Markings of the Turning Point: Preserving the Last Surviving Example of Invasion Stripes on a World War II Bomber

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'Invasion Stripes' were painted on Allied planes to prevent friendly fire during the D-Day invasion, and *Flak-Bait* may have the only surviving example – but the stripes are unstable. Treatment should be informed by characterization of the paint, however even with a suite of techniques the composition remains elusive, particularly the binder. How do the complex and heavily weathered surfaces of an aircraft with an extensive service record challenge techniques of paint analysis, and how can we account for this ambiguity in our decisions?

Figure 1: NASM Curator Jeremy Kinney examines the faint invasion stripes on the underside of the right wing with one of *Flak-Bait*'s WWII pilots, Shermen Best. (NASM)

Figure 2: *Flak-Bait*, a B-26 Marauder, after its last mission in Germany, May 1945. (IWM FRE 7086)

INTRODUCTION. The Martin B-26B Marauder *Flak-Bait* is an iconic artifact of World War Two (WWII) with exceptional originality. It retains signs of wear and tear from surviving over 200 missions. This includes the faint black and white stripes on the wings and fuselage (e.g. *fig. 1*). Curators at the National Air and Space Museum (NASM) believe these are the only surviving example of the distinctive 'Invasion Stripes', which were painted on Allied planes to prevent friendly fire during the D-Day invasion of Normandy in June 1944. Our goal is to preserve all evidence of *Flak-Bait*'s service life as it appeared after its final flight (*fig. 2*). However, the overall camouflage paint was applied at manufacture without a primer, and, after severe weathering, both the camouflage and the Invasion Stripes are unstable and in need of conservation.

A clear coating of Paraloid B-72 (6% in toluene) has already been successfully applied to some components. However, before we apply the coating over the Invasion Stripes, we need to characterize the paint used. This is important for three reasons: (1) the composition is unknown and only anecdotal evidence exists in the literature; (2) using the artifact as a primary source will enhance the curatorial record; and (3) we need to determine compatibility with our selected conservation treatment as it will be an irreversible consolidation.

Initially, the project to characterize the black and white colorants and their binder seemed straight-forward using common methods for paint analysis. However, we soon discovered complications in studying the painted surfaces of an aircraft with an extensive war-time record.

Figure 3: U.S. Archives footage of the 53rd Troop Carrier Wing painting the stripes. (Youtube)

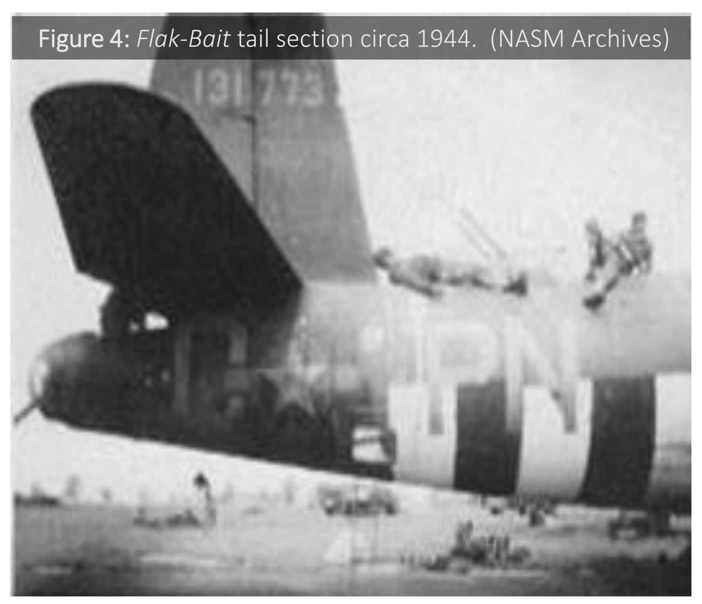


Figure 4: *Flak-Bait* tail section circa 1944. (NASM Archives)

Figure 5: Underside of *Flak-Bait* during its 200th mission, April 1945. (IWM FRE 6402)

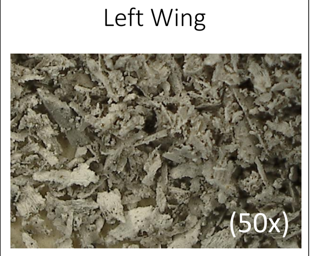
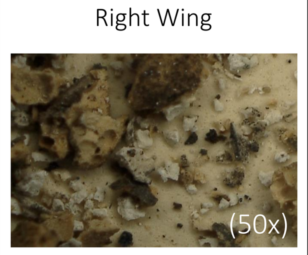
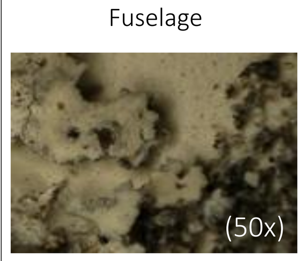
HISTORICAL RESEARCH. Archival footage of a U.S. Troop Carrier Wing recorded the stripes being marked out and painted (*fig. 3*). Memoirs described using 'cans of paint, masking tape and brushes', even improvising with brooms when supplies ran out,[1] whilst others mentioned spraying the paint.[2] Orders from late 1944 indicated the stripes were supposed to be removeable but cautioned some tenacious paint may remain,[3] and the stripes on *Flak-Bait* did wear off over time (*figs. 4-5*). Two types of temporary marking paint were available:

1. **Water-soluble** : British and American troops reported rain washing the stripes off as fast as it could be applied.[4] An Appendix to the British orders specified white and black ('Night') distemper,[5] and a 1946 newspaper reported thousands of galleons of distemper had been hastily manufactured for the stripes.[6] 'Distemper' generally describes various water-borne coatings based on calcium carbonate with glue, casein, or an oil-modified emulsion. In the 1930s, the U.S. Army Air Corps tested 'calcimine', a glue-based distemper, which could be removed by rubbing,[7] and the British Air Ministry specified their distemper should be removeable with hot water.[8]
2. **Gasoline-soluble** : Possibly an oil-based enamel or a coal-tar resin which could be removed by wiping with aircraft fuel.[9]

There is also an anecdotal belief paints may have been scrounged from what was available, ranging from oils to alkyds, nitrocellulose, bituminous paints, and so on. Identifying the binder is important for determining compatibility with the conservation coating, but this also reinforces the importance of using *Flak-Bait* as a unique primary resource to build a more complete history of the Invasion Stripes.

METHODS. Sample locations were documented, then small amounts (<0.5mg) were scaped from the wings and fuselage. Analysis was conducted at NASM and in collaboration with the Museum Conservation Institute (MCI) and the National Museum of Natural History.

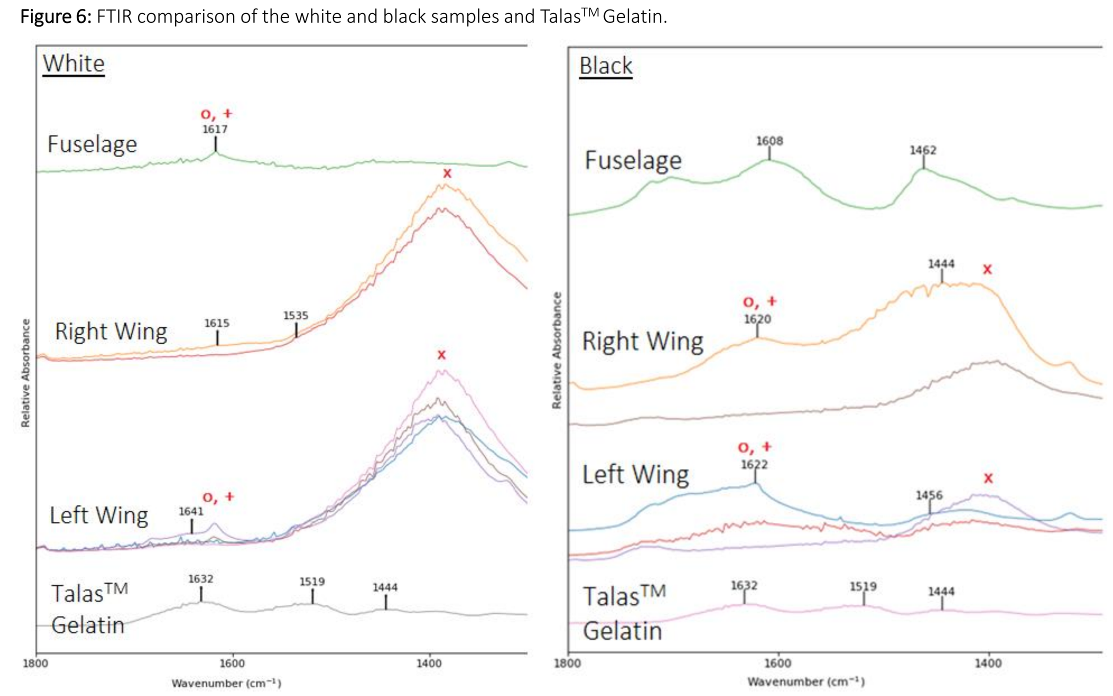
Table 1. Initial results of the analysis of the Invasion Stripes on Flak-Bait.

	White			Black		
	Left Wing	Right Wing	Fuselage	Left Wing	Right Wing	Fuselage
	 (50x)	 (50x)	 (50x)	 (50x)	 (400x)	
pXRF	*[In-situ]* Ca, Ba, Ti, Cu, Fe, Zn, S, Si, K, Mn, Ni, Al, Pb, Sr	*[Sample]* Ca, Zn, Cd, Sr, Fe, Ba, Ti, Pb?, Si?, S?, K?, Mn?, [Al?], [Ni?], [Cu?]	*[In-situ]* Ca, Ba, Ti, Fe, Cu, S, Si, K, Mn, Ni, Zn, Pb, Sr, Al	*[In-situ]* Ti, Fe, Cu, Ca, Si, S, P, K, Cr, Mn, Ni, Zn, Pb?	*[In-situ]* Ti, Cu, Fe, Ca, Si, S, P, K, Mn, Ni, Zn, Cr, Pb?	*[In-situ]* Ti, Fe, Cu, Si, S, Ca, K, Cr, Mn, Ni, Zn, Pb?
FTIR	Calcium carbonate, barium sulfate, gypsum, quartz?	Calcium carbonate, barium sulfate, gypsum?, quartz?	Gypsum	Sulfates, amorphous carbon? *MCI: Gypsum, possibly ultramarine blue*	Calcium carbonate, sulfates, ultramarine blue or amorphous carbon? *MCI - Calcium carbonate, gypsum (selenite), possibly ultramarine blue*	Ultramarine blue or amorphous carbon? *MCI: asphalt?*
Raman	Calcite, barite, anatase?	-	-	Amorphous carbon, ultramarine blue	Amorphous carbon, ultramarine blue	Amorphous carbon, iron oxide?
XRD	Calcite, barite	Calcite, barite	Calcite, barite, gypsum, unknown	Gypsum	Calcite, hauyne (ultramarine), barite	-
LC-MS / Proteomics	(1) Mixed Cow, Horse, Pig, Sheep, Goat, Sturgeon / (2) Cow / (3) Nothing detected	Cow?	Nothing detected	-	Cow, Sturgeon	Nothing detected

DISCUSSION. Inorganic components dominated the analysis, particularly calcium carbonate, barium sulfate, and calcium sulfate or gypsum. Calcium carbonate is expected to be the main ingredient for distemper, a temporary water-soluble marking paint hinted in British documents about the stripes, although it was also used as a colorant or filler in other paints. Interestingly, the black samples from the left and right wings seemed to contain ultramarine blue, which was added to British 'Night' paint.[10] No binder was conclusively identified, although there were unaccounted-for peaks in the FTIR and elements in the pXRF, which might indicate additional components. A distemper-type paint should contain a protein-based binder, and LC-MS with proteomics possibly indicated their presence in some samples from the left and right wings, although not consistently in all the samples and their presence and attribution varied as the data was re-examined. We suggest the problems of this characterization relate to the complex and heavily weathered surfaces of an aircraft which completed over 200 missions during service.

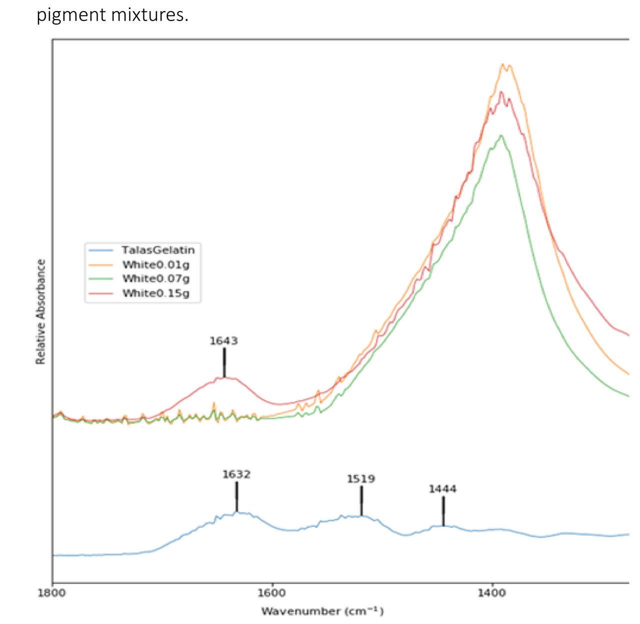
1. Masking. LC-MS indicated proteins in some samples, however in the results of the FTIR analysis (*fig. 6*), the expected amide peaks also seen in a sample of Talas™ Gelatin are indistinguishable from the inorganic peaks for calcium carbonate (x), barium sulfate (o), and calcium sulfate (+). This is likely true for any binder with identifying peaks in this area, such as drying oils with a key peak around 1730cm^{-1}.

Figure 6: FTIR comparison of the white and black samples and Talas™ Gelatin.



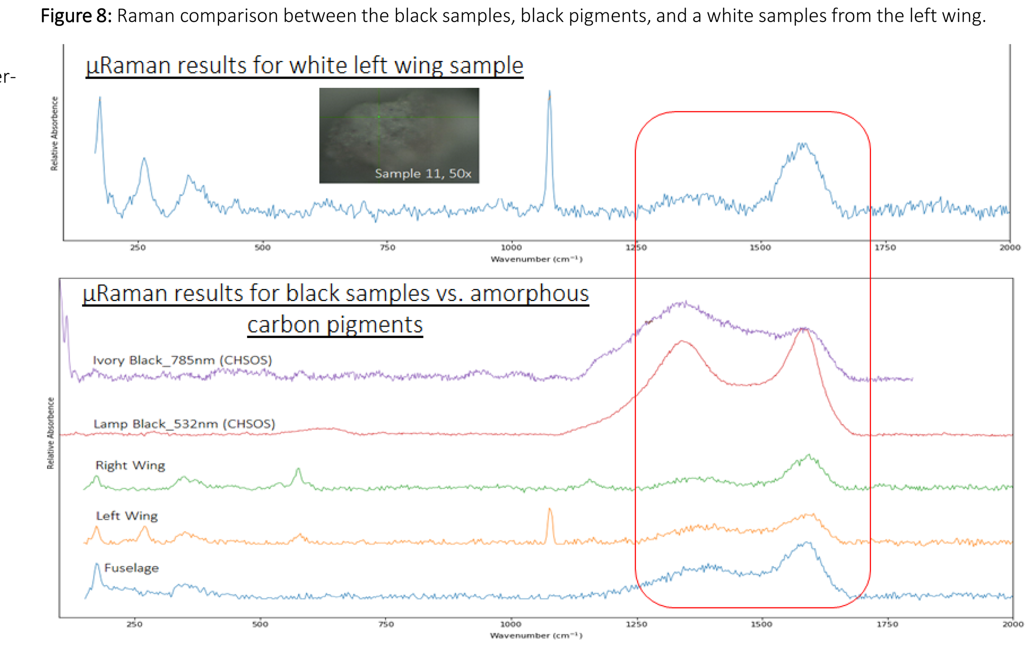
2. Minimal binder and instrumental limits. Weathering can remove binders, particularly if it is water-soluble. Experimental mixtures of calcium carbonate (1g) and Talas™ Gelatin (0.01g, 0.07g, 0.15g) in deionized water were dried to a film and analyzed with FTIR (*fig. 7*). The first amide peak is only detectable with our instrument at the highest concentration (13%), which would compound issues of masking.

Figure 7: FTIR comparison between Talas™ Gelatin and experimental binder-pigment mixtures.



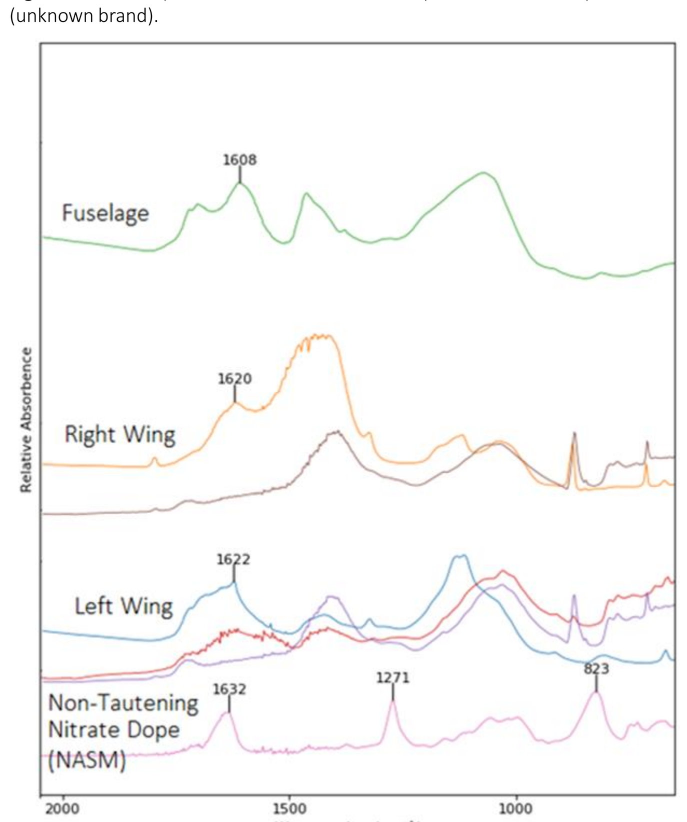
3. Contamination. Lead (Pb) was found but not lead white. We wonder if this might be contamination from leaded gasoline. Amorphous carbon pigments such as lamp black or ivory black were the most common black colorants in the period, but the characteristic peaks revealed through Raman analysis also appear in a white sample collected near one of the engine coverings (*fig. 8*). This could be an error of the analysis or contamination with burnt hydrocarbon residues.

Figure 8: Raman comparison between the black samples, black pigments, and a white samples from the left wing.



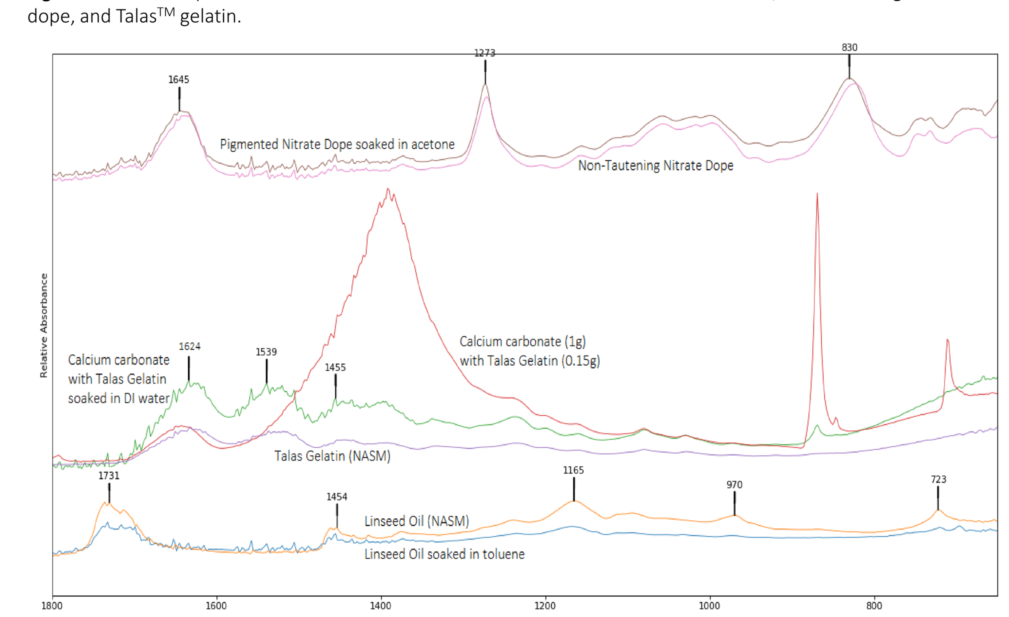
4. Few comparable studies. British 'Night' paint was supplied as a distemper or a cellulose nitrate formulation. The three characteristic FTIR peaks for nitrocellulose seem absent (*fig. 9*). In studies of nitrate plastics these persist even when degraded.[11] But, there are no studies of vehicle paints demonstrating how distinct these peaks should be in a mixture that was only partially binder even before weathering and the dominance of the inorganic components.

Figure 9: FTIR comparison between the black samples and Nitrate Dope (unknown brand).



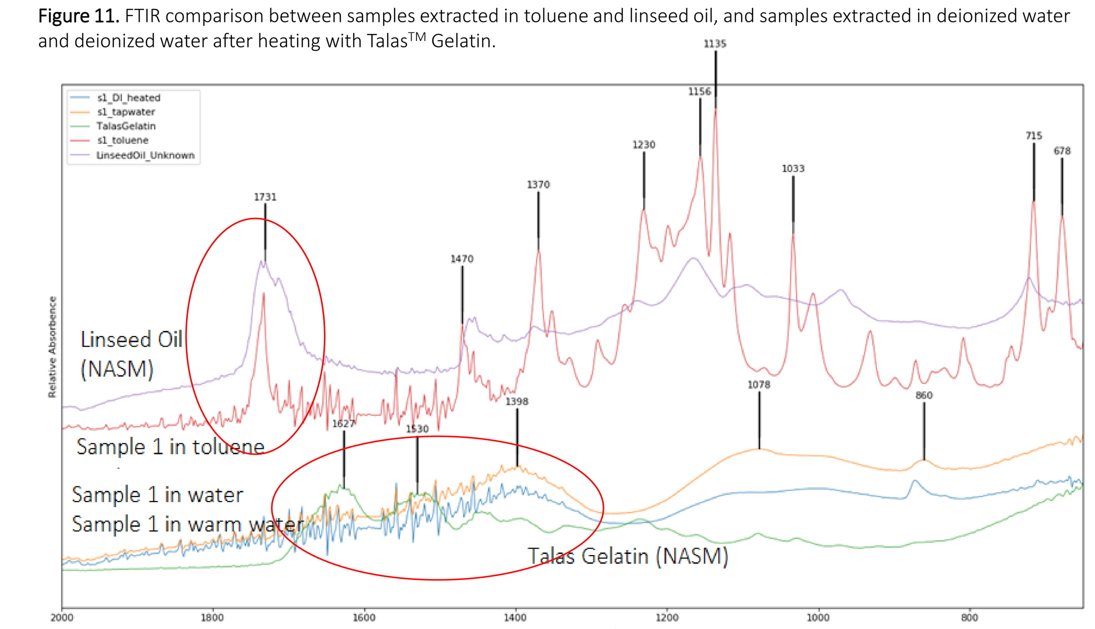
5. Experiment to improve FTIR results using solvent extraction. Known binder-pigment mixtures were soaked in solvent overnight, the liquid pipetted onto a glass slide, and the dried film analyzed with FTIR (*fig. 10*). As expected from their solubility, acetone seemed to extract nitrate dope, toluene extracted the linseed oil, and deionized water extracted gelatin. In the last, calcium carbonate originally masked the binder, but after extraction the characteristic amide peaks are clearly visible.

Figure 10. FTIR comparison between known formulations after extraction and linseed oil, non-tautening nitrate dope, and Talas™ gelatin.



The method was repeated for a white sample from the left wing (*fig. 11*). Only very small fragments were used, and we would expect minimal binder, but it still produced poor results. Toluene may have a produced a clearer drying oil peak around 1730cm^{-1}, but it was still not a definitive match. Even though this sample had the most consistent results for proteins with LC-MS, no amide peaks appeared with the deionized water, even when gently heated (50°C) on a hotplate for 2 hours to promote dissolution.

Figure 11. FTIR comparison between samples extracted in toluene and linseed oil, and samples extracted in deionized water and deionized water after heating with Talas™ Gelatin.



CONCLUSIONS: The faint remnants of the invasion stripes on *Flak-Bait* are a highly significant, likely unique, material record of markings which were so visually iconic of the D-Day invasion force and the turning point for the war in Europe. The original orders suggested a temporary paint and British sources suggested a distemper. Although no references were found specific to the U.S. forces, and there is anecdotal belief any number of paints may have been used. Whilst calcium carbonate was clearly present, identifying the expected protein-based binder was problematic, even using a highly targeted technique like LC-MS, which produced variable results with difficult attributions. We suggest the challenges for identifying the binder are due to masking by inorganic components and instrumental limits, compounded by the complexities of a surface which we expect to be heavily weathered and contaminated from its extensive service life. More reports of using these methods for historic vehicles are needed to understand what these binders should look like in complex, degraded mixtures, and to identify more flexible and adaptive research pathways. A simple experimental method was trialled using solvents to extract the binder from the masking components. Despite promising results on known mixtures, it did not provide clarification for an actual paint sample from *Flak-Bait.* Not being able to identify the binder has ramifications, foremost to deciding on a compatible coating system to preserve the stripes.

WHAT DOES THIS MEAN FOR OUR TREATMENT? The exterior will be coated as part of the larger project to preserve the expectational originality of this rare survivor. Decisions need to be made about the best way to protect the stripes even with these perplexing results. As conservators, we deal with ambiguity as routine practice. We expect the remnants to be somewhat stable as they survived the war, inclement weather, even been transported on an open-bed truck to their current location. But we need to do our due diligence to assess the compatibility of the coating. Some testing should be done directly on the object, for example chemical solubility cannot be replicated. However, we are also considering if experimental methods such as mock-ups can be used to supplement the inconclusive results of the analysis to ensure treatment decisions are ethically grounded. Especially with respect to measuring the compatibility of a consolidant, assessing key criteria such as penetration, displacement due to spray application, and the consolidative effect. We are experimenting with recreating the physical qualities of the stripes, such as friability and coherence or micro-cracking, with high pigment-low binder formulations based on the existing results. We will need to critically consider if the observations of these mockups can be related to the Invasion Stripes on *Flak-Bait,* or if they simply underscore the limits of our experimental method.

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