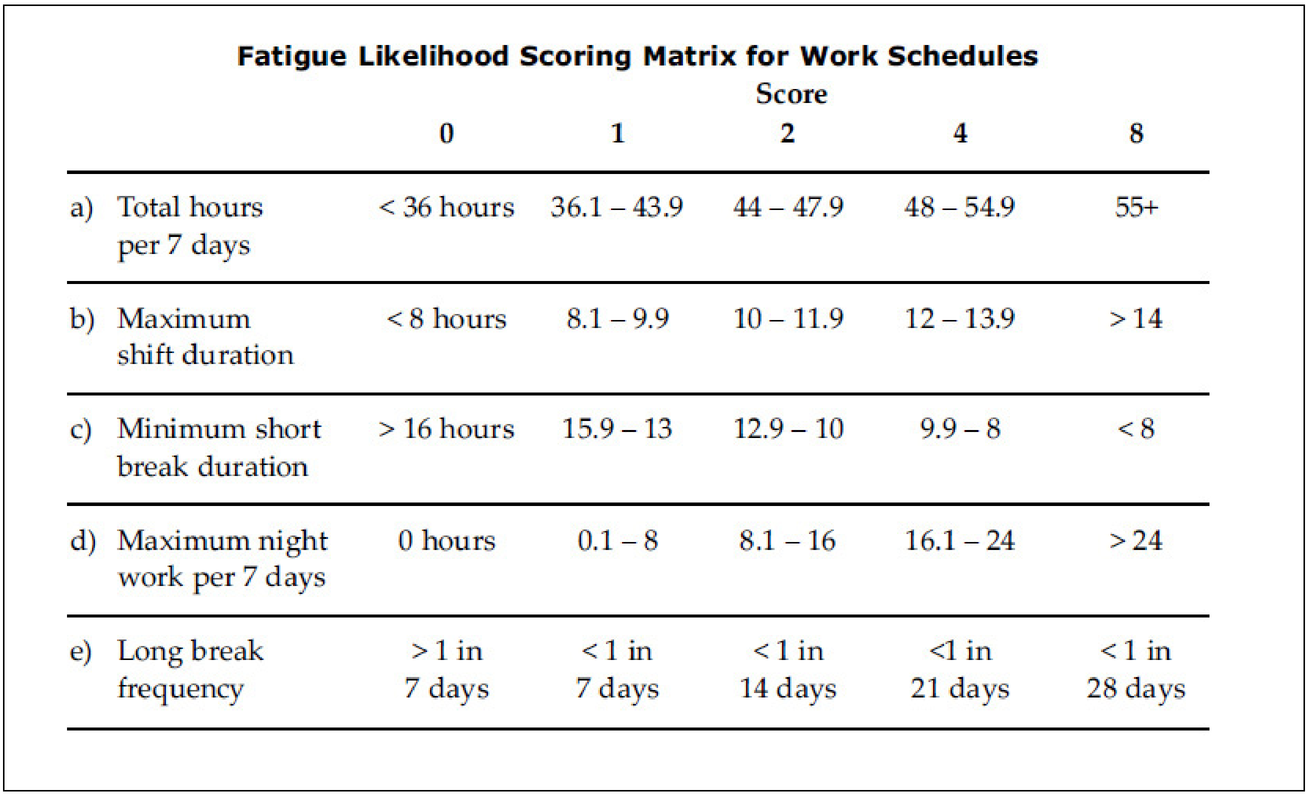
Operation of the aircraft

The crew diverted into Bristol whilst flying on one engine with an oil leak. While ATC were aware that the aircraft was flying on one engine, they were not aware that this remaining engine was also giving the crew cause for concern. Whilst in this case it did not influence the service provided by ATC, it is good practice for flight crew to keep ATC informed about any relevant developments in an emergency situation.

Conclusions

The oil leaks from both engines were caused by damaged O-ring seals at the oil cooler fittings. This damage probably occurred when both oil coolers were improperly re-installed by the same individual during base maintenance. The limited repair instructions had resulted in the unnecessary removal of the oil coolers and the re-installation of the coolers had not been identified as safety critical tasks. Following the oil cooler re-installation it was not documented that an oil leak check would be required, due to incomplete planning of the tasks on a 'defect job card'. The incorrect diagnosis that the slow oil seepage from both engine nacelles was residual oil from a previous leak led to the source of the leaks not being fully investigated at East Midlands.

Appendix 1



Fatigue Likelihood Scoring Matrix for Work Schedules

	Score 0	1	2	4	8
a) Total hours per 7 days	< 36 hours	36.1 – 43.9	44 – 47.9	48 – 54.9	55+
b) Maximum shift duration	< 8 hours	8.1 – 9.9	10 – 11.9	12 – 13.9	> 14
c) Minimum short break duration	> 16 hours	15.9 – 13	12.9 – 10	9.9 – 8	< 8
d) Maximum night work per 7 days	0 hours	0.1 – 8	8.1 – 16	16.1 – 24	> 24
e) Long break frequency	> 1 in 7 days	< 1 in 7 days	< 1 in 14 days	<1 in 21 days	< 1 in 28 days

Extract from Transport Canada's Fatigue Risk Management System, Policies and Procedures Development Guidelines
(TP 14576E, April 2007)

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SERIOUS INCIDENT

Aircraft Type and Registration:	Embraer EMB-135ER, G-RJXJ	
No & Type of Engines:	2 Allison AE 3007A1/3 turbofan engines	
Year of Manufacture:	2001	
Date & Time (UTC):	28 February 2011 at 0956 hrs	
Location:	East Midlands Airport	
Type of Flight:	Commercial Air Transport (Passenger)	
Persons on Board:	Crew - 3	Passengers - 24
Injuries:	Crew - None	Passengers - None
Nature of Damage:	None	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	49 years	
Commander's Flying Experience:	10,290 hours (of which 5,680 were on type) Last 90 days - 122 hours Last 28 days - 23 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

During the landing roll the pilots saw cockpit indications of a fire in the baggage compartment. The aircraft was taxied clear of the runway and brought to a halt on the taxiway, and a PAN call was made requesting the attendance of the emergency services. The pilots carried out the emergency checklist actions, which included discharging a fire extinguisher into the baggage hold, and asked a member of the cabin crew to look into the hold through an inspection hole in the lavatory floor. The cabin crew member reported that the hold "looked cloudy". The commander instructed the passengers to vacate the aircraft promptly through the normal exit leaving cabin baggage behind. The emergency services found no evidence of fire; cloudiness in the hold was thought subsequently to be due to the fire extinguisher discharge.

The operator believed that the incident might have been caused by water ingress into one of the fire detectors.

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ACCIDENT

Aircraft Type and Registration:	AS355F2 Twin Squirrel, G-SEWP	
No & Type of Engines:	2 Allison 250-C20F turboshaft engines	
Constructor's Serial No:	5480	
Year of Manufacture:	1991	
Date & Time (UTC):	28 October 2010 at 0950 hrs	
Location:	31 nm south of Belfast Aldergrove Airport, Northern Ireland	
Type of Flight:	Commercial Air Transport (Passenger)	
Persons on Board:	Crew - 1	Passengers - 3
Injuries:	Crew - 1 (Minor)	Passengers - 3 (Minor)
Nature of Damage:	Aircraft destroyed	
Commander's Licence:	Commercial Pilot's Licence (Helicopter)	
Commander's Age:	42 years	
Commander's Flying Experience:	2,045 hours (of which 185 were on type) Last 90 days - 47 hours Last 28 days - 21 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The pilot lost control of the helicopter whilst manoeuvring at low speed to approach a hilltop landing site in quite strong wind conditions. It descended rapidly with increasing forward ground speed, before striking the ground short of the point of intended landing and passing through a substantial stone wall. The helicopter was destroyed but the occupants suffered only minor injuries. The investigation determined that an error of judgement or perception led the pilot to attempt a downwind approach. A combination of human factors was thought to have contributed to the accident.

History of the flight

The helicopter was engaged on a task for the Police Service of Northern Ireland (PSNI), ferrying personnel and equipment to and from the site of a helicopter accident which had occurred 5 days earlier, on 23 October 2010. The site was in the Mourne Mountains, near to the top of the 626 m (2,054 ft) amsl Shanlieve hill. A PSNI control point, from where passengers embarked for the ferry flights, had been established in a valley about 3 km from the site.

G-SEWP had been similarly tasked the day before, completing seven round trips. The same pilot operated the task, but with a different observer than on the day of

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the accident. Cloud affected the hilltop on occasions and the first three flights terminated at an alternative landing site lower down the hill.

On the day of the accident, the pilot and observer commenced their pre-flight duties at 0700 hrs at their Aldergrove base. A 'check A' was made on the helicopter and the fuel state was confirmed at 65% (about 475 litres). A weather report showed that a warm front was forecast to cross the area, giving rise to cloud on the hilltops. It was thought that a workable period should be available prior to the weather front's passage at about lunchtime, and possibly afterwards as well. Surface winds were expected to be about 10 kt at the surface, and about 20 kt on the hilltops, generally from the south-west.

The helicopter departed Aldergrove at 0744 hrs and flew to the accident area, where the pilot carried out a weather check. Cloud was affecting the hilltops and the helicopter circled the area without overflying the primary landing site near the summit. The helicopter then landed and shut down adjacent to the police control point.

A plan for the morning's task was agreed and passengers were briefed accordingly. It was decided that 'rotors running' turn-rounds would be made, with the observer escorting passengers to and from the helicopter. The observer normally occupied the front left seat in the helicopter, but for mass and balance purposes he occupied the rear right seat for the ferry flights. This also allowed better monitoring and supervision of the passengers. While the pilot and observer wore safety helmets, only headsets were available to the passengers.

The first flight could not be made to the hilltop because of cloud, so the passengers were disembarked at the alternative landing site. However, the next four flights were able to reach the primary landing site, situated a few metres from the summit of the hill, near to a substantial stone wall and a little way upslope from the earlier accident area.

The accident occurred on the last planned ferry flight of the morning. It appeared that the summit was affected by cloud so the pilot initially routed towards the alternative landing site. However, it then became apparent that the summit was clear of cloud, so the pilot continued towards it.

The four previous approaches had been made from the north-east, approximately into wind. Whilst at the summit on the previous flight the pilot thought that the wind had backed and reduced in strength. On the accident flight, because of the possible drop-off at the alternative site, the helicopter approached the hilltop from a westerly direction. It overflew the landing site and started a right turn back towards it (Figure 1).

The pilot's recollection was that he had completed at least a full orbit and was approaching the landing site substantially into wind, although this time on a more south or south-easterly track. With the landing site in view ahead, and whilst making his final approach at about 40 kt IAS, the pilot sensed a sudden loss of airspeed and lift, which he regarded as being due to windshear. The helicopter began to sink rapidly, accompanied by some instability in yaw. The pilot checked forward with the cyclic control in an attempt to gain airspeed and fly out of the situation. The helicopter continued to sink as the pilot raised the collective lever to apply power.

With the helicopter descending rapidly and now with significant forward speed, the pilot flared the helicopter just before it struck the ground. He recalled that it struck the ground a short distance before the intended landing site. The occupants sensed that the rear of the helicopter

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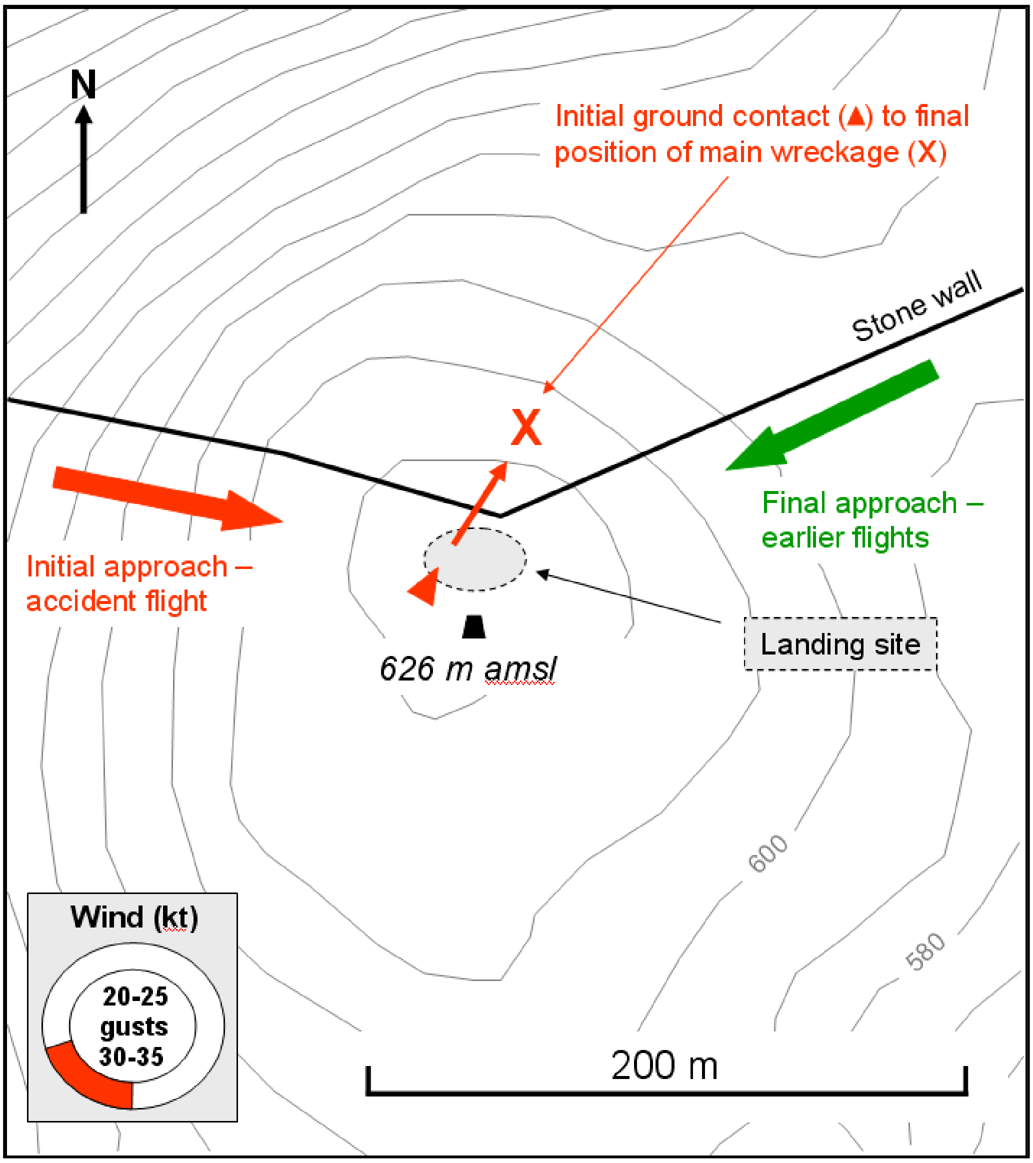

Figure 1

Sketch of accident location

struck the ground first, followed by the main cabin, in a substantial (though essentially upright) impact. The helicopter bounced and continued forward as it started to break up. It passed through the upper portion of the stone wall and came to rest some 36 m beyond.

The pilot and observer extricated themselves from the largely inverted wreckage of the main cabin. The observer then assisted the first of the passengers out, who had been seated in the left middle of the four-place rear seat. The second passenger, who had been seated in the left-most rear seat, was the most severely injured, suffering cuts and bruises which included a laceration of his scalp. He was also helped from the wreckage by the observer.

The survivors were taken to a tent being used by recovery teams working on the original accident site, where they were given first aid. The weather worsened soon after the accident, which initially prevented

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further airborne access to the scene, so a rescue effort was launched on foot by mountain rescue personnel and paramedics. After some time, an RAF Sea King rescue helicopter was able to get to the scene and airlifted the survivors off the hillside. Paramedics arrived with the mountain rescue teams at about the same time as the rescue helicopter.

Accident site information

The helicopter struck approximately level ground in an erect attitude. The softness of the ground, the remoteness of the site and the adverse weather during the subsequent investigation limited the extent of the assessment of the ground markings which could be made.

The general condition of the helicopter, however, suggested a reasonably low rate of descent at initial ground contact. Absence of any earth deposits on the tail-skid (despite the soft peaty soil of the area) indicated no excessively nose-up attitude at initial ground contact. Rapid upset of the aircraft from the level attitude (as a consequence of forward motion with the skids in contact with a soft peaty surface) appeared to have resulted in the main rotor blades experiencing a sequence of ground contacts as they continued to rotate. This caused progressive multiple blade failures, rotation of the helicopter about the main rotor axis and separation of the aft end of the tail-boom. In addition the tail-rotor gearbox separated from the structure soon after initial ground contact. Upset of the helicopter appeared to have caused downward failure of the forward ends of the skids leading to consequent bending failure of those sections of skid between the forward and aft supports. Total destruction of the main blades occurred during the process of translation between the impact point and the final resting place of the fuselage.

The effect of main rotor blade contacts appears to have propelled the helicopter in a generally northerly direction, passing through the top of a dry stone wall, for a total distance from initial impact of approximately 80 metres. The helicopter came to rest in an approximately inverted position with the main rotor mast still attached and the tail-boom separated.

Passenger and eyewitness accounts

The observer and two passengers gave their accounts of the accident. Like the pilot, they recalled flying over the landing site from a westerly direction before turning right. However, unlike the pilot, all three described the helicopter turning through only about 270° before it started descending rapidly, either just after rolling level or as it was in the process of doing so. All three described the wall which the helicopter would eventually strike as being directly ahead and running across their path as the helicopter made its sudden descent.

The observer realised that the helicopter was approximately downwind when it started descending, and thought it had been caught by a strong gust of wind. One passenger clearly recalled hearing the pilot comment "it's into the wind" just before the final descent started, about coincident with a sudden bank to the right. The same passenger became aware of an intermittent warning tone[1] sounding in the cabin, which had not been present before the final descent started and was not present once the helicopter had come to rest.

A police officer working with the recovery teams at the earlier accident site described the helicopter's approaches earlier in the day as being from the north-east, with it touching down in a west or south-westerly direction. On

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Footnote

[1] An intermittent warning horn sounds to indicate that the main rotor rpm is above 410 RPM. Maximum speed is 425 rpm (*AS355 F2 Flight Manual*)

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the last flight, he became aware of the helicopter turning to the right before seeing what he described as a sudden yaw, probably to the right, followed by a sharp descent. The helicopter then went out of sight behind the wall (the witness was part way down the slope) before seeing it come physically through the wall, banked to its left.

Other eyewitnesses saw parts of the accident sequence, although none had a clear view because of their position further down the slope. Most described some form of rolling or yawing motion before the helicopter descended out of sight. Passengers and witnesses described the sound of the engines increasing just prior to impact.

Subsequent examination

The wreckage was salvaged using a heavy-lift helicopter and road vehicles. More detailed examination then took place of the powerplant, systems and flying controls.

Engines

Examination of the engines revealed no evidence of any failure. The intake areas of both engines showed similar evidence of ingestion of wet peat consistent with both units still running after the helicopter had become inverted and the external intake grills were partly buried or immediately adjacent to the peat surface. The liners of both compressors were similarly scored resulting from forceful rotation of the gas generators after soil ingestion; this indicated similar rotational conditions of each engine during the period of ingestion, some seconds after initial ground contact.

Boroscope inspection of both turbine areas indicated that they were in a serviceable condition. Hand rotation of each LP turbine resulted in corresponding rotational movement of the main rotor confirming the integrity of the drive from each engine to the rotor.

Flying Controls

The mechanical controls were disconnected from the servos and examined/functioned (as appropriate) from the cyclic and collective controls through to the servo inputs. No evidence was found of any failure or restriction that was not consistent with the effects of impact or structural distortion arising from the series of impacts.

The three main rotor servos were removed complete with their external flexible pipe systems (other than those piping areas where one system's piping was routed through the bell-housing above the main rotor gearbox). Each system was functionally tested at working pressure on a hydraulic pressure rig. Effectively identical movement rates were recorded for each end of each of the double servos (a total of six functions were being tested). In each case smooth operation occurred as a result of hand deflection of the input levers. No evidence of leakage was observed.

The tail rotor servo was similarly tested and responded in a similar way.

Hydraulic pumps

Both hydraulic pumps were removed for testing. The input splines were observed to be intact on both units. Strip examination confirmed that both pumps were in sound internal condition and thus fully capable of normal operation.

Survival aspects

The standard rear seat harness arrangement was lap straps for each seat. However, for operations with doors removed, the outermost seats on each side had been fitted with shoulder harnesses. While the observer was wearing the shoulder harness as well as the lap strap,

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the passenger in the left outer seat wore only the lap strap. The passenger in the centre left seat had only the lap strap available.

In its final position, the overturned helicopter was prevented from becoming completely inverted by support from the main rotor mast, being inclined in such a way that the front right seat (pilot's) occupant volume was only partly intruded. The back of this seat was distorted in a forward direction consistent with the final ground impact. The bulk of the glass-reinforced plastic shell and transparent panelling of the cabin section was destroyed, leaving only a small section of the right-hand side roof in place, the remainder of the occupied volume no longer being enclosed. The overhead control panel and quadrant area was totally disrupted although it remained attached.

The metal floor structure was distorted with impact damage concentrated at the forward left side but the bulk of the floor remained relatively intact. Although the front left seat survived in a damaged state, the whole of the left front seat occupant volume was totally intruded. This left seat was unoccupied during the accident flight. The rear cabin bulkhead remained intact and provided head protection for the rear seat occupants.

Pilot information

The pilot gained a Commercial Pilot's Licence in 2005 and underwent AS355 type rating training in 2006. He subsequently gained a Flight Instructor rating, and from 2007 worked as an instructor and charter pilot on R22 and B206 helicopters. Following a period of line and role training in early 2010, he started work with the helicopter operator in April 2010 as a full time freelance pilot, flying G-SEWP on charter to the PSNI. The pilot had completed all the helicopter and role training required by the operator.

The pilot arrived in Northern Ireland from England two days before the accident, for the start of a five day period of duty. Immediately beforehand, he had suffered a family bereavement. He did not report this to his company and considered on the day that he was fit for flying duty. However, when the pilot subsequently informed the AAIB of the fact, he thought it possible that it may have been a contributory factor in the accident.

Helicopter performance

A post-accident mass and balance calculation produced an estimated mass at the time of the accident of 2,281 kg. Maximum permissible mass was 2,540 kg. Longitudinal centre of gravity was calculated at 3.31 m aft of datum: a moderately forward position, within permissible limits.

Meteorological information

A report on the forecast and actual weather conditions was prepared by the Met Office. There was an area of low pressure centred to the west of Ireland, with an approaching warm front which lay approximately across the accident area by 1200 hrs. Thus, at the time of the accident, the area lay in a west to south-westerly airflow, with an approximate gradient (or 2,000 ft) wind from 230° at 30 to 35 kt. Surface analysis charts and airfield weather reports were not wholly representative of weather in the Mourne Mountains, but clearly showed the approaching warm front. The Belfast Aldergrove forecast showed temporary periods of rain from 0900 hrs, with broken cloud at 1,200 ft agl, implying a high possibility of hill fog on the mountains.

Wind speeds at airfields in the area were 10 to 11 kt, with no gusts reported. The winds at the accident site would probably have been significantly stronger and closer to the gradient wind speed: 20 to 25 kt with gusts of 30 to 35 kt. There were indications of mountain wave

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activity in the area, with predicted vertical velocities of 200 to 300 feet per minute, which may have caused turbulence effects such as sudden gusts.

Information from the crew and passengers generally concurred with the Met Office report, although no turbulence was experienced. However, the pilot's assessment of a change of wind direction was not supported by the Met Office report.

Vortex ring state

Vortex ring state (VRS) is a phenomenon that occurs when the main rotor tip vortices are recycled into the induced airflow (Aeronautical Information Circular (AIC) 020/2010)[2]. VRS is normally experienced at low airspeeds and significant rates of descent, which result in an airflow in opposition to the induced airflow. The effect is to produce severe instability of the airflow around the rotor disc with subsequent aerodynamic inefficiencies and loss of rotor thrust.

In general terms VRS becomes a possibility when airspeed is below about 30 kt, with a rate of decent greater than 300 ft/min and with power applied. At the incipient stage, there is an increase in vibration and buffet, small amplitude twitches in roll and yaw, and instability in all axes. In the established stage, VRS is characterised by a very rapid build-up in the rate of descent, reduced effectiveness of cyclic inputs and the inability of applied collective to reduce the rate of descent – it may in fact increase it. A fully developed VRS may occur with very little advance warning to the pilot. With respect to the AS355, it is reported that VRS becomes a possibility when airspeed is below 20 kt with a rate of descent greater than 1,000 ft/min.

AIC 020/2010 states the following (original emphasis):

> *'At typical helicopter operating heights, particularly during photographic or surveillance tasks or during steep or vertical approaches, the conditions referred to* [above] *must be avoided since lack of height will make recovery from the condition uncertain ... Pilots should therefore always maintain airspeed when turning or descending* ***and especially when downwind*** *in high wind conditions.'*

Helicopter operator

The helicopter operator provided G-SEWP in support of the PSNI. The operator's operations manual stated that the helicopter was to be operated solely in accordance with the company's Air Operator's Certificate (AOC) and that certain alleviations from conditions of the Air Navigation Order that would be available to the PSNI under the terms of its own Police AOC were not applicable to G-SEWP. The provision of the helicopter to the PSNI had been the subject of discussion between the operator and the CAA, who were satisfied with the arrangements. The operations manual stressed that no special approval had been granted to do anything other than normal AOC public transport operations. The task G-SEWP was engaged on at the time of the accident fell within this category.

Human factors

The death of a close family member has been found to lead to higher levels of stress than any other experience with the exception of the death of a spouse or partner. Such stress will be likely to cause loss of concentration and performance (Green R.G., Muir H., James M., Gradwell D., Green R.L., (1991) *Human Factors for Pilots*).

Footnote

[2] For a full description of VRS see also: W J Wagtendonk (1996) *Principles of Helicopter Flight.*

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When the pilot's bereavement became known after the accident, the operator undertook to emphasise to all its pilots the critical importance of informing the company of any personal issues that may affect their ability to fly safely and efficiently. Furthermore, the operator arranged with the provider of its Crew Resource Management training for this accident to be highlighted during recurrent training, stressing the importance of the fit-to-fly decision in single pilot operations.

Recorded information

Positional information for the helicopter during much of the accident flight was recorded by the Belfast secondary surveillance radar (SSR) (every five seconds) and by a Skyforce Skymap IIIC GPS unit (every 30 seconds) installed in the helicopter. Radar contacts were made once the helicopter had climbed above 1,300 ft amsl but the first recorded point (0947:05 hrs) was on the GPS at 844 ft amsl (about 300 ft agl) with it just to the north-west of the takeoff field. The last GPS recorded point was at 0949:35 hrs with the helicopter at 2,250 ft amsl (196 ft agl) over the landing zone (ie summit of Shanlieve) with a groundspeed of 35 kt. Radar was available until 0949:51 hrs (ie 17 more seconds but only four returns). These additional returns show the helicopter manoeuvring in the vicinity of the landing zone.

Analysis

The helicopter was being operated within the applicable aircraft limits. It was engaged on a task permitted by the operating company's AOC and within the capabilities of the pilot, who had completed all applicable training to the required standard.

The engines, transmission and flying controls appear to have been operating correctly at the time of the accident. The impact took place at a low descent rate with some horizontal motion present. Continuous rotation of the rotor after initial ground contact and overturning caused the helicopter to be driven along the ground for a considerable distance during which the cabin enclosure was destroyed. The severest damage was inflicted to the forward left side of the cabin. The occupant volume at that location was judged to be almost certainly un-survivable; fortuitously, the seat was unoccupied. The final resting attitude of the helicopter protected the occupants seated in other positions from major injury.

The pilot confirmed that he had begun his final approach to the landing site, so his comment about being into wind, which was heard and reported by one of the passengers, was presumably his assessment of the situation. However, physical evidence from the accident site and the accounts of the observer, passengers and witnesses indicate that the helicopter was substantially downwind when it got into difficulty.

As the pilot would have been flying with reference to ground features, it is likely that the helicopter encountered a loss of lift as it turned right to a downwind position, with airspeed having to reduce to maintain groundspeed. This may at first have been masked, as the need to commence a steeper descent than expected (as the helicopter was downwind) would have required a large reduction in power – which was probably the reason the high rotor RPM warning horn sounded. In this condition, the helicopter would not have been susceptible to VRS, but it is possible that the application of power to arrest the rate of descent precipitated VRS, the onset of which may have been sudden because of the rapidly changing situation.

The pilot's recovery actions were correct but, because the helicopter was actually travelling largely downwind, a considerable increase in forward speed would have been required, together with more height than was available, to fly out of the situation. In the meantime the helicopter would remain in 'dead' air, yet with an increasing groundspeed.

It could not be established with certainty why the pilot believed he was starting the approach into wind. Previous approaches had been made from a different direction, and the pilot had intended to refine his approach and landing direction anyway due to a perceived change in wind direction. Visual references on the hilltop would have been limited, with the only prominent feature being the stone wall, which itself changed direction in the vicinity of the landing site. With poor weather in the area and a further deterioration imminent (it occurred just after the accident) visual references were probably further reduced. The weather may also have introduced an element of time pressure to complete the last planned flight of the morning. A change of plan, reduced visual references and deteriorating weather may all have contributed to the accident.

The task to be carried out on the day of the accident, although demanding, was within the capabilities of the pilot. However, although the effects on an individual of a recent family bereavement cannot be measured, it is considered that this was probably the most significant contributory factor in the cause of the accident.

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ACCIDENT

Aircraft Type and Registration:	Cessna 152, G-BOKY	
No & Type of Engines:	1 Lycoming O-235-L2C piston engine	
Year of Manufacture:	1978	
Date & Time (UTC):	1 March 2011 at 1244 hrs	
Location:	Old Sarum Airfield, Salisbury, Wiltshire	
Type of Flight:	Training	
Persons on Board:	Crew - 2	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Nose landing gear collapsed, propeller bent, engine cowling damaged	
Commander's Licence:	Commercial Pilot's Licence	
Commander's Age:	62 years	
Commander's Flying Experience:	405 hours (of which 98 were on type) Last 90 days - 6 hours Last 28 days - 4 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

Synopsis

While landing, the aircraft bounced and, on the second touchdown, the nose landing gear collapsed. The aircraft stopped on the runway and the instructor and student pilot vacated it uninjured. Damage was limited to the nose landing gear, the propeller and the engine cowling.

History of the flight

The flight was planned as a navigation exercise, from Bournemouth Airport to Old Sarum Airfield, Wiltshire, with circuit consolidation training to be carried out at Old Sarum. The student pilot had more than 80 hours of previous experience, including solo time.

The weather conditions at Old Sarum at the time of the accident were: surface wind from 040° /10 kt, visibility 10 km, scattered cloud 1,800 ft, broken could 3,100 ft. The flight to Old Sarum was uneventful and, on arrival, permission was obtained from the tower to join the circuit for touch-and-go landings on grass Runway 06.

Two circuits and landings were carried out satisfactorily. On the third circuit the instructor told the student to go around because the aircraft was too high on final approach. The instructor considered that the fourth circuit was acceptable but the aircraft bounced on landing. The student continued with the attempt to land and on the second touchdown the nose landing gear collapsed.

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The aircraft ran along the runway on its nose and main landing gear for a short distance before coming to rest at the left hand edge of the runway. Both occupants were uninjured and were able to vacate the aircraft unassisted. The magnetos, master switch and fuel were selected OFF before they left the aircraft.

The instructor commented afterwards that he had not appreciated the severity of the bounce and that he should have been more prepared to intervene. He noted that he may have been influenced by the fact that the student had already undertaken 75 hours of training and that he had flown with her the previous day.

ACCIDENT

Aircraft Type and Registration:	Fournier RF6B-100, G-BKIF	
No & Type of Engines:	1 Continental Motors Corp O-200-A piston engine	
Year of Manufacture:	1976	
Date & Time (UTC):	28 February 2011 at 1453 hrs	
Location:	Gloucestershire Airport	
Type of Flight:	Training	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Nose landing gear, propeller, left wingtip and rudder pedals	
Commander's Licence:	Student	
Commander's Age:	38 years	
Commander's Flying Experience:	21 hours (of which 18 were on type) Last 90 days - 6 hours Last 28 days - 2 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

The student pilot had completed several circuits with an instructor before stopping for a break, after which it was agreed that the pilot would fly some solo circuits. On the first of these it started to rain during the downwind leg which turned into hail by finals. The approach to land was uneventful but the pilot started the flare slightly too high. As the aircraft slowed, the pilot continued to raise the nose and the aircraft descended onto the runway during which the nose landing gear collapsed. As it collapsed the nosewheel separated from the nose leg. The propeller suffered damage as it struck the ground and the rudder pedals were bent out of position. The left wing also suffered minor scuffing.

The pilot's assessment of the accident was the flare was started too early and, as the aircraft continued to pitch up, it stalled onto the runway.

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ACCIDENT

Aircraft Type and Registration:	Gippsland GA8 Airvan, G-CDYA
No & Type of Engines:	1 Lycoming IO-540-K1A5 piston engine
Year of Manufacture:	2006
Date & Time (UTC):	28 November 2010 at 1015 hrs
Location:	Near Redland Airfield, Swindon, Wiltshire
Type of Flight:	Aerial work
Persons on Board:	Crew - 1 Passengers - 8
Injuries:	Crew - 1 (Serious) Passengers - None
Nature of Damage:	Landing gear and left wing damaged
Commander's Licence:	UK Private Pilot's Licence
Commander's Age:	61 years
Commander's Flying Experience:	2,686 hours (of which 1,057 were on type) Last 90 days - 75 hours Last 28 days - 13 hours
Information Source:	AAIB Field Investigation

Synopsis

Shortly after takeoff the aircraft stalled at a height that was too low to allow a recovery. There was probably frost on the wing, which caused the aircraft to stall at a speed that was higher than expected.

History of the flight

The pilot arrived at the aircraft at approximately 0900 hrs to prepare it for a flight to drop parachutists. The aircraft had been outside overnight and there had been a heavy frost. The pilot removed a cover from the windscreen and began his pre-flight check during which he noticed no ice or frost on the upper surface of the wings. He returned to the operations building to complete his pre-flight planning and went back to the aircraft in time to start the engine at 1000 hrs. There was a very light wind from the north-west across the grass Runway 06L, the temperature was -4°C and the QNH was 1004 mb. While the engine was warming up, eight parachutists boarded the aircraft and sat down in the cabin. There were three parachute instructors, who were connected to three students, and two other parachutists with video cameras, one of whom was the jump supervisor.

After the pilot judged that the engine had warmed up, he carried out a power check and the before takeoff checks, during which he selected the flaps to TAKEOFF. All indications appeared normal to the pilot and he taxied onto the runway and selected takeoff power, which was 29 inches of Manifold Air Pressure (MAP)

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and 2,500 rpm. The acceleration seemed, to the pilot, to be normal but, although V_R was 60 kt, he delayed the rotation until 65 kt. At about the time the aircraft rotated, the pilot selected the flaps to FULL.

As the aircraft crossed the hedge at the upwind end of the runway, the pilot began a left turn, which was the usual noise abatement manoeuvre to avoid flying over buildings situated on the runway's extended centreline. During the turn, he realised the aircraft was descending and checked the engine instruments, observing that the MAP, fuel pressure and rpm were indicating correctly. He called "BRACE, BRACE, BRACE" and the aircraft hit the ground immediately afterwards in a left wing low attitude. After crossing a ditch, during which the landing gear detached, the aircraft skidded to a halt in the next field. The pilot was able to exit the aircraft through the door on his left but found that he could not stand up because of an injury to his leg. The sliding door on the rear left side of the cabin was jammed and the parachutists were unable to use it to leave the aircraft and so they exited through the same door as the pilot. One parachutist received a whiplash injury but the rest were unhurt. The pilot was subsequently airlifted to hospital.

Witness evidence

Five of the parachutists had flown in G-CDYA many times from the same runway and they commented that the takeoff seemed to take longer than normal. Shortly after the aircraft entered the turn, it started to lose altitude and one parachutist recalled it "shaking a bit" as it started to descend. When the aircraft came to rest following the impact sequence, the jump supervisor tried to open the sliding door but was unable to do so. The occupants decided to follow the pilot and they climbed over his seat and left the aircraft by the front left door.

A witness on the ground thought that the aircraft seemed to stop climbing when it started its turn and did not climb above about 100 ft agl. He also thought that it started to lose altitude about half way into the turn.

Accident site details

The aircraft had contacted the ground on a track of around 340ºM immediately in front of a 1.5 m high hedge, which formed the boundary between two fields. On the far side of the hedge, and running parallel to it, were a ditch and an agricultural concrete track. Marks on the ground indicated that there had been heavy contacts from the outboard left wing and the left landing gear. The nose and right landing gears had also left marks on the ground as the aircraft passed through the hedge, with all the landing gears having been torn off as a result of striking the ditch; the nose wheel was found embedded on the far side of the ditch. The aircraft then slid along on its belly on the stubble surface of the field, slewing to the left before coming to rest on a heading of 240ºM, approximately 25 m beyond the hedge.

The aircraft geometry in relation to the observed ground marks indicated that the aircraft had struck the ground with a bank angle in excess of 25º to the left and approximately level in pitch.

On-site examination of the aircraft

The initial AAIB examination commenced approximately four hours after the accident. The air temperature had remained below freezing all day and it was noted that there was a layer of frost, similar to that which typically accumulates overnight on a car windscreen, on the wing upper surface. The layer, which was difficult to discern against the white paint on the wing, was approximately 1 mm thick and had a texture similar to medium grade sandpaper. There was no evidence of frost on the windscreen; in consequence

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it was concluded that the frost on the wing had likely been present all day, rather than having formed after the accident.

The flap lever, which was located on the floor to the right of the pilot's seat, was found to be in the middle of its three detented positions, ie at the TAKEOFF setting. This corresponded to the observed position of the flap on the right wing, although the position of the left flap had been affected by the relatively severe damage arising from the impact with the ground. As a consequence, the inboard trailing edge of the wing, including the flap, had been deflected downwards so that it impinged on the front edge of the sliding door in the cabin, preventing it from being opened.

Some scuff marks were observed on the concrete track; these were attributed to the stub of the nose leg and the propeller blades. The latter would have struck the ground following the removal of the landing gear, and it is probable that the blade pitch change mechanism was broken at this stage. The blades had then twisted, allowing their flat surfaces to contact the frozen ground, resulting in both blade tips curling over. It was considered that the observed damage was indicative of a considerable amount of power being developed by the engine at impact.

The aircraft had a simple fuel system, whereby the engine was supplied simultaneously from the wing tanks via a collector tank located in the forward lower fuselage. A small sample was taken from the fuel drain on each tank; the appearance was consistent with Avgas, with no evidence of water droplets, cloudiness or debris. There was no evidence of a fuel spillage resulting from the accident. The fuel selector was a simple ON-OFF 'T' handle on the instrument panel, which was found in its forward, ON, position. It was considered prudent to move the selector to the OFF position prior to leaving the accident site for the evening. However, on the following morning it was apparent that fuel had been leaking from beneath the nose, in the area of the collector tank. Approximately 20 litres of fuel were drained from the left tank, with only a small amount being found in the right tank. This was attributed to the attitude in which the aircraft had come to rest; the right wing was at a slight wingtip-high angle, with the left wing being almost level. As a consequence, most of the fuel in the right tank had drained inboard and was lost via the leak around the collector tank, with the possibility of a lower volume being lost from the left tank. The refuelling records suggested there should have been approximately 70 litres of fuel on board at the time of the accident, out of a total capacity of 350 litres. Thus, although it was not possible to assess the quantity of fuel that had leaked into the ground, the amount that was recovered was in excess of that required to sustain the engine.

Following the on-site examination, the wings were removed from the fuselage and the wreckage was recovered to the AAIB facility at Farnborough, where it was subjected to a more detailed examination.

Detailed examination of the wreckage

Airframe

The fuel tank drain valves were located on the underside of the forward fuselage immediately aft of the collector tank, which was also equipped with a drain valve. All had some degree of damage where they had been in contact with the ground. The fuel ON-OFF selector valve was downstream of the drain valves. It was considered that fuel was lost, principally from the right tank, through the drain valves, which were probably partially opened by being pressed against the ground as a result of activity at the aircraft following the accident.

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As noted earlier, the sliding door could not be opened after the accident due to the left wing trailing edge being in contact with the front edge of the door. However, even with the wing removed the door could be slid along its rails only with difficulty. This was subsequently found to be due to distortion in the lower fuselage frames, causing misalignment of the upper and lower rails.

In the absence of the front right hand seat, the instrument panel and control columns were protected from potential interference from passengers by an upright panel, in the approximate shape of a seat back, which was attached to a frame and mounted on the floor in place of the co-pilot's seat. This item, which had been designed and built by the aircraft manufacturer, served to partially obstruct access to the right forward door from the passenger cabin, although the obstruction was less than that with the seat left in place. The panel had been deflected forwards as a result of one of the parachutists leaning against it during the accident although this had had the effect of improving access to the door.

Stall warning system

The stall warning device fitted to G-CDYA consisted of a small vane fitted below and slightly aft of the leading edge of the main wing. An electrical continuity check of the system revealed no faults, and the associated warning horn was found to be operational.

Engine

The engine had been installed in the aircraft from new and had achieved 1,535 operating hours and more than 3,400 flights at the time of the accident. The most recent maintenance was a scheduled 50 hour inspection, which was conducted on 20 September 2010 when the aircraft had logged 1,485 operating hours.

The engine had suffered little visible damage apart from some scuffing of the oil cooler on the underside. However, after removing the cowlings it was apparent that the upper fitting of the nose landing gear had been deflected during the impact with the result that it had penetrated the oil filter mounted on the rear of the engine, causing a small oil spillage.

The engine was taken to an overhaul agent, where, after conducting a detailed inspection and fitting a new oil filter, it was mounted in a test cell that was equipped with an eddy current dynamometer. A pre-oiling operation conducted at this time revealed that the oil pressure was satisfactory. Some difficulty was experienced in starting the engine; this was attributed to the test cell installation not utilising the engine's priming system. The engine ran normally after starting and, after warming, was run to full power. This was found to be around 250 bhp at 2,700 rpm, which was somewhat short of the 300 bhp specified for a new engine. The overhaul agent commented that the value observed was, in their experience, typical for an engine of this type that was three quarters through its 2,000 hour overhaul life.

After testing the engine, the fuel injection servo unit was removed and subjected to a separate bench check. Fuel metering in this type of unit is a function of air mass flow, its associated suction and throttle position. Fuel flows were measured at a number of test points specified in the manufacturer's test schedule; all were found to comply with the specified values apart from a minor deviation in a 'mid range' setting. According to the overhaul agent, this was observed regularly on this type of unit and would have had no effect on engine operation.

Recorded evidence

There were two video recordings of the flight taken from within the cabin and information was available from the GPS unit fitted to the aircraft, which provided data at 10 second intervals. Using this evidence, it was possible to establish to a reasonable degree of accuracy the sequence of events leading up to the accident. The results are shown in Table 1, where the times shown are relative to the time the aircraft passed a recognisable dip in the runway during takeoff.

Interview with the pilot

The pilot stated that the rpm lever could be moved forward through a gate, which would increase the propeller speed from 2,500 to 2,700 rpm and increase engine power from 275 to 300 bhp. He did not recall selecting 2,700 rpm when he realised the aircraft was descending and he did not recall hearing the stall warning horn.

The pilot also stated that he sometimes selected flaps to FULL after passing the dip in the runway, selecting them back to TAKEOFF shortly after lift-off. He would then accelerate to the takeoff safety speed before selecting the flaps to UP. He did not recall when, on this occasion, he selected flaps back to TAKEOFF following lift-off.

Aircraft performance

The aircraft's takeoff performance was calculated using the manufacturer's performance tables, which assume the use of full throttle and 2,500 rpm. The calculation was made using no headwind, an airfield pressure altitude of 580 ft, no runway slope and a takeoff mass of 1,738 kg. V_R was 59 kt and the takeoff safety speed was 70 kt. The distance calculated to lift off was 340 m, and the distance to a height of 50 ft was 520 m, using performance figures for a takeoff on short dry grass. There were no performance figures available

Time (seconds)	Video evidence	GPS evidence
- 2		Groundspeed 47 kt Track 060° T
0	Aircraft crossed a dip in the runway.	
6	Last point where the flaps were seen to be at TAKEOFF.	
8	Lift off. Flaps at FULL.	Groundspeed 63 kt Track 060° T
13	Aircraft at upwind hedge boundary. Left turn started. Flaps at FULL.	
18		Groundspeed 58 kt Track 027° T
24	Impact. Flaps subsequently found at TAKEOFF.	

Table 1

Sequence of events

for takeoff on a grass surface following a heavy frost, but the takeoff distances were adjusted using factors recommended by the CAA to generate estimated values for takeoff on short wet grass. The values obtained were 368 m and 563 m respectively. Using video evidence, it was established that the aircraft actually left the ground after approximately 560 m. The runway is 640 m long.

Stall warning

The Civil Aviation Authority's *Safety Sense Leaflet 3: Winter Flying* discusses some of the problems that pilots might encounter when flying in winter. It states:

> *'Tests have shown that frost, ice or snow with the thickness and surface roughness of medium or course sandpaper reduces lift by as much as 30% and increases drag by 40%. Even a small area can significantly affect the airflow, particularly on a laminar flow wing.'*

The GA8 Aircraft Flight Manual states that the stall is preceded by slight aerodynamic buffet. In addition, the GA8 is equipped with a stall warning system. If the angle of attack increases towards a set value – which corresponds to a speed of five to seven knots above the stalling speed for a given configuration with an uncontaminated wing – it causes the stall warning vane to move, resulting in a warning horn sounding in the cockpit. The horn, therefore, is triggered by angle of attack and is not a direct indication of an aerodynamic stall. If a wing's lifting performance is reduced by frost, the wing will stall at a lower angle of attack and a higher speed than usual and the angle of attack might not be high enough to trigger the warning horn.

The aircraft's takeoff mass was 76 kg below the maximum takeoff mass of 1,814 kg. The stalling speed of a GA8 at idle power and maximum mass is 57 kt with flap at FULL (38°) and 60 kt with flap at TAKEOFF (14°). The stalling speed would be expected to be slightly lower at takeoff power due to slipstream effects from the propeller. If the lift of the wing was reduced by 30%, which was a possibility according to *Safety Sense Leaflet 3*, the 60 kt level flight stalling speed with takeoff flap selected would increase to 72 kt[1].

Information from Table 1 suggested that the aircraft heading changed by 33° in the five seconds after the turn began at the upwind hedge of the airfield, corresponding to approximately 20° angle of bank at 60 kt IAS. If it is assumed that the track at impact was approximately 338°T[2], the heading changed by approximately 49° in the six seconds before impact, corresponding to approximately 24° angle of bank. A level flight stalling speed of 60 kt would increase to approximately 63 kt with a bank angle of 24°[3]. A level flight, contaminated wing, stalling speed of 72 kt might increase to approximately 75 kt.

Survivability

G-CDYA had been modified to carry parachutists and all seats had been removed apart from the pilot's seat on the left side of the cabin. Five parachutists sat on the right side of the aircraft and three on the left. Six of the occupants faced rearwards but the parachutist at the rear on each side faced forward and carried a video camera. The occupants sat on rectangular cushions on the floor and secured themselves in the cabin using straps attached to hard points on the cabin floor, which they passed through their own parachute harnesses.

Footnote

[1] See Appedix.

[2] 340° M adjusted for variation, which was 2° W.

[3] The stalling speed increases with the load factor in the turn. The load factor is given by the secant of the bank angle.

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The GA8 has two forward opening cockpit doors, one on each side of the aircraft, which act as emergency exits. There is a sliding door on the left side of the main cabin, which may be opened in flight but the GA8 flight manual does not specify this door as an emergency exit. The accident was, self-evidently, survivable, and during the impact sequence the aircraft remained upright with the occupants remaining close to where they were seated at impact. During the evacuation, after finding that the sliding cabin door was jammed, all the occupants left the aircraft by the exit to the left of the pilot's seat; none of the occupants considered leaving the aircraft by the exit to the right of the co-pilot's seat.

British Parachutists Association

Pilot qualifications

The British Parachutists Association (BPA) Operations Manual states that, in order to act as pilot in command (PIC) of an aircraft for a flight during which parachutists are to be dropped, a pilot must hold a valid pilot's licence for the type or class of aircraft to be flown and must have at least 100 hrs PIC. Pilots also undergo ground training, at least four lifts supervised by a BPA Pilot Examiner or Club Chief Pilot, and a written examination and flight test. Pilots must complete a proficiency check at least every twelve months. The pilot in this accident was in compliance with the requirements.

Risks other than the parachute jump itself

The BPA website contains a section on managing the risks associated with parachuting. It discusses the risk associated with the airfield environment and the flight leading to a jump and states:

> *'These risks are.....numerically less significant than those of the jump itself. Major international airlines maintain their aircraft and conduct their flights in accordance with 'Public Transport' Requirements. However, many parachute clubs may maintain their aircraft and conduct their flights in accordance with the less demanding requirements of the 'Private Category' Schedules.'*

Air Navigation Order

Schedule 7 to Section 1 of the Air Navigation Order (ANO) details the privileges given to pilots holding a Private Pilot's Licence (PPL). Holders of a UK PPL may not fly for the purpose of aerial work except:

> *'for the purpose of aerial work which consists of.... a flight for the purpose of dropping persons by parachute.'*

Analysis

The aircraft was parked outside overnight prior to the accident and the windscreen, which had been covered, was clear of ice and frost when the cover was removed. Four hours after the accident, the windscreen was still clear, which suggested that ice and frost were not actively forming during that period. However, since frost was found on the upper surface of the wing, it was concluded that the frost would have been present prior to and during the takeoff.

The maximum engine power was found to be approximately 50 bhp less than the rated value. This was attributed to the state of wear expected of an engine approximately 75% through its normal overhaul life rather than as a result of a failure experienced on this particular takeoff.

The distance to lift off, calculated using the manufacturer's performance information, should have been between 340 m and approximately 368 m and yet the aircraft actually left the ground after approximately 560 m. The extra distance used by the aircraft was probably a combination of two factors: the engine was not producing the power assumed in the performance calculation and the aircraft was rotated approximately three to five knots above V_R. It is possible that takeoff performance was reduced due to the effects of frost on the wings but it was not possible to quantify these effects.

As the aircraft began its left turn, the flaps were at FULL and yet the flap selector handle and the flaps were found in the TAKEOFF position following the accident. At some point in the turn, therefore, the flaps were raised by one stage. This would have had the effect of increasing the stalling speed by approximately three knots (in the case of an uncontaminated wing).

The groundspeed of the aircraft, recorded by the GPS approximately six seconds before impact, was 58 kt. The aircraft was turning into a light wind and so the IAS might have been slightly higher. The stalling speed of the aircraft during the turn, with the flaps in the TAKEOFF position and with an uncontaminated wing, would have been approximately 63 kt. The effect of the frost would have been to increase the stalling speed, in the worst case, to 75 kt. The CAA *Safety Sense Leaflet 3* suggests that the maximum reduction of lift might occur with frost that has a surface roughness of course sandpaper, whereas the frost found on G-CDYA was similar to medium sandpaper. Nevertheless, it was clear that the lifting ability of the wing would have been compromised and the stalling speed would have been higher than 63 kt. It seemed probable, therefore, that the aircraft stalled in the turn as a result of frost on the wing. Furthermore, the angle of attack at the stall was probably lower than that required to activate the stall warning horn.

Appendix

Estimation of the stalling speed of the frost-covered wing

The lift of a wing, L, is given by:

$$L = \frac{1}{2}\rho V^2 S C_L$$

Where:

ρ = the density of the air (which is assumed to be constant for the purpose of this comparison).

V = the velocity of the aircraft (knots will be used as the units because, as a ratio of speeds is to be found, the units merely need to be consistent).

S = the representative area of the wing (which is constant).

C_L = the lift coefficient of the wing immediately before the stall (which is assumed in this comparison to reduce by 30% if the wing is covered in frost).

Cont ...

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For a given aircraft, let L represents the lift of its uncontaminated wing in level flight, and L' represent the lift of its frost-covered wing in level flight. As the wings in each case are supporting the aircraft in level flight, $L = L'$. If the lifting ability of the wing, C_L, is reduced by 30% on a frost-covered wing, as suggested in *Safety Sense Leaflet 3*, then the aircraft will have to fly faster to generate the same amount of lift. In order to calculate by how much the speed will have to increase, assume:

$C_L' = 0.7\ C_L$

V = the level flight stalling speed of the aircraft with an uncontaminated wing = 60 kt

V' = the level flight stalling speed of the aircraft with a frost-covered wing

$\frac{1}{2}\rho S$ = a constant, k

Then:

$$\frac{L}{L'} = \frac{kV^2 C_L}{kV'^2 C_L'} = 1 \quad \text{and} \quad \frac{V^2 C_L}{0.7V'^2 C_L} = 1 \quad \text{and} \quad V^2 = 0.7V'^2$$

If V = 60 kt, then V' = 71.7 kt

ACCIDENT

Aircraft Type and Registration:	1) Mooney M20J, G-JAST 2) Vans RV-4, G-MARX
No & Type of Engines:	1) 1 Lycoming IO-360-A3B6D piston engine 2) 1 Lycoming O-320-E3D piston engine
Year of Manufacture:	1) 1980 2) 1996
Date & Time (UTC):	4 September 2010 at 1600 hrs
Location:	Near Ryde, Isle of Wight
Type of Flight:	1) Private 2) Private
Persons on Board:	1) Crew - 1 Passengers - 1 2) Crew - 1 Passengers - 1
Injuries:	1) Crew - 1 (Fatal) Passengers - 1 (Fatal) 2) Crew - 1 (Minor) Passengers - 1 (Minor)
Nature of Damage:	1) Destroyed 2) Extensive damage to landing gear and right wing
Commander's Licence:	1) ATPL(A) 2) CPL(A)
Commander's Age:	1) 73 years 2) 32 years
Commander's Flying Experience:	1) 17,500 hours (of which 100 were on type) Last 90 days - 28 hours Last 28 days - 8 hours 2) 2,000 hours (of which 126 were on type) Last 90 days - 57 hours Last 28 days - 25 hours
Information Source:	AAIB Field Investigation

Synopsis

The two aircraft, a Mooney M20J and a Vans RV-4, were participating in the Merlin Trophy Air Race, which started and finished at Bembridge Airport, on the Isle of Wight. The aircraft were closely matched on speed and after the last turn of the race the Mooney began to overtake the RV-4, shortly after which the two aircraft collided. The Mooney broke up in flight and fell to the ground. The pilot and his passenger were fatally injured. The RV-4 was badly damaged but the pilot managed to land at Bembridge Airport, both occupents having received minor injuries. The investigation determined that the pilot of the Mooney had probably been unable

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to see the RV-4 for approximately the final 39 seconds before the collision.

History of the flight

The Merlin Trophy Air Race, with 20 participants, commenced at 1500 hrs when, in accordance with handicap racing procedures, the slowest aircraft started the race. At 1529:52 hrs the RV-4, G-MARX, was given its signal to start the race, as the sixteenth aircraft and at 1530:07 hrs the Mooney, G-JAST, was given the signal to start, as the seventeenth aircraft in the sequence. The crew of the Mooney were seen to be in good spirits as the race began. The final and fastest aircraft started the race at 1533:26 hrs.

The race progressed normally and the separation between the racing aircraft gradually reduced. On the final turn of the final lap of the race the RV-4 was overtaken by the aircraft that had started the race last. Shortly after this the crew of the RV-4 were aware that the Mooney was overtaking them from slightly behind and below on their right side. The Mooney was then seen, still below them but close in on their left side. The Mooney then moved back underneath them, to their right side, before it disappeared from view. The 'navigator'[1] in the RV-4 advised his pilot not to descend because he had lost sight of the Mooney which he believed was underneath them but slightly ahead. The RV-4 crew then felt a sudden and firm thump, after which the pilot of the RV-4 saw the Mooney passing down the right side of his aircraft and realised that there had been a midair collision. It was immediately apparent to the RV-4 pilot that the Mooney was in difficulty, as it was no longer pointing in its direction of travel. The RV-4 was now vibrating severely and the crew could see damage to their right wing.

The pilot of the RV-4 transmitted a MAYDAY call on 'Bembridge Radio', the frequency in use for the race. He considered landing in a nearby field but decided it would be safer to fly the remaining four miles to Bembridge Airport. The pilot, aware that his aircraft was damaged, attempted to call another of the racing pilots to ask for a visual inspection of his aircraft but the radio frequency was blocked by other pilots reporting what was happening to the Mooney.

The RV-4 pilot positioned his aircraft on final approach for the tarmac Runway 12 at Bembridge Airport. When he tried to lower the flaps, they did not go down symmetrically so he raised them immediately and decided that, given the uncertain state of his aircraft, the grass runway might be safer. The aircraft landed gently on the grass and the right main landing gear collapsed. The aircraft came to a halt, pitched forward onto its nose, and then the left main landing gear collapsed as the aircraft fell back onto its belly. The crew vacated the aircraft immediately but there was no fire. The fire crews were not in attendance because both fire tenders had deployed to the area where the Mooney was last seen.

After the collision, the Mooney was seen to descend and gyrate, breaking up into three main pieces and a considerable amount of smaller debris. The main wreckage fell into a wooded area, whilst the other larger items were seen to fall nearby. Paramedics were quickly on the scene of the main wreckage but it was immediately apparent that the occupants had not survived.

Witnesses

The pilot of a Bulldog aircraft competing in the race was at an altitude of 700 ft just after the final turn. He was

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Footnote

[1] Aircraft with passenger seats normally carry a passenger to assist with navigation and to lookout for other race aircraft. This passenger is referred to as 'the navigator' and he is considered a member of the crew by the race officials.

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slightly above and behind the RV-4 which was pulling away from him on his left side. Also on his left side was the Mooney, which had overtaken him at the same altitude. When the Mooney and the RV-4 were about 100 m ahead of him he saw the Mooney pitch nose down to about 15º and descend. This surprised the Bulldog pilot as that was not a normal manoeuvre to perform in the race and he could see no birds or other reason for the Mooney to perform such an abrupt manoeuvre. Also, the Mooney was still some distance from the point at which aircraft were allowed to descend and when they do descend they normally do so gradually. He then saw the Mooney pitch up, to what he estimated was around 15º, and climb through his level into the RV-4. There was a cloud of dust and it was obvious to the Bulldog pilot that the two aircraft had collided. The Mooney was then seen to pitch, roll and yaw, and its tail detached. The Bulldog pilot had to take action to avoid the resulting debris.

The Mooney broke up into three major components; the tailplane, the port wing and the main body of the aircraft. The Bulldog pilot flew orbits around the scene of the accident and, using his radio via ATC at Bembridge, tried to direct the emergency services to the accident site. When the emergency services arrived at the site, he returned to Bembridge Airport. The Bulldog pilot could not recall hearing any radio transmissions between the Mooney and the RV-4 in the minute prior to the accident.

Recorded data

The radio frequency in use for the race, 'Bembridge Radio', was not officially recorded. However, a video recording captured radio transmissions made during the last few minutes of the race.

Six portable GPS units were recovered from the Mooney and three more were recovered from the RV-4, together with a further GPS data source from the RV-4 pilot's Personal Digital Assistant (PDA). Two good quality data sources from both aircraft were used in the analysis of the accident. In each case, one source recorded pressure altitude and the other recorded GPS altitude, both in conjunction with GPS position and with frequent sampling.

The use of different altitude sources was important, as the recorded pressure altitudes were good indicators of vertical movement. However, the barometric sensors in the GPS units were not calibrated, so they were poor indicators of absolute altitude. In contrast, the GPS altitudes provided less robust motion information but good average absolute altitude values. Combining the data from the two sources provided a means of analysing the relative altitudes of the aircraft.

Radar data was not used in this case because of the aircrafts' low altitude, the multiple contacts in the race and the good quality of the data recovered from the GPS units.

The GPS tracks from the other racing aircraft, provided by the race organisers, helped to identify the location of the witnesses who were flying in the race at the time of the accident, and also established that no other aircraft was a factor in the accident.

The RV-4 started its takeoff roll at 1529:55 hrs and the Mooney followed 14 seconds later. The aircraft carried out four complete circuits of the race with the Mooney slowly catching up.

After the last turn on to the final straight of the fifth and final lap, the Mooney was below and to the rear and right of the RV-4. Figure 1 shows their relative positions and speeds. The RV-4 flew with a relatively stable speed and track, in a slow descent. Whilst

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remaining below the RV-4, the Mooney tracked from the right side of the RV-4 to the left of its track. As it passed beneath the path of the RV-4, the Mooney started a descent, levelling off 70 ft lower. In doing so, it picked up speed and started to pass the RV-4 whilst below and to its left. The Mooney then started to climb and drifted to the right, losing speed, bringing it back to the right of the RV-4 but still beneath. This, in combination with a shallow descent and associated increase in the speed of the RV-4, resulted in a period of approximately seven seconds where the RV-4 was faster than the Mooney. The Mooney then drifted to the left of the RV-4, once more, while descending at a rate of approximately 900 ft/min, resulting in an increased speed and it pulling ahead of the RV-4. After losing 100 ft, it entered a climb, averaging about 800 ft/min, reduced speed again and climbed to the right closing on the RV-4 until the aircraft collided. The collision occurred at 1606:52 hrs at an altitude of about 675 ft amsl, over Rowlands Wood, approximately 3.7nm to the west of the Runway 12 threshold at Bembridge Airport.

The impact disrupted the still air environment inside the cockpits of both aircraft, making the pressure altitude readings unreliable, which explains the upward trace of the Mooney's altitude after the collision in Figure 1.

Obscuration of the pilot's view

The investigation modelled each pilot's ability to see the other aircraft during the moments before the collision. The RV-4 has a bubble canopy, providing good visibility in most horizontal directions and above the aircraft. However, its low wing configuration limits the pilot's view below the aircraft. The Mooney, as well as having a low wing obscuring part of the view below the aircraft, has a solid opaque roof limiting the ability of the pilot to see above the aircraft. This is exacerbated by the pilot's nominal head position being set well back from the windshield. The pilot sits in the left hand seat, well away from the right hand window, restricting his view above and to the right of the aircraft. Given that the Mooney was the overtaking aircraft, the view from this aircraft was analysed in more detail.

Data was gathered from both accident aircraft to show the relative positions of the aircraft leading up to the collision. Also, a similar Mooney was flown to gather data relating the aircraft's attitude to its motion. The data was used to derive the pitch and roll of the Mooney leading to the collision, based on the recorded motion. The positions of the window edges, relative to the pilot's nominal eye position, were also measured and used to create a model of the window apertures. Combining the relative paths of the aircraft with the model of the Mooney windows and the derived pitch and roll of the Mooney, enabled an assessment to be made of when the RV-4 was visible from the nominal view of the pilot in the Mooney.

The results indicate that the RV-4 would not have been visible from the nominal Mooney pilot's position for 39 seconds before the collision (see Figure 2). Varying the parameters to account for modelling errors changed this result to between 37 and 44 seconds.

The Mooney navigator was sitting in the right seat, which would have afforded a better view of the RV-4. However, the calculations showed that the view from the nominal right seat position of the Mooney would also have become obscured at about the same time as the pilot's view.

The view from just inside the right window would have been more favourable, losing sight of the RV-4 for approximately the last 14 seconds of flight. However,

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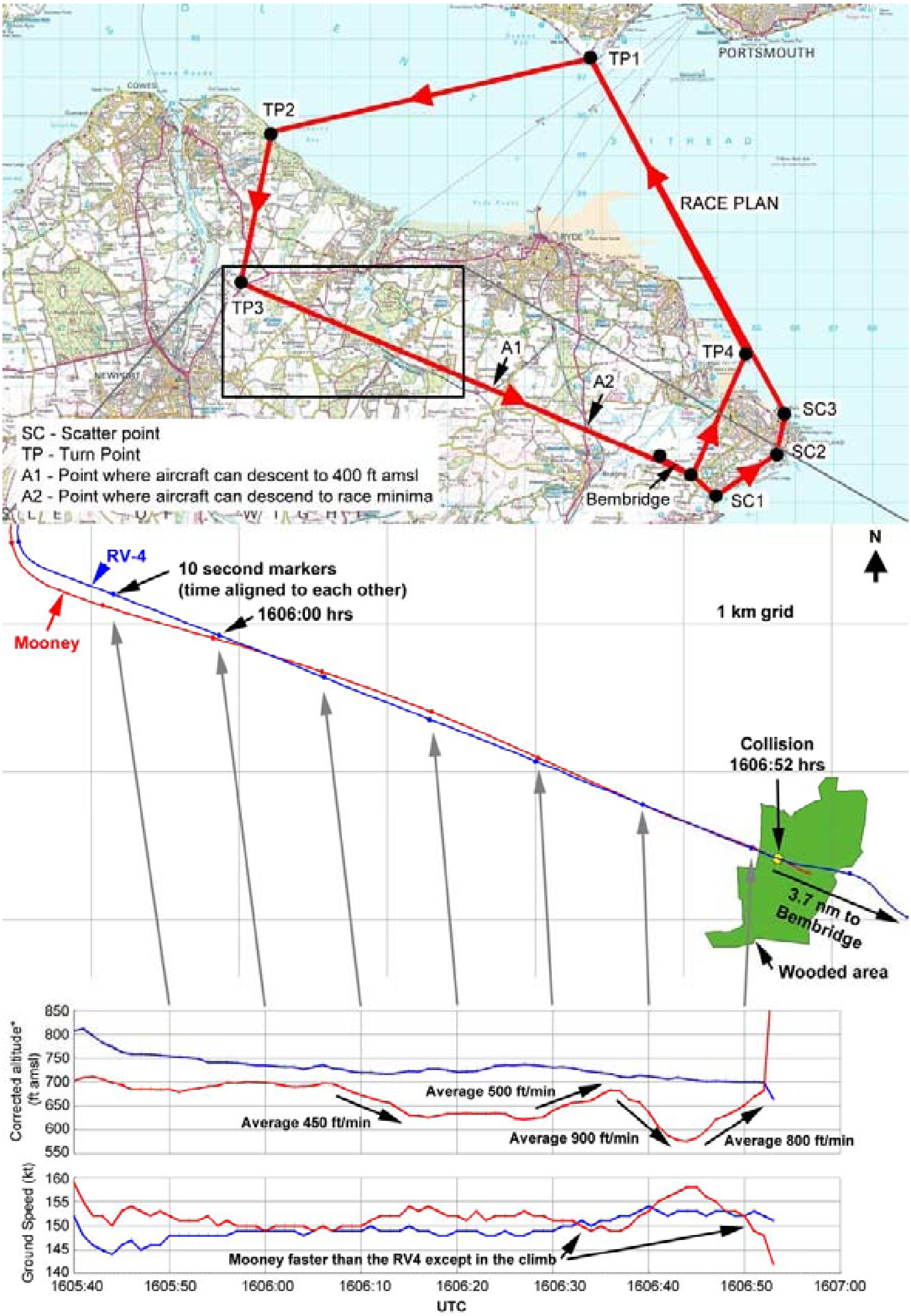

* The altitudes are the recorded pressure altitudes offset to minimise the average deviation from GPS altitude.

Figure 1

Relative motion of the two aircraft leading up to the impact

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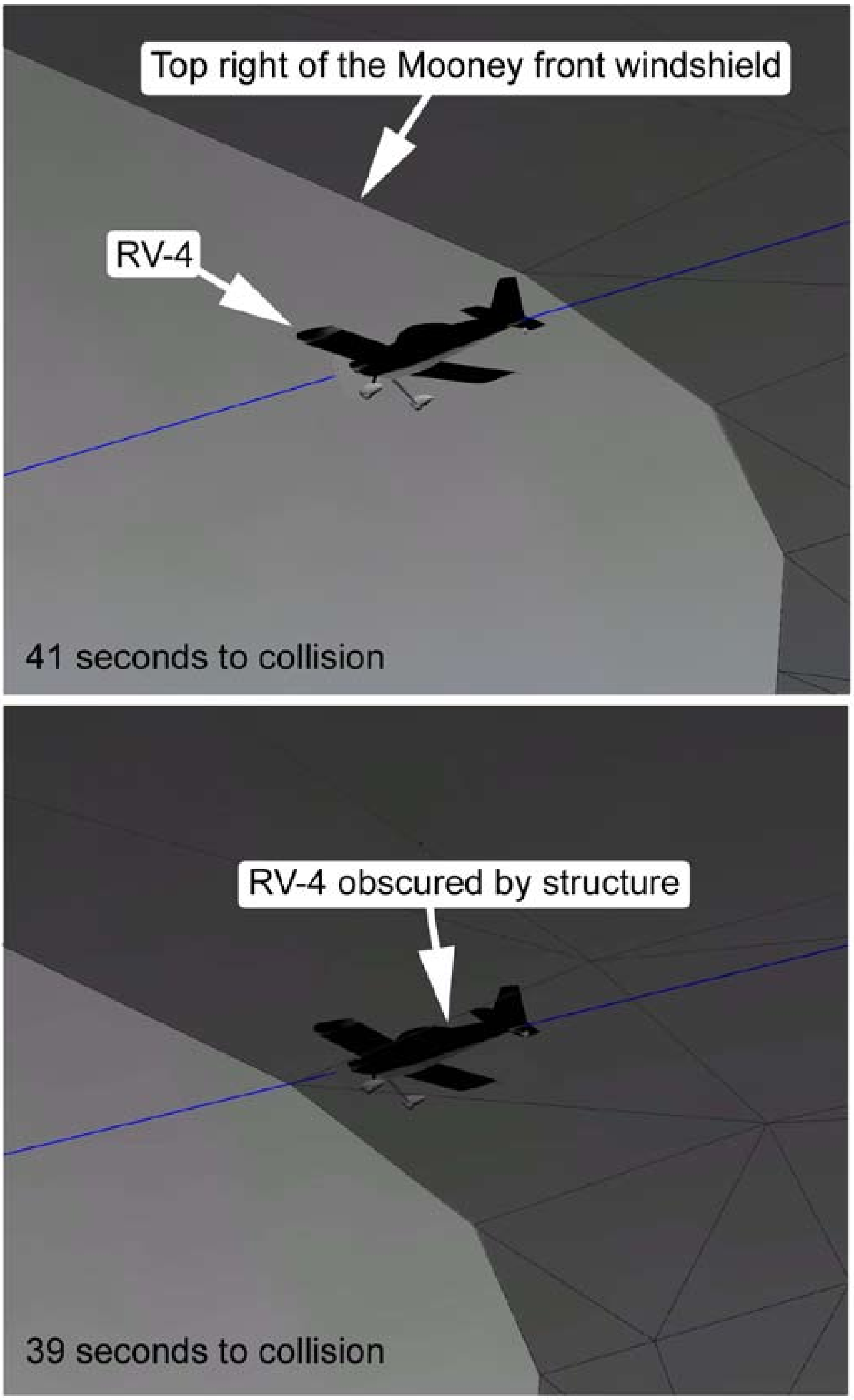

Figure 2

Illustration of the loss of line of sight of the RV-4 from the Mooney pilot's nominal eye position

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the Mooney navigator would have had to move away from his normal sitting position in order to benefit from this view.

At the calculated point where visual contact would have been lost by the Mooney crew, the vertical and lateral separation of the aircraft was increasing and the Mooney was overtaking the RV-4. At this point it should have been possible for the RV-4 pilot to see the Mooney, albeit at an awkward location behind and below the RV-4.

The modelling indicates that shortly after the RV-4 became obscured from the view of the Mooney pilot, the RV-4 wing and then fuselage would have blocked the view of the Mooney from the RV-4 pilot's position. The RV-4's navigator, sitting behind the pilot, would have had a better view of the Mooney until it pulled further ahead.

Test flight in a Mooney M20J

The investigation conducted an exploratory flight in another Mooney M20J to establish the control inputs and aircraft attitudes required to make the aircraft describe the flightpath depicted by the recorded data. The control forces were found to be light and a descent rate of 900 ft/min was achieved using an attitude of approximately 1° nose down. A climb rate of 800 ft/min was achieved using a nose-up pitch of approximately 5°.

Meteorology

On the day of the accident an area of high pressure was centred over southern Norway maintaining a south-easterly flow over southern England. Visibility was generally more than 10 km and early morning haze had cleared by the time of the accident. There was a small amount of cloud at 3,000 ft. The surface wind was from the south-east at between 5 and 10 kt, with the temperature 18ºC. The weather conditions were described by other competitors as "good for air racing."

Aircraft descriptions

Mooney M20J

The Mooney M20J is a four-seat, low-wing monoplane powered by a single piston engine. The aircraft is equipped with a single piece forward windshield and two cabin windows on each side of the aircraft. The presence of the cabin roof structure limits the extent of the pilot's forward view, from the normal seated position, to approximately 19° upwards, in the vertical plane. The aircraft was painted in a white and green colour scheme.

Vans RV-4

The Vans RV-4 is a two-seat, tandem low-wing monoplane powered by a single piston engine. The aircraft has a tailwheel undercarriage configuration. A single piece bubble canopy is provided for the occupants, offering good visibility above the aircraft, although the engine cowling and low wing reduce the extent of the pilot's vision both ahead of and below the aircraft. The RV-4 was painted in a red and white colour scheme. The leading edges of both wings were painted red, with the exception of the fibreglass wingtip fairings. The RV-4's propeller was painted grey apart from the propeller tips, which were painted in three 2 inch wide coloured bands, alternating from white at the propeller tip, followed by a red band and an innermost white band.

Wreckage examination

Collision debris from both aircraft was distributed over a distance of approximately 470 m, on a heading of 118°M. This heading was aligned with the aircrafts' track to Bembridge Airport, some 3.7 nm distant. The debris field was also approximately aligned with the prevailing wind conditions which, combined with the relatively low height of the collision, resulted in little off-axis drift of the lighter wreckage (Figure 3). The wreckage trail was composed of the Mooney, broken into three major sections and many smaller pieces, and fragments of the forward section of the RV-4's right mainwheel spat. The majority of the wreckage came to rest in woodland, with a small quantity of lightweight material from the cabin of the Mooney being blown downwind into open fields immediately to the west of the wooded area.

The Mooney wreckage

The Mooney had broken into three major sections:

- The right wing and fuselage, from the spinner rearwards to approximately 1.0 m behind the wing trailing edge and the inboard 0.9 m section of the left wing
- The empennage and rear fuselage section
- The left wing, which had separated at about 0.9 m outboard from the left fuselage side

The right wing and fuselage section had struck the ground in an inverted attitude, coming to rest on a heading of 176°M. It had fallen onto a track in between trees approximately 10 m tall, and the lack of visible damage to these trees indicated a near-vertical flight path immediately prior to ground impact. The cabin roof structure, from the windshield rearwards, was fully collapsed.

An impact depression, matching the size and shape of the RV-4's right wheel spat, was evident at the severed portion of the rear fuselage, 20 cm to the right of the aircraft's centreline. Paint transfer marks, matching those from the RV-4's wheel spats, were observed on the

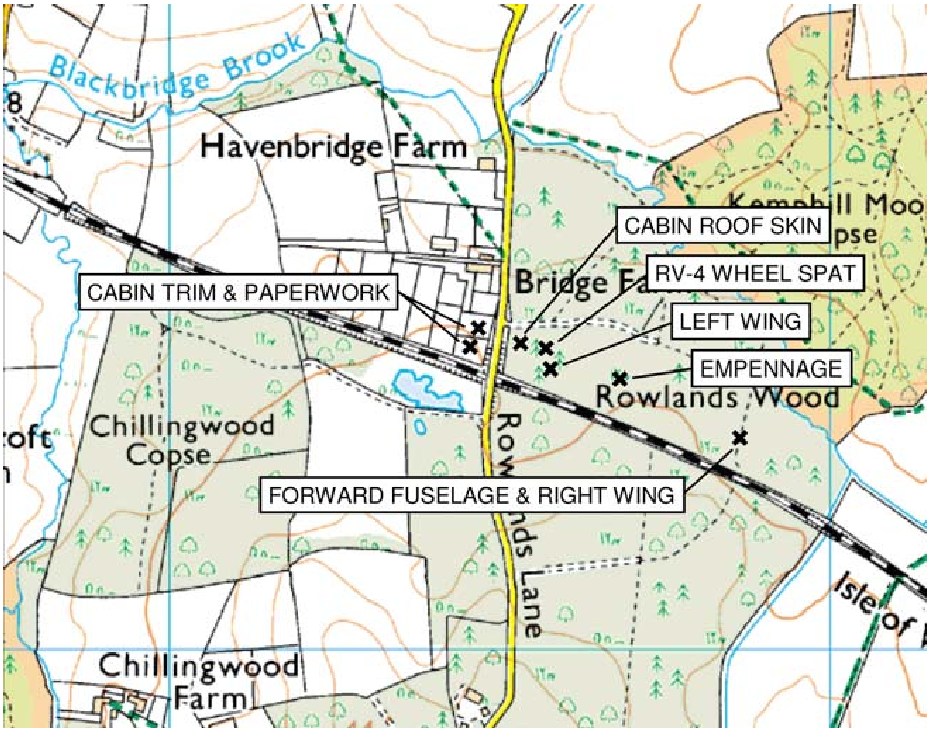

Figure 3

Wreckage plot

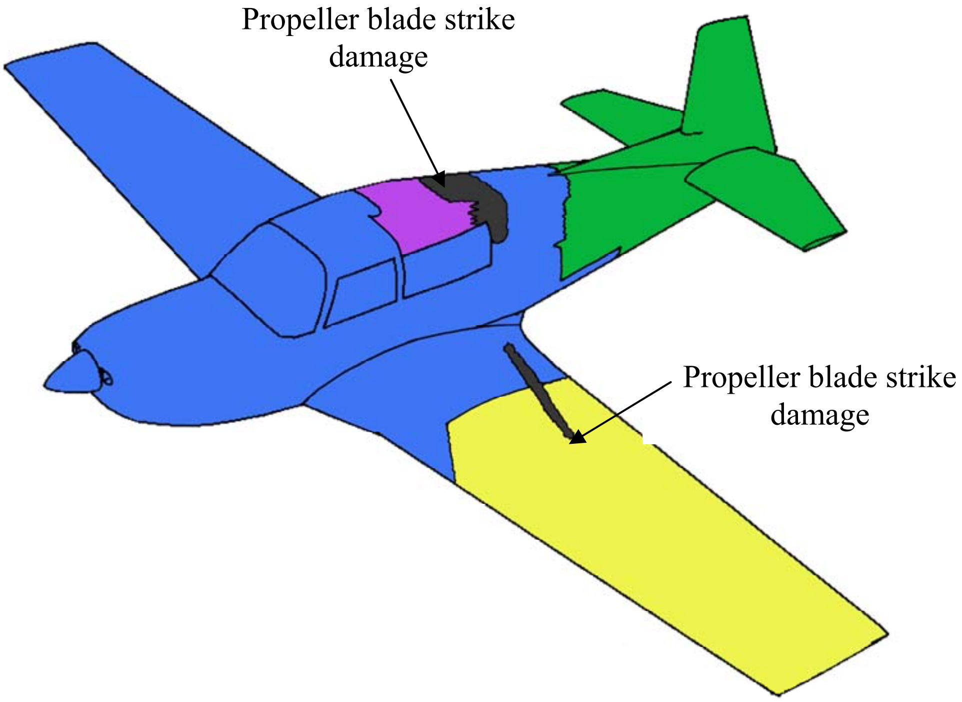

Figure 4

Main sections of Mooney wreckage

sides of this depression and an area of darker marking, made by the RV-4's right mainwheel tyre, was visible in the centre of the depression. Areas of red paint transfer, approximately 0.6 m in length, were visible on the upper left fuselage skin at the severed portion of the rear fuselage. The inboard section of the left wing exhibited damage consistent with downward moving propeller blade strikes in the region of the rear spar, behind the left main wheel well. No fire had occurred and 35 litres of fuel were recovered from the right wing's fuel tank.

The empennage and rear fuselage came to rest in dense woodland, 209 m from the forward fuselage section. Red paint transfer marks were evident on the forward edge of the severed rear fuselage, in a position adjacent to the red paint marks found on the matching forward fuselage section. The left tailplane was deformed upwards and did not show any signs of significant impact damage. The lower 0.5 m of fin leading edge skin was deformed to the left and two fragments of aluminium alloy skin, matching those from the RV-4's right aileron, were embedded in the deformed fin leading edge. The rudder and left elevator control surface mass balance weights had broken away from the empennage and were missing.

The rudder and elevator control pushrods' rod-end bearings had failed in a manner consistent with tensile overload at control connections located at the rear end of the main fuselage section. Three shallow depressions in the right tailplane's upper skin, consistent with propeller blade contacts, were evident close to the leading edge of the right tailplane. These contact marks exhibited red paint transfer and they indicated a propeller rotation direction from the tip to the root of the right tailplane.

The remaining section of the left wing, outboard of approximately 0.9 m from the left fuselage side, came to rest in woodland 331 m from the main fuselage wreckage.

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The wing exhibited overload damage consistent with upward bending due to aerodynamic loads. Damage consistent with upward moving propeller blade strikes was visible over a distance of 0.5 m at the inboard end of the wing, in the vicinity of the rear spar and flap shroud. The rear spar itself had been severed by propeller blade strikes.

A section of cabin roof skin, measuring approximately 0.7 m long by 1.0 m wide, was found in the wreckage trail 393 m from the main fuselage section. It originated from the top of the cabin, above the rear cabin seats. Four propeller slash marks were visible on the left side of this piece of wreckage. Smaller fragments of cabin skin and interior trim from the area behind the roof skin section were found at the downwind end of the wreckage trail, and many of these also exhibited propeller blade strike damage.

The wreckage was recovered to the AAIB's facility at Farnborough for further detailed examination. The control runs were checked for continuity and range of movement, and no evidence of any pre-existing defects was found. The aircraft's maintenance records were reviewed. These showed that the aircraft had undergone an annual maintenance inspection on 16 April 2010 and that the Airworthiness Review Certificate was current at the time of the accident. The aircraft was last weighed on 12 June 2006 and, using these figures, the investigation calculated the aircraft was being operated within its permitted weight and centre of gravity limitations.

Longitudinal trim on the Mooney M20 series is accomplished by pivoting the entire empennage around a pivot located ahead of the tailplane main spar, and is actuated with a manually operated screw jack. Two threads were visible on the end of the screw jack, at its attachment to the trim linkage on the fin main spar. The screw jack mechanism is irreversible and did not show any evidence of damage incurred during the accident. The aircraft manufacturer confirmed that this empennage trim position was consistent with a trimmed speed of between 160 and 175 kt.

The RV-4 wreckage

The aircraft was examined at Bembridge Airport, where it had come to rest on a grassed area immediately to the south of Runway 12, on a heading of 127°M. The aircraft's two-bladed propeller had sustained extensive leading edge impact damage at the blade tips, consistent with contact with a metallic structure. One of the propeller blades had an 8.2 cm long section of its tip missing. The propeller spinner had detached from the spinner backplate and was also missing.

The leading edge of the right wing exhibited impact damage over a length of 0.6 m, with the damage centred at approximately mid wingspan (Figure 5). The right aileron was extensively damaged and the inboard 40 cm of aileron was missing aft of the aileron spar, which itself was bent forwards, consistent with being struck from behind. The right wing's lower skin was heavily scored with marks running in the outboard direction, towards the wing tip. The nature of these markings indicated that they had not occurred during the landing ground roll. The forward section of the right mainwheel spat had detached and photographs taken of the aircraft during landing showed that the right main landing gear leg was bent upwards, with the right wheel almost in contact with the right wing lower surface, immediately prior to touchdown.

Before the aircraft was moved from its resting position, its flying controls were checked and determined to be continuous, with no evidence of any pre-existing control restrictions.

Figure 5

Damage to the RV-4's right wing

Medical and pathology

An aviation pathologist conducted the autopsies. His report concluded that the pilot and passenger of G-JAST died of severe multiple injuries which were caused by the non-survivable crash of their aircraft following a mid-air collision. The pathology investigation revealed no evidence of medical factors which could be pertinent to the cause of the collision.

Handicapped Air Racing

Handicapped Air Racing has been in existence since the 1920's and is organised in the UK by the Royal Aero Club Records Racing and Rally Association (RRRA). Any propeller-driven aircraft, up to a maximum all-up mass of 5,700 kg, which is capable of maintaining a minimum of 100 mph in level flight, may compete. Turbine aircraft may also compete but they are subject to a maximum speed, straight and level, of 250 kt. Each aircraft is tested on the day of the first race for its maximum level in-flight speed. The time it should take to complete the race mileage at maximum speed is then calculated. The aircraft start times are staggered, with the slowest aircraft starting first, so that all aircraft should cross the finish line simultaneously. The race is normally flown at 500 ft above the highest obstacle on the race course until on the final straight, when, after crossing a predetermined point, normally marked on the map as "A", the aircraft can descend to the height that they cross the finish line, normally 100 ft agl. The idea is to give an exciting finish for the spectators and a race atmosphere for the competitors.

In order to compete in the race each pilot must

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hold a Federation Aeronautique International (FAI) competitor's licence and each pilot who has not raced within the last three years is required to undertake a check flight with an air race check pilot.

Air races are conducted at seven or eight venues per year, typically over a weekend. A Chief Steward is appointed for each meeting and he appoints two other stewards. Stewards cannot be competitors in the race. Prior to each race and each practise session there is a briefing, conducted by a race official known as the Clerk of the Course. Attendance at these briefings is compulsory for all competitors. The Clerk of the Course is the sole person responsible to the Stewards for conducting the meeting, in accordance with the official programme. He is assisted by several other race officials.

After the first briefing of the race weekend, each aircraft's race speed is assessed by flying an octagon pattern at the aircraft's maximum speed, with a GPS track logger onboard. This octagon is normally supervised by race officials, and flown at a stated aircraft configuration and fuel quantity. From the GPS track logger, the average groundspeed for the aircraft around the octagon is calculated and the start times for the race are produced. The race is normally a lap distance of around 25 nm and the aircraft typically race for four or five laps of the circuit. After the octagon, there is a race practise session on the Saturday morning, where the competitors become familiar with the turning points (TPs). Then, after a briefing, the first race is held on the Saturday afternoon. The second race, around the same track, is normally held after a briefing on the Sunday.

In order for the air race to take place, the Civil Aviation Authority issued the RRRA with two exemptions from the Rules of the Air Regulations 2007. The first exemption permits aircraft participating in an air race to overtake on either side[2] during the race or practice air race and the second allows aircraft to land when the runway is not clear of aircraft.[3] The RRRA used to be given an exemption to Rule 5 of the air to permit them to allow aircraft to fly within 500 ft of persons, vehicles, vessels and structures, for the final part of the race, but in April 2008 the CAA wrote to the RRRA and explained that this exception was not required as Rule 6(f) allowed them to descend below 500ft when within 1,000 m of the finish line.

Races are conducted with all aircraft using a single common radio frequency and racers are encouraged to use the frequency for flight safety transmissions. This radio frequency is not normally recorded.

The Rolls Royce Merlin Trophy Air Race

The Rolls Royce Merlin Trophy Air Race is normally held every year on the Isle of Wight. Competing in the Merlin Trophy Air Race is a pre-requisite for entry into the Schneider Trophy Air Race, which is normally held the following day. The course is about 117 nm long and consists of five laps of an anticlockwise circuit, of approximately 23 nm, around the north of the Isle of Wright. On the first lap aircraft have to go past several additional waypoints, known as scatter-points. These additional points are intended to allow aircraft to achieve a safe speed prior to turning onto the initial race track.

For this race weekend all competitors were required to be present at Bembridge Airport before 0945 hrs and

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Footnote

[2] Rule 11(1) of the Rules of the Air Regulations 2007 *'An aircraft which is being overtaken in the air shall have the right-of-way and the overtaking aircraft, whether climbing, descending or in horizontal flight, shall keep out of the way of the other aircraft by altering course to the right'.*

[3] Rule 14(2) of the Rules of the Air Regulations 2007 '*A flying machine or glider shall not land on a runway at an aerodrome if there are other aircraft on the runway'.*

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the race officials checked all the paperwork for the competitors and their aircraft. Only competitors whose paperwork was correct were allowed to participate in the race. Competitors were, at this point, also required to sign an indemnity form, as either pilot or navigator, which contained the statement:

> *'I am aware of the risks inherent in aviation generally and air racing in particular and I am willing to accept those risks.'*

At 1000 hrs, the pre-practice briefing was held and, afterwards, the aircraft performed their octagons and the practise runs around the route. The pre-race brief was delayed from its planned time of 1330 hrs, as the refuelling of the aircraft to the race fuel states took longer than planned, and the race briefing commenced at 1400 hrs. The brief contained a reminder to the pilots that they were permitted to overtake on both the left and the right, but that it remained the responsibility of the overtaking aircraft to remain clear of the aircraft it was overtaking. The race commenced at 1500 hrs.

Previous mid-air collisions during air racing

In July 1983 a Cessna 182 Skylane and a Mooney collided during the practise for an air race. The pilot of the Cessna was fatally injured (AIB12/83). In August 1984 a Bolkow Monson B209 and a Piper Arrow PA-28R collided during an air race, the pilots of both aircraft being fatally injured (AIB 3/85). In

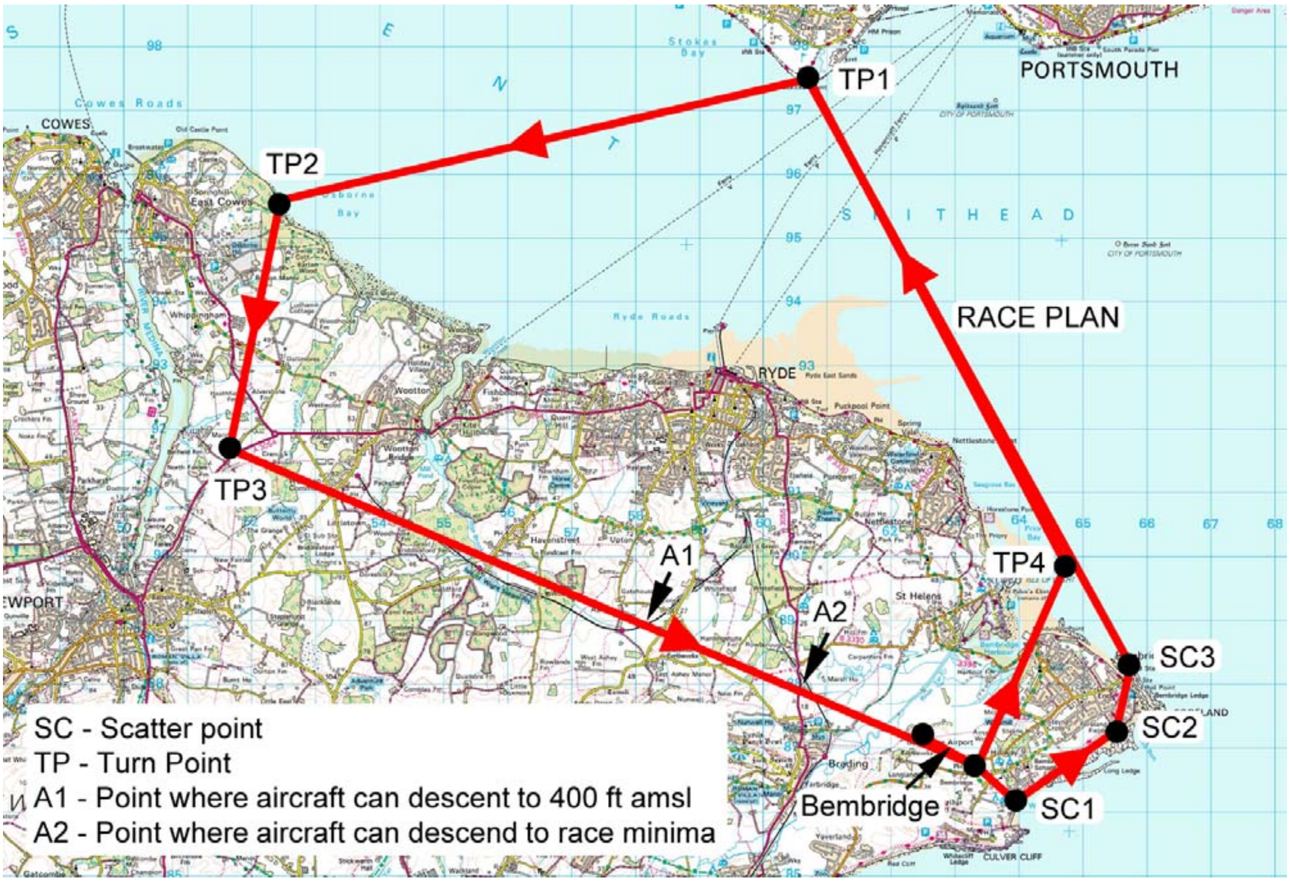

Figure 6

The Rolls Royce Trophy Air Race Course

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August 1991 a Piper PA-28 Cherokee Arrow II and a Glos Airtourer 150 collided during the qualifying heat for the Schneider Trophy Air Race; both aircraft landed safely (AIB 10/91).

Analysis

General

The rules of handicapped air racing are designed to place multiple aircraft in close proximity to each other by the finish of the race. According to these rules it is the responsibility of the overtaking aircraft to remain clear of the aircraft being overtaken. In this situation the Mooney was slowly overtaking the RV-4. Analysis of the recorded data, however, shows that it is unlikely that the pilot of the Mooney was visual with the RV-4 for approximately the final 39 seconds before the collision. When the Mooney pilot had last been able to see the RV-4, the vertical and lateral separation of the two aircraft was increasing but, during the final 20 seconds, the average speed of the RV-4 increased by approximately 4 kt, such that for a period of approximately 7 seconds the RV-4 had the higher ground speed. With other aircraft ahead of the Mooney, and the finish line approaching, it is probable that the crew of the Mooney had lost spatial awareness of the RV-4.

The RV-4 navigator recalled seeing the Mooney to the right and below his position shortly before the impact; the recorded data indicates that this was approximately 15 seconds before impact. Thereafter, it was probable that, although the aircraft were in close proximity to each other, neither crew was able to see the other aircraft.

The pilot of the Bulldog recalled seeing the Mooney achieve attitudes of approximately 15º nose-up and nose-down; yet a flight conducted during the investigation found that the attitudes required to achieve the rates of climb and descent, derived from the Mooney's GPS, were 5º nose-up and 1º nose-down, respectively. Assessment of another aircraft's pitch attitude, whilst flying directly behind it, is difficult, especially when there is relative movement between that aircraft and the observer. Therefore, while the witness in the Bulldog saw the Mooney's change in the pitch attitude, it is likely that the attitude it achieved was similar to that recorded on the investigation flight.

The engineering investigation could find no technical fault which would explain the aircraft's divergence from straight and level flight. The flight test showed that the control forces for the Mooney were light. The control movements required to make it perform its last movements prior to the collision were very small, and, as such, the pilot might have made the control inputs inadvertently, whilst concentrating on something else.

Collision analysis

In order to correlate the pattern of damage sustained by both aircraft during the collision, simple three-dimensional Computer Aided Design (CAD) models of each aircraft were created. The pitch angles of both aircraft were set to be consistent with the airspeed and climb rates recorded on the GPS recorders carried on the aircraft immediately prior to the collision. The analysis showed that the initial contact between the aircraft was between the RV-4's right wheel spat and the top section of the Mooney's rear fuselage, at the forward end of the dorsal fin (Figure 7).

This initial contact was likely to have been followed almost immediately by contact between the RV-4's propeller and the left side of the Mooney's cabin roof skin, above the rear cabin seats (Figure 8). It is likely that the large section of cabin roof skin found in the wreckage trail detached from the aircraft at this point in the accident sequence.

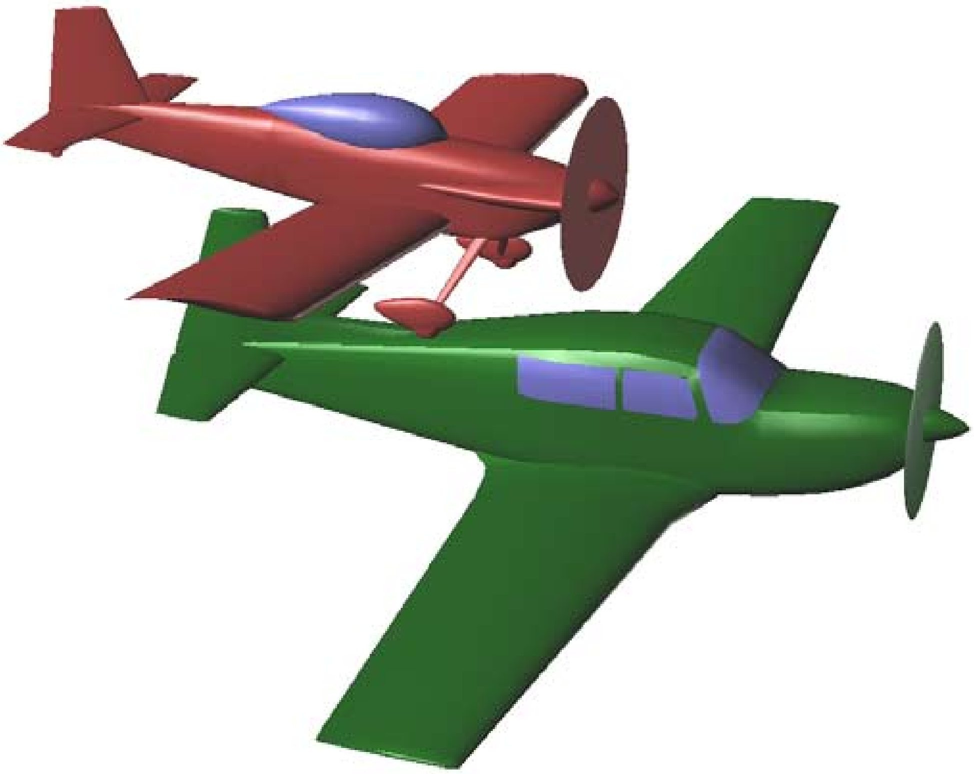

Figure 7

Initial contact

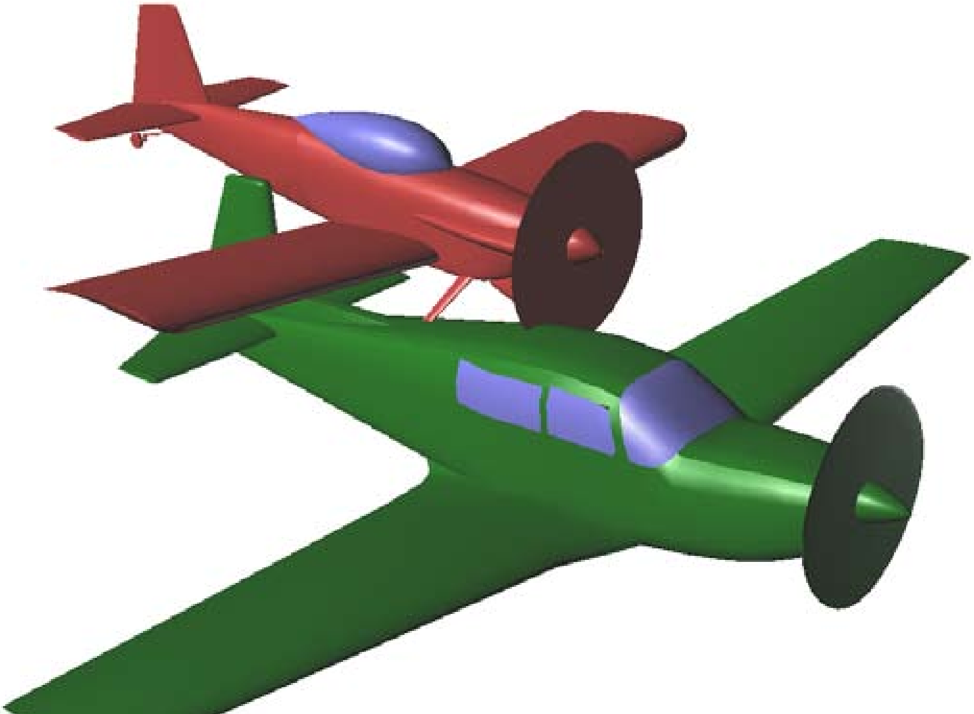

Figure 8

Propeller contact with Mooney's cabin roof

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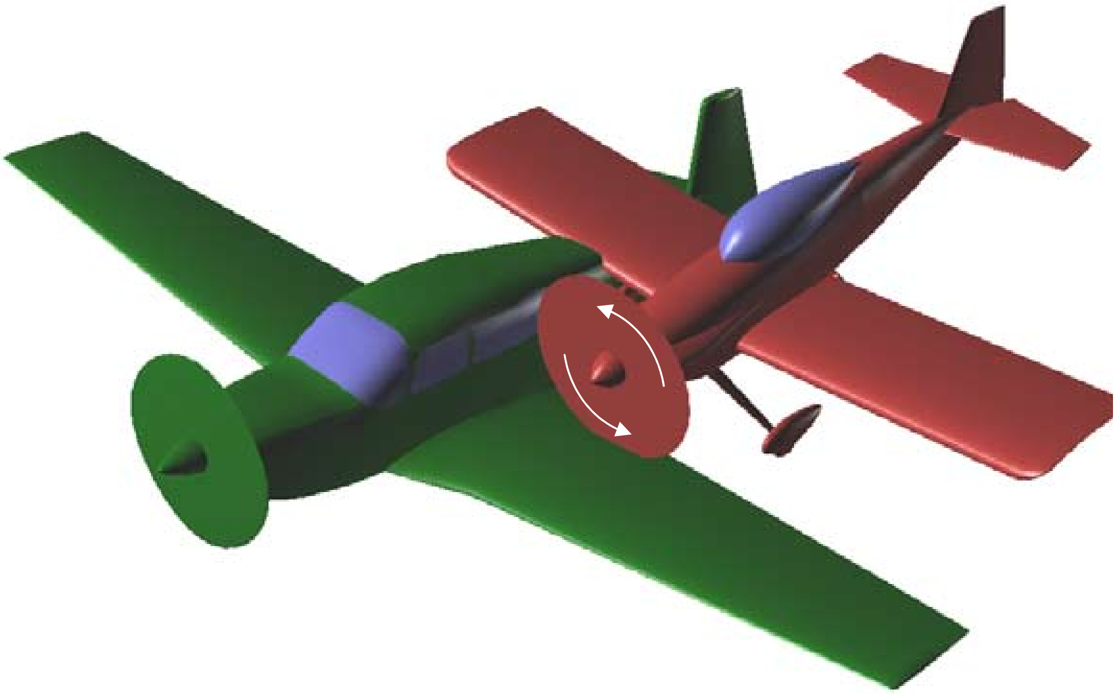

Figure 9

Propeller contact with the Mooney's left wing, showing the RV-4's propeller rotation direction

This was followed by contact between the RV-4's propeller and the inboard section of the Mooney's left wing, severing the wing's rear spar (Figure 9).

The vertical contact force between the RV-4's right mainwheel and the Mooney's rear fuselage, followed almost immediately by the RV-4's right wing, acted at a distance of approximately 3 m behind the Mooney's centre of gravity. This caused the Mooney to pitch nose-up, increasing the aircraft's angle of attack. It is likely that the combination of weakening of the Mooney's wing, due to the propeller damage at the rear spar, and the increased angle of attack at an airspeed of approximately 160 kt, generated an aerodynamic upload on the left wing that it was unable to withstand. The left wing failed in upward bending and subsequently detached from the aircraft.

The physical evidence of the wreckage shows that an impact occurred, in the fore-aft direction, between the lower section of the Mooney's fin leading edge and the inboard end of the RV-4's right aileron. This impact imposed a tensile load in the Mooney's rear fuselage. It is probable that this tensile load, in combination with the damage sustained during the initial contacts with the RV-4's right mainwheel and right wing leading edge, caused the tensile fracture and subsequent detachment of the Mooney's rear fuselage and empennage section.

As the empennage became displaced longitudinally from the forward fuselage section, the elevator and rudder control pushrods rapidly drove the elevators to full downward deflection and the rudder to the full right deflection position. The rapidity of these control surface accelerations caused the rudder and the left elevator mass balance weights to become detached due to inertial loads. The failure of the left tailplane in upload, combined with the absence of any obvious impact damage, indicates that the left tailplane, possibly in combination with full down elevator deflection,

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experienced aerodynamic loads sufficiently high for it to fail in upward bending.

The shallow propeller depressions on the right tailplane upper surface were made at some point following the initial impact, because the red paint transfer left by the propeller must have been produced once the outer two inches of the propeller tips had been removed, during propeller strikes with the Mooney's structure.

Once the rudder and elevator pushrods reached their maximum travel positions, the rearward load acting on the empennage, due to contact with the RV-4, was sufficient to overload the rod-end bearings in tension at their connections with the control pushrods. Following this, the empennage detached completely from the forward fuselage section.

Safety action

As a result of this accident the Civil Aviation Authority and the RRRA are reviewing Air Race procedures and the risk air racing poses to third parties.

Conclusions

The accident occurred because the pilots of both aircraft lost sight of each other whilst engaged in air racing. Analysis of the geometry of the collision showed that the upward visibility from the overtaking aircraft, the Mooney, was very poor, with the pilot probably unable to see the RV-4 for approximately 39 seconds. When the Mooney was in the blind spot of the RV-4, and neither pilot could see the other aircraft, the Mooney pitched up into the RV-4 and a mid-air collision occurred. The investigation could not determine why the pilot made these control inputs, although the investigation considered they would have been small and the Mooney pilot was not aware of the close proximity of the RV-4.

ACCIDENT

Aircraft Type and Registration:	Piper PA-25-260 Pawnee, G-DSGC	
No & Type of Engines:	1 Lycoming O-540-G1A5 piston engine	
Year of Manufacture:	1969	
Date & Time (UTC):	19 March 2011 at 1515 hrs	
Location:	North Hill Airfield, Devon	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Right main landing gear strut damaged	
Commander's Licence:	Private Pilot's Licence	
Commander's Age:	74 years	
Commander's Flying Experience:	461 hours (of which 64 were on type) Last 90 days - 3 hours Last 28 days - 3 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

The pilot had just completed his fifth aerotow of the day and was approaching Runway 26 at North Hill Airfield to land. As the pilot flared, he felt the onset of a stall, so he opened the throttle to reduce the aircraft's descent rate. The aircraft landed, bounced and then landed heavily in a wings level attitude. Immediately, the pilot felt the aircraft drop to the right; it then came to rest in a right-wing low attitude. The pilot exited the aircraft and discovered that the right main landing gear strut was displaced to one side. Despite this, the pilot was able to taxi clear of the landing strip.

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ACCIDENT

Aircraft Type and Registration:	Spitfire Mk 26 (scale replica), G-CCGH
No & Type of Engines:	1 Jabiru Aircraft PTY 5100A piston engine
Year of Manufacture:	2007
Date & Time (UTC):	1 March 2011 at 1244 hrs
Location:	Hawarden Airfield, Deeside
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Damage to propeller and left landing gear leg
Commander's Licence:	Private Pilot's Licence
Commander's Age:	55 years
Commander's Flying Experience:	101 hours (of which 1 was on type) Last 90 days - 6 hours Last 28 days - 1 hour
Information Source:	Aircraft Accident Report Form submitted by the pilot

Synopsis

The aircraft landed heavily on one leg and tipped onto its nose following a poorly-executed approach. The pilot later commented that he was heavily distracted by problems he was having with his VHF radio at the time.

History of the flight

The aircraft had been on a local flight from Hawarden, flying out to areas where the pilot would be in contact with Liverpool Approach and Valley Radar. The pilot reports that the aircraft was generally operating normally, the weather was fine and the winds at Hawarden were light. During the flight, however, the pilot experienced difficulties with his VHF radio, with poor reception, and decided not to contact Liverpool Approach. He then found communication with Valley Radar was only "strength one" so he returned to Hawarden with the intention to land, but found radio communication poor during the rejoin into the traffic pattern.

The pilot changed to the Hawarden Tower frequency and was given clearance to land on Runway 04, with continuing poor VHF communications. He reports that his approach to landing was "poor" and that the initial touchdown was distinctly heavy on the left main landing gear leg, with the tailwheel down. The aircraft then rocked abruptly onto the right leg and went over onto its nose, stopping in a short distance. The pilot switched off the fuel and electrics and was able to open the canopy and leave the aircraft normally. There was

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no fire but there was damage to the propeller and the left landing gear leg.

Following the accident, the pilot was able to identify and correct the radio problem, which emanated from a poor connection of a coaxial cable. It is likely that the worsening of VHF communication during the flight was exacerbated by engine vibration.

Pilot's comment and safety actions

The pilot later commented that he considered the accident was as a result of a poor landing, in which he did not "hold the stick back" sufficiently on touchdown, following an approach to land during which he was distracted by the radio problems. As a result of this accident the pilot has embarked on further tailwheel instruction, and supervised practice, in a two-seat aircraft of similar type.

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ACCIDENT

Aircraft Type and Registration:
1) Tri Kis, G-BVTA
2) Cessna 172S Skyhawk, G-ILPY

No & Type of Engines:
1) 1 Continental Motors Corp O-240-E piston engine
2) 1 Lycoming IO-360-L2A piston engine

Year of Manufacture:
1) 1995
2) 2001

Date & Time (UTC): 19 February 2011 at 1445 hrs

Location: Dunkeswell Airfield, Devon

Type of Flight:
1) Training
2) N/A

Persons on Board:
1) Crew - 2 Passengers - None
2) Crew - None Passengers - None

Injuries:
1) Crew - None Passengers - N/A
2) Crew - N/A Passengers - N/A

Nature of Damage:
1) Fuselage cracked at left wing root, propeller, spinner, engine cowl, windscreen,left wingtip and left hatch
2) Rear fuselage, right wing strut and aileron and engine mount

Commander's Licence:
1) National Private Pilot's Licence
2) N/A

Commander's Age:
1) 49 years
2) N/A

Commander's Flying Experience:
1) 58 hours (of which 7 were on type)
Last 90 days - 7 hours
Last 28 days - 7 hours
2) N/A

Information Source: Aircraft Accident Report Form submitted by the pilot

Synopsis

Whilst manoeuvring G-BVTA on the ground through a tight turn, the pilot's foot slipped off the right rudder pedal and the aircraft collided with G-ILPY.

History of the flight

The pilot was receiving tution from an instructor. At the end of the sortie, he taxied to the threshold end of Runway 23 and turned right onto the embarkation area to allow his instructor to get out and make his way to the hangar area. The intention was that they would meet up again at the hangar for a debrief. The engine was shut

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down and the instructor disembarked, walking away from the aircraft whilst the pilot restarted the engine and commenced the 180° turn to the left necessary to steer the aircraft towards the taxiway; being a relatively confined area, maximum left steering pedal and braking was used.

Having executed the 180° turn and come to a halt to watch for landing aircraft, parachutists, vehicles or pedestrians, the pilot realised that the nosewheel was cocked well over to the left and would need to be straightened, so he applied right rudder pedal and increased engine rpm to 1,300. Just before the aircraft started to move, he applied full right pedal and at this point his foot slipped off the pedal. He believes that the sudden forward lurch of his body also caused his right hand to move the throttle forward, resulting in an increase of 400-500 rpm. The aircraft accelerated rapidly in a left turn and, having turned though about 90°, was heading towards "a large black twin-engined Beechcraft used for parachuting" which was parked on the edge of the runway starter extension. The pilot judged that straightening out now would probably result in impact with this aircraft and also realised that he was unable to apply right rudder (possibly due to his shoe being caught behind the right pedal, he later reasoned). He tightened the left turn further with application of left brake, and successfully avoided the Beechcraft.

He was now approaching a Cessna 172, G-ILPY, which was parked to the left of the Beechcraft, but he momentarily hoped that he would be able to pass between the two aircraft. Unfortunately, the radius of turn had now decreased and the aircraft was now heading diagonally towards the tail of the Cessna. The pilot also believes that, in his struggle to free his right leg, he may have inadvertently nudged the throttle further open. Collision with G-ILPY was now inevitable and his left wingtip clipped the rear fuselage, spinning the Tri-Kis to the left and into the right side of the fuselage of the Cessna, just forward of the engine firewall. The engine stalled at this point and the aircraft came to rest with the left wing wedged under the tail of the Cessna, the spinner and remains of the wooden propeller embedded in the nose and the wing strut of G-ILPY severed.

The airfield owner arrived at the scene within seconds and undid the pilot's harness whilst also switching off the electrics. The pilot, momentarily stunned by the impact of his head on the upper cockpit hatch cover, reassured the airfield owner that he was alright and saw him attend to a fuel leak from a breather tube on the left wingtip. The pilot now realised that his right foot was trapped between the right rudder pedal and the centre console and managed to extricate it, after which he double-checked that the switches were off. He also noted that the throttle setting was depressed by an amount equivalent to about 2,200 rpm in flight. After exiting through the left hatch, which was off its hinges due to impact with the Cessna, he returned a few minutes later to remove the keys and double check the throttle setting.

In a detailed and frank statement, the pilot attributes the accident to his foot slipping off the right rudder pedal and becoming trapped; the resulting lurch of his body also caused him to inadvertently open the throttle. He identifies as causal factors the offset of the rudder pedals and the lack of friction material on them to improve grip. He also felt that the throttle friction device, which requires a button to be depressed in the centre of the knob each time a power adjustment is made, would be improved if it was in the form of a collar behind the knob, so that the throttle could be closed with a single, rearward motion.

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ACCIDENT

Aircraft Type and Registration:	Robinson R44 II Raven, G-EEZR	
No & Type of Engines:	1 Lycoming IO-540-AE1A5 piston engine	
Year of Manufacture:	2006	
Date & Time (UTC):	22 March 2011 at 1150 hrs	
Location:	Fairoaks Airport, Surrey	
Type of Flight:	Training	
Persons on Board:	Crew - 2	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Creasing and indentations to the tail rotor blade.	
Commander's Licence:	Commercial Pilot's Licence	
Commander's Age:	64 years	
Commander's Flying Experience:	9,800 hours (of which 45 were on type) Last 90 days - 50 hours Last 28 days - 18 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

The tail rotor contacted a small bush during training involving landings on sloping ground. Examination of the tail rotor revealed minor damage and the tail rotor was replaced. The instructor stated that, although he was aware of the bush, he incorrectly assessed its position and distance from the tail rotor. The bush has been trimmed.

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ACCIDENT

Aircraft Type and Registration:	Magni M24C, G-CGRT	
No & Type of Engines:	1 Rotax 914-UL piston engine	
Year of Manufacture:	2010	
Date & Time (UTC):	3 February 2011 at 1100 hrs	
Location:	Rufforth Airfield, Yorkshire	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Rotors, rotor head, propeller blades, composite body, pilot door and engine cover	
Commander's Licence:	National Private Pilot's Licence	
Commander's Age:	74 years	
Commander's Flying Experience:	2,870 hours (of which 31 were on type) Last 90 days - 30 hours Last 28 days - 22 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

Synopsis

During a normal rotor pre-rotation in gusty wind conditions, the aircraft became airborne prior to the main rotor achieving full rpm and the pilot lost control of the aircraft. The pilot had experience of flying gyroplanes in the strong wind conditions but on a different type.

History of the flight

The pilot had performed a series of short takeoffs and landings on a clear day with a 20 kt headwind on the runway in use. On his fourth takeoff, during a normal rotor pre-rotation procedure, with the stick full back, the rotor rpm rose to 230 rpm but the aircraft's nose lifted. The aircraft pitched rearward and the tail castor contacted the ground. It then lifted approximately three feet and began rolling to the left. The pilot attempted to recover by pushing the stick forward, applying full power and full right stick.

Despite this attempt, the aircraft gained approximately 10 kt forward speed, continued to roll left and impacted a ploughed field to the left of the runway. The aircraft ended up on its side but the pilot, who was wearing a helmet and full harness, was uninjured. He assessed that the cause of the accident was due to a sudden increase in wind speed during the pre-rotation of the main rotor. The forecast was for an increase in wind strength during the day with reported conditions as gusty, increasing throughout the day to 60 kt.

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Instructor's comments

The pilot's instructor commented that although the pilot had experienced flying in strong winds on a different gyroplane model, it was his first time flying the M24C in such conditions. He also stated that the rearward movement of the stick, rotor rpm, strong wind and low aircraft weight would have caused the aircraft to lift off. Additionally he noted that the normal takeoff rotor speed is 300 rpm and at 220 rpm the directional control from the main rotor is limited. Therefore the aircraft's response to stick inputs made by the pilot would also have been less effective.

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ACCIDENT

Aircraft Type and Registration:	Pegasus Quantum 15-912, G-BYYY	
No & Type of Engines:	1 Rotax 912 piston engine	
Year of Manufacture:	1999	
Date & Time (UTC):	28 March 2011 at 1220 hrs	
Location:	Redlands Airfield, Wiltshire	
Type of Flight:	Training	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Pod and propeller damaged	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	58 years	
Commander's Flying Experience:	17,500 hours (of which 13 were on type) Last 90 days - 221 hours Last 28 days - 60 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

The pilot, who was undergoing a course of training on the aircraft, had completed 10 minutes of dual flight followed by 50 minutes of solo flight when he made an approach to Runway 06N with the intention of carrying out a touch-and-go. He reported that immediately before touchdown the aircraft encountering a sudden gust of wind that caused the aircraft to drift left. The aircraft touched down on the left edge of the grass runway heading towards a rough grass area beside it.

The pilot was aware of a tree "some distance away" and, concerned that the aircraft might collide with it, attempted to get airborne. Acceleration in the rough grass was slower than the pilot expected and the aircraft became airborne with insufficient height to clear the tree or manoeuvre around it. Impact between the pod and the tree stopped the aircraft. The pilot was uninjured but the pod and propeller were damaged.

The pilot concluded that the accident was caused by an unforeseen gust of wind that, at a critical moment, was outside his experience on this aircraft type.

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ACCIDENT

Aircraft Type and Registration:	Renegade Spirit UK, G-MYFM	
No & Type of Engines:	1 Rotax 582 piston engine	
Year of Manufacture:	1993	
Date & Time (UTC):	1 November 2010 at 1500 hrs	
Location:	Farm strip, London Colney, Hertfordshire	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Damage to landing gear and wings	
Commander's Licence:	National Private Pilot's Licence	
Commander's Age:	47 years	
Commander's Flying Experience:	419 hours (of which n/k were on type) Last 90 days - Not known Last 28 days - Not known	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

The Renegade Spirit is a three-axis microlight aircraft with a biplane and tailwheel configuration. During an attempted landing on a 325-metre grass strip the pilot overshot the runway and initiated a go-around. During the go-around the landing gear clipped the top of a hedge, causing the aircraft to hit the ground in the field beyond. In his written report the pilot assessed the cause of the accident as "pilot error".

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ACCIDENT

Aircraft Type and Registration:	Tanarg/Ixess 15 912S(1), G-CEBH	
No & Type of Engines:	1 Rotax 912ULS piston engine	
Year of Manufacture:	2006	
Date & Time (UTC):	19 March 2011 at 1600 hrs	
Location:	Palmer Moor Farm, Doveridge, Derbyshire	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Propeller, left suspension leg and fairings damaged	
Commander's Licence:	National Private Pilot's Licence	
Commander's Age:	63 years	
Commander's Flying Experience:	169 hours (of which n/k were on type) Last 90 days - 8 hours Last 28 days - 4 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

During the approach to Runway 27 at Palmer Moor Farm, the aircraft experienced an area of sink. The pilot attempted to correct this, but the aircraft clipped a fence, veered to the left and struck a chicken wire fence that ran alongside the runway. Damage was sustained to the left suspension leg, fibre glass fairings and the propeller. The pilot was uninjured.

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ACCIDENT

Aircraft Type and Registration:	Thruster TST Mk 1, G-MVIU	
No & Type of Engines:	1 Rotax 503 piston engine	
Year of Manufacture:	1988	
Date & Time (UTC):	28 November 2010 at 1500 hrs	
Location:	RAF Mona Airfield, Anglesey, Wales	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - 1
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Damage to fibreglass cockpit, cabin floor cracked, wing strut bent, fuselage spar damaged and left mainwheel sheared off	
Commander's Licence:	Private Pilot's Licence	
Commander's Age:	46 years	
Commander's Flying Experience:	3,670 hours (of which 1 was on type) Last 90 days - 58 hours Last 28 days - 17 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot	

Synopsis

Just after lift-off, the pilot perceived that the aircraft was not climbing as expected due to a suspected lack of engine thrust. He abandoned the takeoff but after touchdown, the aircraft deviated to the side of the runway causing significant damage. Calculations performed after the accident confirmed that the aircraft was above its maximum takeoff weight by approximately 13 kg.

History of the flight

After completing the engine warm-up procedure, the pilot taxied the aircraft to Runway 04 where he lined up for takeoff with approximately 4,700 ft of takeoff distance available. A second 'full and free' control check was performed prior to takeoff and no problems were identified. Weather conditions were benign but the pilot described the runway surface as "slippery".

He applied full power and the aircraft accelerated, taking off before the intersection with a disused runway. Just after lifting off, at a height of approximately 10 ft, the pilot felt that the aircraft was not climbing so he reduced power and abandoned the takeoff. The aircraft landed back on the runway just past the intersection and to the left of the centreline. Almost immediately it began deviating to the left. The pilot attempted to correct the deviation with rudder but the aircraft left

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the paved surface and ran into heavy mud, bringing it to an abrupt halt and briefly tipping on its nose. Both occupants, who were wearing full harnesses, escaped uninjured.

Aircraft takeoff weight

In 2001 the aircraft was fitted with an approved modification for an enclosed cockpit. The effect of the additional weight of this modification was that there was a need to carefully monitor the aircraft takeoff weight and, if necessary, carry less than the maximum fuel load if the zero fuel weight was high enough. This information was included in the Pilot's Operating Handbook and was placarded on the fuel tank.

The aircraft basic weight was 186 kg with a maximum takeoff weight (MTOW) of 360 kg. The pilot indicated that the aircraft was fully fuelled, carrying approximately 25 kg. The total weight of the two occupants was 162 kg giving a takeoff weight of 373 kg, 13 kg above the MTOW.

Discussion

The registered owner of G-MVIU changed on 20 October 2010. The pilot indicated that when the aircraft was purchased, he did not perform a thorough review of the manuals and was therefore unaware of the weight restriction imposed by the enclosed cockpit modification. It was for this reason that he considered that the aircraft was overweight on takeoff. He also suspected that a shortage of engine thrust may have contributed to the perceived limited climb performance. He assessed that as the takeoff was aborted, he may have reduced power too quickly, leading to insufficient rudder authority available to correct the deviation on the slippery runway.

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2009

3/2009 Boeing 737-3Q8, G-THOF
on approach to Runway 26
Bournemouth Airport, Hampshire
on 23 September 2007.

Published May 2009.

4/2009 Airbus A319-111, G-EZAC
near Nantes, France
on 15 September 2006.

Published August 2009.

5/2009 BAe 146-200, EI-CZO
at London City Airport
on 20 February 2007.

Published September 2009.

6/2009 Hawker Hurricane Mk XII (IIB), G-HURR
1nm north-west of Shoreham Airport,
West Sussex
on 15 September 2007.

Published October 2009.

2010

1/2010 Boeing 777-236ER, G-YMMM
at London Heathrow Airport
on 28 January 2008.

Published February 2010.

2/2010 Beech 200C Super King Air, VQ-TIU
at 1 nm south-east of North Caicos
Airport, Turks and Caicos Islands,
British West Indies
on 6 February 2007.

Published May 2010.

3/2010 Cessna Citation 500, VP-BGE
2 nm NNE of Biggin Hill Airport
on 30 March 2008.

Published May 2010.

4/2010 Boeing 777-236, G-VIIR
at Robert L Bradshaw Int Airport
St Kitts, West Indies
on 26 September 2009.

Published September 2010.

5/2010 Grob G115E (Tutor), G-BYXR
and Standard Cirrus Glider, G-CKHT
Drayton, Oxfordshire
on 14 June 2009.

Published September 2010.

6/2010 Grob G115E Tutor, G-BYUT
and Grob G115E Tutor, G-BYVN
near Porthcawl, South Wales
on 11 February 2009.

Published November 2010.

7/2010 Aerospatiale (Eurocopter) AS 332L
Super Puma, G-PUMI
at Aberdeen Airport, Scotland
on 13 October 2006.

Published November 2010.

8/2010 Cessna 402C, G-EYES and
Rand KR-2, G-BOLZ
near Coventry Airport
on 17 August 2008.

Published December 2010.

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