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Barracuda Aircraft wreck site, Solent, Hampshire

Examination, analysis and conservation of artefacts recovered from a Second World War aircraft wreck

Sarah Paynter, Francesca Gherardi, Angela Middleton, Quita Mould and David Morris

Investigative Science Team

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Summary

Leather artefacts constituting personal belongings as well as aircraft components and a polymer strip were recovered from the wreck of an unidentified Barracuda aircraft by Wessex Archaeology in 2019. The question of identifying this wreck, from among at least two Barracuda Mk II aircraft known to have been lost in the vicinity, was addressed by analysing paint remnants on these components and comparing the results to paint samples from other Barracuda aircraft made by different manufacturers. X-ray fluorescence (XRF) and Fourier transform infrared (FTIR) spectroscopy analyses were used. Objects from the site were furthermore described and conserved for archive deposition. These objects and components will form part of the “Barracuda Live: The Big Rebuild” at the Fleet Air Arm Museum in due course.

Contributors

The analytical work was undertaken by Sarah Paynter and Francesca Gherardi. The conservation work was undertaken by Angela Middleton. Images were taken by Sarah Paynter and Angela Middleton. Graphs were produced by Sarah Paynter, Francesca Gherardi and Angela Middleton. The work on the leather was undertaken by Quita Mould. The specialist background to the aircraft and samples wAS provided by David Morris (Principal Conservator (Naval Aircraft), Fleet Air Arm Museum).

Acknowledgements

We are grateful to Diana Davis (Head of Conservation, National Museum of the Royal Navy) for approaching us to undertake this work and for her support throughout. The 3D digital microscope used in this study was purchased thanks to AHRC Award AH/V011758/1.

Front cover image: Detail view of shoe insole 5545, after conservation, showing date and shoe size imprint.

Archive location

The physical and digital archive is held by the National Museum of the Royal Navy, Portsmouth.

Date of research

The work was carried out between March 2021 and October 2023. The report was finalised in April 2024.

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Introduction

The wreck of a Mk. II Fairey Barracuda aircraft (referred to as the “Solent Wreck” for the purposes of this report) was located on the HVAC cable corridor of the IFA2: Interconnexion France-Angleterre cable route (Wessex Archaeology 2020). The extant remains of the wreck were recovered in 2019 by James Fisher Marine Services under the supervision of the Retained Archaeologist, Wessex Archaeology, using a methodology approved by Historic England under licenses provided by the Ministry of Defence (MOD) under the Protection of Military Remains Act 1986, and the Marine Management Organisation (MMO). About 65% of the aircraft was recovered and is being conserved at the Fleet Air Arm Museum (FAAM).

The Fairey Barracuda aircraft was a British torpedo and dive bomber designed by Fairey Aviation but manufactured by several companies in addition to Fairey, including Blackburn Aircraft and Boulton Paul. In the Second World War more than 2500 Barracuda aircraft were delivered to the Fleet Air Arm (the naval aviation component of the United Kingdom’s Royal Navy). The Solent Wreck is thought to be one of two possible Mk II candidates whose crash locations are noted in Ministry of Defence or National Archive records. These two candidates, identified by Wessex Archaeology and FAAM researchers, are described in the Wessex Archaeology report (2020):

The two aircraft were lost within four months of each other, are the same mark of aircraft, and were both lost due to engine failures on take-off.

- *One is BV739, a Blackburn built Fairey Barracuda Mk. II. This was delivered to 15 Maintenance Unit (MU) from the manufacturer at Brough on 15 July 1943. On 29 September 1943 it lost power on take-off and ditched in shallow water.*
- *The second is LS473, a Fairey built Mk. II aircraft, that failed to obtain climbing speed on take-off on 6 January 1944 whilst being flown by Sub Lieutenant (Air) Sandes Royal Naval Volunteer Reserve (RNVR). It had only been delivered to 15 MU from the manufacturer’s on 24 November 1943, possibly as a replacement for BV739.*

The Wessex Archaeology report concludes that the aircraft was probably LS473, built by the Fairey Aviation Company’s factory at Heaton Chapel, Stockport, based on ‘the internal primer paint scheme, the torpedo crutch, the identity tags and modification plates found on the tube work of the cockpit and engine bearers, the quality control stamps on several parts recovered; and most significantly the engine plate’ (Wessex Archaeology 2020). A degree of uncertainty remains, however, because the crash location records may not be comprehensive and there remains a possibility that other Barracuda Mk II aircraft were also lost in the area.

Aims

The leather objects from the recovered Barracuda wreckage were brought to the Historic England, Fort Cumberland Laboratories for conservation, recording and further investigation, particularly of the paint remnants surviving on some of the objects. Specifically, the aim of the analysis was to determine if the paint composition could be used to confirm the identification of the Solent wreck aircraft as a Fairey-built aircraft, increasing the likelihood that the wreckage was from LS473, flown by Sub Lieutenant (Air) Sandes. A second avenue of investigation was identifying any distinctive characteristics of the footwear found with the wreckage, given that Sub Lieutenant Sandes was Canadian, and so some of the recovered items might be Canadian issue.

Material examined

The leather artefacts

The leather from the Barracuda aircraft excavation was received wet and was clean. Some pieces had marine encrustations and concretions attached. The assemblage consisted of personal items, such as shoes, as well as aircraft fixtures and fittings, such as a leather seat cover. The leather was in good condition, strong and still flexible.

The leather items and their probable identifications are listed in Table 1. Seams on the leather objects have failed however and as a result certain items had become disjointed (for example 5353, 5767.1 - 4). In the case of the shoes there is a degree of uncertainty about how many shoes are present (see Leather identification below), which is indicated by a question mark in Table 1. Metal fittings attached to the leather were covered in slight corrosion products and metal soaps (the organic salts resulting from the interaction of fatty acids and metal cations)**.** One shoe (5768) contained a large concretion on the underside of the sole.

Table 1: List of leather artefacts for conservation and their probable identification; a question mark indicates a tentative identification.

Aircraft		
	Artefact Number	Detailed Name
Seat components	5651.1	Front panel
	5651.2	Back panel
	5651.3	Side panel
Matching straps	5753	Rudder pedal straps?
	5732	
Leather gasket	5753.O	
Leather sleeve	5767.1-4	
Flanged leather panel	5651.4	
Other equipment		
Fastening strap	5753.N	
Polymer textile	5753.X	
Footwear		
Shoe 1	5768	Sole and upper (right foot)
	5752	Left quarter
	5753.D	Left lining
	5753.R	Right quarter lining
Shoe 2	5565.1	Vamp with broad arrow
	5565.2	Counter
Shoe 3	5353	Insole
Shoe 3?	5547	Sole
Shoe 4?	5545	Shoe bottom

The associated paints and polymers

Some of the leather artefacts had remnants of paint and adhesive as well as metal fittings, still attached. Paint remains were found on both the flesh- and grain-side of the leather, whilst the adhesive was only found on the flesh side. These adhering materials, summarised in Table 2, were chemically analysed, either *in-situ* on the object or, when it was not possible to access the area of interest directly on the artefact, small samples were collected for separate analysis. A piece of patterned polymer was also recovered.

Table 2: The analysed items from the Solent wreck aircraft (Figures 2, 4, 6, 7, 10-13 and 19).

Object number	**Description**	**Analysed component**
5651.3	Leather seat plus adhesive	Adhesive
5651.1	Leather seat plus adhesive	Adhesive
5651.4	Leather with adhering paint and rivet holes	Paint and metal fittings
5767.1	Leather with adhering paint and rivet holes	Paint
5767.2	Leather with adhering paint and rivet holes	Paint
5767.3	Leather with adhering paint and rivet holes	Paint
5753.N	Leather with adhering paint	Paint
5753.X	Patterned polymer	Polymer with white particles

The reference paint samples

Additional reference paint samples from other Barracuda aircraft were provided by David Morris (Fleet Air Arm Museum). These were analysed to determine whether the paint schemes from the different subcontracted manufacturers of the Barracuda aircraft could be chemically differentiated. The samples (Table 3) were from Fairey (serial numbers LS931 and PM870), Blackburn (serial number unknown) and Boulton Paul (serial number DP872) aircraft. A further sample from the Solent Wreck, from the metal frame, was also provided.

Table 3: The analysed paint samples from different aircraft manufacturers.

Manufacturer	Serial number	Sample number	Description
Boulton Paul	DP872	DP872-1	Green paint from cockpit (on metal)
		DP872-2	Combing in front of windshield portside (on metal)
		DP872-3	Cockpit structure from portside torpedo control (on metal)
Fairey	PM870	PM870	Paint on metal from cockpit
Fairey	LS931	LS931-1	Paint on metal from cockpit floor structure
		LS931-2	Detached paint from cockpit floor structure
Blackburn	Unknown	BB-1	Leather sleeve from control column with paint on both sides
Solent wreck	Solent wreck -	WF-1	Detached paint samples from TAGs (Telegraphist Air Gunner) window frame

Primers and paints applied to aircraft

Multiple coatings would have been applied to the metal components of the aircraft, including an initial surface treatment or primer to inhibit corrosion and help subsequent paint layers adhere, followed by one or more further paint layers. Methods of preventing corrosion might include chemical treatments, electroplating, cladding or the application of primers containing corrosion inhibitors, such as chromate compounds (Montané et al. 2023). The primer layers are often very thin and can be difficult to detect even in a prepared paint section. From the curators' observations at FAAM, the Barracuda aircraft discussed here typically (but not always) have a thin chromate wash applied as a primer to aluminium components, which has a yellowish colour.

Studies of European and American Second World War aircraft have found that a monochrome interior scheme is typical (Montané et al. 2023): in the case of the Fairey- and Blackburn-built Barracuda aircraft the cockpit interior was typically given a grey lower coat, and a black topcoat. Other internals areas of the aircraft frame and fuselage (including inside the wing and tail areas) typically had a silver topcoat in Fairey-built aircraft but were often left grey in Blackburn manufactured aircraft. Fairey describe the paint as a ‘synthetic pigmented varnish’. The Boulton Paul-built aircraft typically had a cream/beige lower coat applied, followed by a dull green topcoat in the inner cockpit area, but were left as beige for other internal areas of the frame and fuselage.

The exteriors had further paint layers in multiple colours, such as green, black, blue and tan, which was dependent on many factors. In this study, both aircraft under consideration as candidates for the Solent wreck were relatively new, and the colour scheme is more likely to be the one applied initially by the manufacturer. During service however, aircraft might be repainted during repair, and if the aircraft was moved to another squadron or unit, or a different theatre of war requiring a different camouflage scheme. The type of paint used might also vary over the course of the war according to the resources available to the maintenance unit, wherever they were based.

In this report many of the paint analyses were undertaken without detaching the paint from the component. This illustrates that future researchers would be able to analyse paint schemes on aircraft *in-situ*, using portable XRF, and compare with the results from this study to identify the products of different aircraft manufacturers. The limitations of this approach, however, are that it is difficult to accurately identify distinct layers of overlying paint without preparing a cross section. Since no paint sections were prepared, priming treatments on the metal components could not be identified with certainty. Where it was possible to differentiate multiple layers of paint, however, these have been described by colour and analysed individually; the terms undercoat and topcoat are sometimes used to differentiate the lower and upper layers. For the majority of the Barracuda parts examined here, only the lower paint layers (grey or beige) survived.

Methods

Leather recording

The leather was examined wet. A basic record of the material was made, noting all the diagnostic features present. This included measurement of relevant dimensions and species identification where possible. The technological descriptions of the items given here are for inclusion in the site archive. The material is summarised below incorporating the contextual information available at the time of writing.

All measurements are in millimetres (mm), + indicates a measurement of an incomplete item. As the material was examined wet, no allowance has been made for any shrinkage post drying.

Leather species were identified by hair follicle pattern using low-powered magnification. Where the grain surface of the leather was heavily worn identification was not always possible. The grain pattern of sheep and goat skins are difficult to distinguish and have been grouped together as sheep/goat when the distinction could not be made. Similarly, the term bovine has been used when any uncertainly arose between mature cattle hide and immature calfskin. Shoe bottom components are assumed to be of cattle hide unless stated otherwise.

The terminology used in the catalogue is that in common use in the archaeological leather literature (for example Volken 2014) with the addition of terms used by the contemporary shoemaking trade (Garley 2014) as appropriate. In the text 'shoe' is used as a generic term describing all types of footwear including boots. The term 'surface coating' has been used for a material on the surface of the leather thought to be paint. Similarly, the term 'adhesive' has been used.

3D digital microscopy

The artefacts and the samples collected from the artefacts were observed by 3D digital microscopy, using the Keyence VHX7000 3D digital microscope across a range of magnifications.

Micro X-ray fluorescence (µXRF) spectroscopy

Samples collected from the components in the assemblage were analysed using a bench-top Bruker M4 Tornado micro X-ray fluorescence (µXRF) spectrometer with beam conditions of 50kV and 400µA. This is a non-destructive surface analysis technique and where possible the objects were placed in the machine in their entirety. Where the objects were too large or irregularly shaped for the XRF chamber, then small samples were removed and analysed separately. Small flakes of paint were also removed from the TAGs window frame of the Solent Wreck remains housed at the FAAM for analysis (Tables 1 to 3). The samples from the other manufacturers of Barracuda aircraft, which were used for comparison (Table 2), were provided as painted pieces of metal, which were put into the XRF intact. Being a surface analysis technique, the results can be affected by weathering and alteration of the material post-burial and by adhering dirt and corrosion products. The substrate beneath thin layers of paint may also be detected; here these were aluminium alloys in most cases.

Fourier transform infrared (FTIR) spectroscopy

Samples collected from the leather and metal objects were also investigated by Fourier transform infrared (FTIR) spectroscopy to obtain qualitative chemical information on some of the characteristic compounds of the organic materials and the paints. The FTIR spectra were acquired by a Spectrum 100 spectrometer (Perkin Elmer) equipped with a DTGS detector, fitted with Attenuated Total Reflection (ATR) diamond-ZnSe crystal accessory. Spectra were recorded over the range 650-4000 cm-1, with a resolution of 4.00 cm-1, and were averaged over 32 accumulations.

Portable X-ray fluorescence (pXRF) spectroscopy

Many of the larger leather artefacts could not be fitted into the chamber of the Bruker Tornado µXRF due to their size, so these were analysed using a portable XRF (pXRF). The portable XRF is a Thermo Niton XL3t, which was used in CuZn mining mode, with each analysis taking 60 seconds, made up of the following settings: 10 seconds main, 30 seconds low, 10 seconds high and 10 seconds light. The leather artefacts were placed on a granite slab during the analysis to prevent X-rays passing through the leather and wooden table-top, both for safety reasons and to provide a background of known composition in case X-rays from the substrate were also detected. The granite is composed predominantly of compounds of aluminium and silicon and no contribution from this background material was noted in the results.

Conservation methodology

X-radiography

Alongside microscopic examination, leathers with metal components or concretions were imaged by X-radiography, for documentation purposes but also to inform cleaning (Figure 1). X-radiography was undertaken using a Comet MXR320/23 CP X-ray machine in a walk-in bay, together with the Computed Radiography (CR) equipment: a Kodak Industrex HPX-1 Plus scanner and Kodak Industrex XL Blue Digital Imaging Plates (DIP) with copper screens. Imaging plates were scanned at 25µ resolution. Quality was ensured using an Image Quality Indicator (IQI): Duplex wire type EN462-5. Carestream Industrex Digital Viewing Software was used to scan, view and process the digital X-ray images.

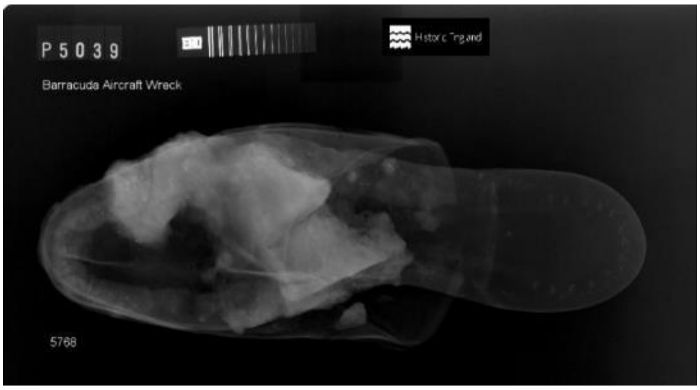

Figure 1: X-radiograph of shoe 5768, visualising the concretion attached to the underside.

Cleaning

The leather was cleaned mechanically under running water, using sponges and brushes. An ultrasonic scaler was used around metal fastenings for loosely adhering corrosion products. Any hard concretions were removed by air-scribe.

In agreement with the National Museum of the Royal it was decided to leave any remains or residues on the leather if this could be used as evidence of use or give information on the placement in the aircraft.

Impregnation and drying

Archaeological leather only rarely survives drying without prior impregnation. The leather was impregnated with 30% polyethylene glycol (PEG) 400 over 2 weeks. Following PEG impregnation, the leathers were briefly rinsed, dabbed dry and pre-frozen for one week, at

−30°C in a domestic chest freezer, before vacuum freeze-drying, which eliminates drying stress as the frozen water is removed by sublimation. Freeze-drying commenced in a LyoDry Midi Freeze Dryer s/n F012. The chamber temperature was set to −30°C and the condenser temperature to −45°C. The drying cycle was interrupted regularly to weigh the leathers and examine them for flexibility, distortion, and surface changes. The endpoint was determined when weight loss plateaued or slowed down significantly. Drying took about 31 hours. Only slight, powdery PEG residue was present after drying, which was removed by brushing (Figure 2).

Figure 2: Leather shoe 5768 before conservation (left) and after conservation (right).

Consolidation

Following impregnation and drying, some of the paint remains became brittle and flaky, and in some cases had become detached. Where still attached, these were consolidated with 10% Paraloid B44 in acetone (w/v), applied by brush. Others were collected and retained as samples.

Re-shaping

During freeze drying, leather will shrink a bit and some pieces may experience distortion. One such example was shoe insole 5353. This was gently re-shaped by placing it inside a closed system (box with tight-fitting lid) over a semipermeable membrane covering a box filled with water (Figure 3). Over the course of a couple of days the humidity inside the box rose and water molecules entered the leather fibre structure, making it supple. At this point it was sandwiched between layers of polyethylene foam (Plastazote®) and fluted polypropylene sheets (Corex®) and gently straightened out again (Figure 4). The sandwich boards were secured with ties and tapes and the leather placed back into the box, with the lid slightly open. As the water slowly evaporated, the humidity reduced to ambient, and the leather remained in the more sympathetic shape appropriate for an insole.

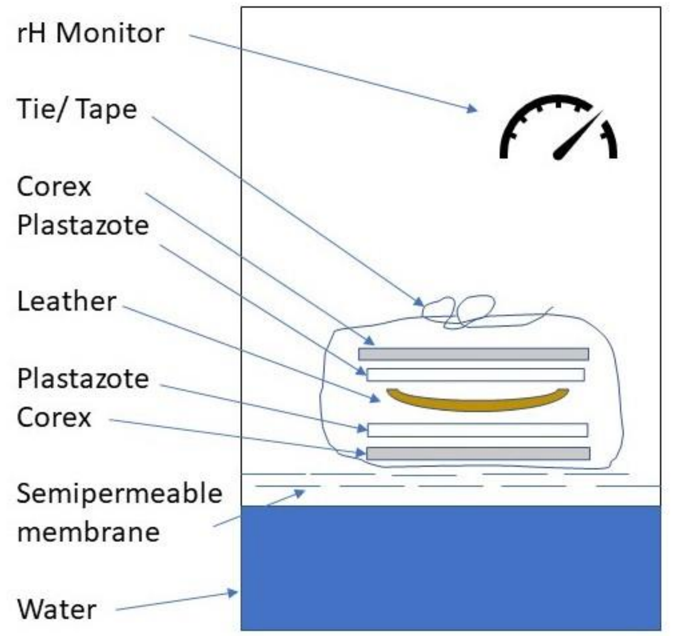

Figure 3: Schematic representation of set-up for reshaping insole 5353 (graphic by Angela Middleton).

Figure 4: Shoe insole 5353 during re-shaping: after moisturising and regaining suppleness (left), with the re-shaping sandwich being applied (centre), inside the humidity box and with the sandwich attached (right).

Results

Description of leather artefacts

Aircraft components

Researching and identifying leather aircraft components was outside the scope of this report but suggestions for the identification of these items are given here. Easily recognisable were the front panel (5651.1), back panel (5651.2) and side panel (5651.3) from the leather cover of the TAG bucket seat (Wessex No 5651, Wessex Archaeology 2020, plate 55). Two matching straps (5753, 5732) are likely to be what are described in the gazetteer of finds (Appendix 3 Wessex Archaeology 2020) as rudder pedal straps (Wessex No 5753). A leather gasket (5753.O) was also identifiable. Four sections (5767.1-.4) of a cone-like leather 'sleeve' or cover for a projecting lever, such as a joystick, have metal rivets by which it had been attached to the body of the aircraft. A flanged leather panel (5651.4), moulded to cover and secure a cylindrical item, has similar rivets; both covers have remains of the same paint coating around the rivets.

Other equipment

A fastening strap (5753.N) comes from a substantial box or case, the angled strap of cattle hide is robust and was secured by metal rivets rather than stitching. It has two large oval holes, originally with metal facings or eyelets, through which a metal fastening on the front of the box passed. Two fastening holes may suggest that the contents varied, and it needed to be adjustable.

The footwear

Initial examination suggested that three shoes are represented by the shoe parts recovered, but there may be four. It is certain that at least two shoes are present (shoe 1: 5768, 5752, 5753.D/R and shoe 2: 5565.1/.2); they are of differing constructions and so come from two separate pairs of shoes. An insole (5353) and a sole (5547) may come from a third shoe. In addition, the shoe bottom (5545) assumed to belong to the upper components of shoe 2 (5565.1-.2) found with it, may come from a different shoe: the upper vamp (5565.1) and quarters with a distinctive reverse 'P' shape side seam, appear to be of riveted construction, while the shoe bottom (5545) found associated with them is of welted construction.

Two complete insoles, both for the right foot are present, one (5545) is an Adult 7 in an English shoe size, the other (5353) is an English shoe size 10 and is stamped as such at the seat. The smaller insole (5545) is stamped Y 1924 8; being marked 8 but measuring a

7 suggests it may be a product of the USA or Canada. It cannot be assumed that 1924 indicates a date as it could potentially be a military store or part reference number.

The shoe parts recovered that could be associated are described below:

Shoe 1

A complete sole of riveted construction with the vamp still attached (5768) for the right foot (Wessex Archaeology 2020 Wessex plate 68). The side seam on the shoe vamp is distinctive being sewn with an inverted ‘U’-shaped line of stitching. This side seam is also present on a left quarter (5752) and lining (5753.D), and a right quarter lining (5753.R) suggesting they belong to the same shoe.

Shoe 2

A complete vamp (5565.1), with an integral tongue and stitching in the shape of a broad arrow below, is shown along with the counter (5565.2) on plate 43 (Wessex Archaeology 2020). They were found associated with a complete shoe bottom of welted construction for the right foot (5545) (Wessex Archaeology 2020, plate 42) (but see possible shoe 4 below). The right shoe quarter with three lace holes (not examined) shown in plate 41 (Wessex Archaeology 2020) can be seen to have the same distinctive side seam, a reversed ‘P’ shape, as the vamp (5565.1). These four components are described as flying boot fragments 5545 (Wessex Archaeology plates 41, 42, 43), recovered along with a fragment of a possible jumper (5505) (not examined and conserved as part of this project) during excavation of the port wing (Wessex Archaeology 2020, 18 section 3.4.32). Unfortunately, the right quarter with a front opening with three lace holes, seen in Wessex plate 41 is currently missing and was not examined.

Possible shoe 3

The complete shoe bottom of welted construction for the right foot (5545) found associated with shoe 2 (5565.1-.2) appears to be of a differing construction (welted) to the vamp 5565.1 (riveted) and so likely to come from a different shoe.

Possible shoe 4

A complete insole (5353) and sole (5547) may be associated.

All the shoe parts identified were recovered from the port wing but it remains possible that some of the shoes found at the crash site may not derive from the Barracuda wreck itself. The components of ‘shoe 2’ (Wessex plates 41, 42, 43) and ‘possible shoe 4’ (Wessex plate 42) were thought to be fragments from a flying boot of RAF Escape Boot design (Wessex Archaeology 2020, 18), probably due to the presence of the three lace holes on the front opening of the quarter shown in plate 41. Comparison of the description and accompanying images of the 1943 Escape Boots provided by the Imperial War Museums (https://www.iwm.org.uk/collections/item/object/30015916) suggests that the Escape Boot (EQU 3868) varies in several regards to the footwear represented by the shoe parts found. Escape Boot (EQU 3868) has a double row of stitching running across the vamp at the toe in the manner of a mock toe cap; the vamp has downward curving wings and a separate tongue; the lace holes have metal eyelets. These are all features lacking on the vamps (5768 and 5565.1) recovered from the Solent wreck. It is possible that variations in Escape Boot design may have been in production which might account for the differences seen. While the separate sheepskin boot leg of the Escape Boot (EQU 3868) may not have survived the marine environment, one might expect the metal zip to be present.

Identification of tanning method

Chrome tanning was developed in the later 1800s and came to replace traditional vegetable tanning during the 20th century for many applications with certain exceptions, such as shoe soles (Covington 1997). Sometimes multiple tanning methods are used on a single object. Chromium is a heavy element and easily detected by portable XRF (Shelley and Huang 2008) so a selection of the leather objects from the Solent Wreck were investigated by pXRF to determine the method of tanning used. These were compared to some reference materials, which were:

- Medieval vegetable tanned leather from an archaeological site (Novgorod, Russia)
- Modern chrome-tanned sheep leather
- Modern vegetable-tanned goat leather

The results were conclusive with respect to chrome tanning: the level of chromium in the modern chrome-tanned sample was around 40,000 ppm and in the chrome-tanned Solent Wreck samples between 11,700 to 20,000 ppm, whereas the vegetable-tanned modern, archaeological and Solent Wreck samples contained either no detectable chromium or a very small amount (less than 190 ppm) (Table 4). From the Solent Wreck assemblage, the leather fittings from the aircraft and the upper of shoe 5768 were chrome-tanned; whereas none of the shoe soles were chrome-tanned, as is typical.

A further observation is that the archaeological leather consistently contains elevated levels of calcium (up to 3 wt%) and iron (up to 2 wt%) relative to modern samples (Table 4). This may be due to the precipitation of iron and calcium from the surrounding environment forming mineral phases within the porous leather structure, but this requires further investigation. Similar raised levels of iron and calcium have been noted previously

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in analysis of a gilded book cover from another marine wreck site, *The London*, (lost in 1665) (Analytical Methods Committee 2021).

There are also elevated levels of copper (up to 3500 ppm) and zinc (up to 4000 ppm) in the leather from the Solent Wreck, possibly due to the proximity of metal components and fittings and the porosity of the material (Table 4). Copper and zinc are mobile elements often found at raised levels in areas of concentrated human activity (Bintliff and Degryse 2022).

Lead is also slightly raised in the Solent Wreck material, with the highest levels detected in shoe 5545. The absolute figures reported may also be affected by the thickness of the leather and the texture of the surface, however, and the impact of different colourants or recent conservation treatments is unknown.

Chlorine was detected in the reference modern leather samples, both chrome and vegetable tanned, but was not detected in any of the archaeological or Solent wreck material.

The Solent wreck leather objects were all analysed post-conservation and it has yet to be established whether any of the conservation treatments may contain or introduce trace amounts of chromium. Nevertheless, the disparity between the chrome-tanned and vegetable-tanned Solent wreck objects, and in medieval and modern leather, was very clear from the chemical analyses.

Materials identification

Polymer 5753.X

A single piece of polymer, with a scale pattern in white and black, was also recovered (5753.X) (Figure 5). The pattern resembles reptile skin with a dark cross hatch on a white ground.

Figure 5: Patterned polymer, possibly edging, 5753.X.

XRF analysis detected high levels of chlorine, likely to be a constituent of the polymer. The white opacity is due to titanium oxide (with minor barium) and the dark areas are coloured by an iron-containing clay-type mineral, as alumina and silica were detected (with minor chromium).

FTIR analysis of a sample from 5753.X shows the object is made of poly(methylmetacrylate) (Figure 6) and the presence of chlorine suggests it is a haloacrylate. Haloacrylates are substituted with a halogen atom, usually chlorine. They have been synthesised since 1938 and they are harder, stronger and with higher softening temperature compared to normal acrylics. These polymers were probably used because of their flame-retardant properties. In 1939, Imperial Chemical Industries in UK produced this polymer and during the war, the synthesis was optimised by different companies in the USA (National Institute of Industrial Research 2005). In the sample some white particles were also observed and identified as polyethylene (Figure 7).

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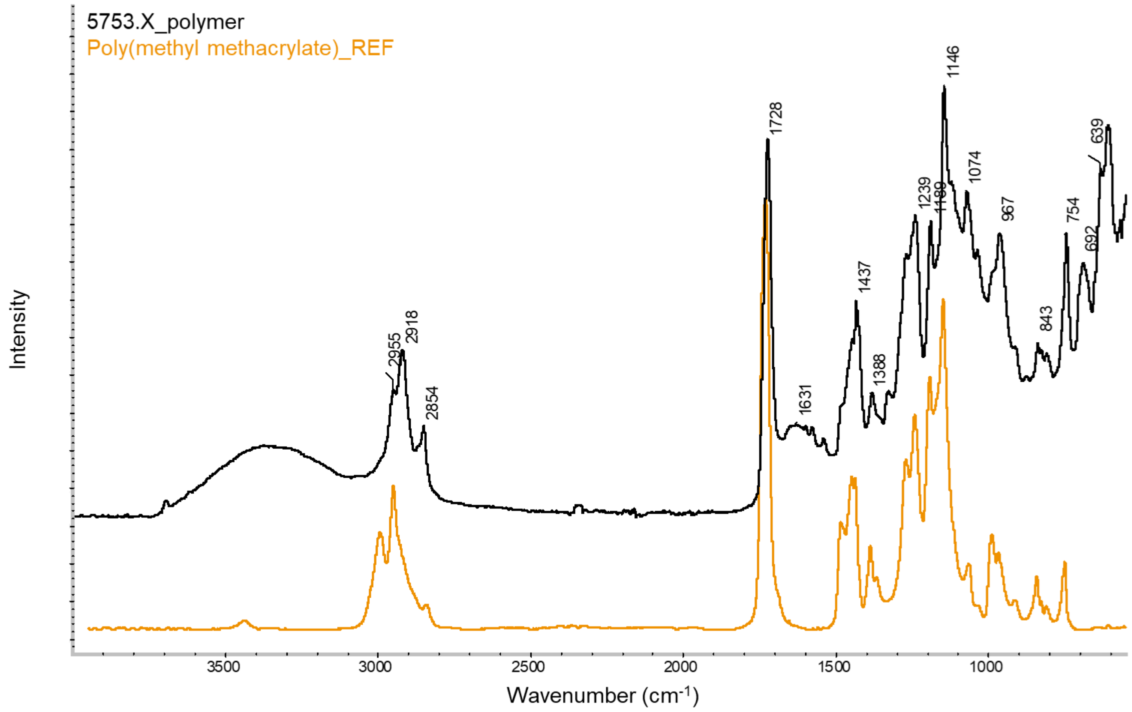

Figure 6: FTIR spectrum of the sample of polymer 5753.X identifying polymethyl methacrylate.

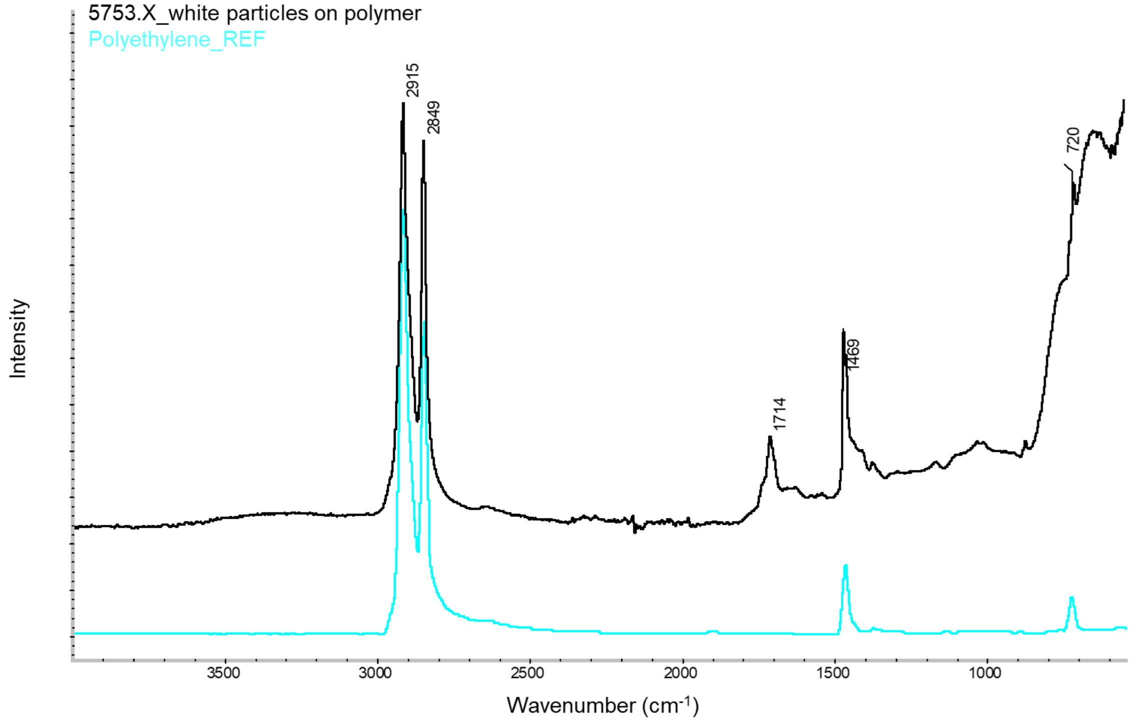

Figure 7: FTIR spectrum of the sample of polymer 5753.X identifying polyethylene as the white particles on the material.

Adhesives

Several of the leather artefacts had the remains of a flexible, semi-transparent adhesive around their edges on the flesh side of the leather (eg. 5651.1 and 5651.3). These remains were sampled and analysed using FTIR for identification (Figures 8 and 9).

Figure 8: Part of the seat component 5651.1, leather (flesh side) with latex around the periphery.

Figure 9: Part of the seat component 5651.3, leather (flesh side) with latex around the periphery.

FTIR analysis found that adhesive samples from 5651.1 and 5651.3 are made of latex, a natural rubber based on polyisoprene (Figures 10 and 11); reference spectra of papaya latex and polyisoprene are added for comparison. Inorganic additives (silicates) were added to the polymer as fillers.

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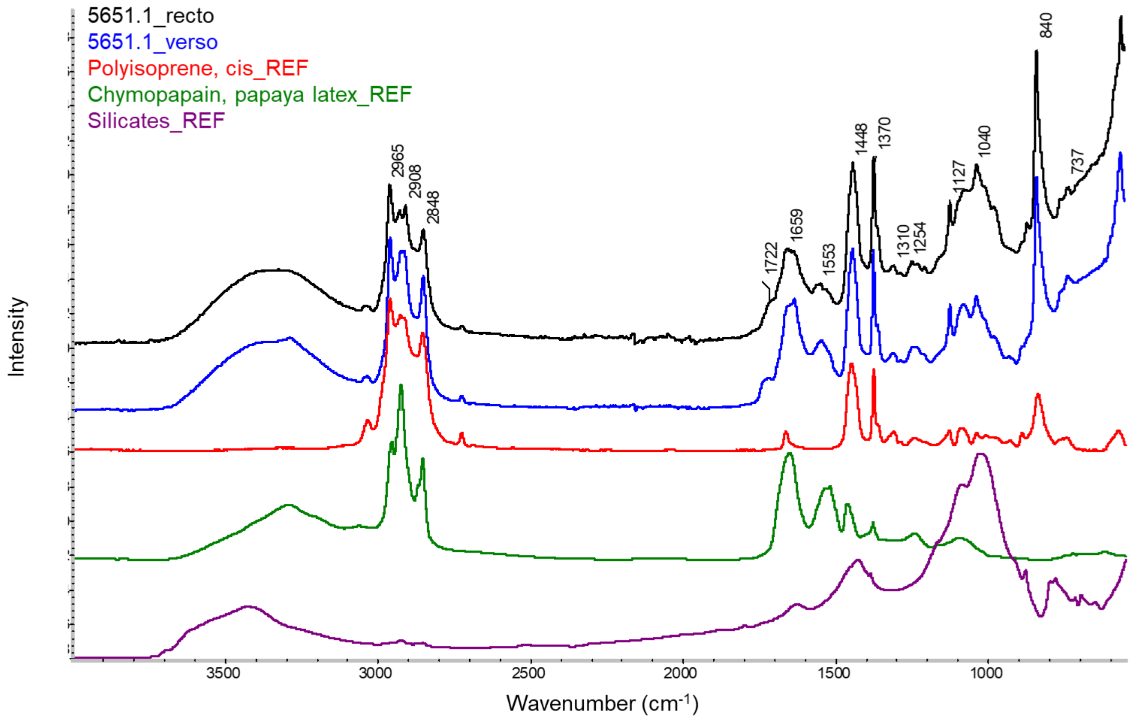

Figure 10: FTIR spectra for both sides of the adhesive sample collected from 5651.1 with reference spectra.

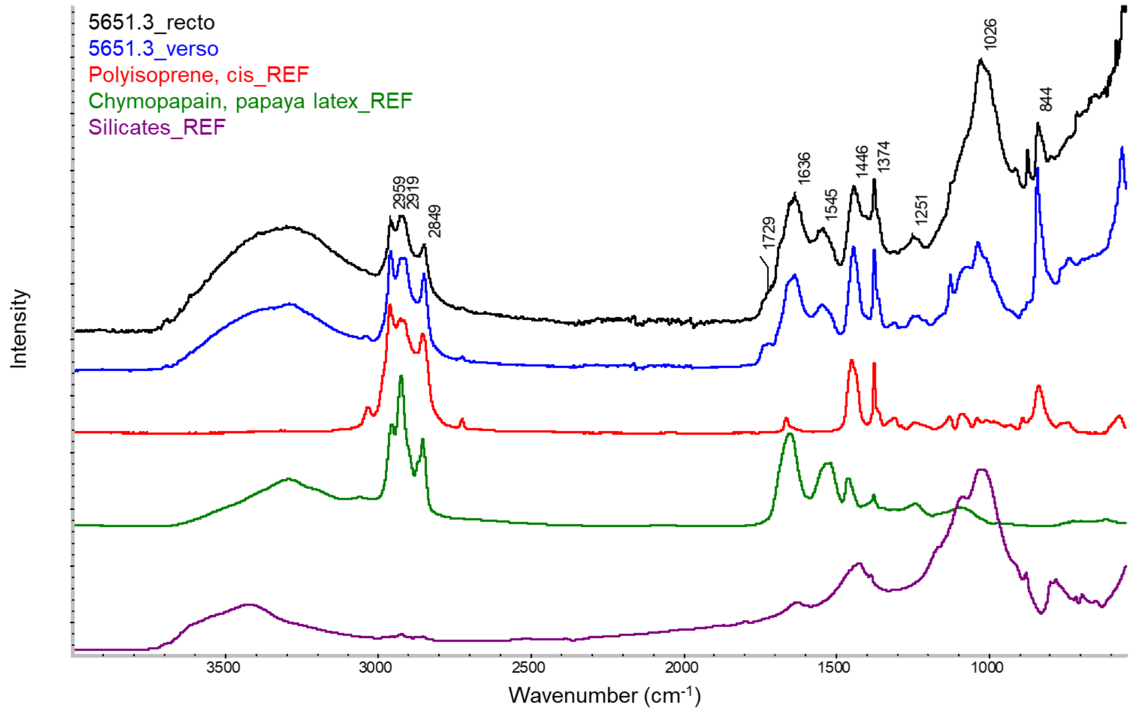

Figure 11: FTIR spectra for both sides of the adhesive sample collected from 5651.3 with reference spectra.

Metal fixtures

Some of the leather objects had metallic fixtures. The metal fittings in 5651.4 were analysed using µXRF (without vacuum) and found to be an aluminium alloy (Figure 12).

Paint on leather aircraft components

The internal cockpit colour scheme of the Solent Wreck was grey. The remains of a glossy, brittle, grey paint were present on many of the leather aircraft components recovered from the wreck (eg. 5651.4, 5767.1, 5767.2 and 5767.3) (see Tables 1 and 2 for descriptions and Figures 12-15), mainly on the reverse (flesh side) of the leather pieces and often surrounding the fixtures. It appears that this grey gloss paint was applied originally to metalwork, and that it was transferred to some of the leather where leather and metal components were in contact. A lower coat of white paint could be differentiated beneath the grey in some cases.

In some areas, the remains of thin matt grey paint in the same shade are adhered to the upper surface (grain side) of rigid leather items as well eg. 5651.4 (Figure 13); in these instances, the paint survives mainly in recessed areas, where it was probably protected from wear, but it may have been applied over a larger area originally.

Figure 12: Both sides of 5651.4 showing paint adhering to the leather and metal reinforcement of the rivet holes.

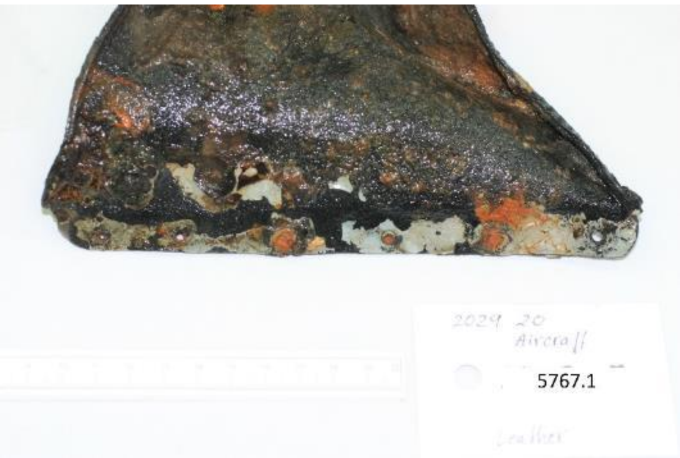

Figure 13: Paint adhering to the leather on 5767.1.

Figure 14: Paint adhering to the leather on 5767.2.

Figure 15: Paint adhering to the leather on 5767.3.

Samples of the paint layers were analysed using both FTIR and µXRF and the two techniques provided similar results. The FTIR results provide information on the binder used in each paint as well as the pigments present. The µXRF results provide information about the elemental composition of the pigments and are used to illustrate the different elemental proportions in the paints used by the various Barracuda manufacturers in the following section 'Comparison of paint from different Barracuda manufacturers'.

Two layers were visible in the sample from 5651.4, a white lower layer and a grey upper layer. The FTIR spectrum of the paint sample from 5651.4 (Figure 16) confirms the presence of titanium and zinc white pigments in the lower white layer of paint. The upper grey paint layer is an alkyd paint with a silicate-based pigment (such as green earth) and lithopone, which is a mixture of barium sulphate and zinc sulphide (Figure 17). No binder was found in either of these layers.

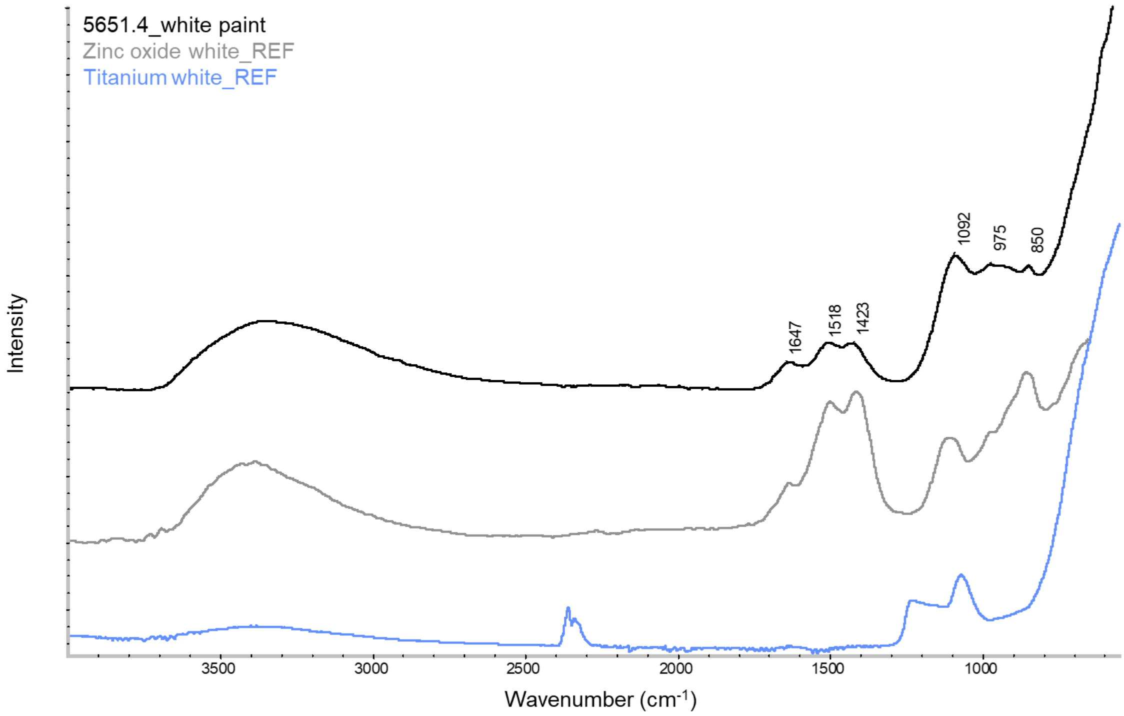

Figure 16: FTIR spectrum of the lower white paint layer sample from 5651.4 with reference spectra.

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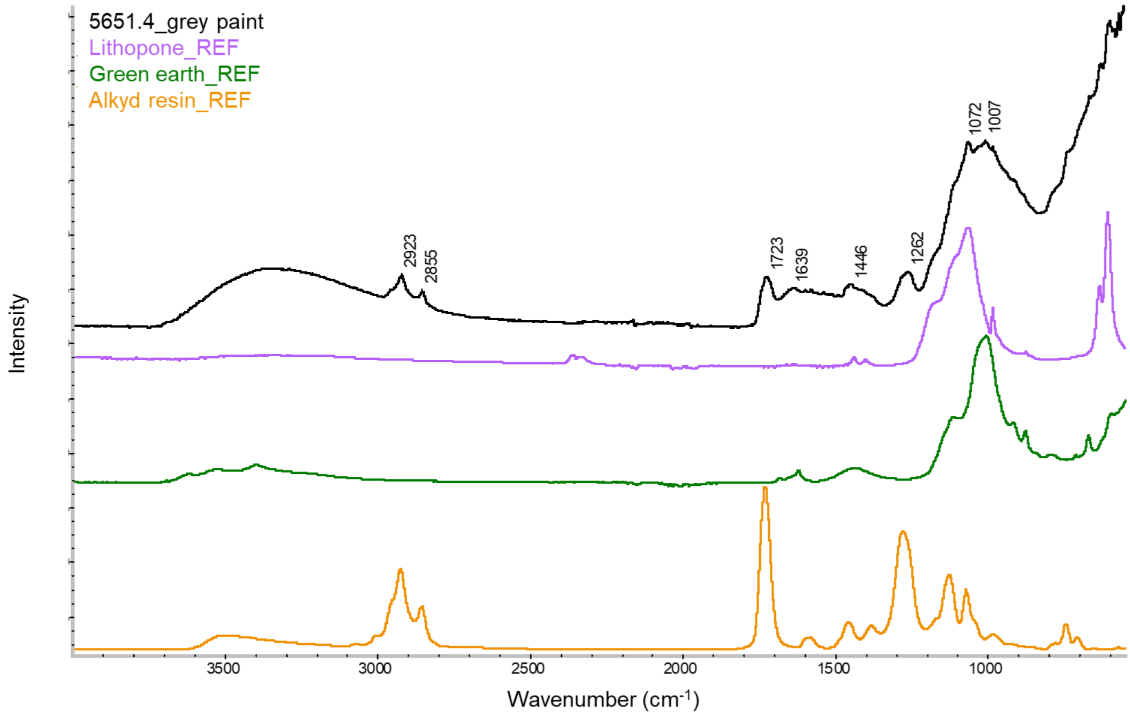

Figure 17: FTIR spectrum of the upper grey paint layer sample from 5651.4 with reference spectra.

The analysis of a grey paint sample from 5767.2 gives a spectrum (Figure 18) that is very similar to the grey paint in sample 5651.4, so they are probably the same. It is an alkyd paint with a silicate-based pigment (such as green earth) and lithopone.

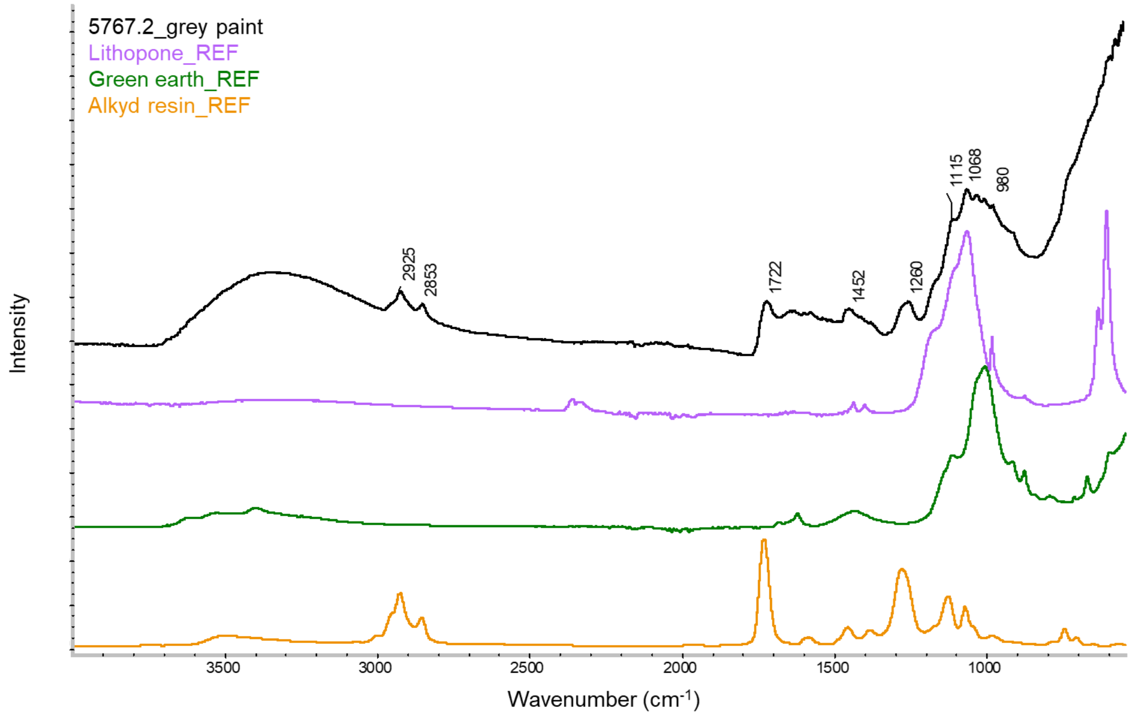

Figure 18: FTIR spectrum of the grey paint layer sample from 5767.2 with reference spectra.

On 5753.N, the white lower paint layer and grey upper paint layer are both visible. A sample of the grey paint is again an alkyd paint with pigments based on silicates (such as green earth) and lithopone (Figure 19). This is confirmed by XRF data showing the presence of barium (Ba), zinc (Zn), silicon (Si) and sulphur (S) (Table 5). Titanium (Ti) was detected in the white paint, proving that titanium white was present in that layer as before (Figure 20 and Table 5).

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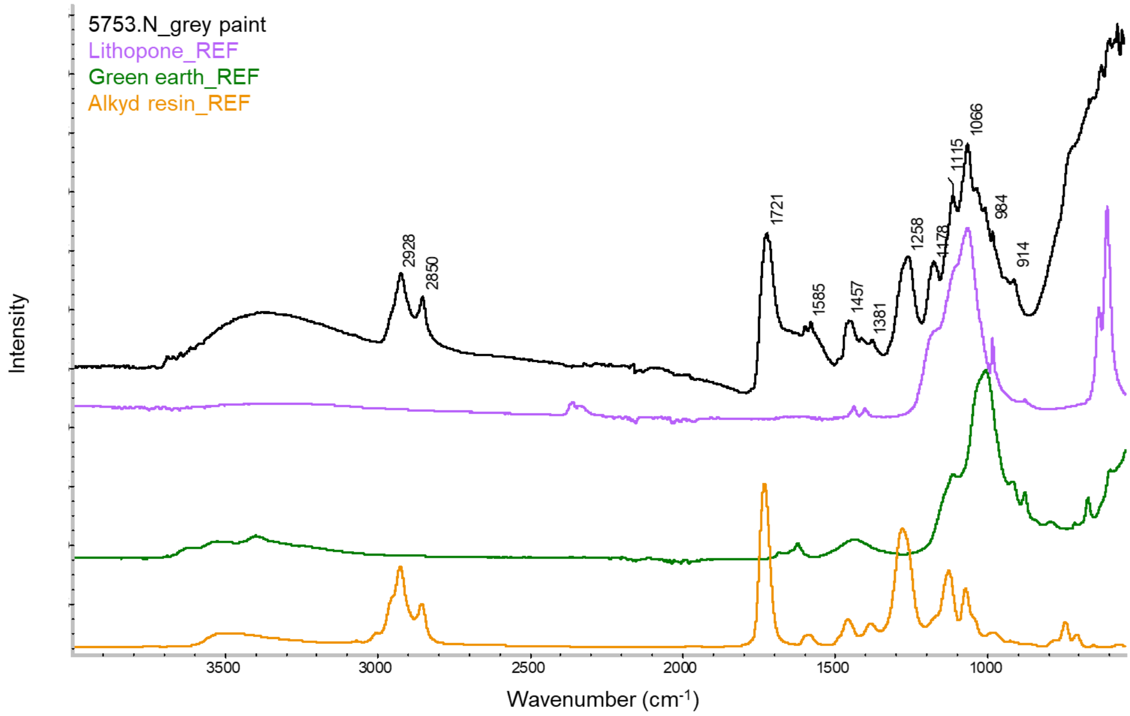

Figure 19: FTIR spectrum of the grey paint layer sample from 5753.N with reference spectra.

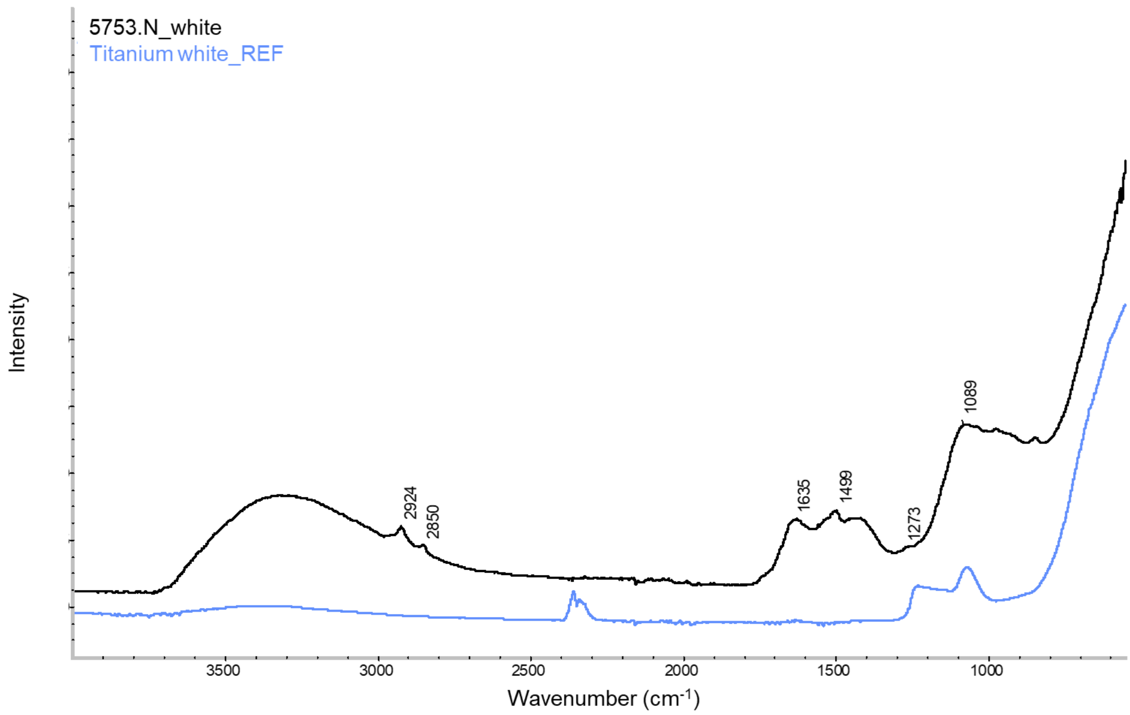

Figure 20: FTIR spectrum of the white paint layer sample from 5753.N with a reference spectrum of titanium oxide.

In summary, there was a grey paint scheme in the cockpit, sometimes with a layer of white paint beneath. FTIR (and XRF) analysis indicate that the grey paint applied to both leather and metal is the same and is an alkyd paint containing the pigments titanium oxide, and lithophone (barium sulphate and zinc sulphide, because the amounts of barium and sulphur detected are correlated). There is also a silicate-based pigment with a clay mineral component (indicated by the silicon and aluminium content), like green earth. There are minor amounts of chromium, lead, iron, antimony and phosphorus as well. Some of these compounds were used in primer/conversion treatments for metals as well as in paints, but because they are also detected in the paint applied directly to the leather, as well as that applied to metal, it is likely that they are minor additions to the paint itself (most probably as dryers of the alkyd binder).

Comparison of paint from different Barracuda manufacturers

The Mk. II Barracuda aircraft produced by Boulton Paul, Blackburn and Fairey had slightly different paint schemes applied. Paint samples from aircraft made by each of these manufacturers (see Table 3, Figures 21 to 28) were compared with the paint samples from the Solent wreck site objects in order to match its specific manufacturer. This approach was likely to succeed in this case because both the candidates for the Solent wreck were new aircraft, so would still retain their factory applied paint schemes.

Components from the Fairey and Blackburn Barracuda manufacturers can appear superficially similar because they are painted grey in each case, whereas the Boulton Paul cockpit colour scheme was cream with a final coat in dull green. Originally, more distinctive additional coloured paint layers were applied on the exterior of the craft for camouflage. Unfortunately, these more distinctive external topcoats do not survive well and typically were not applied in the aircraft interior (Montané et al. 2023). Without these more distinctive topcoat colours it can be difficult to differentiate between the craft made by each manufacturer, as is the case with the Solent Wreck.

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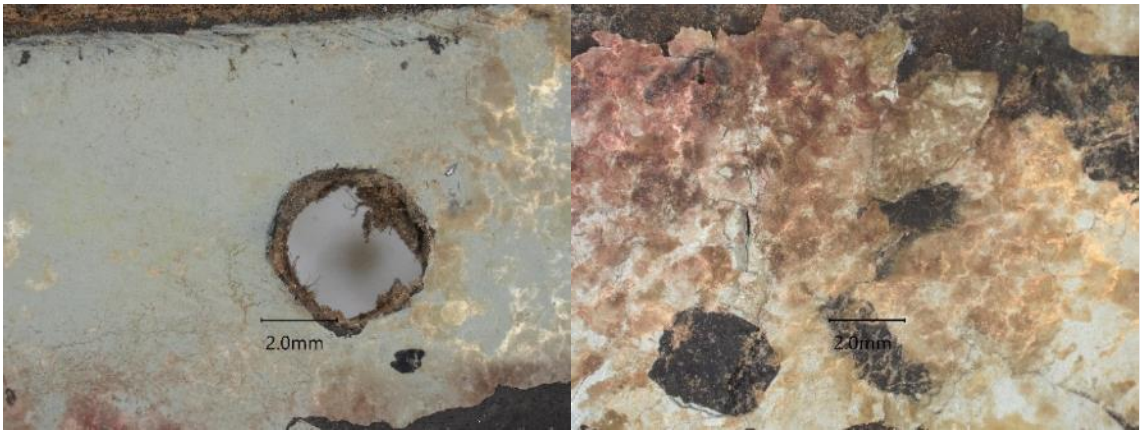

Figure 21: Optical images at different magnifications of the leather gaiter from control column of Blackburn Barracuda, showing grey paint, with small patches of black pigment, over a black fibrous substrate.

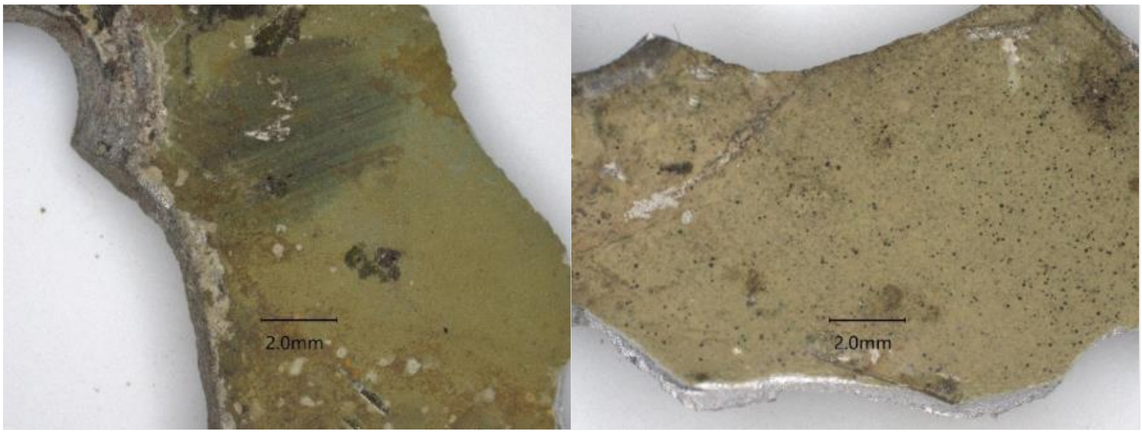

Figure 22: Optical images of the metal from the cockpit structure from the portside torpedo control of Boulton Paul DP872 with beige paint on both sides and some surviving green topcoat paint on one side (left image).

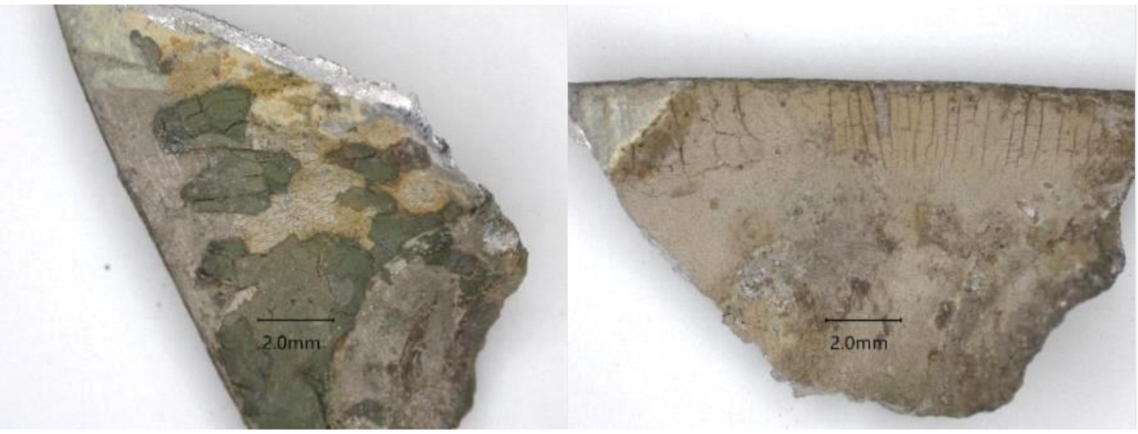

Figure 23: Optical images of the metal from the combing in front of the portside windshield from Boulton Paul DP872 showing both beige paint and green topcoat on one side, but only the beige layer surviving on the other.

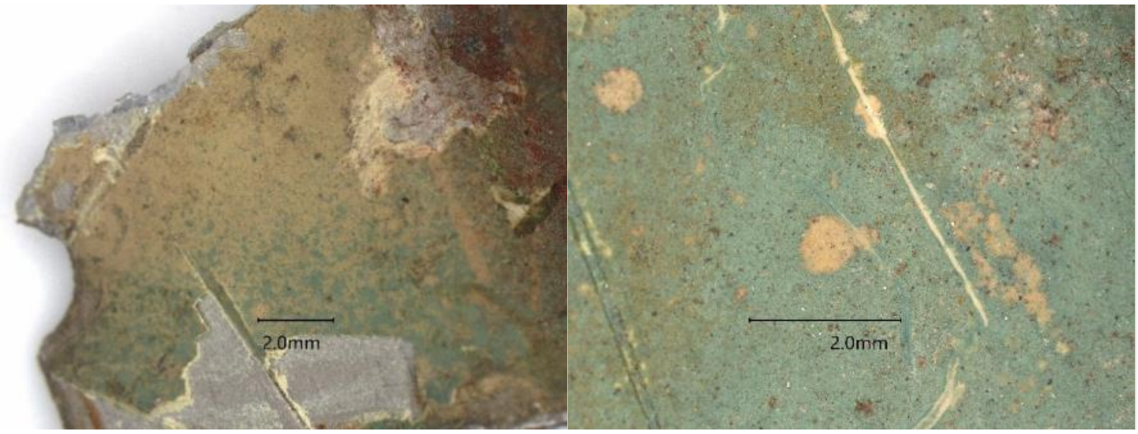

Figure 24: Optical images of the metal from the cockpit of Boulton Paul Barracuda DP872, both sides with surviving beige paint and green topcoat.

Figure 25: Optical images of the metal from the cockpit of Fairey built Barracuda PM870 showing the grey/green paint, metallic substrate and small area of green pigmented topcoat paint on one surface (left).

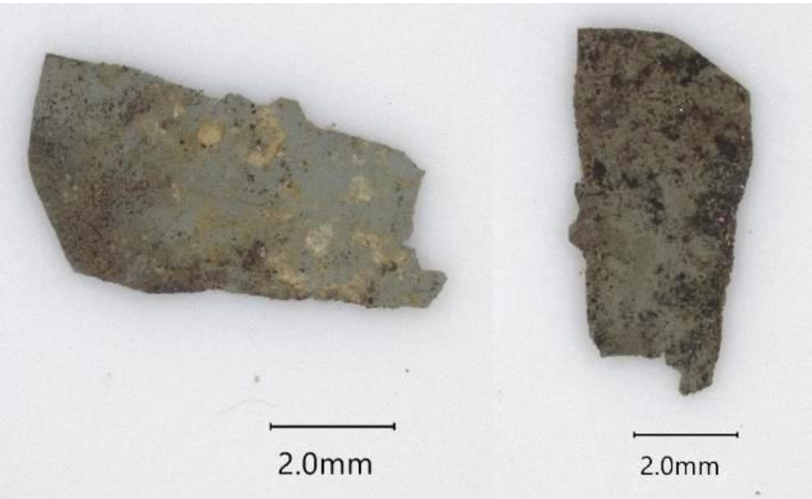

Figure 26: Optical images of the paint sample from the cockpit floor structure of Fairey Barracuda LS931 showing grey/green paint.

Figure 27: Optical images of a piece of painted metal from the cockpit floor structure of Fairey Barracuda LS931, with grey paint on both sides and an additional silver layer on one side (right).

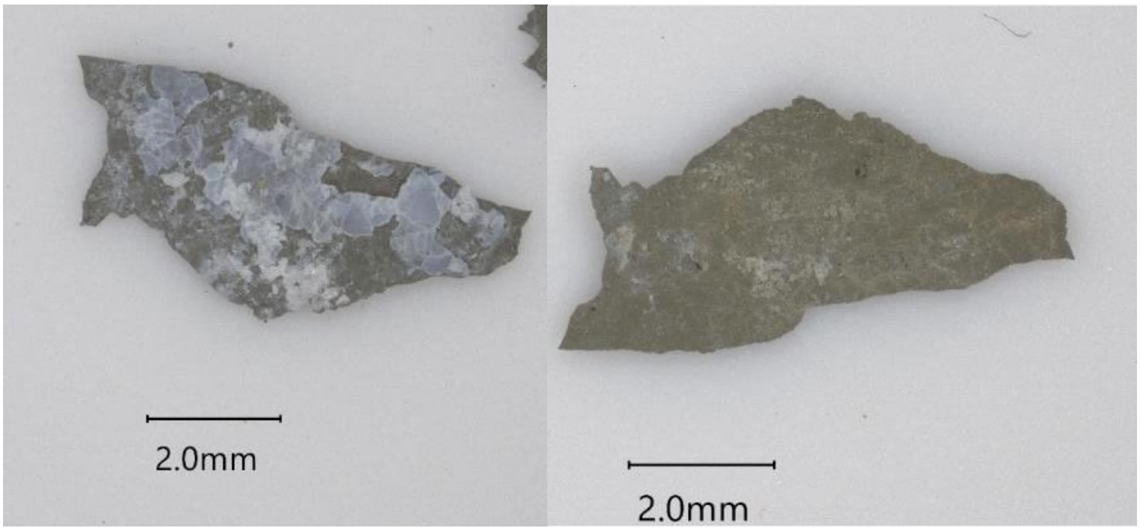

Figure 28: Optical images of two sides of a paint flake from the TAGs window frame of the Solent Wreck showing the grey/green paint and a white residue on one side (left).

Despite the visual similarities, the µXRF results for the paints used on each make of aircraft show distinct differences (Figures 29 and 30). Although many of the same pigments are present, particularly compounds of sulphur, barium, titanium and zinc (Table 5), the proportions of the major pigments in the paint differ between manufacturers, and there are also some diagnostic elements including antimony, chromium, iron and cobalt, which enable the manufacturers to be identified (Table 5).

The Boulton Paul beige paint formulation contains the highest levels of barium and significant amounts of zinc and titanium; the increase in zinc may account for the creamier colour of this paint. There is no antimony in the beige paint, but the green topcoat contains a little, together with lead and chromium and high levels of iron and titanium.

The Blackburn grey paint formulation is similar to the Fairey one, since it contains high levels of titanium with smaller amounts of barium. It differs from the Fairey formulation however because it contains slightly more zinc but no antimony; there may also be some chromium and cobalt present (although this isn't certain because there are also high levels of chromium and iron in the leather substrate of this sample).

The grey paint formulation used by Fairey Aviation contains high levels of titanium, mid-levels of barium and small amounts of zinc, iron and antimony; the antimony is particularly distinctive. This formulation matches precisely the grey paint used on the Solent wreck aircraft components (Figure 31).

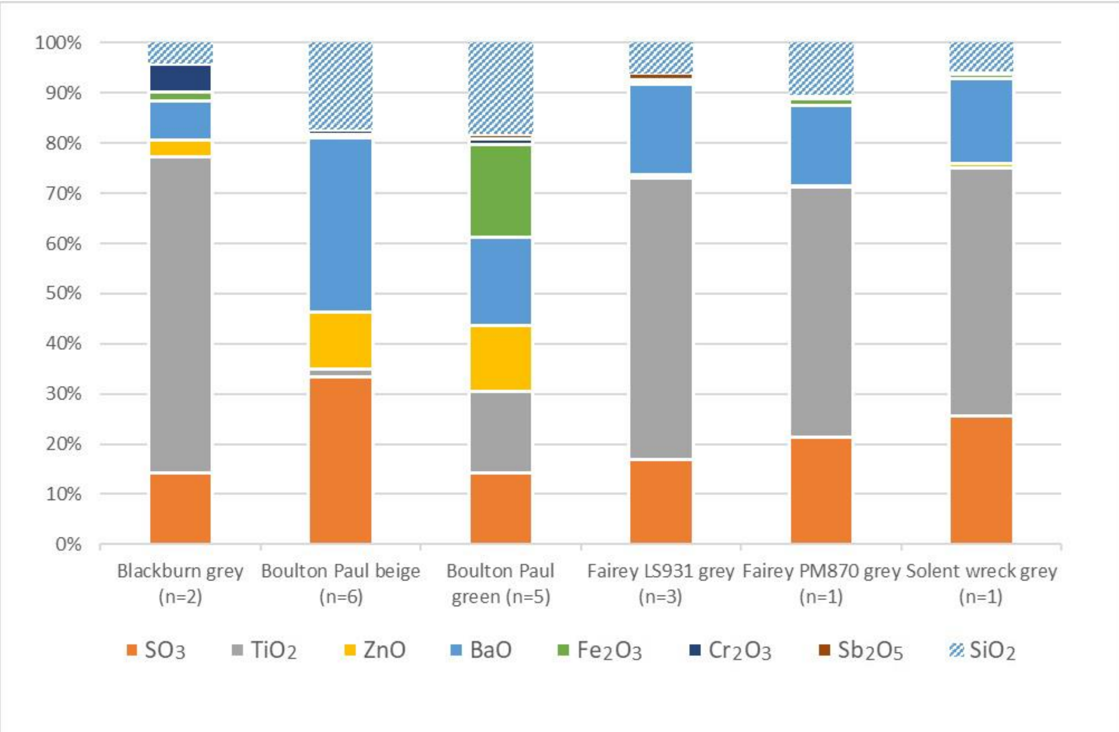

Figure 29: Chart showing the key components of the paints analysed (wt%), normalised to 100%, showing the similarity between the Fairey grey paint from other aircraft and the grey paint from the Solent wreck (detached sample WF-1).

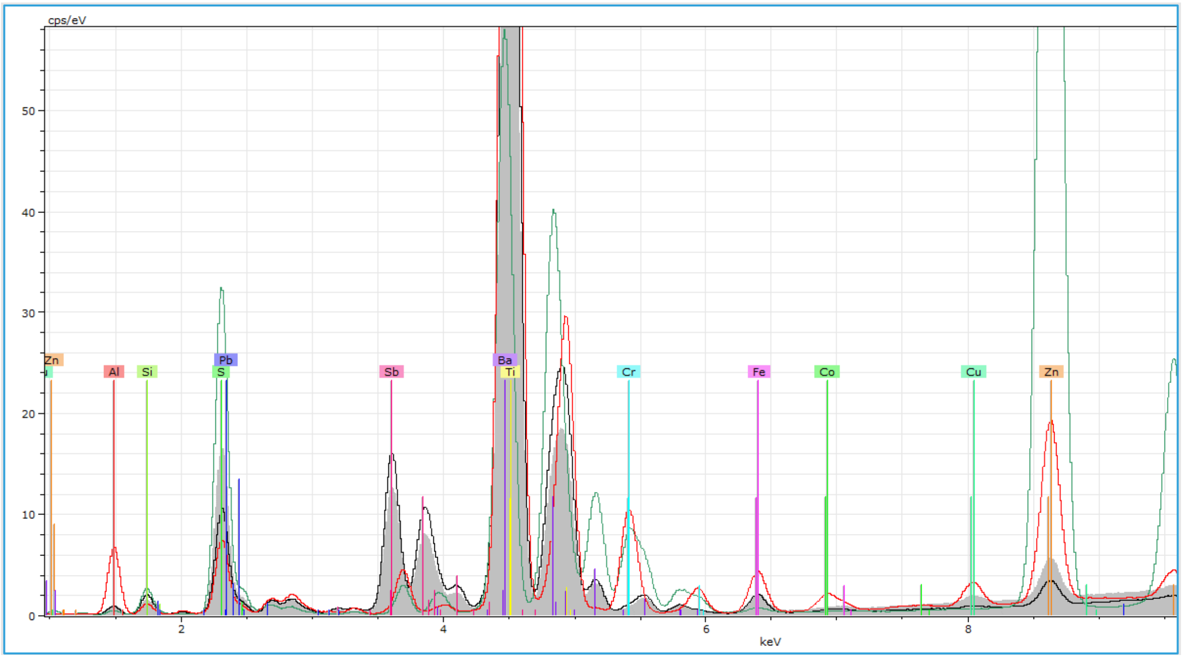

Figure 30: XRF spectra for the paints from Fairey (black line), Blackburn (red line) and Boulton Paul (DP872) (green line) aircraft with the Solent wreck (solid grey spectrum), sample WF-1.

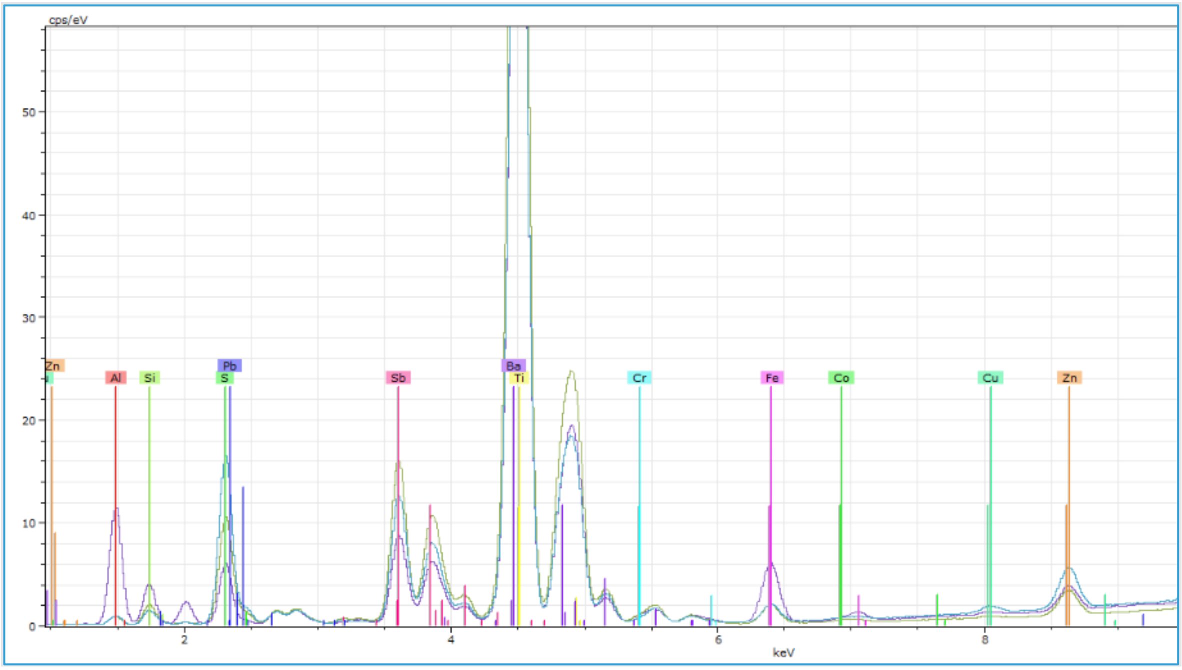

Figure 31: XRF spectra showing the close match between the grey paint from Fairey aircraft LS931 (green line) and PM870 (purple line) and the sample from the Solent wreck TAGs window WF-1 (light blue line).

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Conclusion

The multi-analytical approach taken here has positively identified that the aircraft wreck was a Barracuda manufactured by Fairey Aviation, rather than a Barracuda manufactured by either Boulton Paul or Blackburn, and this points towards the wreck being the remains of LS473. Identifying these wreck remains now opens other avenues of archival research and allows a deeper understanding of this recovery from the Solent.

The paints used by the different manufacturers of Barracuda Mk. II aircraft were all based mainly on barium, zinc and titanium pigments. There are similarities with the reported treatments applied to a 1950s French aircraft (Brunet et al. 2019). Nonetheless these pigments were present in different proportions, and with some distinctive additives, allowing the paints used by each manufacturer to be differentiated. Fairey Aviation used a grey alkyd paint over a white under-layer dominated by titanium with some barium and only low levels of zinc; it also contained antimony, which was absent from the other paints except for small amounts in the surviving topcoat of the Boulton Paul model. The Solent wreck aircraft grey paint matched precisely the grey paint from Fairey manufactured aircraft LS931 and PM870.

Aircraft LS473 of 817 Squadron was flown by Sub Lieutenant (Air) Sandes RNVR from Canada. Further research is required to investigate potential links to the RCAF, for example, the possible US or Canadian shoe sizing for the partial remains of shoe 5545. There were no other aircrew present when this aircraft went down and there were no casualties.

The haloacrylate polymer 5757_X would have been novel at the time. This polymer warrants further investigation to confirm it is conclusively associated with the crash site.

Chrome tanning was used for all the leather fitted in the aircraft cockpit and the upper of shoe component 5768. All the leather contained raised levels of iron, calcium, copper and zinc from the marine environment.

The certain presence of two different pieces of footwear and at least a further shoe, possible four in total, is difficult to explain, unless introduced from elsewhere during later disturbance such as shellfish dredging.

The leather artefacts have since been deposited with the National Museum of the Royal Navy where they will form part of Barracuda Live – The Big Rebuild at the Fleet Air Arm Museum, a project that aims to rebuild a Barracuda aircraft from various aircraft wreck components (https://www.nmrn.org.uk/visit-us/fleet-air-arm-museum/barracuda-live-big-rebuild).

The leather together with the aircraft remains form a tangible reminder of the past and will add to the delivery of the people stories associated with the rebuilt Barracuda. This will add another layer of interpretation on the project and help develop audiences beyond the technical enthusiasts already engaged.

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Table 4: pXRF results (wt% elements) for leather from the Solent Wreck site compared to reference material. Detection limit around 0.1wt% for lighter elements (Al to Ca), 0.01wt% for heavier elements, bd = below detection, rpt = repeat analysis.

Object	**Pb**	**Zn**	**Cu**	**Fe**	**Cr**	**Ti**	**Ca**	**K**	**Al**	**Si**	**Cl**	**S**
Granite background	bd	bd	0.07	1.54	bd	0.52	1.58	2.34	15.91	28.20	0.15	bd
Seat 5651.2	bd	0.15	0.08	1.14	1.56	0.03	2.33	bd	0.38	0.98	bd	0.88
Seat 5651.2 (rpt)	bd	0.13	0.07	0.59	1.62	0.03	2.24	bd	bd	0.73	bd	0.80
Seat 5651.1 grain	bd	0.16	0.08	0.44	1.73	0.03	3.56	bd	bd	0.23	bd	3.02
Seat 5651.1 flesh	bd	0.13	0.07	0.73	1.50	0.01	2.29	bd	0.42	0.94	bd	1.39
Collar stick 5767.2	bd	0.14	0.29	1.80	1.68	0.15	2.28	0.22	0.63	2.26	bd	2.06
Collar stick 5767.2 (rpt)	bd	0.14	0.36	1.84	1.95	0.09	2.52	0.20	1.12	2.18	bd	1.88
Shoe 5545 sole grain	0.06	0.21	0.12	1.00	bd	0.02	3.37	bd	0.61	0.98	bd	1.45
Shoe 5545 sole flesh	0.21	0.15	0.07	1.98	bd	0.17	1.84	0.47	1.43	6.30	bd	1.13
Shoe 5768 upper external at toe	0.02	0.24	0.13	0.90	1.17	0.06	2.88	0.23	1.74	3.74	bd	1.52
Shoe 5768 sole internal at heel	0.04	0.10	0.05	1.01	0.02	bd	1.78	bd	0.45	0.45	bd	0.96
Shoe 5565.2 heel back flesh	bd	0.25	0.06	0.45	bd	bd	2.07	bd	bd	0.83	bd	0.94
Shoe 5565.2 heel back grain	bd	0.26	0.06	0.52	bd	0.01	2.45	bd	0.38	0.31	bd	1.04
Shoe 5565.1 upper external grain	0.05	0.10	0.09	1.24	bd	0.05	2.00	bd	0.50	1.32	bd	1.14
Shoe 5565.1 upper internal flesh	0.04	0.09	0.08	0.83	0.01	0.06	1.62	0.18	0.76	2.46	bd	0.84
Strap 5732 flesh	bd	0.37	0.08	0.36	0.02	0.04	3.11	bd	1.29	2.89	bd	1.22
Strap 5732 grain	bd	0.39	0.07	0.36	bd	0.03	3.36	bd	1.21	2.30	bd	1.34
Veg tanned goat modern	bd	bd	bd	0.07	bd	bd	0.25	0.12	bd	bd	5.39	1.02
Veg tanned goat modern (rpt)	bd	bd	bd	0.03	bd	bd	0.27	bd	bd	bd	4.62	1.17
Chrome tanned sheep modern	bd	bd	0.01	0.67	3.84	0.06	0.13	bd	bd	bd	4.67	2.49
Chrome tanned sheep modern (rpt)	bd	bd	0.02	0.65	4.03	0.07	0.21	bd	bd	0.505	4.41	2.54
Novgorod NF40 medieval	bd	0.02	0.01	1.40	bd	0.10	4.08	0.70	1.95	12.48	bd	0.75
Novgorod NF40 medieval (rpt)	bd	0.02	0.02	1.36	bd	0.07	5.20	0.47	1.82	8.07	bd	0.95

Table 5: µXRF results under vacuum (wt% oxides except Co and Cu which are wt% element) for paint samples from different manufacturers of Barracudas compared with a sample from the Solent Wreck Barracuda. Normalised data, detection limit around 0.1wt% for most elements, 1wt% for sodium and magnesium, bd = below detection. Rpt indicates a repeat analysis, shaded rows are an average of the samples for that manufacturer.

Manufacturer	**Sample**	**Description**	**Sb_2O_5**	**PbO**	**SiO_2**	**SO_3**	**TiO_2**	**ZnO**	**BaO**	**Al_2O_3**	**Cr_2O_3**	**P_2O_5**	**Fe_2O_3**	**MnO**	**CaO**	**Na_2O**	**MgO**	**K_2O**	**Co**	**Cu**
Blackburn	BB-1	Grey	bd	0.44	2.11	5.63	52.73	2.01	1.11	28.27	2.58	bd	0.73	0.18	1.14	2.25	bd	0.12	0.18	0.21
Blackburn	BB-1	Grey (rpt)	0.25	0.91	3.29	13.14	29.91	2.38	9.18	30.49	4.79	bd	1.39	0.23	0.74	2.59	bd	0.31	bd	0.07
Blackburn	*Average*	*Grey*	*0.13*	*0.68*	*2.70*	*9.38*	*41.32*	*2.19*	*5.15*	*29.38*	*3.69*	bd	*1.06*	*0.20*	*0.94*	*2.42*	bd	*0.22*	*0.11*	*0.14*
Boulton Paul	DP872 1	Beige	bd	bd	5.92	28.65	0.83	15.72	24.34	1.90	0.87	bd	0.06	0.03	0.89	18.14	2.55	0.09	bd	bd
Boulton Paul	DP872-1	Beige (rpt)	bd	bd	8.04	28.43	0.82	15.43	24.18	0.80	0.68	bd	0.05	0.04	0.80	17.10	3.49	0.08	bd	bd
Boulton Paul	DP872-2	Beige	bd	bd	15.22	23.87	1.49	4.45	28.36	8.24	0.67	bd	0.45	0.36	1.58	2.66	6.34	0.76	bd	4.66
Boulton Paul	DP872-2	Beige (rpt)	0.29	bd	17.67	22.12	1.24	6.66	27.12	4.34	0.72	bd	0.42	0.24	1.75	3.40	8.45	0.58	bd	4.45
Boulton Paul	DP872-3	Beige	bd	bd	15.95	27.04	1.47	6.40	28.27	2.19	0.53	bd	0.52	0.36	1.25	3.82	6.72	0.38	bd	4.72
Boulton Paul	DP872-3	Beige (rpt)	bd	bd	17.96	24.98	1.75	3.40	29.88	2.22	0.79	bd	1.03	0.46	1.18	1.73	8.27	0.50	bd	5.27
Boulton Paul	*Average*	*Beige*	bd	bd	*13.46*	*25.85*	*1.27*	*8.68*	*27.03*	*3.28*	*0.71*	bd	*0.42*	*0.25*	*1.24*	*7.81*	*5.97*	*0.40*	bd	*3.18*
Boulton Paul	DP872-1	Topcoat green	bd	0.20	11.81	18.71	9.73	17.64	19.27	3.65	1.00	bd	3.64	bd	3.68	9.43	bd	0.19	bd	bd
Boulton Paul	DP872-1	Topcoat grn (rpt)	bd	0.16	12.08	18.77	6.32	18.93	22.57	4.58	1.06	bd	2.33	bd	2.24	9.30	bd	0.55	bd	bd
Boulton Paul	DP872-3	Topcoat mid-grn	1.37	1.62	20.55	9.03	18.27	4.72	10.38	5.09	0.86	2.36	20.61	0.10	bd	2.37	bd	0.14	bd	2.24
Boulton Paul	DP872-3	Topcoat mid-grn (rpt)	1.33	1.65	18.32	7.80	16.80	7.46	10.72	4.53	0.99	3.07	23.00	0.10	bd	1.33	bd	0.15	bd	2.45
Boulton Paul	DP872-3	Topcoat drk grn	0.94	1.21	13.09	4.63	15.98	5.93	10.44	11.78	1.13	4.31	26.56	bd	0.12	1.76	bd	0.88	bd	1.10
Boulton Paul	*Average*	*Green*	*0.73*	*0.97*	*15.17*	*11.79*	*13.42*	*10.94*	*14.68*	*5.93*	*1.01*	*2.02*	*15.23*	bd	*1.21*	*4.84*	bd	*0.38*	bd	*1.16*
Fairey	LS931-2	Grey	1.54	0.96	6.15	12.14	53.50	0.50	17.57	5.52	0.14	bd	0.65	bd	bd	bd	bd	bd	bd	bd
Fairey	LS931-2	Grey (rpt)	1.17	0.86	5.21	11.86	50.94	0.43	16.22	11.75	0.13	bd	0.43	bd	bd	bd	bd	bd	bd	0.17
Fairey	LS931-1	Grey	0.86	0.46	5.25	21.95	47.03	0.69	15.17	6.32	bd	bd	0.56	bd	bd	bd	bd	bd	bd	0.06
Fairey	*Average*	*Grey*	*1.19*	*0.76*	*5.54*	*15.32*	*50.49*	*0.54*	*16.32*	*7.87*	*0.11*	bd	*0.54*	bd	bd	bd	bd	bd	bd	*0.09*
Fairey	PM870	Grey	0.45	0.29	7.09	14.56	34.12	0.23	10.84	27.38	bd	bd	0.97	0.16	bd	bd	bd	bd	bd	3.39
Solent Wreck	WF-1	Grey	0.63	0.42	5.06	23.13	44.59	0.85	15.27	6.70	bd	bd	0.63	bd	bd	1.84	bd	bd	bd	0.11

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