# Spirit of St Louis Replica (Ryan M1/M2 NYP), ES-XCL

| **AAIB Bulletin No: 1/2004** | **Ref: EW/C2003/05/05** | **Category: 1.3** |
|---|---|---|
| **Aircraft Type and Registration:** | Spirit of St Louis Replica (Ryan M1/M2 NYP), ES-XCL | |
| **No & Type of Engines:** | 1 Continental W670-6A piston engine | |
| **Year of Manufacture:** | 1997 | |
| **Date & Time (UTC):** | 31 May 2003 at 1650 hrs | |
| **Location:** | Coventry Airfield, West Midlands | |
| **Type of Flight:** | Private | |
| **Persons on Board:** | Crew - 1 | Passengers - None |
| **Injuries:** | Crew - 1 (Fatal) | Passengers - N/A |
| **Nature of Damage:** | Aircraft destroyed | |
| **Commander's Licence:** | Air Transport Pilot's Licence | |
| **Commander's Age:** | 59 years | |
| **Commander's Flying Experience:** | 21,200 hours<br>(of which 190 were on type) | |
| | Last 90 days - 89 hours | |
| | Last 28 days - 18 hours | |
| **Information Source:** | AAIB Field Investigation | |

## Synopsis

Shortly after takeoff from Runway 23, whilst climbing and manoeuvring gently to begin its display sequence, the aircraft's right wing suffered a major structural failure and the aircraft fell steeply into an industrial compound bordering the airfield. There was no post impact fire. The pilot survived the impact, but died shortly afterwards from his injuries. The failure in fatigue of a combined right landing gear and wing strut support fitting was determined to have precipitated the wing failure.

## History of flight

ES-XLC was a replica of the Ryan 'Spirit of St Louis' in which Charles Lindbergh made the first solo transatlantic crossing in 1927, and was taking part in the Coventry Airshow. The aircraft had been flown to Coventry airport from Sweden 10 days prior to the airshow, by a Swedish National pilot who possessed a Swedish licence, and it was hangared in the intervening period. It was last reported to have been in Estonia in May 2002. On the day of the accident the aircraft was pushed outside using a tail tow bar and parked whilst the pilot, who held a Swedish Display Authorisation which was acceptable for airshows within the UK, attended the airshow pilots' briefing. Whilst awaiting the time to display, the Ryan was subject to buffeting from the 'propwash' during the start up and power checks of a Noratlas aircraft parked approximately 70 metres in front, and this required several people to hang onto the Ryan's wing struts. Eventually the Ryan was moved further away. It was started up some 20 minutes before its display slot, taxied to holding point 'Charlie' and took off using Runway 23. The wind was 170°/7 kt and the ATC clearance was to 'TAKE-OFF AND DISPLAY'. The takeoff appeared normal and the aircraft made a gentle turn to the left, climbing to approximately 300 feet, before commencing a level right turn back towards the airfield as planned. During this turn the right wing leading edge was seen to roll backwards, followed rapidly by the right wing folding upwards relative to the fuselage. The aircraft started spinning to the right and descended rapidly into industrial buildings on the airport boundary. Rescue services, including the airport's air ambulance, were on the scene within a few minutes and the pilot was air lifted to hospital where he died from his injuries.

## Wreckage distribution

The nose of the aircraft impacted an area of hard-standing, the outer part of the left wing striking the roof of an industrial lean-to building as it did so. The main wreckage, which comprised virtually the whole of the aircraft including all of the primary structure, was contained within a very small area. A few small of items of lightweight material, comprising mainly fragments of thin plywood and fabric, were found within the airfield boundary, beneath the aircraft's final flight path.

The left wing had been reduced to fragments by the impact with the roof, and most of the resulting debris was scattered on the ground to the left of the fuselage remains; the remainder was lodged in the damaged roof structure. The outer panel of the right wing, with the aileron still attached, had remained substantially in one piece but the inboard section of the right wing had broken up and its remains were wrapped around the nose of the aircraft. The remains of all the wing support struts and related hardware lay within the boundary of the main wreckage.

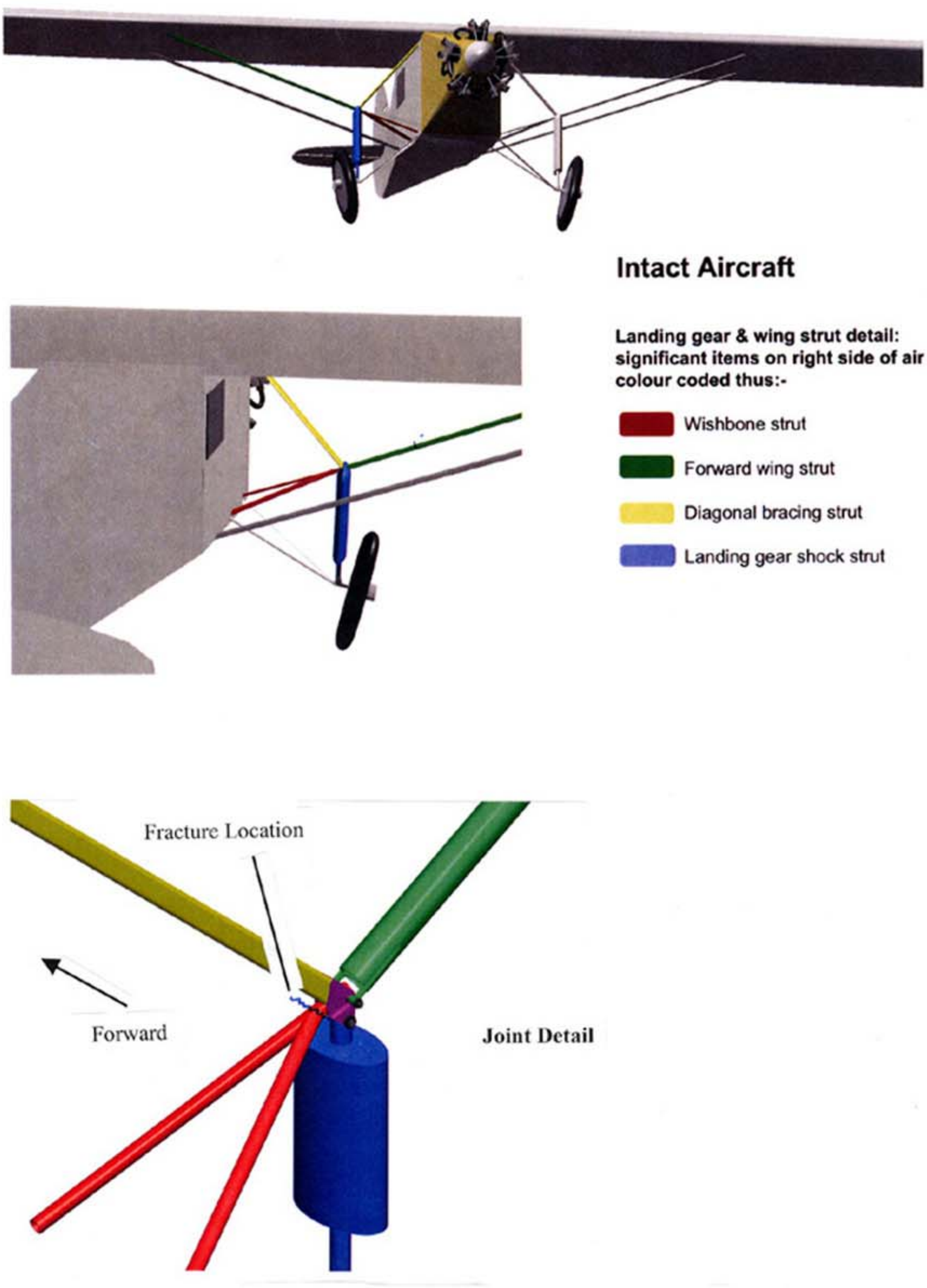
The fuselage forward of the cockpit had been disrupted and crushed back towards the firewall, breaking apart the fabricated metal fuel tank. (This tank had been constructed along similar lines to that of the fuselage tank of the original Spirit of St Louis, and was similarly positioned, but had a smaller fuel capacity than the original.) The cockpit itself was largely intact, but the left side of the instrument panel had been partially broken, consistent with an impact from the pilot's head. The rear fuselage, tailplanes, elevators, and the fin and rudder were substantially undamaged. The engine and propeller were displaced approximately one metre from the point of their initial impact with the concrete surface.

Overall, the pattern of damage to the aircraft was consistent with it having impacted the ground pitched slightly beyond vertical, but with a horizontal velocity component towards the belly of the aircraft. This caused it to flip back over the right way up, before finally coming to rest.

## Landing gear/wing strut support

A tubular steel wishbone strut, mounted from the lower edge of the fuselage and braced to the upper edge, locates and supports both the upper end of the right landing gear shock-strut and the lower end of the forward right wing strut, Figure 1. The wishbone comprises a main strut (the forward leg of the wishbone) of 1.25" outside diameter (OD) steel tube and 0.0625" wall thickness, and a diagonal bracing strut (the rear leg) of 1.0625" OD steel tube and 0.0625" wall thickness. These are welded together at their apex, but the forward leg extends outboard slightly beyond the apex joint, where it is welded to the bracing tube connecting to the top of the fuselage frame. This joint is stiffened and braced by a pair of steel 'fish-plates' welded on either side of the wishbone strut main tube and the fuselage bracing tube, and this also forms, in effect, a pair of locating sockets for the top of the landing gear strut and bottom of the wing lift strut.

**Figure 1: Landing Gear and Wing Strut Support Structure**



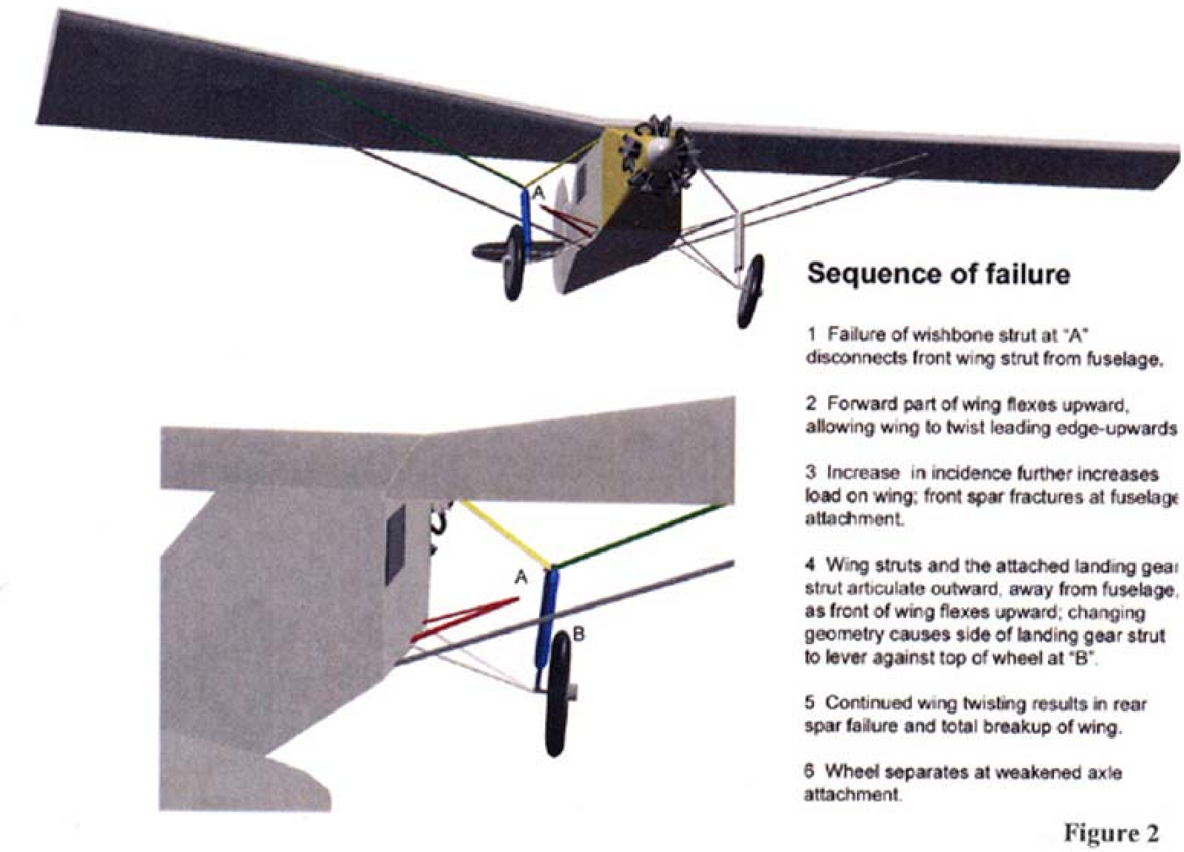

Landing Gear and Wing Strut Support Structure

Figure 1

## Wreckage examination

A detailed examination of the wreckage, in situ, quickly established that the outboard end of the tubular wishbone strut had failed in flight as a result of a fatigue crack. Initial examination revealed that the crack extended through approximately 90% of the cross-section area and that surface corrosion was evident over much of the fatigue crack fracture surface. The final 10% of the fracture surface, which exhibited characteristics consistent with a tensile overload mode of failure, was clean. The geometry of the external bracing struts on the 'Spirit of St Louis' design is such that the fatigue failure of the wishbone strut would effectively dislocate the lower end of the right wing forward lift strut, which supports the right wing front spar. This would allow the lower end of the lift strut, together with the top end of the right landing gear shock strut, to articulate upward and outward. The expected outcome would be the immediate overload failure of the front spar at its root end, ie, the point of maximum bending moment, followed immediately by break-up of the remaining inboard wing structure. The inboard part of the rear spar would also be expected to fail due to the consequent upward and rearward twisting of the wing, Figure 2.

**Figure 2: Sequence of failure**




Inspection of the fracture surface using a hand lens suggested that the fatigue crack originated in a region of weld forming part of a joint, connecting the two tubes of the strut at its apex. It was also noted that the part of the strut containing this welded joint which lay beyond the outer ends of the aerofoil shaped fairings covering the two strut members and was thus fully exposed, had been over-sprayed with a yellow 'chromate primer' type of paint. This paint was of a different colour to the paint used elsewhere on the tubular framework of the aircraft and had evidently been applied after the aircraft had been built, Figure 3.

**Figure 3: Fractured end of right wishbone strut**

View on fractured end of right wishbone strut showing evidence of 'fresh' chromate primer type paint around weld area

**Figure 3**

**Wing structure**

The remains of the wooden spars of the right wing exhibited evidence consistent with a failure of the front spar in an upward bending mode, at its point of attachment to the right side of the fuselage frame, and a failure of the rear spar in a combination of upward bending and rearwards twisting, also close to the point of fuselage attachment. The overall mode of wing failure was thus consistent with, and was clearly the consequence of, the failure of the wishbone strut. This assessment was confirmed subsequently by a study of video and still images of the aircraft during the break-up, taken by members of the public attending the air display.

### Landing gear

Video footage of the accident showed the right main landing gear wheel separating from the aircraft part way through the airborne break-up sequence. Examination of this wheel, which was found within the main wreckage area, adjacent to the point of initial ground impact, showed that the wheel had detached due to a fracture through the axle immediately inboard of the brake back-plate, at what appeared to be a welded joint. The articulation of the wing and landing gear struts which occurred as a direct result of the fatigue failure of the wishbone strut, described previously, would also have induced a severe levering-type contact between the side of the shock strut and the right wheel rim, tending to fracture the axle and allow the wheel to separate and fall free. The failure of the axle weld was consistent with this scenario. Subsequent detailed study of the video evidence confirmed that the wheel was partially levered off the axle by this mechanism, although it did not finally separate until about two seconds later.

Whilst the wheel failure evidently played no part in the wing failure, per se, a cursory examination of the axle fracture surface suggested that the original weld was of poor quality, and that the weld had not fully penetrated the thickness of the material.

## Metalurgical examination

In light of the known circumstances of the accident, ie, evidence found of a failure in the wishbone strut due to fatigue cracking, and the resulting mode of failure of the right wing, subsequent detailed examinations were focussed primarily upon the fatigue fracture in the failed wishbone strut. In addition, the welds at other locations on the failed strut, and at the wheel axle fracture, were studied to assess overall weld quality. To this end, these items were taken to an independent metallurgical laboratory for detailed examination and analysis under AAIB direction.

### Wishbone fracture

The fatigue crack had originated at the apex of a weld in the wishbone, at the joint between the two legs of the wishbone and evidence was found of multiple fatigue initiations at the mid-wall of the tube, inboard of the toe of the weld. The weld metal behind these multiple initiations contained a large number of slag inclusions, porosity due to shrinkage and gas inclusion, and oxide films, the presence of which would have seriously reduced the load bearing capacity of this part of the tube and provided potent stress concentrating features.

The fatigue crack, Figure 4, had propagated initially in a radial direction, towards the outer surface of the tube and across the width of the welded region. Thereafter, two crack fronts had continued to propagate independently of one another, each by a fatigue mechanism, traveling circumferentially around the tube wall for about 75% of the circumference, in a plane normal to the tube axis. At this point, the fractures turned and grew longitudinally until final overload failure occurred through the remaining approximate 10% of the section, at 45° to the tube axis in both planes.

**Figure 4: Detail of fatigue crack / overload fracture surface**

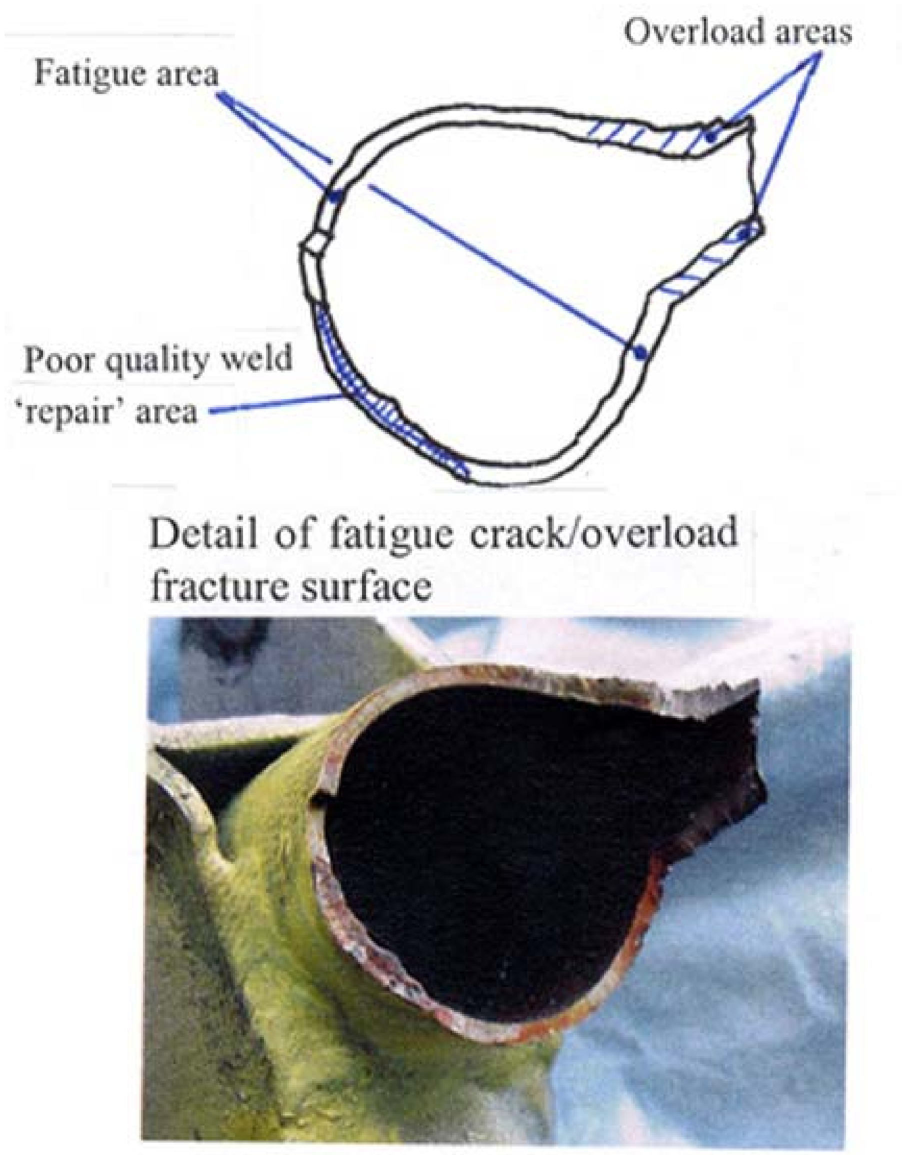



**Figure 4**

The fatigue fracture was characterised by beach marks, with intervening bands of fine striations having a spacing which was often of less than one micron. The numbers of beach marks in the various regions of the fracture were estimated using optical microscopy, and the following results obtained:

Upper half of fracture: 132

Lower half of fracture: 169

Damage prevented a full count from being made in the outer edges of the initial region of cracking. Making due allowance for this, and for the fact that as the fracture progressed to the longitudinal region less severe stresses would produce significant beach marks, the above estimates should be viewed as minima.

## Welds

The external appearance of the weld local to the fracture initiation was out of character with the remainder of the tube-to-tube weld, which indicated that re-welding of this area had been carried out after initial manufacture. Microsections through this region confirmed that capping deposits were present and that high temperatures had been achieved, producing large grain sizes in the microstructure at the surface. However, grain refinement had occurred in what appeared to be the original burnt-through weld deposit, and the alignment of this deposit appeared to be poor relative to the tube being attached. The sections showed the presence of oxide films which reduced the effective material thickness, locally, to about 76% of the original tube.

In the original weld region, ie that part of the joint which had not been subject to re-welding, the surface appearance exhibited a good profile and a microsection showed complete penetration of both tube walls. This had produced a fully cast structure in this region with only minor spherical silicate and oxide inclusions.

Examination of the welds in an adjacent (complex) joint on the wishbone strut, involving both tubes and plates, showed no signs of cracking despite the high levels of deformation induced during the airborne breakup and subsequent ground impact. A microsection through this joint revealed generally sound tube-to-plate welds, with imperfections restricted to a primarily cosmetic region of the joint.

In summary, the area of re-welding in which the fatigue crack had originated was of poor quality, and this was probably exacerbated by inadequate preparation. In contrast, based on the limited samples examined, the overall quality of the original welding of the wishbone strut (and by implication of the tubular fuselage structure generally) appeared to have been high.

## Wishbone rear attachment

The wishbone to fuselage rear attachment had failed primarily in overload at the junction of a short spigot-tube. This formed a socket type attachment, into which the rear arm of the wishbone was inserted, and retained by a single shear bolt, where the spigot was welded to the fuselage frame. There was no doubt that this overload failure occurred during the breakup and/or the subsequent ground impact. However, a small thumbnail of fatigue cracking was found in the fracture, which originated at the outside of the tube at multiple initiation sites aligned at 45 degrees to the axis of the tube. Cracking had then propagated by a fatigue mechanism through about 75% of the wall thickness, in what appeared to be a limited number of steps: probably less than 10 in number, probably due to cyclic overload, and possibly the result of abnormal stressing during the breakup sequence.

## Chemical Analysis & Structure

Analysis of the front wishbone tube member showed that it conformed to the specification for AISI 4130 material. The hardness was determined to be 265 HV10, which indicated that the fully spheroidised microstructure had been finished by cold drawing of the tube.

## Wheel axle failure

A machined stub axle tube with an integral flange appeared to have been butt welded onto the end of the wheel attachment tube, which appeared to be of the same diameter. Failure had occurred at this weld, apparently due to overload, since no evidence of any progressive cracking could be found.

It was clear that only one half of this weld exhibited adequate penetration to the bore of the tube. The remaining half, delineated by clearly defined groove across the end of the stub axle and which had evidently served as an alignment mark during assembly, showed only 20 to 50 % penetration. It is likely that given time, fatigue cracking would have developed in the area of inadequate weld penetration.

## Video evidence

On the day following the accident, shortly after the fatigue failure in the wishbone strut had been identified, a video of the break-up sequence became available to the AAIB. A preliminary study of this video showed the right wing leading edge twisting upwards and backwards, followed by the complete disintegration of the inboard wing structure within approximately 0.75 of a second. The aircraft then rolled rapidly to the right, and entered a steep barrelling descent into the ground. The video evidence, therefore, corroborated the conclusions which had been reached already from the structural examination, that the failure of the wing had been precipitated by the failure of the outer end of the wishbone strut. Subsequently, additional photographic and video evidence was made available, a study of which reinforced these conclusions.

## Aircraft information

The documentation available to the AAIB was limited to:

- Airframe and engine log books
- Pilot's operating handbook
- Photocopies of the original certificates of registration and airworthiness
- Weighing report
- Copy of a Swedish report into a ground handling incident in 1998, during which the (unmanned) aircraft ran away after engine start and collided with an obstacle on the ground
- Photocopies of the Estonian annual inspection report certificates

The documentation suggested that ES-XCL was built in Estonia in 1997 from drawings used in the construction of the flying replica displayed at the San Diego Aerospace Museum in the USA. Although owned and operated by a Swedish group, ES-XCL was registered in Estonia and operated on an Estonian Certificate of Airworthiness (N°1308, first issued on 29 August 1997) in the Experimental Category. The special conditions section of the Certificate of Airworthiness specified that the aircraft must be flown under VFR Day Conditions only and that a leader [aircraft] was required on ferry flights.

The copy of the Pilot's Operating Handbook provided to the AAIB by the joint owners was a typescript document which bore no identifying number or formal document title. However, it was evident from its content that it served as the de facto operating manual for ES-XCL. Its index listed the following sections:

- Operating Handbook
- Normal and Emergency Checklist
- Daily Inspection
- Flight Test Program.

From the signatures contained therein, it was apparent that the Operating Handbook had been prepared and produced primarily by the joint-owner of the aircraft, who was also the pilot at the time of the accident.

# Maintenance

## Inspection schedule

A condition of the Certificate of Airworthiness was that the aircraft should be operated and maintained in accordance with the pertinent flight manual, N° 1308. The only inspection schedules which could be located for this aircraft were those contained in the operating handbook which, in the absence of any other relevant documentation, was presumed to serve as the pertinent flight manual. The inspection items were listed under the headings *'Daily Inspection', '25 hr', '50 hr' and '100 hr'.*

The '*Daily Inspection'* listed a total of seven checklist items, the first item of which stated*, 'Check general condition on [sic] fabric, leaks, propeller, spinner and tires.'*; none referred explicitly to structure or flying controls.

The 25 hr inspection comprised a total of eight checklist items, of which the sole reference to structure was contained in item 6, '*Check fabric and tires for wear'*.

The 50 hr inspection comprised a repeat of the seven items contained in the 25 hr check, plus two additional items requiring the draining and refilling of the engine oil tank, and a check of the tire pressures; none made any reference to structure or flying controls.

The 100 hr inspection comprised the items listed for the 25 hr and 50 hr checks, plus a further 6 items, which addressed primarily engine and landing gear mechanical items; none made any specific, or even any indirect, reference to structure or flying controls.

In summary, the inspection schedule contained no items which addressed, directly or indirectly, the integrity of the aircraft's primary structure, flying control systems, control surfaces, or their attachments.

## Log books

The most recent entry in the airframe logbook, dated 21 May 2003, records a total of 190 flight hours and 192 flights since manufacture.

An entry dated '9/98' notes,

*Dism [dismantled?] after incident for repair of a forward wing strut, 100 hr inspection, propeller sent for repair suspension greased, wing assemb [assembled?] Feb 99.*

No further details, or any other reference to work carried out at this time, was contained in any of the available documentation. The total number of flights recorded in the log book at the time of that incident was 101, although there appeared to have been an error in the carry-forward totals and the actual total number of flights appears to have been 103, based on a summation of flight entries on the preceding pages.

The sole remaining entry in the airframe log book pertaining to maintenance actions comprised a note of a 100 hr inspection and test flight, dated 18/4/2003 and 8/5/2003 respectively; the latter signed by the pilot involved in the accident, and the former by another individual whose (illegible) signature was accompanied by neither an inspector's stamp nor any other form of identification. At the time of this inspection, the aircraft had a recorded total of 171:30 flight hours and 178 flights.

The concluding section of the airframe logbook listed the inspections shown in the table below as having been carried out, but contained no information about the results of the inspections, or of any remedial work carried which may have been carried out as a consequence, or any signature or inspector's stamp.

| Check | Date | Total hours |
|---|---|---|
| 50 | 11/5/1998 | 43.55 |

| | | |
|---|---|---|
| 100 | 15/2/1999 | 91.15 |
| 100 | 13/2/2000 | 94.10 |
| 100 | 5/5/2001 | 122.30 |
| 100 | 18/4/2003 | 171.30 |

## Repairs

The airframe logbook contained no record of the weld repair, from which the fatigue failure in the wishbone strut had originated, and no detailed information was given as to the nature and extent of the repairs carried out following the ground incident in September 1998. Also, no reference to either of these activities could be found elsewhere in the documentation provided to the AAIB.

## Estonian Civil Aviation Administration aircraft inspection report

A copy of the aircraft inspection report covering the inspection for the aircraft's renewal of its Certificate of Airworthiness, dated 8 May, 2003 at 171 hours total time, validated the Certificate of Airworthiness until 8 May, 2005. This made no reference whatsoever to the condition of the aircraft at the time of inspection. A similar certificate, dated 15 May 2002 at 122 hours total time, and which validated the certificate of airworthiness until 15 May, 2003, also made no reference to the condition of the aircraft at the time of inspection.

## The 1998 ground incident

The sole information available, concerning the incident in 1998, was provided by the pilot-in-command at that time, who was the pilot of the aircraft involved in the fatal accident. In a report submitted to the Swedish Civil Aviation Administration, a copy of which was provided to the AAIB by the Swedish authorities, the pilot described the aircraft running out of control, unoccupied, following an engine start. Prior to the engine being started, the aircraft had been parked with its tail on the grass and both main wheels on the concrete surface. No chocks were employed, but a couple of small stones had been placed in front of the right main wheel. After the engine started, the aircraft started to move. Before the pilot could catch up with it, the aircraft had swerved through a low fence and come to rest against a container, which was struck by the propeller.

The visible damage to the aircraft was described as "...a scratched right wing tip, front right wing strut slightly bent, propeller and hub. Various paint scratches."

No details were given of the repairs required to rectify the damage caused by this incident.

### *The weld repair carried out to the wishbone strut*

Inquiries carried out by the Swedish authorities on behalf of the AAIB, were unable to establish when the weld repair in the wishbone strut was carried out, or by whom; nor could it be established why the repair had been necessary. However, it is understood that the family of the deceased pilot believe that the weld repair was not associated with the repairs carried out after the ground handling incident in 1998, which they understand did not involve any welding.

### *Approval to fly within UK Airspace, reference Airworthiness Notice (AN) No.52, issue 2*

Responsibility for permitting aircraft to fly in the UK, whilst registered in another State, rests with the Secretary of State for Transport. However, the UK CAA issues Exemptions to Article 8(1) of the Air Navigation Order, which requires aircraft which fly within UK airspace to possess a Certificate of Airworthiness, to meet, in the case of European countries, an agreement, as detailed in AN No.52. This states that under the terms of recommendation INT.S.11/1 of the European Civil Aviation Conference (ECAC), adopted at the eleventh Intermediate Session of ECAC in June 1980, member States (which includes the UK, as a founder member of ECAC, and Estonia) accept home-built aircraft with a Certificate of Airworthiness or a Permit to Fly issued by another Member State, to fly in their country without any restrictions other than those stated in such documents. All ECAC Member States agreed to this recommendation. Since then, European Union (EU) legislative changes have removed constraints on aircraft ownership within the EU and it was regarded by the CAA that AN No.52 could, therefore, become a mechanism for importing to the UK foreign registered home-built aircraft which have not been shown to comply with UK safety requirements.

The UK CAA believes that the intent of the ECAC recommendation was to permit overflight, or short visits, by home-built aircraft to any ECAC member state and, as such, has amended AN No.52 to introduce a time limit to the General Exemption. The revised Exemption now requires that the aircraft owner shall provide specified information to the CAA for each visit to the UK. However, the owner is not required to gain CAA approval or authorisation before making the trip. Instead, the owner is required only to supply the information not later than 28 days after each trip has been completed. Provision has also been made for an applicant to make a case for a specific exemption, such as for an extended stay or to participate in public flying displays. Operational Safety Regulations imposed in the regulation of flying displays, under Article 70 of the Air navigation Order 2000, provides for the potentially greater risks involved in such events and imposes safeguards designed to ensure that aircraft are flown in a manner such that they do not endanger the public. However, it is possible that a major structural failure of an aircraft taking part in a public flying display would render it uncontrollable and likely not able to comply with the imposed safeguards.

## Analysis

### Cause of the wing failure

The evidence from the wreckage of the aircraft and the analysis of the video and still photographs of the accident, leaves no doubt that the fundamental cause of the break-up was the fatigue failure of the wishbone strut on the right side of the aircraft, which supported both the top of the right main landing gear strut the forward main lift strut of the right wing. The characteristics evident in the fracture surfaces of the failed wishbone strut show that the crack had already propagated through the greater part of the cross section, leaving only about 10% of the total load-bearing area of the strut intact, before the aircraft took off on its final flight. Consequently, the strut was already in a highly weakened and fragile state prior to the manoeuvre being undertaken when wing failure occurred. The final manoeuvre itself, comprising a relatively gentle turn to the right, would not have generated abnormally large loads in the strut. A subjective assessment of the video footage suggests that this manoeuvre probably would have loaded the wing to a slightly greater extent than the gentle climbing turn to the left which immediately preceded it, which is the likely reason that the failure did not occurred on take off or during earlier stages of the flight.

It is clear that the weakened strut must have been very close to the point of failure for some considerable time and not only during the earlier stages of the accident flight. Indeed, the evidence is that the final fracture of the strut, and the consequential wing failure. could have occurred virtually any time in the aircraft's recent history.

The metallurgical analysis has shown beyond any reasonable doubt that the fatigue failure originated in a weld repair, which was of poor-quality both in absolute terms and when compared with the quality of weld used in the original construction of the strut.

Attempts to establish correlation between the fracture growth pattern and the aircraft's flight cycles proved problematic, due primarily to a lack of detailed information about the typical loading pattern in the strut during a typical flight. However, the geometry of the strut and its associated wing and landing gear strut is such that it would have been subject to an overall tensile loading environment at all times, arising from both the landing gear vertical reaction loads and wing lift loads carried by the forward wing strut. This being so, one might reasonably expect the strut loading pattern to comprise a broadly steady state load whilst in flight, with relatively small perturbations due to turbulance superimposed on top of the overall lift-induced loads, separated by potentially larger peak loadings induced by the landing gear during touch-down. Whilst manoeuvre and severe buffet loadings in flight could potentially exceed the loads induced by the landing gear, taken overall it is considered most likely that the dominant loading pattern in the strut would have given rise to a banded pattern of fracture growth, with the bands comprising beach marks produced during each landing interspersed with finer striations associated with in-flight loads. If this assumption is correct, then the number of beach marks should reflect the number of flights during the period of crack growth, which in turn suggests that the crack was actively propagating for at least 169 flights, ie for most of the aircraft's life span of 191 flights.

Consideration was given as to whether the period when the aircraft had been subject to slipstream buffet on ground, whilst parked behind the Noratlas aircraft which was undergoing full power engine runs, may have significantly accelerated the fatigue growth. Superficially, the pattern of surface corrosion on the fracture surface suggested that the final period of growth after the crack had turned and was propagating longitudinally in the tube, could have been associated with this episode. However, the metallurgical examination did not reveal any significant change in the character of the fracture over this region, which might reasonably have been expected had this been the case, and on balance it was concluded that there was no evidence to suggest that the ground runs involving the Noratlas had actually accelerated the fracture by any significant extent.

Whilst the small region of fatigue found in the fuselage attachment spigot for the rear tube of the wishbone strut played no significant part in its final failure, per se, or the wing failure, the design of this fitting is a cause for some concern. Specifically, whilst the strut is pin jointed at its forward end and at the landing gear and wing strut attachments, here it is effectively a 'built-in' joint due to the tight fit between the rear wishbone tube and the attachment. Corrosion evident between the tube and the spigot made it so, even if there had originally been a small clearance. Potentially, this set-up could give rise to bending stresses in the spigot, both from in-service loading and from any misalignment of the components, which ultimately could result in fatigue cracking of the type observed on ES-XCL. A study of the photographs showing this fitting on the original Lindberg aircraft suggest that the spigot may have been swaged out to produce a deliberately looser fit. If this actually was the case, then it would have accommodated some change in alignment before bending stresses came into play, and consequently the original design of fitting may have been less susceptible to fatigue in the spigot fitting.

In summary, whilst a degree of uncertainty remains as to the precise correlation between the pattern of in-service loading and the fracture growth characteristics, the weight of evidence suggests that the fracture probably started actively propagating at an early stage in the aircraft's life, probably at around 20 flights. The nature of the fatigue origins, which clearly resulted from the physical structure of the poor-quality weld repair, are such that any initiation period would have been relatively inconsequential, and therefore fatigue propagation is likely to have begun very shortly after the weld repair was carried out. If the assumptions above are correct, then it follows that the weld repair is likely to have been carried out significantly before the ground incident in 1998, which the logbook indicates occurred after approximately 103 flights. This conclusion accords with the reported belief of the deceased pilot's family, that repairs to the aircraft following this incident did not involve any welding.

## Airworthiness implications of the failure

Whilst it is clearly apparent that the fatigue fracture initiated as a direct result of the poor-quality of the weld repair, on the available evidence it is not possible to conclude positively that the failed region of the wishbone strut in its original form, ie prior to it being weld repaired, would not have been susceptible to fatigue cracking at some stage; indeed, it is conceivable that the weld repair was prompted by the discovery of a crack in the original weld.

The wider airworthiness implications of the wing failure on ES-XCL are limited by the comparative rarity of the aircraft type involved. Nevertheless it would appear that a significant, albeit small, number of Ryan B1/B2/'Spirit of St Louis' aircraft have been constructed worldwide since 1927, including several based on a variety of original Ryan aircraft of similar generic type. Of these, some are currently active construction projects and others are airworthy (or potentially airworthy) specimens. At an early-stage in the investigation, it became evident that those involved with currently active projects and flying aircraft were expressing serious concerns about the airworthiness implications of this accident for their own 'Spirit of St Louis' replica projects. It was primarily for the benefit of these groups, operating under the auspices of a range of disparate airworthiness authorities, that the AAIB Special Bulletin S2/2003 was published as a means of promulgating, at an early stage, the preliminary findings establish from the on-site phase of the investigation.

Subsequent research suggests that there remains some uncertainty as to the precise form of construction used in the wishbone strut of the original Lindberg aircraft designed by Donald Hall, the chief engineer and designer of Ryan Airlines Corporation. Whilst his 'Spirit of St Louis' design was based loosely on the Ryan M2, it evolved ultimately into a very different aircraft in terms of its shape, size, weight, and in the form of construction used. Of particular significance, the increased wingspan of the Lindberg aircraft was accompanied by a wider landing gear track, achieved by moving the landing gear shock struts outboard of the fuselage side. These were supported by the wishbone strut and its associated bracing strut to the top of the fuselage frame, the equivalent of which failed in fatigue on ES-XCL. A similar landing gear configuration appears to have been employed subsequently on certain of the Ryan Brougham series of aircraft. No Ryan aircraft of this configuration are currently listed in the UK civil register, although it is believed that examples may still exist elsewhere.

It is understood that ES-XCL was built following the form of construction used in the replica aircraft at the San Diego Museum. From a study of photographs of the original Lindberg aircraft, there would appear to be minor, albeit significant, differences in the form of construction of the wishbone strut in the area of the failure. Specifically, it would appear that in the original construction, the two tubes forming the strut were jointed together within the region bounded by the two fish-plates; the tubes being welded to these plates as well as to each other. On ES-XCL, the two tubes forming the strut were joined together at a point just inboard of the fish-plates and, consequently the welded joint was formed between the tubes only; the side plates were welded separately onto each side of the primary (forward) strut.

Without resort to extensive stress analysis, it is not possible to determine which of the two designs is preferable, but the original Lindberg aircraft configuration is likely to have provided a stiffer and stronger connection overall. It is unlikely that the load paths and the corresponding stresses within the original strut will bear more than a superficial similarity to those in the design of strut used on ES-XCL. However, regardless of the relative merits and of the two forms of construction, the fact that the fatigue fracture had propagated through approximately 90% of the cross section before final failure occurred shows that the static strength of the strut on ES-XCL was more than adequate. It also suggests that this design of strut will be able to accommodate a visibly significant crack at this location, provided that the actual joint is not enclosed by the strut tube fairings, which would preclude a visual inspection. It is likely that a crack at this location would be discoverable before it reaches a critical size, possibly by simple visual inspection, but almost certainly when using dye-penetrant methods, provided that the inspection schedule makes adequate provision for such inspections and that they are properly implemented.

In summary, the specific fatigue failure on ES-XCL was caused by the poor-quality weld repair, and consequently there do not appear to be any direct implications for other replica aircraft of this design currently operating. However, aircraft using the original Donald Hall design of strut may also be vulnerable to fatigue cracking at this location. Therefore, given the structurally critical nature of the strut, regular inspection of this area would appear to be a sensible precaution regardless of the particular form of construction used.

### Inspection and maintenance of ES-XCL

It is significant that the maintenance schedule for this aircraft contained no reference to any form of structural inspection or maintenance, or even to any inspection relating to the primary flying controls. The log book, which would normally be expected to contain entries logging every significant maintenance activity carried out on the aircraft, contained no such entries beyond the briefest record of the dates of inspections carried out, and the single reference to the aircraft being damaged and dismantled for repair in 1998. As a consequence, it has not been possible to establish when the critically significant weld repair was carried out, or the reasons for the repair, or to determine who carried out the repair.

## Safety Recommendations

As the omission of an effective regime of inspection and preventative maintenance was apparent from the aircraft's documentation at the time the aircraft was certificated, this accident calls into question the process which permits an aircraft of this type to operate in the UK and at a public flying display. Specific inquiry into the quality of the regulatory function underpinning airworthiness oversight in the State of Registry by another State, both of whom are members of ECAC, is not conducted, as the airworthiness standard of aircraft such as ES-XCL is assumed to be acceptable. This was not the case with ES-XCL.

It is therefore recommended that:

### Safety Recommendation 2003-115

The Civil Aviation Administration of Estonia should review their regulatory function, which underpins the airworthiness oversight of aircraft such as the 'Spirit of St Louis' replica that are issued with a Limited Certificate of Airworthiness in the Experimental category, so as to be assured that such aircraft are maintained to an internationally agreed standard, especially if such aircraft are based in a different State.

Despite the safeguards imposed on the manner in which aircraft are flown at public flying displays, structural failure of this aircraft rendered it uncontrollable, and it crashed into an industrial area, open to public access, adjacent to the airfield. The nature of the defect in ES-XCL was such that the structural failure was likely to have occurred at any time in its recent flying history, as the aircraft was in a gentle turn when the failure occurred, and not being manoeuvred aggressively.

It is implicit that if such an aircraft as ES-XCL has been issued with the appropriate documentation by the State of Registry, which is a member of ECAC, then the airworthiness of that aircraft is not in question. Accordingly, there is no procedure by which the CAA carries out a physical inspection of such aircraft, or assesses the underlying maintenance/inspection requirements of a foreign Authority, especially as some 400 to 700 requests for exemptions are received annually. However, should such an aircraft wish to operate for an extended period within the UK, then it would need to be transferred to the UK Register and comply with the appropriate UK Airworthiness requirements. A major contributory factor in this accident was the lack of any effective regime of inspection and preventive maintenance, or record thereof, directed to the aircraft's primary structure and flying controls.

It is therefore recommended that:

### Safety recommendation 2003-116

The CAA, in conjunction with the Department for Transport, should review the process by which foreign registered replica homebuilt aircraft are granted Exemptions to Article 8(1) of the Air Navigation Order, which permits such aircraft to fly within UK airspace and at public air displays, without an appropriate Certificate of Airworthiness. Such a review should consider the possibility of requesting specific assurance from the State of Registry that such aircraft are maintained, and records have been kept, in accordance with the requirements of that State.