AVIATION ARCHAEOLOGY: HISTORY, THEORY, PRACTICE AND DIRECTION

A Dissertation

by

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ABSTRACT

Aviation archaeology as a field of study has struggled with competing academic, professional, and public definitions and priorities since its establishment. In some ways, this sub-discipline of historical or underwater archaeology mirrors the development of nautical archaeology. Like nautical archaeologists who overcame the barrier of the oceans and pioneered methodology to suit, the proponents of aviation archaeology have also used the discipline to overcome a barrier of historical perception and tradition. The practice of aviation archaeology, however, has been characterized by opposing viewpoints and stakeholders often exhibit a non-collaborative attitude towards other groups and sometimes their own colleagues. These stakeholder groups are each focused on their own priorities, be they theory, methodology, conservation, exhibition, or re-use, and each group is arguably attempting to shape the future of aviation archaeology through their projects or publications. This dissertation is a critical evaluation of the current state of aviation archaeology, including its history, stakeholders, literature, and defining projects. This leads to the identification of a series of best practices in aviation archaeology and a theory of interpretation and display of recovered aircraft.

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NOMENCLATURE

AUV	Autonomous Underwater Vehicles
BAAC	British Aviation Archaeological Council
BuNo	Bureau Number: US Navy aircraft designator- similar to S/N
CAF	Commemorative Air Force
CRM	cultural resource management
CTD	Conductivity, Temperature, and Depth
DPAA	Defense POW/MIA Accounting Agency
DNR	Department of Natural Resources
DSV	deep-submergence vehicle
ECU	East Carolina University
E/V	Exploration Vessel
INA	Institute of Nautical Archaeology
JCCC	Joint Casualty and Compassionate Center (UK)
JPAC	Joint POW/MIA Accounting Command (now DPAA)
KIA	Killed-in-Action
MACR	Missing Air Crew Report
MBARI	Monterey Bay Aquarium Research Institute
MBNMS	Monterey Bay National Marine Sanctuary
MIA	Missing-in-Action
MOD	Ministry of Defense
NASM	National Air and Space Museum

NHHC	Naval History and Heritage Command (US)
NHPA	National Historic Preservation Act
NMSA	National Marine Sanctuary Act
NNAM	National Naval Aviation Museum
NOAA	National Oceanographic and Atmospheric Administration
NPS	National Park Service
NRHP	National Register of Historic Places
OET	Ocean Exploration Trust
POW	Prisoner-of-War
RAF(M)	Royal Air Force (Museum)
ROV	Remotely Operated Vehicles
R/V	Research Vessel
SHPO	State Historical Preservation Officer
SMCA	Sunken Military Craft Act
S/N	Serial Number: US Air Force aircraft designator- similar to BuNo
TAMU	Texas A&M University
TIGHAR	The International Group for Historic Aircraft Recovery
UAB	Underwater Archaeology Branch, (US NHHC)
USAFM	United States Air Force Museum
WAMM	Western Australian Maritime Museum
XRF	X-ray fluorescence

1. INTRODUCTION

Aviation archaeology is a relatively new, and to some, an unconventional subfield of archaeology. It uses archaeological methodology to study aircraft deposition sites in all conditions and in all types of landscapes as a result of wrecks, ditchings, abandonments, accidental loss, etc. Research can also cover a wide range aviation properties or heritage objects such as military or private airfields and structures, passenger terminals, aerial exploration base camps, and any manner of aviation-related objects. This subfield can also include aerospace (both atmospheric and space flight) heritage sites and artifacts, as well as the world's space exploration history.

It should be observed, nonetheless that many archaeologists and other non-archaeologist stakeholders define the subfield of aviation archaeology, or aerospace archaeology almost by its want of definition and scope. Some claim the subfield should not exist, and question the validity of studying items still in use today, linking aircraft with contemporary machines such as the motor vehicle. The archaeology of the car exists, however, and joins aviation archaeology as a development in contemporary archaeological study aimed not at describing the immediate past, but studying human development of technology and cultural development as a response to it.[1] The problem for many is that objects in the subfield of contemporary archaeology straddle the line between modern-day usage, history, and archaeology, and are notoriously difficult to characterize. This field is also anthropological in nature, dealing with a culture of the people who have both used the item for its original purpose and then, in some cases, actively attempt to prevent the item from becoming an artifact. A majestic, but not inappropriately so, description of

[1] Lemonnier 2013.

aviation archaeology by Capelotti advises that there are “those who would study such wreck sites for what they can tell us about the progression of earthbound humans into the third dimensions of air and space, or the ways in which our technological society wages war.”[2] Understanding aircraft and aerospace sites allows for the development of broader landscape studies, for either battlefield archaeology, war history, or community history.[3]

Many variables have influenced the practice of aviation archaeology, most notably logistical and practical limitations, as well as organizational viewpoints. This thesis examines the practice and the various influences on aviation archaeology, and how these influences should be taken into account when considering the future of aircraft-related sites as they are studied in, or recovered from, their natural environment. It also examines their role in our future historical narrative.

I argue that in order to effectively practice aviation archaeology, an archaeologist must be aware of the history and influences on the subfield because they will influence the research, planning, and execution of projects. The ideal methodologies for aviation archaeology sites are research goal-based and well rounded, can include multiple types of documentation, and can sometimes incorporate expertise, tools, and technologies developed for other fields and adapted for aviation sites. Effectively planned and executed projects in turn will shape the future of the field.

Additionally, the remains of aircraft in archaeological sites are subject to the same environmental factors as other archaeological materials and must be stabilized if removed from

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[2] Capelotti 1996, 16.
[3] Farrell 2011; Scott and McFeaters 2011; Firth 2015.

situ. Project planning must take into account the formation processes of aviation sites and how they differ from other sites, as well as the goal of any conservation processes and the eventual role of the excavated artifact. Aviation artifacts require interpretation; the type and level of which varies based on their eventual use (e.g. in a museum, the treatment will depend largely on the exhibition’s learning goals). Anticipating these end results will influence a treatment process beyond stabilization.

Stakeholder concerns from a variety of organizations have largely determined the methodologies used and the development of the subfield of aviation archaeology over the past half-century. This dissertation instead presents a set of best practice methodologies based on the research value of the aircraft as an archaeological artifact (focusing on determining that value given the existence of historical documentation and the merits of each case) and the recognition of influences from practical limitations and outcome goals. These best practices will help align the subfield with modern archaeology and historic preservation goals. The dissertation outlines the development of the subfield, clarifies best practices for each step in the archaeological practice, and discusses progressive interpretive display methods. It will also argue for the transparency of research goals, the relevance of proper and varied documentation methods, as well as knowledge of deterioration and conservation practices.

While discussing aircraft projects from several eras and including some terrestrial-based project concerns, this dissertation will largely focus on underwater aircraft wrecks from the 1930s-1950s. Largely because of the history of aviation archaeology stakeholder priorities, earlier developmental focus has been on individual terrestrial wreck and site projects. Current research projects show academic focus is on including aviation sites in maritime landscape and battlefield archaeology communities. Investigation emphasis on inter-war to post-WWII propeller-driven aircraft is due to the site formation processes that give researching these wrecks an advantage; the speed at which aircraft flew during the pre-jet era factors into the likelihood of articulated remains.

1.1 Research Questions

These represent the primary research questions addressed below.

1. How has the field of aviation archaeology developed until now and what factors have influenced it? And ideally, how should the field develop in the future?
2. What are the most effective methodologies for documenting aviation archaeology wreck sites underwater? What should be the purpose of research on these sites?
3. What are the best ways to preserve and interpret aviation sites or artifacts to audiences?

I address these general questions using a critical summary of the treatment of wrecked aircraft to date and illustrate them by a series of case studies involving field research and museum display of submerged aircraft wreck sites. These case studies will exemplify documentation methodology, corrosion studies, site formation, and a range of final research products including digital archaeology and museum exhibits. I present a standardized digital methodology for aircraft wreck survey and advance the incorporation of 3D modeling in aviation museum display.

My goal is to illustrate underwater survey and display methodology by using three sites as example case studies of the full archaeological process: the airship USS *Macon* and its biplanes, B-24 *The Tulsamerican,* and a PBM-5 Mariner S/N 59172. USS *Macon* is a Navy rigid airship built in 1933 and lost off the coast of California in 1935 at a depth of 450 m. The wreck site contains some of the oldest known aviation material submerged in salt water in US waters, including four intact Curtiss F9C Sparrowhawk biplanes. Despite its age and marine organism activity, the metal and organic remains of the aircraft appear to have retained a high level of integrity. The National Park Service (NPS) assessed the eligibility of the wreck site for the National Register of Historic Places (NRHP) in 2006, and listed it in 2010. As co-PI, in 2015 I helped lead a joint National Oceanographic and Atmospheric Administration (NOAA), US Navy Naval History and Heritage Center (NHHC) Underwater Archaeology Branch (UAB), and Ocean Exploration Trust (OET) endeavor to benchmark site formation processes for this early modern-metals aviation site. We recovered a small sample of duralumin frame from the airship which I compared to a similar piece recovered in 1991. This study, as well as visual site survey interpretations, can show a timeline of deterioration that will inform general archaeological knowledge of the potential longevity of aviation sites in deep water. Our team planned the survey considering the non-recoverability of the aircraft or airship remains, and the depth and isolation of the site versus public desire for information and imagery.

On *The Tulsamerican*, I develop a standard for underwater aircraft documentation that results in the creation of 3D models, which are both exciting and accessible to the general and museum public as well as academically informative. *The Tulsamerican* was the last B-24 bomber manufactured at the Douglas Aircraft factory in Tulsa, OK, rolling out of the factory doors in summer 1944. The plane was purchased solely via war bonds by Tulsa factory workers and citizens, and as such, they were allowed to name it, paint its nose art, and sign their names and write messages on the fuselage. For this project the survey reflects the primary purpose of displaying this particular aircraft's cultural importance in a museum setting, which is designed to include its history, its present state, and an indication of what might happen to it in the future. For conservation studies, the survey includes research into aluminum decay rates. There are potentially over 11 B-24s underwater around the island of Vis, Croatia, where *The Tulsamerican* also lies, and during my 2015 fieldwork I took ECorr and pH measurements of three full or partial B-24s to build the only deterioration signature database for a particular aircraft type at depth in salt water.

Martin PBM-5 Mariner S/N 59172 sank in 1949 in Lake Washington, WA, which is an extremely dark and low visibility area. The aircraft wreck site is one of only a few known underwater Mariner sites, and, although half of this aircraft resides in a museum on display, only one complete and restored PBM-5 exists in the world. The Mariner site presents an opportunity for archaeological documentation to complement current displays and provide an alternative source of interest for aviation museum visitors.

I discuss best practices for all three projects sites based on their histories, stakeholders, site formation, and anticipated survey results. I develop associated museum displays showcasing the artifacts and digital products, including visitor-manipulated 3D models of the aircraft sites underwater. In all three cases, digital visualization of the wreck site allows for the documentation and understanding of the wreck without the need for its recovery.

2. THE HISTORY OF AVIATION ARCHAEOLOGY

Aviation archaeology is a relatively new subfield and arguably in the later stages of becoming an accepted research field by academic, professional, and federal practitioners. It remains, however, in its adolescence in terms of practice, development of standards, and potential. Aviation archaeology has been 'practiced' in various forms beginning soon after WWII, although most organizers of early projects used the term to describe salvage and relic hunting. Over time, the field has developed to include four distinct categories of stakeholders, each with their own concern and patterns of resource use, some straddling two or more categories. These stakeholder groups have largely determined how the subfield has developed so far, and each category's influences continue to develop aviation archaeology. What follows is a summary of general points in the subfield's history to present; outliers of course exist, but in this section I identify and focus on averages and trends.

2.1 Background Information

The study of aviation archaeology begins by understanding deposition and site formation processes. Narrowing the field of study to vintage aircraft built prior to the jet age (1950 and earlier) allows for a generally greater level of integrity of the artifact in situ.[4] This is primarily because of the destruction of jet aircraft during a crash event due to higher speeds and the fact that 'modern' sites are often subjected to considerable post-deposition modification as large pieces, or even entire aircraft, are removed as part of the modern forensic investigation of aircraft wrecks.

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[4] English Heritage 2002.

After WWII fallen aircraft littered the UK and mainland Europe. Farmers in these areas also began to dig up crashed aircraft and their parts when they returned to plowing fields. Partly to coordinate a public response and partly to reclaim materials, soon after the war the British government led a highly effective national scrap metal initiative (Figure 2.1). The ability to profit from scrap and the desire for war trophies spurred the uncontrolled looting of WWII aircraft wreck sites in the UK into the 1960s and 1970s, under the guise of aviation archaeology.[5] In the US, government-controlled scrapping of deemed 'surplus' post-war aircraft took place on military airfields. Concentrated looting efforts, however, did not take place in the US on unrecovered crashes of training aircraft as they were often too remote, although evidence of smelting at crash sites in the southwest US states dates to the 1950s and graffiti on some wrecks dates to within a few years of the WWII crash dates.[6] Many aircraft types were lost due to post-war scrapping, and aircraft numbers that were once in the hundreds or thousands were severely reduced.

[5] Moshenska 2012, 101.
[6] Fuller 2009.

Figure 2.1- A pile of German aircraft on a British field, photographed near the end of the Battle of Britain. Reprinted from Taylor 2011.

In 1969 and 1970, respectively, the movies *Battle of Britain* and *Tora Tora Tora!* were released and influenced a movement to salvage and restore complete WWII aircraft for display and flight. The majority of aircraft used for the crucial flying scenes of these movies did not exist, in which cases the film companies modified surviving aircraft frames to closely resemble the appearance and flying ability of the original aircraft. In 1970 the production company for *Tora Tora Tora!* donated several of those aircraft to the then-named Confederate Air Force (CAF, now Commemorative Air Force), who soon after began flying performances of mock battles for airshows around the nation.[7] Some of the aircraft used in *Battle of Britain* came to the US in lieu of payment to an American stunt pilot and kept in private storage, but many are

[7] Allen 2014.

presently in museums in the UK and Europe. During this time the collection of vintage aircraft began to be associated with monetary value.

Although some government-funded aviation museums are older, many aviation museums in the US and UK opened in the 1960s and 1970s.[8] This period also coincided with the retirement of WWII veteran pilots. A number of private collectors of WWII aircraft opened public, non-profit aircraft galleries in the 1980s and 1990s. Generally, history and aviation enthusiasts controlled vintage aircraft resources from the 1950s to 1990s. Early aviation museums and vintage aircraft collectors were primarily interested in where to source disappearing vintage aircraft and how best to use surviving WWII aviation heritage; one of the early divisions of aircraft in this group of stakeholders was into 'flying' vs 'static' collections. Aircraft today are considered valuable resources and belong to (and change ownership from) either museums, governments, or individuals, and can also change back and forth in status from original wreck or abandonment state to active restoration or passive display/storage. The rarer an example is, the higher its value based on its restored state, although in a few cases the value is based on an unrestored item's history.[9]

2.2 Stakeholders and Trends

Stakeholders are present in any field where there are different opinions on how to use a valuable resource. Vintage aircraft are comparable to archaeological artifacts in regards to having a monetary value associated with their sale, trade, or collection, which is largely centered on either provenance or association with a key historical figure. Several authors have written

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[8] Crouch 2007.
[9] Editor 2015.

about stakeholder groups in aviation archaeology, mostly to describe the different enthusiast or amateur groups and their activities.[10] For the purposes of this dissertation, key stakeholder groups in the field of aviation archaeology include academics, federal organizations, professional contractors, and either history or aircraft enthusiasts or salvors with no formal archaeological training (Table 2.1).

Table 2.1- Stakeholder Groups

Stakeholder Group	***Description***	***Example Organizations (US)***
Academic	Any person who is not otherwise affiliated with a professional contracting firm or works for the Federal Government, who has at least a Master's degree in archaeology.	University students and professors
Federal	Any organization that has the power to lawfully restrict access to and mandate treatment/preservation of artifacts.	NOAA, NPS, NFS, NHHC
Professional	An organization, or business, who hires degreed archaeologists and performs archaeological investigation of sites.	Search, Inc., R.C. Goodwin & Associates, AECOM
Enthusiast	An individual with pertinent aviation history or aircraft knowledge, a historian, family members, an aviation museum.	BentProp, History Flight, Individuals, Museums

Note: This table refers to stakeholders practicing or influencing aviation archaeology only, and does not necessarily represent all stakeholder groups in the vintage aircraft or aviation history worlds.

[10] Hoffman 1998; De la Bédoyère 2000; Vander Stoep 2000; Holyoak 2002; Fix 2011; Moshenska 2012.

Most individuals or organizations overseeing aviation archaeology projects belong to one obvious group, but members from each group may change affiliation or collaborate on projects. Enthusiast organizations often include contracted professional archaeologists on their projects, and federal organizations often work with academic archaeologists. Aviation museums generally fall into the enthusiast category, but with the rise of degreed curators and conservators dealing with aircraft preservation their affiliation category is increasingly blurred. Stakeholders from these groups exist in virtually every country, but my study of early stakeholder influences on the field focus on amateur activities in the US and UK, which were focused on sourcing aircraft materials for collecting. The UK and US each have all four groups of stakeholders, each emerging and exerting influence at different points in aviation archaeology's history. One difference between groups of stakeholders is the type of influence practitioners had and continue to have on the field, by either carrying out projects, legislating resources, or writing policy.

2.2.1 Amateur and Federal Stakeholders

Early collectors of the 1960s and 1970s, many of whom had a direct connection with vintage aircraft from personal experience, were the first group of stakeholders with influence on how vintage aircraft wrecks were treated. As Fix notes, "to the generation of men and women who built, maintained, and flew these aircraft, conducting an in-depth archaeological investigation on a wrecked plane was, and in some cases remains, tantamount to performing an archaeological investigation on yesterday's car wreck."[11] To early collectors, aviation material was a resource that could be used to further aircraft projects as they saw fit; sometimes the state of this surplus material was part of a wreck.

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[11] Fix 2011, 994.

UK-based enthusiast groups, called ‘aviation archaeologists’, or ‘relic-hunters’ in reference to their digging activities, conducted excavations in small groups and as individuals from the 1960s.[12] In the heyday of amateur digging of aircraft sites in the UK there also arose a market for the sale of WWII relics, as well as the looting of personal artifacts from wreck sites. B. Robertson describes a 1972 digging of a B-24 Liberator in England using phrases such as “remove engines and other valuables,” “the site had been pretty well picked clean,” “quite a souvenir,” and notes that the majority of the removed wreckage went to private collectors (Figure 2.2).[13] By 1981 evidence suggests that roughly 43% of terrestrial RAF wrecks in the UK had suffered some sort of amateur digging.[14] British citizens voiced distaste for looting aircraft wreck sites after a few violent explosions during amateur excavations of ordnance and a BBC documentary showed a failed amateur excavation of a WWII hero’s crash site.[15] The public supported passing the UK government’s 1986 Protection of Military Remains Act, which requires permitting for disturbing any military site.[16] Enthusiast diggers responded relatively well to government claims on aircraft resource. Remaining groups and individuals in the UK organized themselves into aviation archaeology clubs and pursued permitted digging. The British Aviation Archaeological Council (BAAC) restructured to act as an umbrella agency for amateur archaeology groups in the UK, who now follow permitting procedures from the Ministry of Defense (MOD) and the UK’s Joint Casualty and Compassionate Center (JCCC).

[12] De la Bédoyère 2000.
[13] Robertson 1978, 46–48.
[14] Holyoak 2002.
[15] Cornwell 2006.
[16] Holyoak 2002.

Figure 2.2- Pieces of B-24 42-94835 pulled out of an English Field in 1972. Most of these pieces remain in private collections. Reprinted from Robertson 1978.

Early amateur activity on vintage aircraft wreck sites in the US is a similar mix of tampering, looting, loose documentation, and collection of relics that most call ‘wreck-chasing’, although at the time, stakeholders viewed the value in WWII aircraft as tangible remains instead of research. In the US, mostly individuals and volunteer groups associated with museums found wreck sites in terrestrial sites and began using parts for aircraft restorations, as well as souvenirs. Museums and organizations like the CAF were especially notorious for seeking out wreck sites to find parts to restore aircraft in the 1960s-1980s. In the 1990s amateur enthusiasts loosely separated into those who were largely solitary and focused on finding and documenting wrecks for personal reasons or souvenir hunting, and those who sourced spare parts from wreckage.

Also in this decade, government stakeholder groups emerged in the US, the UK, and Canada largely as a reaction to amateur activity; they held starkly different opinions to amateur groups regarding the control and treatment of aviation artifacts. These government departments began to restrict access to what enthusiasts viewed as surplus property that belonged in museums and private collections, as opposed to in situ. Through the influence of degree-holding archaeologists, the US Navy, the US Army Corps of Engineers, State Historical Preservation Officers (SHPO), and even the National Air and Space Museum (NASM) began publishing statement pieces in the mid-1990s regarding the treatment of wreck sites or the preservation of aircraft.[17] The National Parks Service released a new bulletin in 1998 for nominations entitled "Guidelines for Evaluating and Documenting Historic Aviation Properties."[18]

In North America, the first decade of the 21st century saw reactionary moves by federal governments to block what salvors saw as standard behavior.[19] Instead of a new law for aircraft remains, lawmakers tried tentative efforts to protect wreckage under the National Historic Preservation Act (US), the American Antiquities Act (US), and the Historical Resources Act (CA), while enthusiasts sometimes circumvented these efforts to continue their activities. The US Navy clarified its position on retaining ownership of vintage aviation resources, while the US Air Force took an opposite stance, allowing salvage projects to continue on those aircraft.[20] Attention turned to Canada, where a number of vintage aircraft wrecks were intact in remote areas or freshwater lakes where the preservation is better. Government organizations in this

[17] Butler and Simms 1994, Cooper 1994, McManus 1994, Whipple 1995, Wills 1996.
[18] Milbrooke et al. 1998.
[19] Mikolasek 2003; Chenoweth et al. 2006; Deal 2006; Rogers 2006; Stafford 2008.
[20] Don Brooks Aviation and S. Yormak 2000; Neyland 2002; Scoltock 2008.

decade also began contracting or performing survey projects in-house.[21] The number of projects and publications rose dramatically in 2000-2010, which illustrates the increased level of interest by varied stakeholders.

From 2010 to the present a decline in individual enthusiast activity in the subfield of aviation archaeology may be due to a number factors, most likely a combination of decreasing viable (valuable) wrecks, increasing federal jurisdiction, and increasing collaboration. Enthusiast groups have evolved to including volunteer or contract archaeologists and historians as part of survey and recovery projects either on their own or by request from government agencies. The number of publications in aviation archaeology continues to increase, with most in the current decade from degreed archaeologists working with government or amateur organizations.[22] US federal organizations responsible for cultural heritage artifacts have begun to create internal policies and procedures related specifically to aviation artifacts, including efforts to survey such resources for inclusion into maintenance and education programs.[23]

2.2.2 Professional and Academic Stakeholders

Academic stakeholders emerged early in the 1980s; a news piece in The International Journal of Nautical Archaeology on the emergence of the field of study and the report on an RAF Wellington in Loch Ness is one of the first mentions of aviation archaeology in an academic journal.[24] A well-known chapter from Gould in his 1983 book *Shipwreck Anthropology*, titled

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[21] Coble and Naval History & Heritage Command 2000; English Heritage 2002; Coble 2005; 2006; Wessex Archaeology 2008; Cody and Auwaerter 2009.
[22] Ellis 2011; Wessex Archaeology 2013; 2013; Brown 2014; Gane et al. 2014; Delgado et al. 2016a; Haigler et al. 2016; Cantelas et al. 2017.
[23] Delgado, James P. Interview by Megan Lickliter-Mundon, June 7, 2017. Catsambis, Alexis. Interview by Megan Lickliter-Mundon June 19, 2017.
[24] Nautical Archaeology Trust 1981.

"The Archaeology of War: Wrecks of the Spanish Armada of 1588 and the Battle of Britain, 1940", was the first explanation of the study of aircraft wrecks and their context in the greater landscape of battlefield archaeology.[25] Gould's chapter was a call to arms to the academic community which was not answered until the mid-to-late 1990s, when a few academic articles and the first theses and dissertation was written on wreck sites, methodology, and theory.[26] Many academics interested in aviation archaeology in the 1990s wrote justifications of the subfield while employed at federal stakeholder agencies discussed above. Academic interest in aviation archaeology tends to ebb and flow in 5-10 year periods, and after the mid-to-late 1990s there are few notable academic publications until a flurry of activity in Australia in the mid-to-late 2000s.[27] Professors tended to publish more than students until after 2010, when there was another surge of student-led publications and theses.[28] Academic stakeholders began influencing the subfield by writing justification pieces, but recently academic focus has been on leading through example by taking on public projects.

Professional interest in aviation archaeology, which I identify as work by contract archaeologists or trained heritage professionals, has largely been absent until recent years. Academic stakeholders who have left universities have largely influenced aviation archeology by leading policy change through their positions in government organizations. Recently, some cultural resource management (CRM) firms have begun to take on aviation archaeology projects in either survey, excavation, or conservation or aviation artifacts.[29]

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[25] Gould 1983.
[26] Capelotti 1996; Goldstein 1997; Rogers et al. 1998.
[27] Degrigny 2004; Jung 2004; MacLeod 2004; McCarthy 2004; Jung 2005.
[28] Burgess 2013; Chaters 2013; Osgood 2014; Bell 2015; Daly 2015.
[29] Beeker and Smith 2005; Binnie 2006; Gane et al. 2014.

2.2.3 The Value of Vintage Wrecks in Museums

Aviation museums, even in cases where they exist as little more than a tax haven for private collectors, have influenced much of the development in how aviation artifacts are treated and valued. The renewed interest in WWII aircraft after 1970 drove collectors and salvors to search out surviving examples of airframes. The monetary value for WWII aircraft has skyrocketed since 1970, and continues to be tied to authenticity; a completely rebuilt-from-new-materials warbird is worth much less than the same aircraft type with historical material in it, even if it is only the data plate. Neyland notes this is similar to other types of archaeological looting based on museum value: “in the crush to build collections, aircraft museums have been an impetus for recoveries and have been instrumental in creating a market value for historic aircraft.”[30] As the salvageable aircraft began to disappear from storage yards, surplus depots, and easily accessible wreck sites, museums and private collectors began to look for aircraft in more difficult-to-reach places. The National Naval Aviation Museum began contracting with a local salvage company for the recovery of aircraft in Lake Michigan in the 1980s, beginning a decades-long recovery program that has resulted in over 31 aircraft added to the NNAM’s collection either in Pensacola or on loan. A 1992 private recovery of a P-38 from 82 m under a glacier in Greenland demonstrated success in archival research and the ability to recover aircraft from extreme environments.

Museums and private salvors have relied on archaeologists only recently, and only when permitting requirements force the partnership. In 2014 the Royal Air Force (RAF) Museum

[30] Neyland 2002, 773.

raised a Dornier Do.17 after consulting with Wessex Archaeology.[31] Underwater Admiralty Services, a US-based salvage company, also worked with archaeologists as part of their permit requirements for two aircraft recoveries in Canada in the 2000s.[32]

2.2.4 Stakeholder Trends

In the past 20 years concentrated efforts and the voices of members from all stakeholder groups have served to encourage more thorough documentation of wreck sites.[33] The International Group for Historic Aircraft Recovery (TIGHAR) published early expressions of aviation heritage and artifacts treatment, as well as ran a series of short aviation archaeology field schools focused on teaching enthusiasts how to produce site maps. NOAA's Maritime Heritage Program office recently began underwater field schools on survey techniques for sunken WWII wrecks in Hawaii. Other than these, individual projects have produced site maps but no stakeholder group has agreed on a common methodology adapted from other archaeological field research.

Separation between federal, academic, and amateur enthusiast efforts still exists with much skepticism from all sides as to the expertise and effectiveness of the others, although collaboration has increased in frequency and variation between the different stakeholder groups. Overall, aviation project initiatives are increasingly due to academic and government efforts, as opposed to enthusiast efforts that dominated aviation archaeology's early history. In the US federal organizations such as NOAA have been pushing collaborative efforts since the 2000s, mainly with other federal organizations.[34]

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[31] Wessex Archaeology 2011; Symonds 2014.
[32] Minaskuat Limited Partnership 2005; Deal 2008.
[33] Fuller and Quigg 2011.
[34] Terrell 2002.

Students have published most of the theoretical or statement pieces, while reports on quality survey work in the field in the last two decades has come from academia, contract firms, and museums. Academic aviation archaeology theory publications seem to be resurging after a slow period.[35] Enthusiasts have published project reports, updates, and opinion pieces in aviation history magazines and increasingly online in websites and/or forums. Increased interest in aviation wrecks as archaeological sites has resulted in project publications from Germany, France, Sweden, Norway, Italy, Portugal, and Croatia.[36]

US Federal interest in recovering remains of Missing-in-Action (MIA), Killed-in-Action (KIA), and Prisoner-of-War (POW) military persons led the government to combine a Defense Department task force (The Joint Task Force–Full Accounting (JFA-FA)) and two Central Identification Laboratories for DNA testing into a central command agency (The Joint POW/MIA Accounting Command (JPAC)) in 2003. Accounting includes finding, identifying, and repatriating military personnel whose remains are MIA or currently unidentified, including in aircraft wrecks. JPAC performed full research, recovery, and identification projects on aircraft wrecks, mostly terrestrial, with in-house archaeologists and historians (Figure 2.3).[37] In 2015 the organization was restructured and renamed the Defense POW/MIA Accounting Agency (DPAA) and began contracting projects to strategic partners. This spurred increased interest from several academic, contract, and enthusiast organizations to focus efforts on surveying aircraft wrecks with associated MIA service members for potential future excavation.[38]

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[35] Christian 2014; Deal et al. 2015.
[36] Legendre 2001; Rak and Vladar 2010; Ferreira 2012; Pollock and Bernbeck 2015; Sinobad 2015; McWilliams 2017.
[37] Holland and Mann 1996; Moore II et al. 2002; Pietruszka 2015.
[38] Terdiman 2014; Gray 2017; Terrill et al. 2017.

Figure 2.3- DPAA Archaeology Team members excavate an aircraft wing during a recovery mission for a US Navy pilot (2015). DOD Photo by Staff Sgt. Erik Cardenas, U.S. Air Force/Released, reprinted from Drennon 2018.

2.3 Challenges to a Single Approach

2.3.1 Range and Scope

The environments in which people find wrecked, abandoned, or accidently lost aircraft are wide-ranging. Aviation or aerospace cultural heritage objects and sites exist present on both land and underwater. Aerospace artifacts and the lunar landing site are also arguably examples of cultural heritage sites on the Moon.[39] Terrestrial aviation remains are not limited solely to

[39] Capelotti 2010a; 2010b.

aircraft. Airfields, experimental wind tunnels, waypoints, hangars and other airfield-associated buildings, properties associated with famous persons, and a variety of other types of sites can be aviation cultural heritage objects or areas. Several aircraft crash or abandonment sites in extreme environments exist because the remains are less likely to be found or disturbed.[40] More terrestrial aircraft excavations have taken place in Europe, where aerial battles left aircraft in fields and marshes.[41] In several ways, survey, identification, treatment, and display of artifacts from any aviation site will remain similar no matter the deposition, but challenges exist in terms of stakeholder opinions, archaeological methodology, and monitoring concerns.

In general, archaeological survey on terrestrial aviation sites more closely aligns to traditional methodology and outcomes. [42] Aircraft, however, have been slow to gain regard as historical objects, and only recently has that sentiment begun to change. Research trends follow the development of technology and the concerns of a rapidly-approaching centenary for WWII archaeology. One of the main challenges to aviation archaeology is the lack of standards in terms of treatment and the differing viewpoints about aviation heritage materials. This remains prevalent in terms of aircraft on federal properties in the US. Although there have been efforts to catalogue terrestrial aircraft crash sites on some federal properties, a full index, or a standard approach to site preservation and treatment, is lacking.[43] In the US, a recent trend in community archaeology projects focusing on aviation wrecks has led to valuable partnerships and stewardship.[44] Another challenge is the high monetary value of vintage aircraft and the fact that

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[40] Capelotti 2007; Falch 2013; Brockman et al. 2015.
[41] Legendre 2001; Rak and Vladar 2010; Moshenska 2012; Osgood 2014; Sinobad 2015.
[42] Butler and Simms 1994; Babson et al. 1998; Lake 2002; Cody and Auwaerter 2009.
[43] Milbrooke et al. 1998; Hunt et al. 2012.
[44] Ellis 2011; Fuller (www.aviaitonarchaeology.org).

their value is tied to authentic parts, either with or without provenance. This fact places a monetary value on aircraft parts that exist in wreck sites today. Souvenir hunting, while not as prevalent now as in the last three decades, still exists, as does historical site vandalism (Figure 2.4).

Figure 2.4- Etched and spray-painted graffiti mar the skin of this US Navy C-117 aircraft, wrecked on the beaches of Iceland in 1973. Local farmers used to use it as a target for gun practice, and now tourists use it as a climbing ground. Photo by the author.

2.3.2 Legislation

Preservation protection for aviation properties or cultural heritage objects, including wreck sites, exists in terms of ownership or location. The US Navy claims ownership of all modern and vintage Naval aircraft, including terrestrial and underwater crash sites, regardless of their crash location, except in cases where the aircraft was sold or scrapped. The US Air Force (the US Army Air Corps (1926-1941) and US Army Air Forces (1941-1947)) exercises no rights over wrecked aircraft prior to 1961, allegedly because of destruction of original records by fire. US Air Force policy favors salvage claims in all cases except when human remains are associated with the wreck sites.[45] In these cases, the US Air Force suggests cessation of intrusive activities until proper recovery of the remains can be made.

Wreck sites of any vintage aircraft, military or otherwise, are subject to the laws governing the land or underwater floor upon which they lay. Federal lands include National Parks, National Forests, military installations, land owned or administered by the United States Army Corps of Engineers, the Bureau of Land Management, the Department of Fish and Wildlife and the bottom areas of the National Marine Sanctuaries. Current language of cultural resource protection laws on federally or state-owned lands and marine areas is not aviation specific, however, there have been several court cases focused on interpretation of these laws, mainly for salvage rights to underwater aircraft.[46] Any intrusive work on federal property triggers a Section 106 review under the Preservation Act of 1966, which determines historical significance and eligibility for the National Register of Historical Places, and for aircraft or aviation heritage objects and properties there is a specific guide for this process.[47] Usually the State Historic Preservation Officer makes the final determination regarding an aviation site's eligibility for the national register, but there is no universally acknowledged standard. National

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[45] Neyland 2002.
[46] Historic Aircraft Recovery Corp., Docket no. 03-CV-150-P-S; International Aircraft Recovery, LLC., D. C. Docket No. 98-01637-CV-JLK; International Aircraft Recovery, LLC., No. 98-1637-Civ; International Aircraft Recovery, LLC., No. 99-13117.
[47] Milbrooke et al. 1998.

Parks Service Law 36CFR2.1 requires a permit for disturbance of any historical site over fifty years old on National Park land. Aircraft listed on the Register are more than just recognized as such, they also are legally protected.

While in some US states aircraft are named as cultural heritage resources, often the language of protection laws follows federal language on general historical objects. Aircraft on state-owned land can also be protected under a variety of environmental or heritage policies. On private land aircraft wrecks, except those still owned by the Navy, become property of the landowner and any disturbance is subject to their permission.

In 2004 the first iteration of the Sunken Military Craft Act (SMCA) passed in Congress, protecting all military wrecks underwater from disturbance.[48] The SMCA protects all US military vessels and aircraft underwater anywhere in the world and from any branch of the military.[49] Regulations establishing an expanded permitting process went into effect on March 1, 2016.

In the United Kingdom, regardless of nationality or the date or locations of the crash, all military aircraft crash sites are protected in the Protection of Military Remains Act. Under that act, passed into law in 1986, it is a criminal offense for anyone without a license to tamper with, damage, move, remove or unearth any part of a crashed military aircraft.

Federal protection of aircraft wreck sites has been patchy in terms of legal action, and some of the more well-known cases of wreck damage occurred because of loopholes in federal law that cannot prevent the damage of wreck sites by federal museums or other federal

[48] TIGHAR 2000.
[49] Dromgoole 2013.

organizations. For example, the US Navy-backed SMCA protects sunken aircraft from recovery by amateur groups but not necessarily from other branches of the Navy. Another loophole allowed military museums to trade assets to members of the public until 1996 with the rewording of 10. U.S. Code 2572.

2.3.3 Stakeholder Opinion

Stakeholder opinions and actions are still some of the strongest influences on the development of aviation archaeology and cultural heritage artifact treatment. For example, I have experience with two terrestrial crash sites of WWII aircraft within the jurisdiction of the US Forest Service. In each case, a museum has approached the forest service archaeologist to gain salvage rights to the aircraft.

The first case is a B-23 ‘Dragon’ bomber S/N 39-052, which crashed in January 1943 in Idaho’s Payette Forest near Loon Lake. Over the years, individuals and groups frequenting the site engaged in several types of interactive behaviors, ranging from theft and vandalism to legitimate heritage management (Figures 2.5-2.6). In most cases though, the behaviors have contributed to the history of the aircraft as much as the initial crash event. In 2000 an amateur aviation heritage group, The International Group for Historic Aircraft Recovery (TIGHAR), determined that extensive and recent damage to the aircraft had been sanctioned by the US Forest Service, allowed by the SHPO, and carried out by the hands of the United States Air Force Museum (USAFM) at Wright-Patterson AFB, Ohio. The aircraft was determined, through Section 106 review, to be ineligible for NRHP listing because of a lack of integrity in design, materials, and workmanship and because the crash site was less than fifty years old at the time of determination. The State Historic Preservation Office had actually determined the aircraft as ineligible in 1991 after a request for removal, but no removal had occurred until 1999.[50]

Figure 2.5- TIGHAR enthusiasts document the B-23 wreck site in 2009. Photo by the author.

This case is an interesting study into the motives of both museum and federal permitting agencies concerning individuals' aviation heritage values. According to TIGHAR, USAFM

[50] Section 106 Report Findings, USDA-FS and ID SHPO, 1991.

representatives were “careful to inquire as to the Forest Service’s interest in the wreck at Loon Lake but it was apparent that preservation of the site was ‘not on their scope.’”[51] This is important in terms of values, as the Forest Service archaeologist made the original recommendation of ineligibility to the SHPO; the value of the aircraft was seen not as a community heritage object, but as part of a restoration project. On the other hand, the museum voiced the reason for leaving the rest of the airframe in situ as for the community, even though their salvage of bulkhead components damaged the integrity of the structure and severely changed its appearance, effectively flattening an otherwise intact airframe.

[51] Papers, Emails from Craig Fuller: Aviation Archaeological Investigation & Research, Fuller 2009.

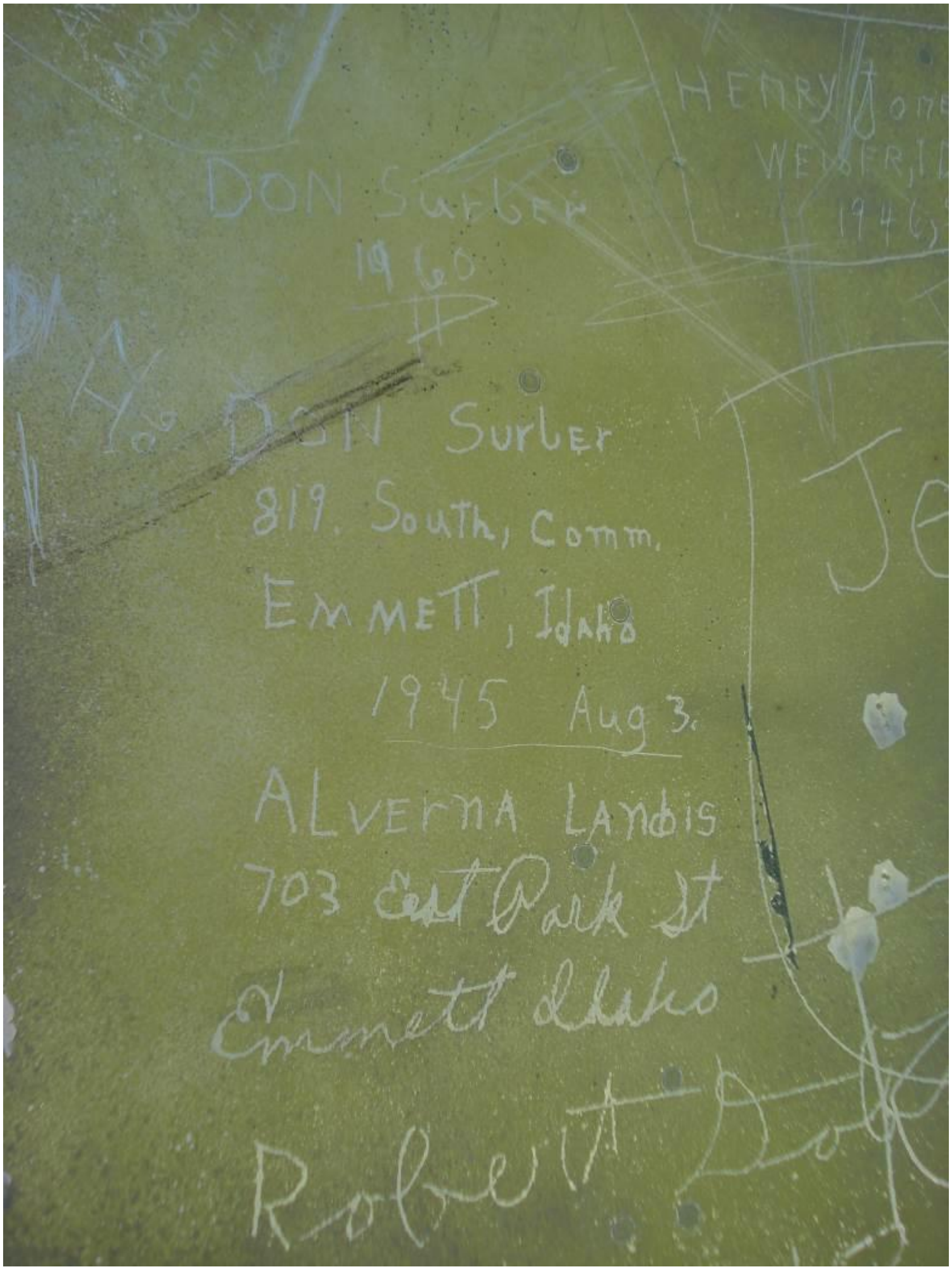

Figure 2.6- Etched names and addresses on the B-23 at Loon Lake date from within a few years of the crash to present day. Photo by the author.

The second case is a search and rescue SB-17G S/N 44-85746A, crashed into a mountaintop during a daylight mission. The aircraft tumbled down a slope and came to rest in a valley, where it burned, after which the remaining crew members scavenged the wreck for structural and survival material.[52] The crash site lies inside of the Buckhorn Wilderness area of the Mount Olympic National Forest, and within a reasonable hike from the closest trail (Figure 2.7). Similar to the Loon Lake B-23 site, this SB-17G has been heavily vandalized since its crash. Planes of Fame Air Museum in California first contacted the USFS Archaeologist for this region in 2005 requesting to salvage the site for parts to contribute to their ongoing restoration, and again recently, asking for a similar determination to be made in order to clear the site for salvage. In the case of the B-23 Dragon, the parts were taken to the museum in Ohio and copied, with the original pieces either going into permanent storage or being scrapped. That likely will be the case with the air museum in California: usually crash site artifacts are too compromised to be restored directly onto display aircraft, structural elements especially. USFS regional archaeologist Neil has stated that she refused the initial request, but had received feedback from other USFS representatives who questioned why she would not give up the aircraft.[53] Unfortunately is still actively looted, with artifacts being sold on Ebay as recently as 2018.

[52] McCurry 2013.
[53] Neil, Stephanie, USDA-FS archaeologist. Interview by Megan Lickliter-Mundon on April 29, 2014.

Figure 2.7- Remains of SB-17G 44-85746A in Olympia National Park, WA. Photo by the author.

This case has several similarities to the Loon Lake case. If a Section 106 is done the findings will likely be the same- the Olympic site has been continuously vandalized and possibly is too lacking in integrity. There are no shortages of B-17s on display in air museums around the world but there are none configured in this search-and-rescue style. There is only one real difference in the two sites and that is the opinion of the presiding archaeologist. In 1988, when the Idaho FS surveyed the Loon Lake site for eligibility the overwhelming mindset was to consider aviation material solely as scrap, which did not warrant protection, being only valuable as parts. That same determination held ten years later, but would it be questioned now, just under twenty-five years after the initial determination? In Washington, the USFS archaeologist is at least raising the question of determining the best preservation plan for this example of aviation heritage, even if the outcome might in this case remain the same. The Section 106 eligibility justification could also be that under Criterion D the site indeed has potential to offer information, which is exactly what the museum values it for as well. In the case of these two sites, even though the outcome of salvage with little documentation in the Loon Lake case and potential salvage with required documentation in the Washington case is similar, the mindset that changed to consider preservation practices is significant.

2.4 Literature Review: Theory and Practice

Aviation archeology as a subfield has developed primarily via to two categories of influence, activity, and theory- projects and publications. This section serves as a critical review of projects, publications, and the trends in both categories that allow researchers to trace the development of the field.

2.4.1 Project Trends

'Excavation' of aircraft wreckage has been aimed overwhelmingly at the full recovery of significant parts such as the engines and air frame, and is most often carried out by enthusiasts or salvage contractors for museums or private owners. Partial archaeological excavation, in terms of human remains or small finds, has been carried out primarily by DPAA (also formerly by JPAC), or their contractors, Dutch professional archaeologists, and researchers from the Western Australian Maritime Museum.[54] Full recovery of aircraft by archaeologists is often deemed unnecessary in terrestrial sites and cost-inhibitive in terms of conservation in underwater sites. Ethical arguments either for, or against, full airframe recoveries remain disagreements about the best environment for preservation (in situ vs recovered).[55] Around the world, museums have

[54] Jung 2008; Dagneau 2014.
[55] Brockman 2011, De la Bédoyère 2000, Schwarz and Fix 2010.

traditionally carried out salvage work with varying levels of documentation. To date (and in published record) the only full, archaeological excavations and recovery of an aircraft wrecks is are Swedish 'Catalina Affair' DC-3, which was shot down over the Baltic in 1952 and excavated in 2004, and two wrecks in Dutch waters by an archaeological contract firm, Leemans Speciaalwwerken.[56] The Royal Air Force Museum in London contracted Wessex Archaeology to perform a recovery feasibility survey on a German aircraft off the coast of Kent in 2010 (Figure 2.8). The Dornier Do 17, which was raised by engineering contractors for the RAF Museum, also benefited from extensive data visualization (Figure 2.9).[57]

Figure 2.8- Contractors lift the Dornier Do 17 from Goodwin Sands in 2013. Reprinted from Symonds 2014.

[56] LUTAB 2007.
[57] Symonds 2014.

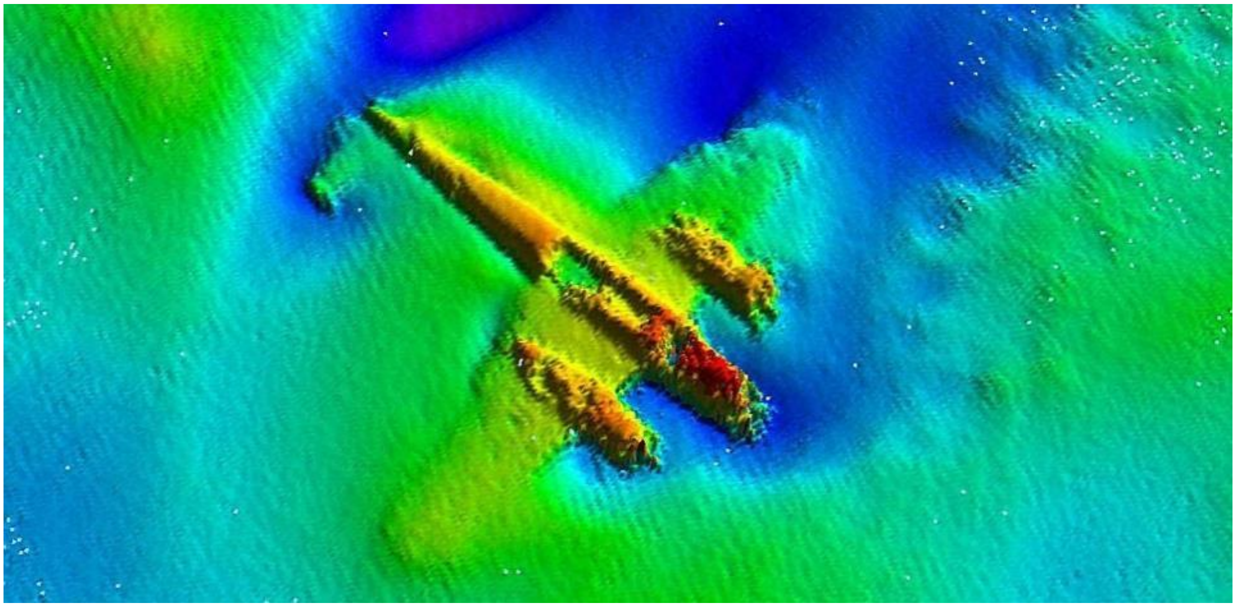

Figure 2.9- Sonar image of the Dornier Do 17 on Goodwin Sands, UK. Reprinted from Symonds 2014.

Not all submerged aircraft are suitable for recovery. Some aircraft wrecks in the US rest within the boundaries of National Marine Sanctuaries or other federally-protected areas under their regulations, such as a Martin Mars flying boat in Hawaii and the remains of the USS *Macon* dirigible and its associated Sparrowhawk biplanes in California. Reports from the consistent monitoring and survey of the USS *Macon* site under its management plan shows continuing degradation.[58] Past requests for recovery have been denied but given the value of the Sparrowhawks and dirigible remains, in terms of historical significance and rarity, future thoughts on the risk of in situ decay versus possible recovery damage and the overall success of conservation techniques might change. Recently federal organizations, such as NOAA and NPS, are focusing on building documentation of cultural historic resources within those protected

[58] Grech 2007; Lickliter-Mundon et al. 2016.

areas, such as the Midway Atoll in the Papahānaumokuākea Marine National Monument & World Heritage Site (Figure 2.10).[59]

Figure 2.10- Maritime archaeologists document the remains of a Brewster F2A-3 Buffalo at Midway Atoll, caption and photo reprinted from Keogh 2017.

Like in the US and UK, aviation archaeology projects in other countries are on the rise. A maritime engineering firm located Halifax bomber HR871 off the coast of Sweden and divers from the Swedish Coast and Sea Center are mapping, modeling, and excavating it for the Bomber Command Museum of Canada. Leemans Speciaalwerken, a Dutch contract archaeology

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[59] Ho and Seymour 2017; Keogh 2017.

firm, is currently finishing a large-scale project to excavate the RAF/RCAF Lancaster R5682 bomber from Alde Feanen using a cofferdam system in order to find MIA remains. Leemens Speciaalwerken had excavated a Vickers Wellington bomber and recovered MIA remains using a similar system in IJsselmeer in 2016. In terms of archeological survey and publication, one can argue that in the last decade Australian wreck sites benefit from the majority of serious studies.[60]

3D laser scanning is well-known as a viable technology for heritage preservation and is being actively explored for archaeological use, although less developed are its uses for aviation archaeology. Project planning for aircraft and aviation artifact scanning must factor in difficulties surrounding the reflective, smooth surfaces. Terrestrial aircraft wrecks, and even restored aircraft were subject to scanning and 3D modeling efforts for the first time this past decade (Figure 2.11).[61] Currently laser scanning is an untapped resource for aviation archaeology projects, both terrestrial and underwater. The measuring accuracy and the ability to obtain and review information with minimal handling of an artifact is invaluable to archaeology.

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[60] McCarthy 2004, Smith 2002, Jung 2008, McCarthy et al. 2002.
[61] Mutual Concerns of Air & Space Museums Symposium 2016: 3D Modeling Aircraft or Large Objects- Ideas for Collections and Display; Vickers 2012; WarbirdsNews 2015.

Figure 2.11- A 3D scan or the interior and exterior of a Lockheed Lodestar at The 1940 Air Terminal Museum in Houston, TX. Model by R. Warden, assisted by L. Champagne and the author.

Technology is a tool that is being increasingly used to market interest in either ship or aircraft projects, no matter their depth. Contract archaeology firms such as Wessex Archaeology use a variety of sonar imaging to create a report with enough information for a museum to decide upon recovery value. The museum, in turn, will use the images to engage public interest and aid funding of the recovery process. NOAA uses a number of Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUV) to map sites in their marine sanctuaries. During the most recent survey of the USS *Macon* site in the Monterey Bay National Marine Sanctuary, an ROV created a complete photomosaic of the site, which will allow NOAA to continue monitoring site disturbance. Underwater aviation archaeology documentation trends have followed both the maturation of maritime archaeology and technology, and their respective availabilities (or visibility).[62] The availability of small ROVs and affordable diver-operated

[62] McCarthy 2004.

cameras, such as the GoPro, allow for creative and inexpensive photomosaics and for basic survey map efforts.[63]

Organizations that either answer to, or interact with, the public with some educational product in mind have been harnessing the ability of underwater imagery to captivate audiences. Modern sonar, photomosaic, and 3D model imagery are informative for survey as well as exciting visual products for education and outreach. Partnerships between technology and historical groups attract funding, attention, and more team members to projects. A recurring partnership between the Stockbridge Advanced Underwater Robotics High School Team and the non-profit organization The BentProp Project, Ltd. (BentProp) allows students who build ROVs to travel to Palau with the BentProp team to survey sunken US aircraft searching for potential MIA air crew (Figure 2.12).[64] Private donations increased after the RAF Museum, which contracted Wessex Archaeology to perform a recovery feasibility survey on an intact WWII German aircraft, released sonar images of the aircraft that attracted public and media interest.[65]

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[63] Edwards and Cooper 2013, Edwards and Cooper 2015.
[64] Terdiman 2014.
[65] Websites: goo.gl/wSDsYj; goo.gl/UPLSTB; goo.gl/oDJ4iR.

Figure 2.12- A student built ROV surveys a submerged aircraft in Republic of Palau. Photo taken by Stockbridge High School Advanced Robotics Team, courtesy of BentProp.

Finally, the preference for shallow-water recovery of large artifacts is no surprise given the enormous funds required for the excavation and subsequent conservation. Most aircraft that are recovered from any depth come from of freshwater lakes, as the corrosion process after recovery is not as accelerated as from a saltwater environment. Deepwater aircraft are not usually considered for full recovery because of the high costs associated with the necessary equipment. Remote sensing performed by non-related organizations, such as oil companies, are increasingly reporting discoveries of deepwater aircraft wrecks and survey has also become more viable, especially on US WWII aircraft, due to increased federal inclusion of contemporary heritage in large-scale exploration initiatives.

2.4.2 Notable Projects

The three case studies that follow are shallow water and deepwater examples that outline how archaeological techniques of research, site survey, excavation, the use of deepwater technology, recovery, and conservation can apply to aviation sites.

F6F-3 Hellcat BuNo 66237

In March of 1970 Lockheed's research submarine *Deep Quest* discovered an F6F-3 Navy Hellcat off the coast of San Diego, California, in excess of 1000 m below the surface.[66] The aircraft had been lost in 1944 but the pilot, Robert F. Thomas, escaped and was rescued. Upon seeing the aircraft during its recovery he commented, "it was the greatest fighter of them all, but it floated about as well as it glided --like a brick."[67] Scientists aboard the submersible took still pictures and video because they were surprised at the seemingly sound structure and by the fact that the aluminum surfaces appeared not to have degraded. The navy decided to salvage the aircraft, and in October of 1970, on its second attempt, *Deep Quest* used its manipulation arms to secure a lifting line to the aircraft.[68] The aircraft was lifted to a depth where divers could help control the Hellcat's recovery onto the waiting Navy dry dock vessel *White Sands* (Figure 2.13). Upon recovery, the Hellcat was in beautiful condition with only minimal structural damage; surprisingly the paint, plexiglass windows, and most components were almost completely intact and little corrosion had occurred (Figure 2.14).

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[66] Shumaker 1958-2009.
[67] Simpson 1975.
[68] Stafford 2008, 35.

Figure 2.13- Divers rig F6F-3 Hellcat BuNo 66237 for lifting. Reprinted from Stafford 2008.

Figure 2.14- The Hellcat immediately after recovery in 1970. Reprinted from Stafford 2008.

After the salvage, scientists in San Diego met the ship to study the sea life that was attached to the aluminum surfaces. According to Bascom: “the most important find from the point of view of a ship archaeologist was the condition of a hardwood headrest in the cockpit; it had been completely riddled by that old enemy of wooden ships, the molluscan wood borer

Xylophaga".[69] Unfortunately, the Navy did not include planning for the future of the aircraft during the survey, and consequently no real measures were taken to prevent the corrosion of the aircraft after its removal from the ocean. The Hellcat was given a series of freshwater rinses with detergent while in San Diego harbor. After remaining in at North Island Naval Air Station for four years, awaiting restoration work and display in the San Diego Air & Space Museum, it was moved to the Pima Air & Space Museum in Tucson, AZ due to the low local humidity.[70] By that time, the blue paint was already faded and the engine nacelle displayed an advanced state of pitting corrosion. Even in Arizona, the deterioration process continued unabated. The engine fell off and by 1991 the tail section collapsed. In the early 1990s the National Naval Aviation Museum expressed interest in acquiring this last-known example of the aircraft type. NNAM contracted Black Shadow Aviation, which used parts from two other aircraft to combine with it to build a new Hellcat (Figure 2.15). The exhibit label at the time identified the aircraft as BuNo 66237, even though less than 85% of it is original.

[69] Bascom 1976, 112.
[70] Simpson 1975.

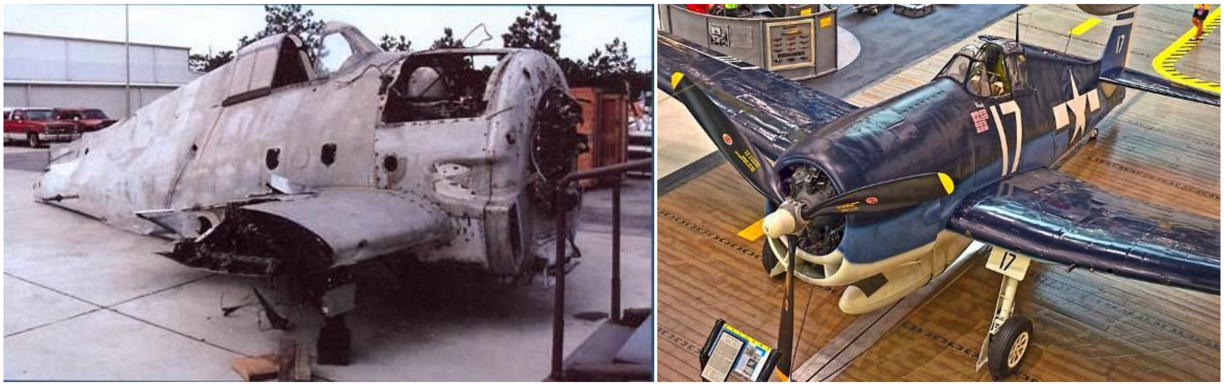

Figure 2.15- Remains of BuNo 66237 after 20 years of deterioration in the desert (L) and recently after restoration (R). Left photo reprinted from Stafford 2008, right photo reprinted from Del Coro 2013.

BuNo 66237 is notable in that it is the first non-contemporaneous vintage aircraft to be recovered from salt water, and also the first to be recovered from deep water. It is a classic example of aircraft treatment determined by stakeholder values of the time, which one can see in the recovery, subsequent abandonment, and eventual restoration actions. A similar scenario involved the F3F-2 Wildcat BuNo 0976, recovered by Navy deep-submergence vehicle (DSV) *Turtle* in 1990, almost twenty years after the Hellcat, from 580 m off California.[71] The aircraft was in an extremely good state of preservation and was restored by San Diego Air & Space Museum. The only difference between these two examples is that the F3F-2 was not left for long prior to the recovery and, therefore, more could be saved. The ideas and values about the aircraft from the viewpoint of the US Navy remained unchanged in those twenty years.

[71] Veronico 2013.

Dyke Lake B-17

A B-17G was raised from Dyke Lake, Newfoundland, Canada in 2004, after a lengthy court case to determine ownership. Multiple stakeholders influenced and benefitted from the recovery project. B-17 S/N 44-83790 was built at the Douglas Aircraft Co. factory in Long Beach, California in 1945, months before the end of WWII. It was ferried to Texas for storage before being refitted and assigned search and rescue duty in Washington, then Massachusetts, and finally Greenland in 1947. On Christmas Eve 1947 the aircraft was flying with a crew of three, five passengers, and two deceased persons (one in a heavy coffin) from Harmon Field, Labrador, to the airfield at Thule, Greenland when it became lost and low on fuel.[72] The crew decided to belly land the aircraft on the then-frozen Dyke Lake, which they did without injury, and set up camp on the lake shore (Figure 2.16). Rescuers from Goose Bay, Labrador, found the B-17 on Christmas Day and dropped supplies by air to the camp. The next day, the B-17 crew was rescued by a jet-assisted C-47 on skis.[73] In February 1948 technicians returned to the aircraft to salvage armament, communications equipment, and other valuable items. The aircraft sank in the lake in the spring thaw of 1948.

[72] Minaskuat Limited Partnership 2005.
[73] Veronico 2014.

Figure 2.16- B-17 S/N 44-83790 on the frozen lake soon after the crash. Reprinted from Minaskuat Limited Partnership 2005.

Don Brooks, an aviation enthusiast and owner of several WWII aircraft, became interested in recovering and restoring WWII aircraft at a young age. He began looking for this B-17 in 1992 because of the possibility of it being intact and preserved in the cold, fresh lake water. Brooks initiated contact with the Canadian provincial government about permitting the recovery of the wreck, but was met with resistance:

> We couldn't get permission to recover the airplane. They finally said, well, there was a law, a federal law that prohibited them from giving us the salvage rights, because if it had been there over a certain length of time, it was considered an

> historical asset, kind of like dinosaur bones. That protected them from being disturbed.[74]

Once found the recovery, the aircraft's transportation to the US, and the restoration would cost millions. Brooks, along with Robert Mester and Mark Allen from the salvage company Underwater Admiralty Services, initiated a search project for the aircraft in 1998. Initial priorities included relocation of the camp used by the crew and passengers prior to their rescue. The survey team soon found a communications antennae, but no large components of the wreck. Well into the survey they decided to move the sonar search location 12 km away, to off shore of a local man's fishing camp site where items from a B-17 were known to exist as scattered trash. The aircraft was found near to the fishing camp site largely intact by sonar at 8 m depth, but missing the nose and tail. The team positively identified the aircraft as B-17 44-83790 by the empty coffin in the bomb bay area.

The B-17's condition was positive in terms of aluminum and paint preservation, but due to the non-disturbance nature of the first survey, no one could determine the level of structural decay, if any. Brooks entered into a four year court case with the Canadian provincial, and finally the Canadian federal government.[75] In the 2004 resolution the judge ruled traditional maritime salvage right applied to aircraft, and the B-17 was deemed salvageable to anyone who would pay the costs associated with recovery, which in this case the provincial government decided against.[76] There are multiple erroneous reports that Brooks agreed, as part of the settlement, to fund the conservation of recovered associated artifacts, a local exhibit on B-17 44-

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[74] Veronico 2014, 68–69.
[75] Brooks Aviation Inc. v. Wrecked and Abandoned Boeing Sb-17g Aircraft, 2002 FCT 503 (CanLII).
[76] Brooks Aviation Inc. v. Boeing SB-17G, 2004 FC 710.

83790, and to fly another restored B-17 to the province in 2005.[77] No agreement to fund any conservation or exhibit existed and the provincial government took responsibility for the items and costs. A true reported term of the agreement, however, is that the salvor, Underwater Admiralty Services, was required to engage an archaeologist as part of the recovery team:

> The primary role of the Archaeologist would be to: a) obtain a full recording (photographic and video) of the salvage and dismantling of the B-17 (both underwater when possible, and on land); b) complete an inspection of land areas (if required) to ensure that no historic resources were impacted by project activities; c) report to the PAO at least once a week or as considered necessary; d) and completion of a final report on the work pursuant to the Archaeological Investigation Permit Regulations to be submitted to the PAO within the specified time period.[78]

The recovery took place in August 2004 (Figure 2.17). The salvage company documented the aircraft and its interior underwater by video survey, noting the aircraft's condition and missing parts. A sonar survey of the rest of the area did not reveal the missing tail or nose sections. The B-17 was secured and lifted using a set of purpose-made float bags with 31,750 kg capacity. Once on the surface, the B-17 was washed to remove river sediment and the recovery team began towing the aircraft to shore, which took 58 hours.[79] The project archaeologist submitted the final report in 2005 after the successful recovery.

[77] Minaskuat Limited Partnership 2005.
[78] Skanes 2005, 27.
[79] Veronico 2014.

Figure 2.17- The B-17 as it first came to the surface supported by list bags. Reprinted from Skanes 2005.

During the survey the archaeologist removed several objects from the aircraft for conservation and eventual museum exhibit display, such as gauge parts, two flashlight-type batteries, and a near complete pair of aviator's sunglasses in their case. At the time of the survey the contracted archaeologist also surveyed the camp where the crew and passengers from B-17 44-83790 had camped for two nights. He noted that the area was relatively untouched, and that several artifacts remained in situ while scavengers had clearly removed others in the past.[80] A selection of items were recovered from the camp for conservation and museum display.

[80] Minaskuat Limited Partnership 2005, 176.

After the legal battle, recovery and the restoration the costs associated with obtaining B-17 44-83790 were quite high, and stakeholder expectations were that it become a fully restored, flying example. At the time of the Dyke Lake B-17 proposal, Brooks did not own a B-17, but during the four year court case, he purchased and restored the B-17 N390TH *Liberty Belle*, using it to perform in airshows around the country (in 2011 *Liberty Belle* burned to the ground as a result of an engine fire). Brooks currently owns three incomplete B-17s, and after the fire destroyed *Liberty Belle* there is less certainty about the eventual role of the Dyke Lake airframe. The 2000 Brooks Aviation recovery proposal notes that the Dyke Lake B-17 is a good candidate for restoration, but any future restored version will consist of at least three B-17s.[81] This illustrates the situation where the value of a reconstituted aircraft does not depend on the originality of the artifact, but rather the monetary value of the perceived originality. It also raises a question as to whether future salvage projects will be required to more fully define the level of restoration prior to project approval, or whether or not it matters once the artifact's ownership is settled.

Swedish DC-3 Wreck, 1952, Baltic Sea

The first, and one of the few, complete archaeological excavations and recoveries of an aircraft wreck underwater is the Swedish 'Catalina Affair' DC-3, which was shot down over the Baltic Sea on June 13, 1952 (Figure 2.18). This took place during the early days of the Cold War, and even though Sweden had declared neutrality they were still strategically located between the Soviet Union and Western Europe and watched closely by both sides. Sweden bought several surplus Douglas DC-3s after WWII and outfitted Tp 79 No. 79001 with American-made radio

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[81] Thompson 2017.

surveillance equipment. It flew missions close enough to Soviet military bases in the Baltic Sea to pick up radio communications, but not close enough to arouse suspicion. On the day it disappeared, the aircraft held eight crew members from the Swedish Air Force. No radio communication or mayday was received, but when the DC-3 did not return a ship and aircraft search party were dispatched. Rescuers found an oil slick and several floating objects, but they were widespread in location and undiagnostic in type. On the second day of search operations, a Soviet MiG fighter aircraft shot down a Swedish PBY Catalina flying boat that had strayed into Soviet airspace in foggy conditions. A passing German vessel picked up the survivors, and the incident led authorities to believe that the same the DC-3 experienced the same fate. The Swedish government was reluctant to admit espionage so the DC-3 loss was recorded as an unknown accident and the family of the crew members were never given either information or closure. The whole story is referred to as the 'Catalina Affair' in order to minimize references to the DC-3.[82]

[82] Tengnér 2012.

Figure 2.18- Tp 79 No. 79001 prior to outfitting in Sweden. Reprinted from LUTAB 2007.

Almost immediately, historians and interested parties began researching the incident. In 1992, after the collapse of the Soviet Union, the new Russian government released records pertaining to the incident and confirmed long-held fears. A Soviet MiG had been sent to deal with an aircraft identified as flying a reconnaissance pattern along the coast. The faster MiG was able to sneak up on the DC-3, outmaneuver it, and shoot it down in neutral waters. Information about the incident became public and the treatment of the situation in 1952 was publically viewed as inappropriately callous to the families of the victims. The Swedish Military, various historians, and several Swedish marine contractors began the search for the aircraft and missing crew.[83]

[83] Magnusson et al. 2006.

The DC-3 was found on sidescan sonar on June 16, 2013, just over 61 years after it had been lost, by a team from Deep Sea Productions and Marin Mätteknik AB (MMT), a Swedish maritime operations company (Figure 2.19). MMT and Deep Sea Productions video surveyed the wreck site to establish its identity using a Tritech SeaKing ROV with HD cameras and lights, and equipped with a CTD for water chemistry readings. The aircraft was verified by the type and the presence of the painted Swedish Crowns insignia on the fuselage and wings. The insignia also served to call into question the portion of the Soviet pilot testimony that no insignia was apparent on the aircraft when he shot it down. It was later discovered that one of the insignias on the fuselage was pierced with bullet holes.[84]

[84] LUTAB 2007.

Figure 2.19- Sonar scan of ‘The Catalina Affair’ DC-3. Reprinted from LUTAB 2007.

Given the importance of finding not only remains of the crew, but also discovering the timeline of the wrecking event, investigation of the wreck site was forensic in nature and, therefore, archaeological in terms of documentation. Research questions focused on forensic analysis, but documenting site formation processes remained essential to that study. This forensic-led approach introduced a number of valuable insights into aviation archaeological project planning, such as determining whether crew members escaped based on the decayed life-preservation equipment, determining the difference in site formation of battle and wrecking versus corrosion damage, and determining the cause of the crash. The Swedish government decided to completely excavate the wreck site and surrounding area. They did not plan to eventually display the aircraft and associated artifacts, but this became a secondary goal during the course of the excavation. As such, conservation of artifacts served only to facilitate the immediate verification of the incident report. Conservators recommended long-term conservation measures after the completion of the reporting process.[85]

The aircraft was discovered at 125 m upright and lying on a tilted angle with one wing torn off and lying parallel to, but in contact with, the fuselage. The cockpit area was the most severely damaged, suggesting a nose-first and slightly tilted crash into the sea. Corrosion had caused pitting in the metal and weakened the structural stability of the wreck. Mud had also seeped into the interior of the aircraft. A large amount of equipment, detached parts, engines, propellers, etc. were spread over an area of approximately 600 m in diameter. Sophisticated bottom-penetrating sonar was able to locate even small items for ROV retrieval. Later that year the Swedish military vessel *Belos* arrived on site with three ROVs and one submarine for the excavation. One mini VideoRay ROV verified, videoed, and mapped the location of small finds associated with the wreck, a medium sized ROV mapped finds located further away from the primary wreck site, and the submarine *Mantis* and work class ROV *Argus* prepared the aircraft for excavation.

The survey team took coordinates from the nose of the aircraft and set up a grid system over the entire site. They mapped finds via the grid system along with positionings taken from the ROV (Figure 2.20).[86] One seat containing the remains of one of the crew members was found around 200 m from the aircraft. The salvage team built a steel basket for the recovery of the aircraft, which was lifted from the sea floor by ROVs hoisting the fuselage by straps into the

[85] Tengnér 2009.
[86] LUTAB 2007.

basket, then the basket was moved to the ship by crane. After the removal of the main portions of the wreck and smaller finds, *Muskö*, a specialty contract ship, arrived to perform the last stage of excavation. This ship was outfitted to perform freeze dredging: it could lower freeze plates onto the bottom, which would freeze large blocks of sediment and bring them to the surface. Once on board, the sediment blocks were excavated by hand and according to the existing grid pattern. Over 200 cubic meters of sediment was excavated this way (Figure 2.21).[87]

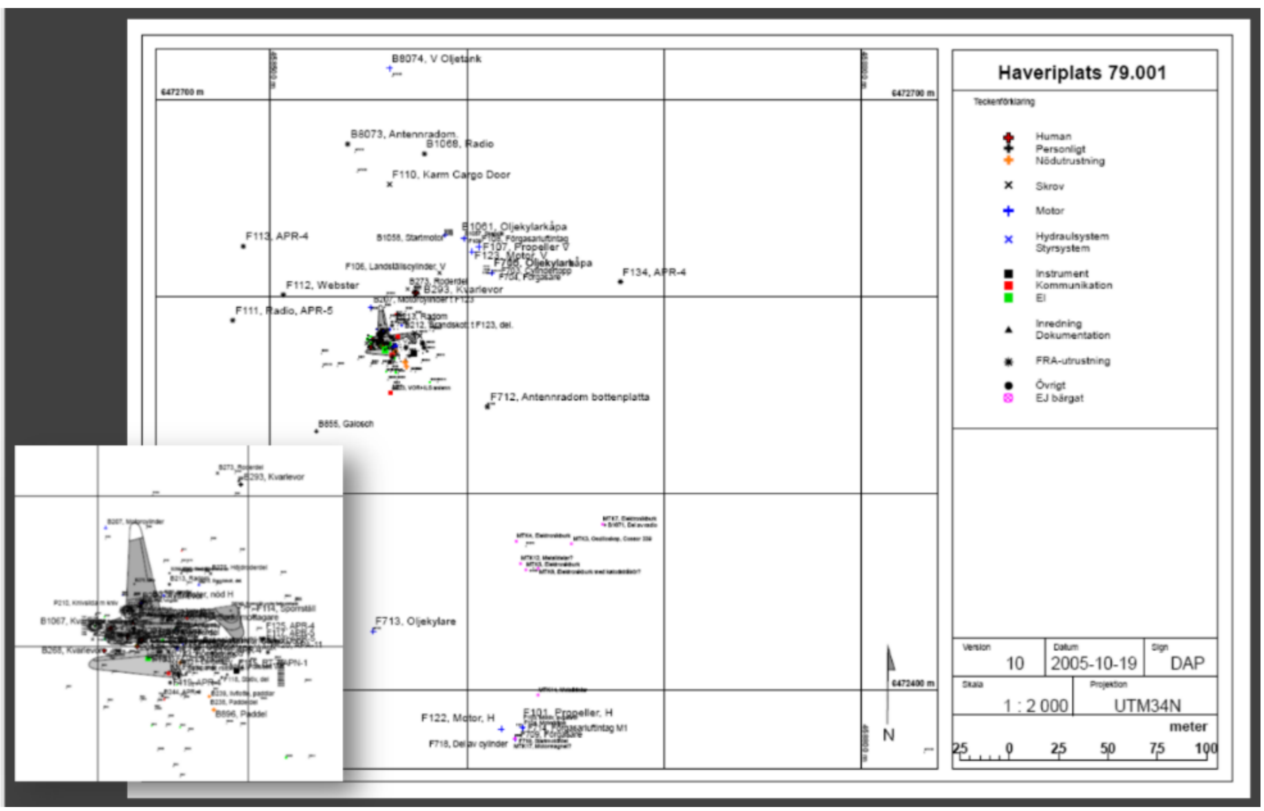

Figure 2.20- Partial grid map of the DC-3 site. Reprinted from LUTAB 2007.

[87] FriGeo AB 2005.

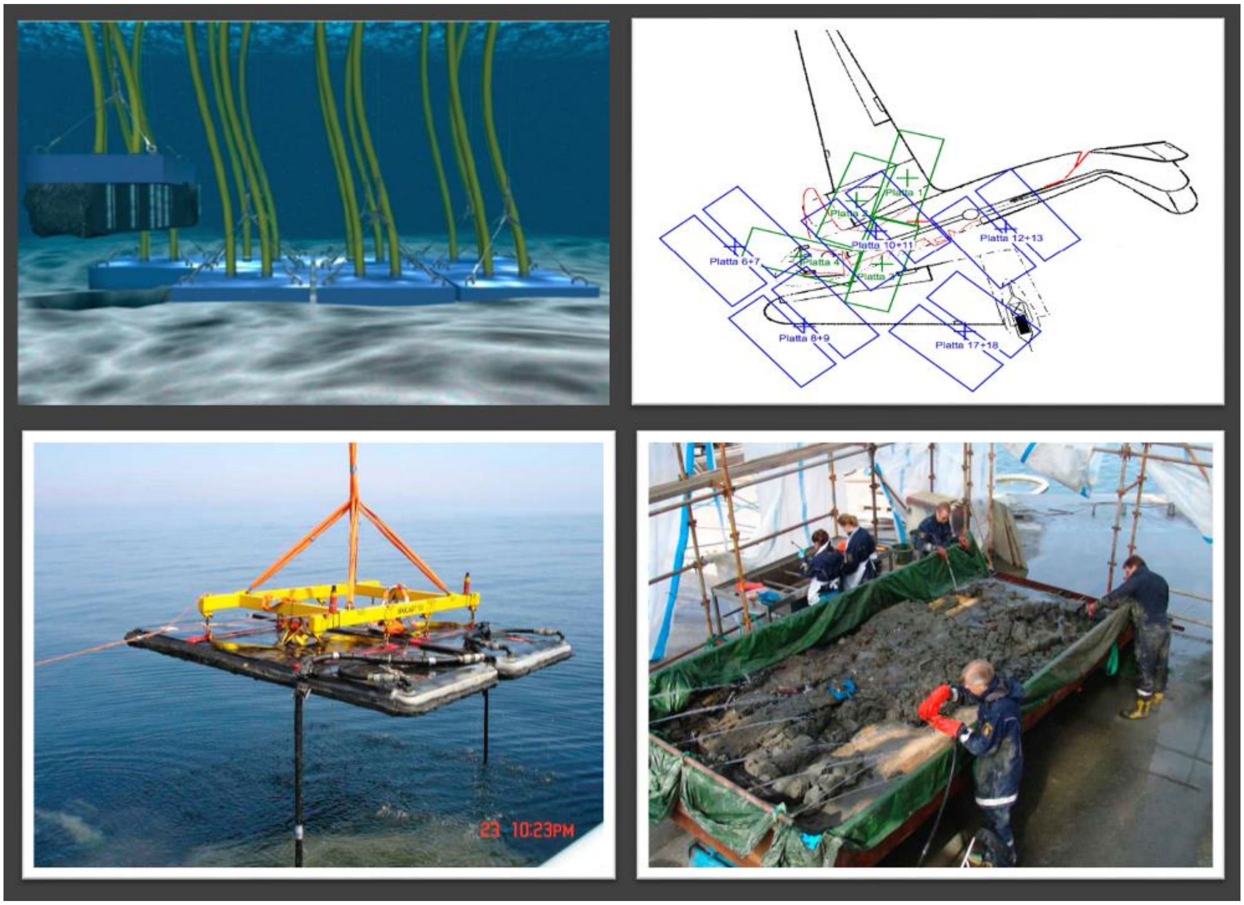

Figure 2.21- Illustration and images of the freeze-dredge process. Reprinted from LUTAB 2007.

The entire site was taken to a submarine bunker and reconstructed for analysis, after which the interior of the aircraft was excavated and the finds recorded (Figure 2.22). Remains of three other crew members were found. Examination of the aircraft showed that bullets, shrapnel, and equipment were violently moving around the interior of the fuselage, making it unlikely crew members had survived the attack or the crash event. Interestingly, however, the interior manual lock on the passenger door was shown to have been moved to the open position. Regardless, no other crew members have ever been found.

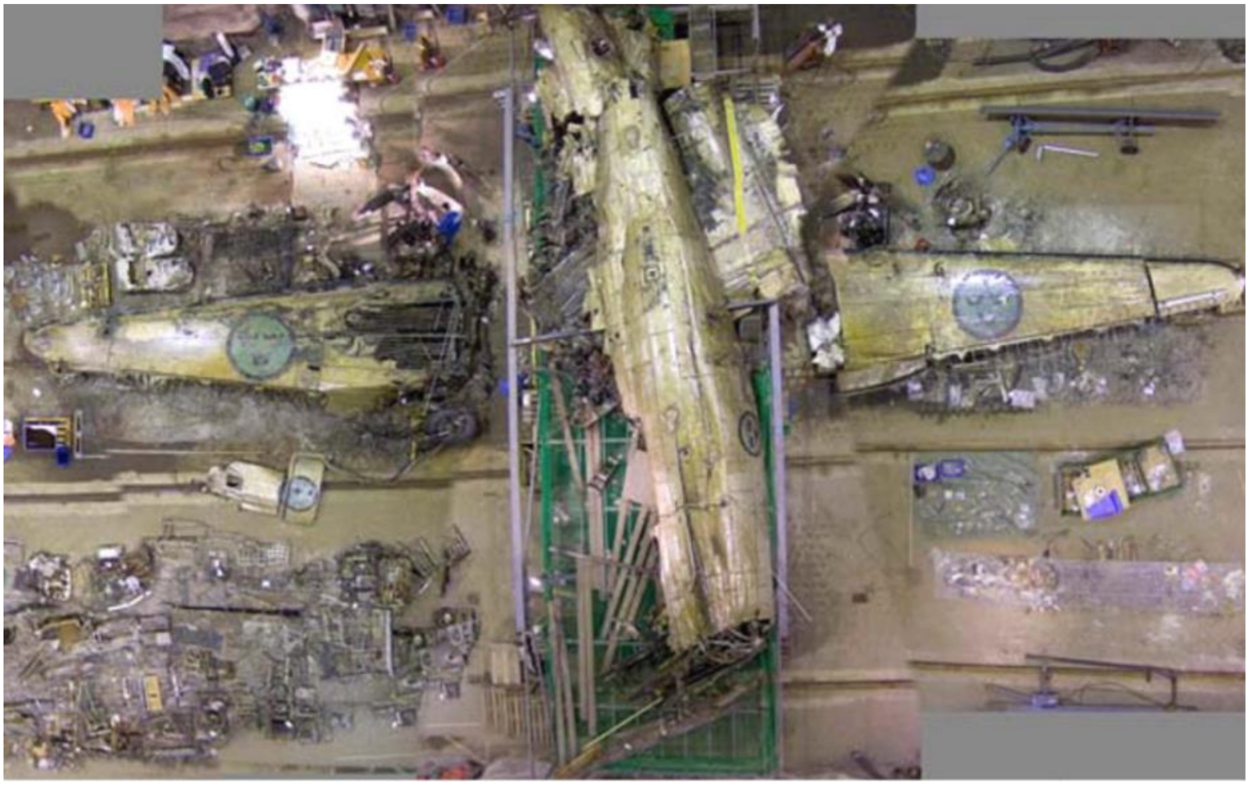

Figure 2.22- The DC-3 after it was raised and arranged for forensic study. Reprinted from LUTAB 2007.

The fuselage was treated with an oil-based corrosion inhibitor that proved difficult to work with for future conservators, and later influenced the overall tone of exhibit lighting (in order to hide the yellow color).[88] To clean the interior space of the wings and other cavities, holes for drainage were cut into the undersides of more damaged surfaces. Conservators noted that the most pitted surfaces were under-wing areas that had been covered with sediment, and this study led to greater understanding of aluminum in archaeological sites underwater based on oxygen content.

[88] Tengnér 2009.

A variety of different finds on the aircraft meant a variety of different conservation requirements. In terms of museum display, however, the variety was a boon for the eventual interpretation of the history and the human element.[89] Paper, silk, leather, fabric, glass, metal of all kinds, and even chocolate were documented and conserved. Flygvapenmuseum in Linköping won the display and built a new building to house the wreck. The museum made the choice to not fully restore the DC-3 after realizing the historical and visual significance of the aircraft could be interpreted much better in its unrestored state. The resulting museum display seeks to both visually and emotionally capture the viewer's interest in the history, discovery, excavation, and aftermath of the 'Catalina Affair'. Visitors walk into a darkened room and make their way through cases that strongly call to mind archaeological exhibits. The cases and introduction panel prepare them for seeing the DC-3, laid on a plinth with dramatic lighting and in the same condition in which it was conserved (Figure 2.23). The exhibit tells the history of the event in panels surrounding the wreck, allowing visitors to witness the full extent of the destruction while reading about how it occurred. On one large wall the video of the DC-3 underwater as taken from MMT's ROV is shown to give context of where and how this aircraft was found. The cases of objects are separated into technical and personal, with one large showcase also showing the conserved door with the open lock and painted crown insignia full of holes. The personal effects cases show leather shoes, uniform parts, weddings rings, glasses, and other items associated with the four recovered crew members.

[89] Tengnér 2012.

Figure 2.23- The ‘Catalina Affair’ exhibit at Sweden’s Flygvapenmuseum. Photo by the author.

In a separate room the visitor has a chance to review the historical documents associated with the cover-up of the incident. The room is separated into parts and is reminiscent of a 1950s office and a sterile waiting hall. Here the visitor can hear recordings of both the military and victims’ family members as they interacted with the press at the time of the loss. The exhibit is designed to make the viewer feel present in the uncertainty of the event. The final room shows the methodology of the excavation and study of the wreck in order to determine a timeline of events from the attack to present day. Flygvapenmuseum will hold the wreck and associated artifacts in perpetuity. If not displayed, then this material would ultimately have been destroyed.

Even though not necessarily by aviation archaeologists themselves, the conception and design of the Swedish DC-3 wreck display was heavily influenced by the quantities of finds and the quality of documentation methods while excavation the wreck site. It was understood that the excavation of the site would destroy the site entirely, and that documentation had to be incredibly detailed in order to fill in gaps in historical knowledge and then tell that history to the world.

2.4.3 Method and Theory in Publications

Similarly to historical, industrial, and maritime archaeology, aviation archaeology theory has evolved from pushing the boundaries of the accepted scope of archaeological study. While proponents of aviation archaeology have written in general about the potential for the study of aircraft sites to yield cultural and material information, few authors from the discipline's early period managed to provide specific examples and most of these early (1980-2005) publications aimed to justify its validity as a subfield.

For their part, mainstream academics were slow to fully embrace aviation archaeology as a legitimate subfield of archaeology. In this regard, the development has evolved similarly to maritime archaeology, and in particular, the study of historical iron, steel, and steamship wrecks.[90] This field of shipwreck study, now completely accepted, was once one of the most hotly contested in maritime archaeology.[91] McCarthy summarizes the two sides at the heart of the debate as it affected the study of modern wrecks, with his observations presented here:

> Keith Muckelroy, one of the doyens of maritime archaeology, saw the study of iron and steamship wrecks as an unnecessary duplication of information

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[90] Burgess 2013.
[91] McCarthy 2000.

> appearing in archives and museums. Anthropologists, on the other hand, have long-since argued strongly against this position and opted for a 'cross-temporal' approach; one that is not encapsulated in a specific period of the past. Professor George Bass, a leading maritime archaeologist, specialising in the shipwrecks of the 'classical period' and producer of innumerable works on underwater archaeology noted 'the value of archaeological research on ships recent enough for photographic records to be available', for example. His was a sentiment echoed by many in the underwater archaeology field.[92]

McCarthy's analyses can apply as much to aircraft as they did to modern iron and steel watercraft. In contrast, however, aviation archaeology itself was not often singled out for attack as was the study of the modern shipwreck, rather the rise of contemporary archaeology; aircraft and aviation property study were largely ignored by the academic community until just before the current century.

Well-known and respected anthropologist and pilot Richard Gould published one of the earliest introductions to the study of aircraft in 1983, arguing that, along with recognizing site formation processes, examining the relationship between the material remains and human behavior should be the focus of future aviation site study.[93] He presents the concept that when thoroughly documented, aircraft wreck sites, either single-site or as part of an archaeological landscape, will be able to illustrate a signature of the culture that produced them- or in simpler terms 'what it is and what it was doing'. In his parallel between the purpose of the ships in the

[92] McCarthy 2004, 82.
[93] Gould 1983.

Spanish Armada and the aircraft in the Battle of Britain Gould discusses how exactly archaeology should be able to enhance our understanding of history. He admits that the purpose perhaps cannot, and should not, be a confirmation of military strategy or, in aircraft's case, technology. Gould argues that with contemporary archaeology, one can derive interpretations that are not usually available from historical records. Unfortunately, in this case, the aviation archaeological records on which he based this study were not obtained in accordance with accepted archaeological standards. Thus, he used the case of the Spanish Armada's historical records versus archaeology to draw parallels to the types of questions that can be inferred from similar aviation site data. Were the alloy metals strong? Did the quality change over time? Were they technologically appropriate for the battles? These are questions, he suggested, that might help scholars interpret more over-arching analyses of human behavior.

In the 1990s a few more position papers appeared arguing for a slowing down of the perceived rapid loss of uncorrupted historical aviation material by introducing notions about historic preservation, ethical restoration standards and practices, and voicing support for the archaeological treatment of aircraft sites.[94] This loss resulted from what scholars have referred to as 'antiquarianism' in this subfield and other fields of archaeology, although for about 20 years aviation sites in particular suffered from looting efforts spurred by the renewed interest in vintage aircraft from museums and enthusiasts. Authors during this time argued for the value of intact material but rarely clarified specific examples of what lessons (if any) they learned from the archaeological interpretation of aircraft material.

[94] Diebold 1993; McManus 1994; Whipple 1995; Wills 1996; Goldstein 1997; Milbrooke et al. 1998.

In 1996 Capelotti completed a doctoral dissertation on a terrestrial site of airship remains in the arctic. The study sought to truth the historical record and interpret one individual's contributions to aviation and exploration science.[95] Capelotti's research design was influenced by Gould, and he sought to discover if, with a hypothesis derived from the historical record and tested by the examination of material remains, he could accurately make these interpretations. He also posited that perhaps an over-arching interpretation on behavior, exploration, and the pushing the boundaries of our natural world might also be possible from solely the archival and material record. Although after a thorough study of both archaeological site and historical record Capelotti's study did draw new conclusions based on the material remains, he pointed out that larger-scale human behavior interpretations were impossible at that time. Clearly, he field needed to mature from a greater amount of research data order to draw better conclusions.

Even though traditional archaeologists and aviation historians believed that the record was largely complete, by 2000-2001 a number of papers outlined instances where potential problems existed in the historical record concerning aviation.[96] In his paper Holyoak pointed out that wreck material, which might not survive elsewhere, can be used when the historical record is not complete. Cassidy clearly lays out examples of this phenomenon in his book about the Short Empire type flying boats, which now exist solely in archaeological remains because associated historical design and construction records were destroyed during WWII air raids on the Short factories.[97] Navy researchers have also called for the testing of material evidence hypotheses and the historical record using aircraft recoveries.[98] In this time, there was a growing awareness of

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[95] Capelotti 1996.
[96] De la Bédoyère 2000; Holyoak 2001.
[97] Cassidy 1996.
[98] Wills 1997a; Coble 2005; 2006.

the importance of the archaeological record for those studying aviation, its technologies, and its people.

Arguably some of the best recent references illustrating the potential for a wide range of interpretations based on aircraft wreck site excavation and research are Jung's dissertation and subsequent articles on a set of submerged WWII aircraft remains at Darwin Harbour in Australia's northern Territory and in Roebuck Bay in Western Australia.[99] The Roebuck Bay collection of aircraft sites, deposited as a result of a Japanese surprise attack on the area in WWII, suffered from both incomplete historical documentation, poorly understood site formation processes, and extensive post-depositional human disturbance. Invited, on the basis of his prior experience at the PBY Catalina wrecks in Darwin Harbour, to join the Western Australian Museum's excavation team, Jung's resulting study was a seminal and far-reaching contribution in both method and results. Research, survey, and limited excavation by the WA Museum's team, led by McCarthy, however, illustrated the vast potential for these battlefield landscape sites to provide insight into the history of the wrecks, the natural and cultural site formation processes, and into human behavior during a wartime evacuation. In his various works Jung outlines the Museum's survey techniques for ten of the submerged and semi-submerged aircraft and presents the team's results as an adjunct to his own research, including his innovative analyses of site formation processes as the wrecks caught fire and sank. The study focuses more on wreckage identification, based on an expert technical knowledge of each type (examining contents, fittings and fixtures, oral histories, and exhaustive archival and technical research), than on the actual recovery of the aircraft, but also provides a site plan and some general observations

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[99] Jung 2008.

about the state of the remains. Lastly, Jung's dissertation details the museum's excavation of one of the flying boat sites from the attack. He concludes that the overall level of organic decomposition is relatively low and cites some examples of remains such as cosmetics and leather. Jung, McCarthy and the other archaeologists and conservators from Western Australian Maritime Museum (WAMM) excavated thirty-five artifacts, several of which were personal effects of passengers.[100] All of the items were designated as protected and now reside in the WAMM's collection. They are now being examined from numerous perspectives, not the least being through the lens of the 'archaeology of the refugee', a concept to which the Roebuck Bay wrecks ideally lends itself.[101]

De la Bédoyère raises an interesting point about human behavior in terms of superstition, and points out that researchers can certainly study the archaeological record for evidence with which to test these hypotheses.[102] Gibbs supports this, arguing that any such catastrophic event that results in archaeological remains will be subject to cultural events that influence site formation processes even prior to the actual wreck event.[103] Researchers have also explored the human behavior of memorializing, in terms of aircraft in war, aircraft as seen in museums, and behaviors concerning aircraft in situ.[104]

We must also acknowledge the links between aviation archaeology and other recent subfields of historic archaeology, which include battlefield archaeology and WWII archaeology, and the expansion of landscape archaeological theory to include underwater sites. One of the first

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[100] McCarthy 2018.
[101] McCarthy, M. Personal Communication 2018.
[102] De la Bédoyère 2000.
[103] Gibbs 2006, 8.
[104] Holyoak 2002; McKinnon and Bell 2014.

studies to call out the discussion of underwater cultural heritage as part of a battlefield landscape, regardless of the physical form (hangars, airfields, shipwrecks, aircraft) was concurrent with Gould's article in 1983 with the research on the USS Arizona site and the Japanese mini-submarine aircraft carrier.[105] Anthropologists and archaeologists have since largely presented support for looking at aircraft sites as parts of a larger landscape, that in order to interpret the data one must include the associated areas, buildings, airfields, battle sites, etc., as necessary supplemental research. Lake further expanded this point in relation to the paradoxes of the inter-war period of the early 20th century, and the suddenly changing role of both the aircraft and war.[106] Maritime landscape, battlefield, and even airscape studies are becoming more popular, both with calls for research and in-progress writing.[107] An appropriate future study could compare the Roebuck Bay sites and the downed flying boat in Kaneohe Bay, Hawaii from the Pearl Harbor attacks, for example.[108]

2.4.4 Aviation Archaeology Interpretations and the Path Forward

In preparation for this dissertation and as part of it, I have visited or dived on aircraft sites and and/or researched recovered aviation artifacts in over 30 locations and over 10 countries. During this time and in some cases before it, I worked for several aviation museums, interned for two US federal heritage management organizations, surveyed sites as an academic and as a professional contractor for archaeology and conservation, and designed exhibits for aviation heritage galleries. This exposure has afforded me the ability speak from the position of all four groups of stakeholders discussed earlier, and see projects through each of their different general

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[105] Delgado et al. 1989; Delgado et al. 2016b.
[106] Lake 2002.
[107] Known publications currently in-progress from Delgado, J., Burgess, A., and McKinnon, J.
[108] Rogers et al. 1998.

perspectives. These experiences have led me to realize these common questions, generalized in the section as version of my research questions, dominate any discussion of aviation archaeology: What is aviation archaeology, how should it be best practiced, and who is best suited to perform the work? I argue that a solidification of site formation-based research and project planning based on expected outcome will not only produce site reports that can be mined for data to support future research in landscapes, behavior, etc., but will also help extend the life of aviation heritage objects either in situ or in museums.

In order to reach a broad-based definition of aviation archaeology based on those experiences, it is pertinent to first refer to the works of Capelotti, Burgess, and Fix, and in particular note that Fix offers the most well-rounded summary of previous definitions.[109] Academics seek alternative definitions to aviation archaeology mainly to widen the scope of the field. Early research and projects single-site and artifact-based in nature, but now the field encompasses all facets of theory discussed above as well as subfields that are limited to different environments or focus on one type of heritage object. Aviation properties (airfields, aviation support structures, etc.), so far, are terrestrially bound and, therefore, can be subject to terrestrial methodologies while keeping in mind the specific research concerns as outlined in previous sections. Underwater sites in this continuum, however, are almost all aircraft and so their study can fall into Fix's fourth category: "Aircraft archaeology - is the archaeological study of both heavier- and lighter-than-air aircraft, in both terrestrial and underwater sites."[110] Fix also correctly points out that the accepted definition for aviation archaeology can change between

[109] Capelotti 1996; 1998; Fix 2011; Burgess 2013.
[110] Fix 2011, 1001.

stakeholder groups based on their research values and priorities. I will add to Fix's definition an explanation that is perhaps obvious to academics, but helpful for other stakeholders: Archaeological study and documentation on aircraft wrecks in terms of site formation (wreck event, material deterioration, and/or environmental and human disturbance), together with research, will allow for preservation, recovery, and display decisions to be made which are in the best interests of the artifact.

McCarthy summarizes the necessity of determining site formation processes in his 2004 article, and introduces the concept that aircraft should be considered for what they eventually might provide, be it, among others, an interesting dive site, a research site, or, in his case being a public archaeologist, i.e one employed by the state and therefore obligated to look to as many public products as possible, a museum display.[111] The longevity of the dive site, the information it might provide, or the survivability of the material during a recovery attempt are all subject to a thorough understanding of the aircraft's site formation processes. He also notes that in some cases, the possibility of the presence of human remains on site may necessitate a visual survey over excavation, or in situ preservation vs recovery, so to not disturb a war-grave. A researcher can also be aware of the historical value of a particular aircraft prior to survey, but during site excavation, as Jung experienced, aircraft can also lend themselves to a high degree of artifact interpretation.

As with any subfield of archaeology, researchers in aviation archaeology mainly reference the benefits of uncovering and documenting material remains, which places greater importance on the excavated (or recovered) artifact. This raises the question of whether an

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[111] McCarthy 2004.

aircraft site has any value based on an imaging survey alone. Naturally, one could argue that documentation of any kind will at least help future archaeological and historic preservation efforts, but will a suite of site maps give researchers insight into over-arching questions of human behavior either now or in the future? And even though parallels can be drawn, aviation sites differ greatly from older archaeological sites in that much more information will be available in archives, and for most sites, a majority of historical research questions can be answered by archival research. Outlier sites such as those presented by Capelotti and Jung are not representative of the thousands of non-descript aircraft that have similar backgrounds and deposition stories. This point makes it difficult to elaborate on the exact manner in which material from *all* aviation sites can be valuable for archaeological study.

On the basis of what I have learned in preparation for this work, I now argue that the main reason why the common justification for the success of aviation archaeology doesn't excite non-academics is that it relies too heavily on an academic idealism, wherein researchers often fail to spell out exact examples of what has already been learned from sites in favor of simply repeating that documentation of sites will help us interpret human behavior in the future. Archaeological interpretations of human behavior can possibly be determined from excavation of historically exceptional single aircraft, while the rest of the wreck sites can contribute knowledge about site formation and continue to add to, and ground-truth, historical documentation. In a sense, I can see the links between Bass' arguments for a historical particularism in early shipwreck archaeology study to this stage in aircraft wreck study.[112] That is not to say that researchers cannot find, in examples of everyday, ordinary aircraft, key pieces of information

[112] Bass 1983.

that would otherwise be lost with relic and souvenir hunting, or heavy-handed restoration. One such example is from Capelotti's research in vintage aircraft restoration, where a rock found strategically placed to sabotage a WWII prisoner-built Nazi aircraft in NASM's collection represents a deeper layer of archaeological study.[113] This information is not the only valuable product to come from the study of aircraft; information without theoretical overtones, although perhaps not as alluring, is crucial for planning the recoveries of aircraft that only exist underwater, or actively preserving aircraft in situ for as long as possible. New technologies will also make the product of visual surveys more helpful for present and future archaeologists. Above all, however, the study of aircraft wrecks, especially in WWII, is the study of the stories of individuals whose lives these aircraft touched, and how they contributed to our modern history.

Finally, who is best suited to practice aviation archaeology? Most academic authors referenced in this section argue that documentation is not enough for the effort to be considered archaeology, and it is true that permitting requirements in most countries require an archaeologist with at least a Master's degree be present for any intrusive activity. Enthusiastic amateurs, citizen scientists, armchair archaeologists- are all labels that describe non-degreed individuals who seek knowledge. Their knowledge of archaeological technique, theory, and methodologies might be lacking, but it is similar to archaeologists who have no knowledge of aircraft components, systems, flight mechanics, or materials science. An archaeological study must provide complete identification and interpretation of the aircraft and deposition, along with site formation, in order to be useful for future study. Stakeholders from all categories should be

[113] Capelotti 2006.

aware of what information to include in site reports, from non-intrusive up to a recovery, to make them useful to researchers from either group.

2.5 Section Discussion

Aviation archaeology follows the course of archaeology in several ways, including tracing its beginnings to the interest of the general public. In most instances this was to view, touch, or possess aircraft remains. While human curiosity and relic-collecting behavior have been common factors for centuries, the somewhat legendary status attributed to aviators and aircraft in both peace and war (some quite recent), exacerbate the desire to recover relics from aviation sites. Documented in its earliest form at crashes of turn-of-the-century hot-air balloons and airships, Capelotti views aviation relic-collecting behavior as one of the more substantial formation processes.[114] Therefore, like any other subfield of archaeology (where similar behaviors are evident), stakeholder groups will always include non-archaeologists, and associated artifacts have a perceived value. Likewise, in terms of amateur or enthusiast practitioners: "one might draw easy comparisons with the nineteenth-century antiquarians whose digs and collections now constitute substantial proportions of the collections of the British Museum and other provincial museums in [the UK]."[115]

One of the ways in which aviation archaeology differs from other subfields is the development of the discipline. In contrast with antiquarian collecting, some archaeologists tried to exert their influence only after other stakeholder groups had been finding, and in many cases successfully recovering, aircraft for decades. Despite there being a multitude of 'anti-touch'

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[114] Capelotti 1998, 7.
[115] De la Bédoyère 2000, 21.

position papers on the subject in the 1990s and 2000s, undocumented looting and recovery of aircraft sites continues. Amateur attempts at documentation of wreck sites still represent the largest number of field surveys. Governmental agencies have been slow in gaining confidence in regulating aviation site interaction for archaeological purposes, and while academics are now generally more interested in studying aviation remains, change is slow, partly because there are so few professionals in the field. As a result, the various groups have completely different ideas about how sites and aircraft should be treated.

On the positive side, while at the beginning of the circa fifty year history of aircraft recoveries professional versus amateur involvement were at opposite ends of the scale, many amateur groups (avocational practitioners) now work under the umbrella of heritage protection agencies or professional archaeologists. Thus with the involvement of academic, federal, museum, and avocational stakeholder groups we are all closer to a mid-point. If the next half century will help define the direction in which the field takes, all stakeholder groups need to reach a consensus about the future path of the subfield, nonetheless. From what I have observed, in order to effect this change, an aviation archaeologist must, first and foremost, encourage other stakeholders to consider the best interests of the artifact above the needs of the individual or the repository to which their finds are destined. Museums, as one of these many repositories, are not immune from this requirement.

3. UNDERWATER SITE FORMATION

Site formation in underwater aviation sites is arguably the most important study area in the archaeological process, and also the least documented and discussed in terms of the processes that affect aircraft sites. Aircraft are not meant to be underwater, and so the bulk of the historical research on a particular site will usually be up to and perhaps including the crash event. Once underwater, however, the environmental effects on aircraft material can vary, producing a wide range of appearances in aviation materials. Published site formation research in this subfield comes primarily from academic theses and papers. One of the first site formation studies, in the absence of historical record, was to confirm a specific aircraft's role in the December 7, 1941 Pearl Harbor attack.[116] The combined evidence from archaeological investigation demonstrated the aircraft was under power and preparing to take off when strafed by machine gun fire, as opposed to having been simply abandoned. A number of Jung's articles, as well as his thesis, look into the site formation associated with multiple aircraft downed at one time, in order to build a pattern of deposition according to the attack strategy.[117] And in their Master's theses, both Pruitt and Bell discuss shallow sites and the effects of both deposition and human interference over time.[118]

In this section I outline general trends for site formation explanation and give several examples. Outliers exist, complicating every suspected site formation pattern concerning an aircraft. In order to recognize site formation in underwater aircraft sites, an archaeologist must also identify basic processes, aircraft-specific concerns, and common wreck event patterns.

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[116] Rogers et al. 1998.
[117] Jung 2006; 2008; 2009.
[118] Bell 2010; Pruitt 2015.

These interpretations should be included in any analysis of an underwater aircraft site and may help researchers both track deterioration over time and build regional or depth-based models for decay rates.

3.1 Materials and Pre-Deposition Effects

The earliest terrestrial-based aircraft were designed to be light, sturdy, and not necessarily in contact with salt water. The interest in a variety of seaplanes and flying boats arose relatively soon after the invention of the airplane, especially in the US and UK, who were, at the time, major powers separated by an expanse of sea. Several sponsored technology contests for finding an effective means to traverse long those distances encouraged development of aircraft that could land on water. Seaplanes were also a practical way to circumnavigate the lack of terrestrial flight facilities by their ability to use existing maritime infrastructure. Wooden aircraft with associated steel components like engines, as most were until about 1930, have similar site formation processes to wooden ships. Aluminum, a lightweight and strong metal, and its alloys (common alloy materials are copper, magnesium, zinc, and tin among others) became favored for aircraft construction due to its drop in cost in the 1920s. Aluminum or aluminum alloys can present in several different ways underwater.

Aluminum self-passivates, which means that when exposed to oxygen, aluminum will generate its own layer of oxidation and protect itself against corrosion. This protection does not create immunity; the hulls of flying boats were treated extensively with an anti-fouling agent for operation in a marine environment and the fuselage similarly protected against spray. In WWII aircraft aluminum was also anodized as well as sprayed with an anti-corrosion zinc chromate primer, which further protected the metal against pitting. As MacLeod notes, however:

> The corrosion potentials of the aluminum alloys were found to be very sensitive to compositional variation associated with both the form and function of the fittings and with the known supply problems during the latter part of the Second World War.[119]

Aircraft are extremely sensitive to the particular environments in which they end up, and it is partially because of metal fabrication and aircraft construction techniques, both of which can be highly variable. In most aircraft, corrosion problems begin with the added metal ingredient in an alloy. Any impurities or defects can also cause a greater susceptibility to the effects of salt water. In a similar vein, aircraft components compromised by the crashing event will suffer decay at an accelerated rate. This can be due to, among others, the buckling or tearing of metal, fire or extreme heat, or proximity to other metals. For example, a recent study looks at the effects of radiation on aircraft paint decay in salt water.[120]

Deposition studies also will shed light on site formation, which can also be the case vice versa. Deposition of aircraft in water can include an uncontrolled crash regardless of speed, a controlled landing (ditching), abandonment, scuttling, or accidental or intentional dumping loss, such as off a carrier or other ship (Figure Chart 3.1). An underwater aircraft site has a greater likelihood of presenting as intact if the wreck event was non-violent and there has not been interference by environmental or human activity- although storms, tidal or reef turbidity, fishing, and diver-related activities have the ability to reduce an otherwise intact site to pieces.[121] If an aircraft presents as broken, or if large areas are missing, the site formation might also be affected

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[119] MacLeod 2006, 135.
[120] Delgado et al. 2018.
[121] Beeker and Smith 2005; Wessex Archaeology 2008.

by the wreck event and/or the construction technique. Wreckage from a controlled ditching could present as similar to a crash, especially if the aircraft was compromised prior to landing. For example, a WWII aircraft that had bomb bay doors open, or lost a tail section during the ditch, could result in a greater disarticulation of parts. The severity of a bent propeller will, in most cases, indicate the speed and angle of the water impact, or if the water was frozen at the time. Missing or disarticulated propellers could imply a more severe wreck event. Landing gear and flaps will present as either retracted or in landing position, and can be used to determine the final flight mode. Completely disarticulated wrecks most likely indicate a catastrophic deposition or subsequent extreme weather event.

Multiple aircraft or close, but disassociated parts can exist in dump sites. Site formation and historical research often provide obvious clues as to whether a site is dumped aircraft parts or not, such as uniform groupings, missing or extra parts, or incorrect types mixed in. WWII dump sites, especially, can contain other military surplus items such as vehicles or tanks co-mingled with aircraft. Researchers have also noted 'sites' where the remains of one or more aircraft have been arranged to appear as a wreck site to encourage tourist visitation.[122]

Some aircraft present with wrinkled or bunched skin. This could be part of the wreck event damage but could also be due to sinking mechanics. An aircraft full of gas (usually in the wings), bombs, or cargo, may sink quickly and achieve enough velocity to cause damage on bottom impact. If the wings are empty, they may serve as floatation aids, and if there is damage to another area, the water-filled compartments may wrench apart on the surface. Similar to ships, an aircraft's cargo may move, implode, or be jettisoned during the wrecking or sinking

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[122] McKinnon and Carrell 2014.

process.[123] One of the more interesting site formation questions that deserves future research is the presentation of an aircraft as inverted or upright. There seems to be a general trend that damaged aircraft, if they still have forward sections with engines, will invert prior to hitting the sea floor in sites deeper than 40 m. This may be because of the weight of the engines and the relatively quick water ingress into damaged aircraft; several intact aircraft in deepwater sites present as upright. There are also several exceptions to this general rule, and statistic-based research would be beneficial to future studies.

Figure Chart 3.1- Aircraft Deposition Examples

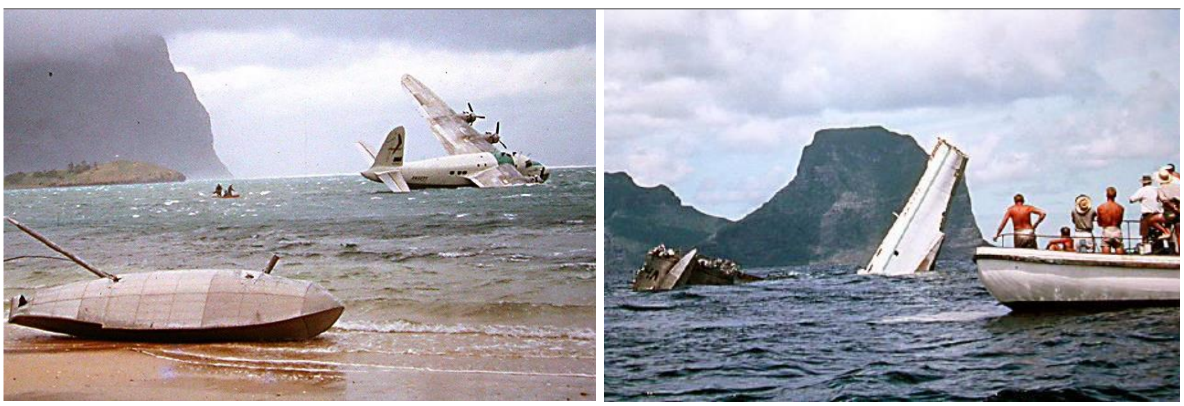

Figure 3.1a- A Short S-25 Sandringham VH-BRE was damaged in a storm in Australia in 1963 (L). It was salvaged and the remains scuttled (R). Photos from M. Holle Collection, reprinted from Smith 1994.

[123] Wachsmann 2013.

Figure 3.1b- A B-29 ditches successfully off Iwo Jima in WWII. Reprinted from Keeney 2014.

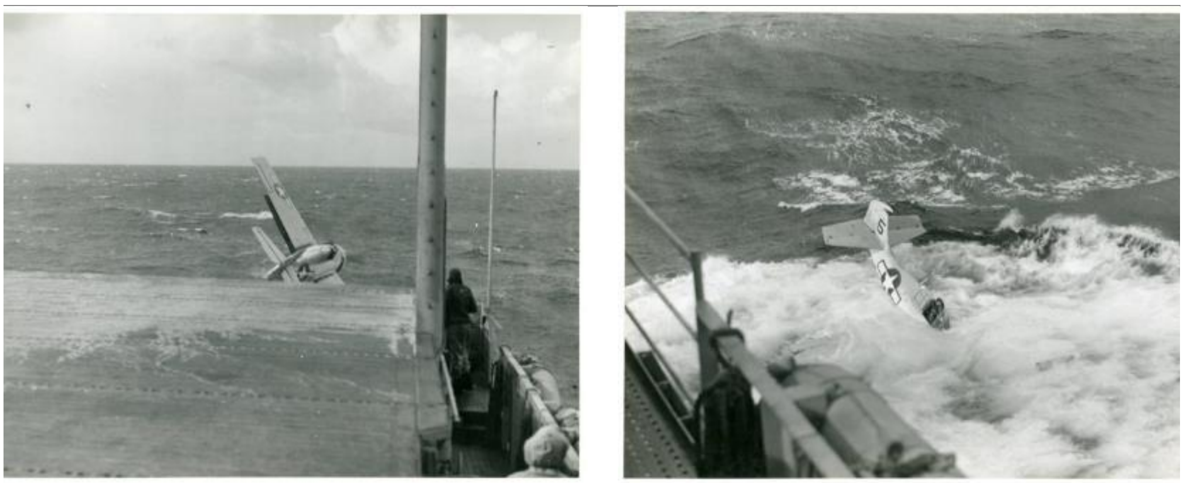

Figure 3.1c- An FM-2 Wildcat stalls on carrier take-off (L). The pilot manages to escape the aircraft in 3 seconds; the plane sinks in eight seconds (R). Photo and notes from National Archives.

Figure 3.1d- Pan American Airlines Flight 6 was forced to ditch in the Pacific enroute from Hawaii to California in 1956. All passengers survived but the aircraft sank. Photos from US Coast Guard.

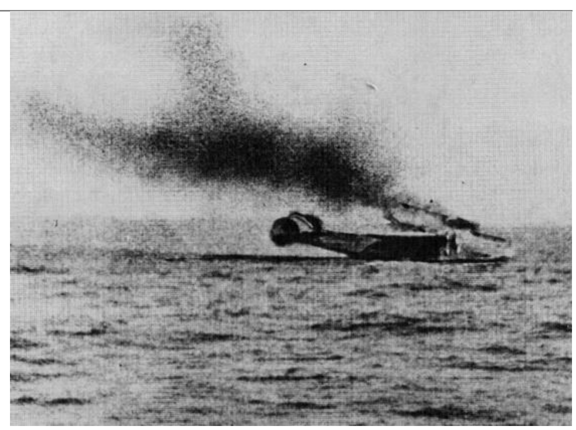

Figure 3.1e- (L) Boeing 314 *Honolulu Clipper* misses smashing into USS San Pablo a second time while under tow in 1945. Note the already damaged starboard wing and the missing engine. It was scuttled soon after to avoid being a navigation hazard. Photo US Navy. (R) *Bermuda Sky Queen*, another 314 flying boat, had the same fate after its rescue by US Coast Guard Ship *Bibb* in 1947. *Bibb* fired on *Bermuda Sky Queen* for 10 minutes until it sank. Photos from US Coast Guard.

Figure 3.1f- An uncontrolled crash of an A-20 Havoc hit off the coast of Indonesia by anti-aircraft fire in WWII. Photo from National Archives.

Figure 3.1g - A dump site for WWII aircraft off the Marshall Islands. Note the missing engines and wings from three of the aircraft. Photo by Brandi Mueller/AP, reprinted from Cenciotti 2015.

3.2 Underwater Site Formation

Underwater aircraft site formation can be influenced by several post-deposition factors, including environment and human interference (Figure Chart 3.2). Aluminum, like other metals, will eventually corrode, which is to gradually dissolve or wear away, when submersed in a body of salt water. This corrosion still occurs, albeit to a lesser extent if the pH is not highly acidic, in freshwater environments. Aluminum and most of its alloy metals will seek to lose electrons within an electrolytic environment like salt water and since aircraft surfaces are exceptionally thin, structural damage and integrity are lost quickly. Archaeological scientists and conservators concerned with aircraft corrosion are well aware of the effects of corrosion on multiple-material components and their attachment points.[124] A galvanic reaction occurs when dissimilar metals are in contact with each other, such as with structural attachment points and rivets in aluminum skin. These areas will decay first, although structural decay is not always visually obvious as happening.[125] Engines on WWII aircraft have distinct deterioration patterns due to their mechanical composition. Magnesium parts will corrode first in favor of aluminum and iron, and then aluminum cowlings, skin, or other components will disappear from around ferrous and stainless steel parts. Unfortunately, this often includes the magnesium engine casing upon which data plates are frequently riveted. In areas of low current, the resulting corrosion products appear surrounding the engines (usually deepwater sites). Due to the alloy differences in rivet and skin aluminum, localized corrosion will also usually appear as spot-pitting following frames and rivet lines.

[124] Fix 2011, 990.
[125] McCarthy 1997.

Naturally, corrosion is more likely to cause accelerated degradation in high-energy zones such as tidal zones, areas that have strong currents, and areas where items are under biological attack.[126] Aluminum does not concrete as iron does, nor do aircraft usually present with much coral or marine growth, although exceptions exist. Mussels present in fresh water environments will colonize an aircraft similarly to any other underwater structure or site. In oxygen-rich environments, where aluminum passivates to create its own oxidization layer, biological or marine growth on top of aluminum surfaces will prevent this protection, allowing accelerated corrosion. Aircraft covered in either sediment, silt, or sand can present in varying states of decay, indicating that water chemistry has more to do with corrosion potential than oxygen access. Sand movement, however, can strip the surface area of aircraft skin to the attachment points if the current is strong.

Human interference in a wreck site can be obvious or imperceptible. Unfortunately, divers will also have looted many shallow wrecks that have been located. Small, disarticulated objects or objects of high perceived value, like cockpit instruments, guns, propeller blades, or steering yokes, will often be removed from a site first. Divers can also harm wreckage by frequently touching fragile surfaces or knocking parts with compromised structural stability. A common diver activity is to pose in the open cockpit of underwater aircraft, and observed by archaeologists, but never formally studied, is the tendency for those cockpit areas to be more damaged than other areas of the same wreck. Fishing activity can displace or dislocated items or parts on a wreck from a few centimeters to up to meters or kilometers away.[127]

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[126] Schumacher 1979.
[127] Evans et al. 2009; Brennan et al. 2012.

Figure Chart 3.2- Site Formation Examples

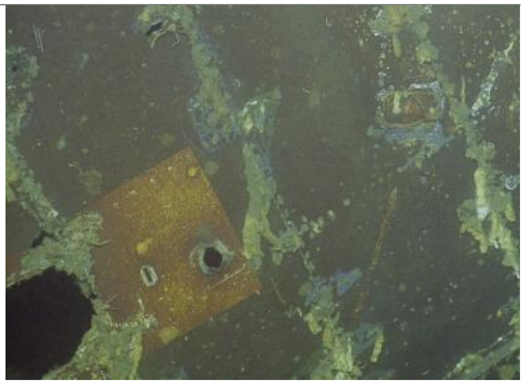

Figure 3.2a - Examples of layered paint loss (L) and paint color decay (R) on aircraft from the Bikini Atoll atomic tests. The aircraft on the right was inside a steel ship hangar. Screenshots courtesy the OET/NOAA 2017 USS *Independence* survey.

Figure 3.2b - A WWII B-17 wreck in 72 m off Vis, Croatia. The aircraft successfully ditched- damage to the nose is a combination of flak, possible bottom impact, and corrosion damage. Photo reprinted from Underwater 360 2018.

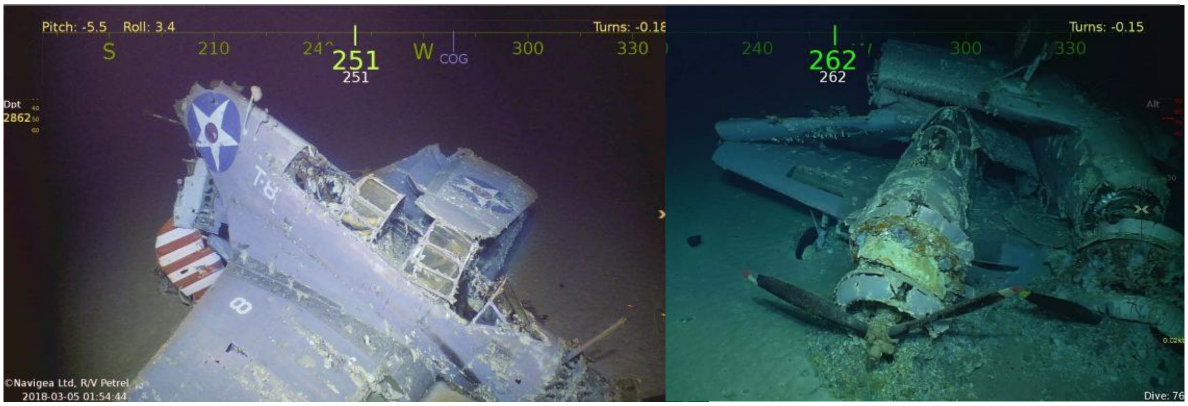

Figure 3.2c - Bright paint and organic covers on the flight control surfaces of this TBD Devastator remain remarkably intact (L). Aircraft from this site, the USS Lexington aircraft carrier, are all in similar condition and show deepwater preservation (2800m+). Note the comparatively accelerated deterioration of the engines (R) and the corrosion products fanning out from them on the sea floor. Photos reprinted from Paul Allen's website (The Editors 2018).

Figure 3.2d - An inverted WWII B-29 at 380 m found off Saipan. Shifting sands have worn away the exposed wing skin, showing the structure underneath. Note the scour pattern in front of the engine and the relatively excellent condition of the stainless steel cowling. Photo courtesy NOAA Office of Ocean Exploration.

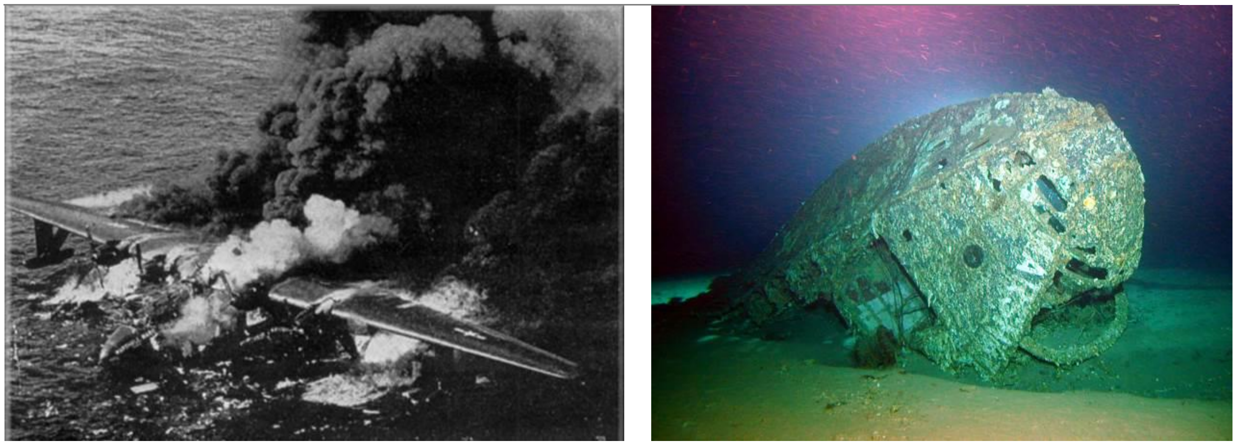

Figure 3.2e- In 1950 a US Navy Martin Mars flying boat was forced to land off Oahu by an engine fire. The aircraft, Marshall Mars, sank to about 427 m after thoroughly burning. The NOAA Office of Ocean Exploration conducted this non-disturbance survey in 2004. The study showed the effects of accelerated corrosion due to fire. Photos from US Navy (L) and NOAA/HURL (R).

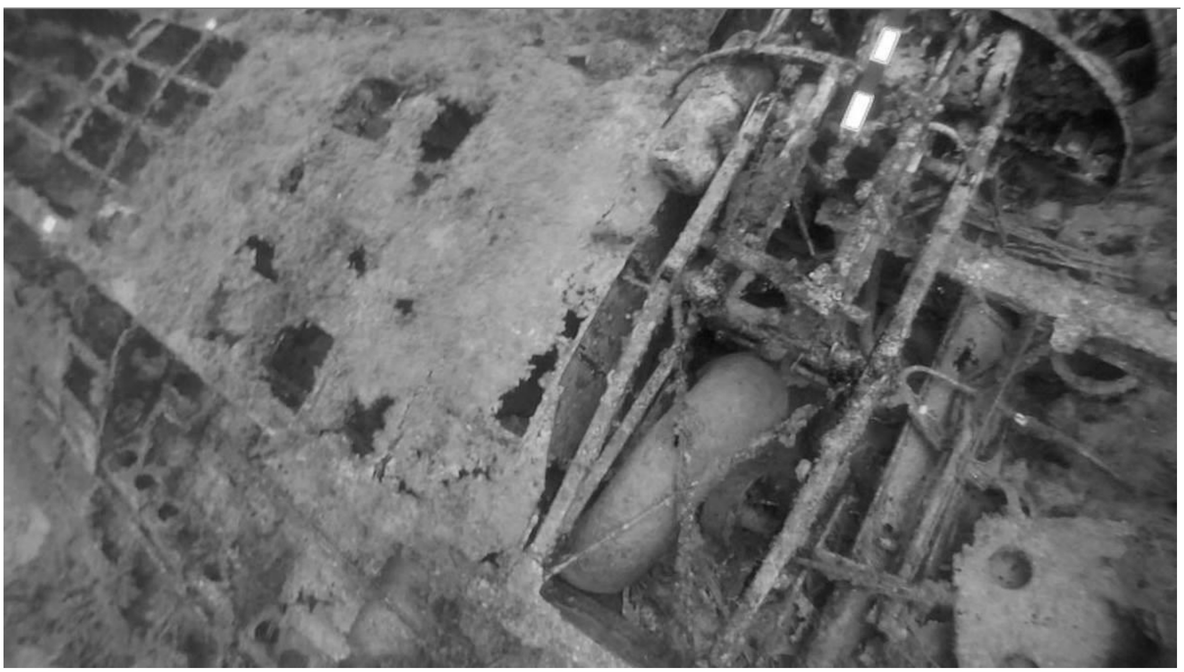

Figure 3.2f- The undercarriage and corroding skin of an RAF Bristol Blenheim Mark IV. Note the pitting corrosion eating away the thinner skin and exposing structure. Note also the intact tire. Photo reprinted from Burgess 2013.

Figure 3.2g - Netting and rope wrapped around the structural interior of a B-17 wing in the English Channel. The shifting sands have scoured away the skin over time. Photo courtesy of The BentProp Project, Ltd.

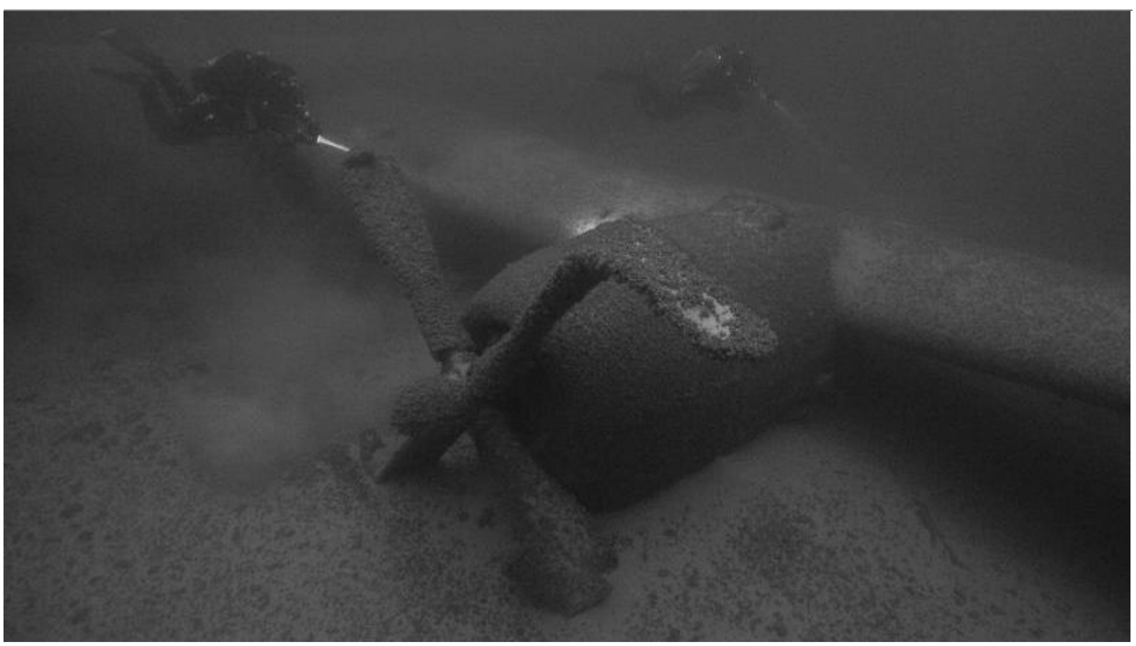

Figure 3.2h - Mussels cover the B-29 in Lake Mead, NV. The wreck site was formerly at a depth where only technical divers could reach it, but a drought has caused the lake levels to drop to 30 m. Photo from NPS website by Brett Seymour, Submerged Resources Center.

3.2.1 Water Chemistry and Depth

Formation processes for aircraft wrecks located in fresh water and salt water due to pre-deposition and deposition events are similar, as the environmental effects on the material follow some general rules. Depth, temperature, salinity, pH, and oxygen content all seem to play roles in the rate of material decay on aircraft sites. Freshwater wrecks experience corrosion, but seemingly at a less rapid rate than saltwater wrecks. Aircraft in freshwater environments also tend to be more structurally sound. This is possibly due to the electrolytic environment that salt water and metal generates, its effect on the metal contact points, and the lack of this reaction in fresh water. Aircraft have also been reported as more intact, and in better states of preservation, in fresh water when covered with sediment or silt.[128] Also, and possibly because of the preference for fresh water aircraft recoveries from sediment, the accepted convention for aviation materials is that they follow the same general rules for shipwrecks; that buried material is always in better condition. This does not appear to be true for wrecks in salt water, and in many cases more corrosion is seen present in aircraft buried under sediment or with heavy coral growth. In the case of the 'The Catalina Affair' Swedish DC-3, the underside of the wings, which were in anaerobic mud, suffered more advanced pitting corrosion than the rest of the aircraft due to differential aeration corrosion.[129] Researchers must consider these accepted viewpoints and trends, even when not necessarily true, when determining formation. Directed research should focus on corrosion potential and site publications on comparative studies in saltwater aircraft integrity, especially with some aircraft in fresh water lakes that are covered in mussels.

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[128] Wills 1997b; Wessex Archaeology 2008.
[129] Tengnér 2009; Vicki Richards personal communication 2018.

Many historic aircraft discovered in shallow water high energy environments have been largely chemically corroded with only framework and heavy engines remaining. Several, however, have also been found largely intact in depths of less than 20 m. Deepwater finds tend to follow a more definable pattern of site formation, and present as less subject to corrosion, yet, examples have proven this statement false as well. If an aircraft is largely intact upon sinking and falls into an environment where it is deep, cold, has relatively low bacteria and sediment levels, and does not have a strong current, chances are good that the airframe will remain intact. Both freshwater and saltwater wrecks that are in cold areas generally suffer less rapid decay than aircraft in warm water.

Doped canvas flight control surfaces remain intact on otherwise undisturbed sites in cold fresh water.[130] In salt water, organic remains of flight control surfaces or fuselage skin has been documented on fewer sites, but all are in extreme depths in the Pacific Ocean.[131] Organic remains of clothing, military items, and human remains have been recovered from multiple shallow aircraft sites in salt water, indicating the prevalence of such items. Magnesium components, such as those common in aircraft engines, are the first to decay, followed by thin aluminum, in preference to ferrous parts. Stainless steel and brass parts often remain perfectly intact and corrosion-free. It is common to find tires still present on aircraft sites, regardless of the water chemistry or depth. Painted metal is commonly present on both aircraft in salt water or fresh water, and marks from pencils can be seen in some cases.[132]

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[130] Nautical Archaeology Trust 1981; Wills 1997b; Chenoweth et al. 2006.
[131] Grech 2007; Lickliter-Mundon et al. 2018; The Editors 2018.
[132] Stafford 2008; Tengnér 2012.

There simply has not been enough study of the subject to explain the inconsistencies and outlier cases in aircraft corrosion theory. More studies of the corrosion rates and potential on shallow aircraft dive sites would give insight into these site formation processes. To begin with, experimental research and inclusion of water chemistry rates, and if possible, historic water quality readings in the area, will help researchers analyze and interpret trends in deterioration. Water quality readings should include depth, temperature, salinity, conductivity, and dissolved oxygen. Dissolved oxygen on a submerged saltwater site, which can change over time, potentially has a greater effect on aircraft metal components than other archaeological materials, due to aluminum's passivity. The pH of water and the associated pH of the aluminum also seem to have an effect on corrosion potential, and recent studies that have included these measurements are good examples of standards.[133] Case studies in the later chapters of this dissertation add data to these research questions about aircraft and water chemistry.

3.3 Case Illustration, B-26, Fiji

A well-known dive site, B-26 S/N 41-17590, is off the coast of Fiji dispersed over a 200 m x 20 m area at a depth of 20-25 m. In 2017, Project Recover, a collaborative group comprised of BentProp and researchers at University of Delaware and Scripps Institution of Oceanography, initiated a two-week survey to document the wreck and area using a towed side scan sonar and diver teams including academic researchers, volunteer enthusiasts, and myself as the contract archaeologist. The specific objective of the survey was to create an archaeological report and recommendations about the likelihood of successfully excavating MIA crew remains from the site. We provided the site report and recommendation to the Defense POW/MIA Accounting

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[133] McKinnon and Carrell 2014.

Administration, whose employees consider the site for potential excavation and artifact repatriation. As such, survey planning focused heavily on pre-deployment research for aircraft parts identification, Missing Air Crew Reports (MACRs) showing crew member locations at the time of the wrecking event (Figure 3.16), and collecting local knowledge and history of the site for disturbance evidence. The survey itself was centered on identifying site formation processes that would help our team interpret the wrecking event. Interpreting the wrecking event is essential to predicting the locations of remaining crew resting places. It was necessary that mapping efforts be quick, thorough, and also define logistics for possible future excavation team members.

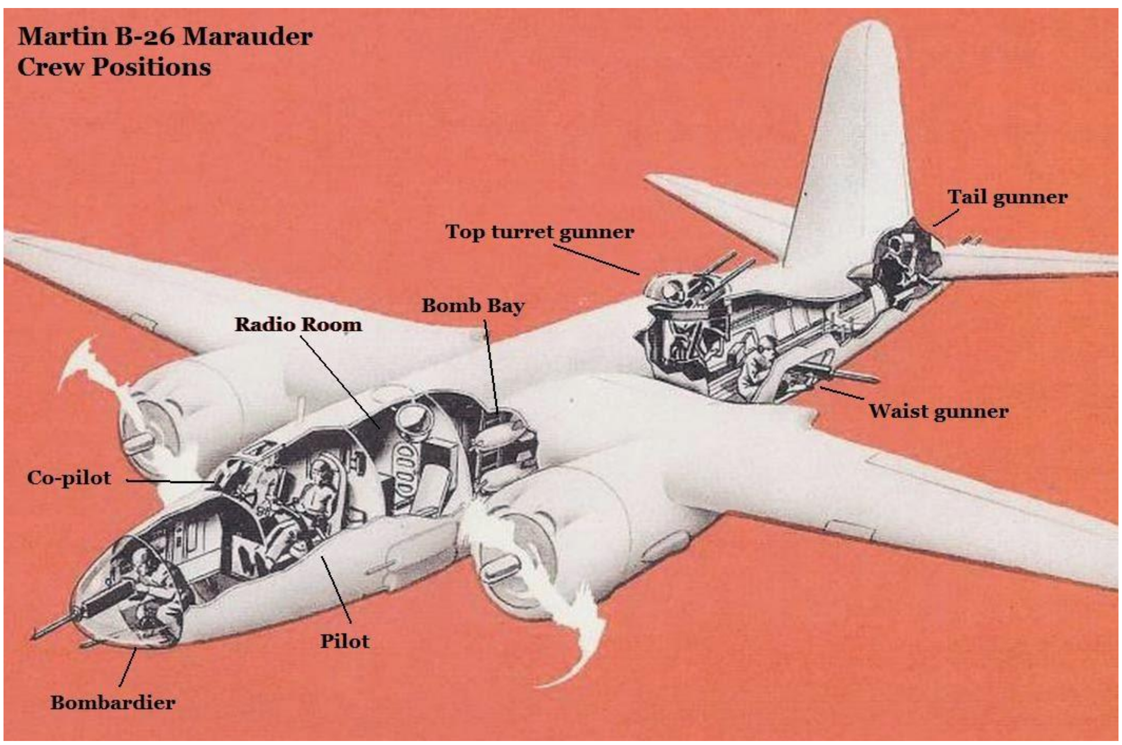

Figure 3.3- Crew positions on a B-26 Marauder. Photo from USAF B-26 manual, 1943, reprinted from OldAFSarge 2014.

Given the wreckage dispersal, I recommended our documentation methodology be a strategic series of N/S center lines from which we take offset measurements. We measured each artifact from one (sometimes two) of four 30-35 m reference lines situated strategically between tall coral heads and pieces of wreckage as to avoid obstruction. On the resulting site map (Figure 3.17), the debris field is comprised of about 90 distinct objects in four groups. A diver-laid rope runs throughout the wreckage from southeast to northwest.

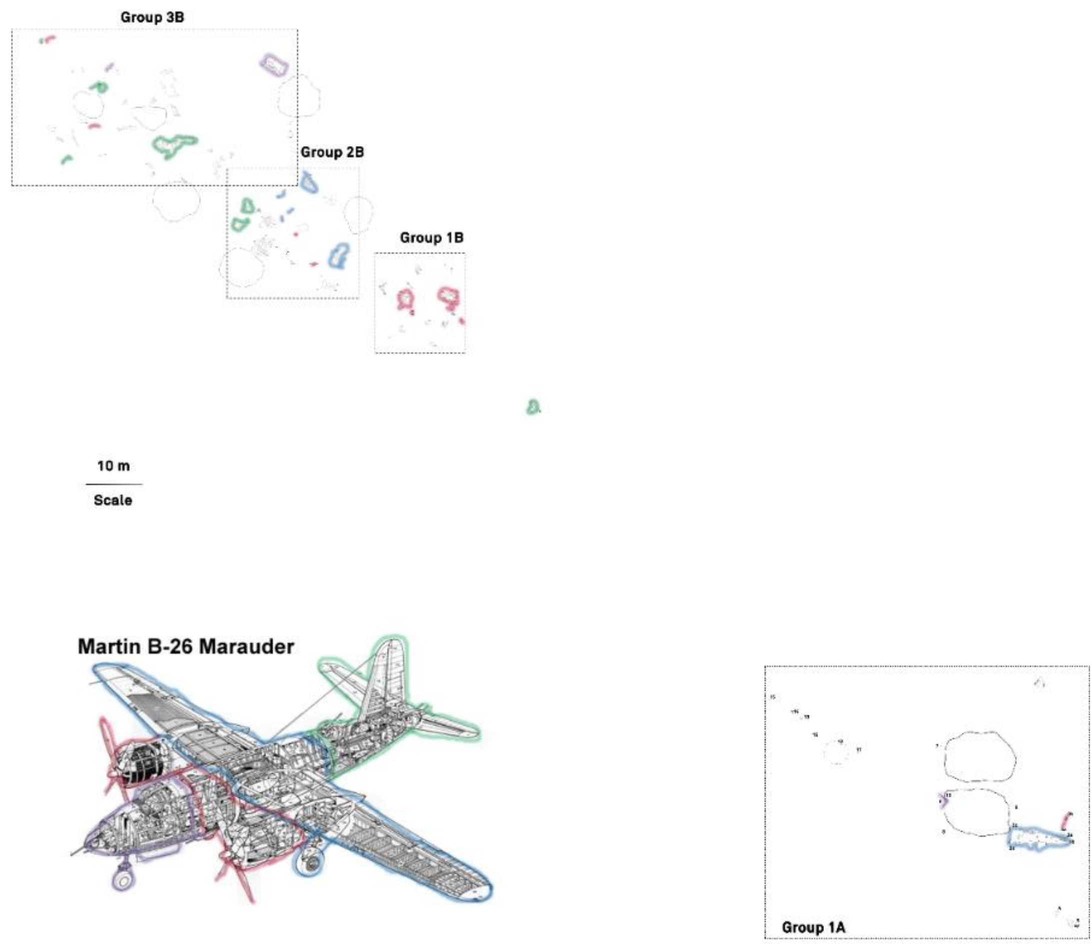

Figure 3.4- Site map of B-26 41-17590 with distribution of identified wreck pieces highlighted against the area of the aircraft. Drawn by the author.

Group 1A contains most of a port wing, a propeller, and either the pilot's or co-pilot's yoke and control shaft situated close to two coral heads. The main bulk of the wreckage lies in the northwest section of the debris field, which is loosely indicated by the three groups moving northwest along the line of debris. The largest objects in this area are the two engines, a curved piece of fuselage, a similarly sized section of the bomb bay, and a large section of the horizontal stabilizer. Even though we recorded a high number of components, and accounting for the nature of this non-intrusive survey (some remains may lie buried), the wreck site constitutes only about 65% of the entire aircraft, suggesting significant site decay or component loss.

Explanation of the formation processes for the B-26 wreck site begin with an interpretation of the deposition process to illustrate the wreckage distribution pattern. The MACR and statement accounts suggest a violent, uncontrolled crash into the water. Observation of the wreckage distribution, as well as the location and orientation of the yoke pieces, suggests the B-26's point of impact was near the southeast extremity of the wreckage on the site map (Group 1A). This impact caused an immediate inversion, or perhaps a cartwheel, of the aircraft, such that the port wing sank inverted, the yoke tumbled to the opposite side of the coral head from the crash direction, and the rest of the aircraft was broken up and propelled to the northwest, seemingly landing more or less as consecutive areas of the aircraft. Both cockpit and tail section wreckage is dispersed over the entire site. Wreckage presents as completely disarticulated, with the largest single piece being around 85% of the port wing.

Object dispersal in the site map's Groups 1-3B widens from southeast to northwest, which is consistent with an aircraft parts being thrown across the water. Generally, parts from each section of the aircraft align loosely with the Groups in the Site Map Area. Most parts from the forward center section are in Group 1, most parts from the center section are in Group 2, and most from the tail are in Group 3. Components from the tail section and cockpit section, however, as well as propellers, are found randomly throughout the entire wreckage dispersal area. This would suggest that the tail and cockpit areas were the first damaged in the wrecking event, or in this case, the tail was already damaged and the cockpit was the first and possibly the most violent area of impact, which would throw pieces the furthest. Since the tail lacked integrity when the wrecking event occurred, it could have thrown pieces all traveling at different rates of speed and, therefore, landing at different distances from impact.

There are no nets or other indications of disturbance from fishing activities and there is little to no trash on site. However, around 1987 local divers discovered the site and it became a popular diving location for locals and visitors. According to local knowledge the site has changed; there was much more wreckage that has slowly disappeared, including radios, bullets, and other small pieces. A YouTube video uploaded in 2011 recorded a dive on the B-26 site starting from the nose gear and travelling down the dive rope to the wing. Of note are many objects in different locations, and a considerable amount of decay on at least two objects, than documented during the 2017 survey. Taking into account the 2011 video, diver accounts, and the nature of dive sites we suspect this site is significantly disturbed, which affects its overall integrity, especially when considering crew member final resting places.

In this example of a diver-led documentation survey, the desired outcome heavily influenced the planning process. For BentProp and DPAA, a site survey report resulting from a project such as this one is intended to include recommendations on the whereabouts a viability of recovery of MIA crew member remains. The type of survey methodology chosen reflects this, as well as the definition of the site formation processes. In these particular examples the wrecking event, and any human or environmental interference, that heavily impact site formation will directly affect the priority for this site's excavation for recovery of MIA remains. The documentation also yields other important site formation information relevant to aviation archaeology, and may possibly be used in future interpretive works, if accessible to researchers. It also serves as a baseline snapshot of the site for future maintenance surveys.

3.4 Section Discussion

Understanding site formation processes is key to the study of underwater aircraft wrecks. Research should include determining the deposition, i.e. the wrecking or abandonment event. Formation processes, generally either environmental or human, have the ability to change the aircraft's appearance and structure over time to mask its identity, contents, and the causes of its loss. Knowledge of aircraft components, alloys, and their chemical changes in salt and fresh water is critical. Water chemistry plays an important role in aircraft site formation, but no predictive rule holds true across all sites, and trends vary regionally. Nonetheless, recent studies, including those conducted by the author on in situ aircraft, will, as they grow in number and in the expertise level of those conducting them, help determine deterioration rates and establish a platform for baseline information, as well as outline the requirements for future projects. As was observed at an equivalent study of submerged WWII aircraft and ship sites studied in Chuuk Lagoon:

> Detailed physical chemical data on the dissolved oxygen concentration, salinity, and temperature profiled need to the recorded for each site to enable predictions of corrosion rates to be made with a reasonable degree of certainty….Collections

> of such data will involve longer fieldwork allocation owing to operational and diving safety issues associated with working [at depth].[134]

After interpreting site formation an archaeologist can better understand the remains, and make recommendations on maintenance surveys, excavation (if required), and conservation treatments. Site formation, when matched with historical records, can often extend the timeline of an aircraft's known history. This expanded timeline information, i.e. from service through wrecking or abandonment and on to the present day, is valuable for museums who wish to tell a much fuller story of a particular aircraft to visitors, who today have interests and understandings far different than those of their parents and grandparents.

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[134] MacLeod 2003, 86.

4. METHODOLOGY

Aircraft as artifacts can be a source of technological and social material relevant to the industrial history at the time of fabrication, the workers who built them, the personal lives of the crew members who flew them, the culture of the passengers they carried, and an exhaustive list of other considerations.[135] The aircraft itself is an archetypal artifact with which an archaeologist can "examine the interaction of technology and culture" of a technological revolution after the introduction of the combustion engine.[136] Until recently, the 'why' of aircraft wreck survey has been to discover the type and identification by basic visual, or in some cases, destructive survey without methodology.[137] Both complex and general research questions are valid for underwater aircraft wreck survey, as the wreck can yield an abundance of multi-disciplinary information. Certainly amateur enthusiasts and even archaeologists both survey and report using varied methodology, however, and sometimes in ignorance of what information an underwater aircraft wreck can provide. Reporting and methodology standards are essential for development of the field and for cultural resource management.

The ideal methodologies for aviation archaeology sites are research goal-based and should anticipate the eventual role of an excavated artifact or the in situ site. Project planning must take in account the formation processes of aviation sites and how they relate to, or differ from, other archaeological sites. Effectively planned and executed projects in turn will allow for interpretation, but again this will be largely based on considering the results and the eventual use of the artifact or documentation. An aviation archaeologist should expect to ascertain site

[135] McCarthy 2004.
[136] Capelotti 1998.
[137] Capelotti 1998.

formation processes in every survey, but the information might yield different products in each project. Well-rounded projects should include representative stakeholder groups, can include multiple types of documentation, and can sometimes incorporate expertise, tools, and technologies developed for other fields and adapted for aviation sites.

In this chapter I will focus on discussing aviation archaeology methodology in terms of the different survey types most commonly planned, which are initial discovery, identification and documentation surveys, monitoring surveys, and partial or full excavations. Accommodating practical or budgeting concerns usually differentiates underwater methodologies from land-based efforts, and deepwater surveys or excavations from shallow water projects.

4.1 A Selection of Notable Methodologies

4.1.1 Research and Documentation of Airframe Surveys

In 1997 Wills completed a study on the documentation of a recovered SBD-2 Dauntless aircraft prior to restoration efforts.[138] At the time, cultural resource management of aircraft was largely unheard of, but the US Navy's Underwater Archaeology Branch was among the first federal organizations to enact internal policies of this kind.[139] SBD-2 BuNo 2106 is a rare example of the aircraft type that was not only present during the December 7, 1941 Pearl Harbor attacks, but went on to serve in WWII, and participate in combat aboard USS *Lexington* in the Pacific Theater. BuNo 2106 was being used as a carrier trainer in Lake Michigan in 1943 when it stalled and crashed into the lake. The pilot escaped unharmed. The aircraft was recovered in 1994 by the Navy and taken to the National Naval Aviation Museum (NNAM) for study and

[138] Wills 1996.
[139] Cooper 1994; Whipple 1995.

restoration. Wills' research on the Dauntless was to serve as a model for similar future research.[140]

Wills performed extensive research on the aircraft's history and then a detailed survey of the airframe. Damage from the Lake Michigan crash and the recovery was found as expected, but so were modifications, repairs, reinforcements, and paint changes from its varied use. This information was important not only because these areas were likely to be lost during the restoration, but also because these stories would enrich the aircraft's future display.

4.1.2 Predictive Modeling

In Australia near the northwest coast at Broome lie the remains of fifteen flying boats and one US Air Force B-24A that sank after a WWII attack raid. The aircraft were strafed, bombed, and burned by Japanese Air Forces that the Australian military had hoped were not within range. Among the military aircraft had been passenger flying boats that were modified by the RAAF; stripped of their luxurious interior and equipped with guns they carried families, valuable RAAF personnel, mail, and equipment away from the expanding Japanese territory. After the attack, some shallower aircraft were salvaged for war materials and then blown up to avoid them becoming navigational hazards.

In 2007 researchers undertook a project based on a wartime image of the deadly Broome Raid.[141] The image was captured by a Japanese pilot just after the raid and shows smoke columns in the bay with identifiable terrestrial landmarks. The picture was geo-rectified and plotted with

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[140] Wills 1997a.
[141] Jung 2007a.

known wrecks and targets from a sonar survey. The survey pinpointed the likely locations of four missing flying boats, subject to ground-truthing dives.

In 2013 Jung announced the discovery of a missing PBY Catalina from the same group of downed aircraft, located during an impact survey for an Liquefied Natural Gas (LNG) plant.[142] The search area had been predicted in 2008 through a research project focusing on images of military ships maneuvering in relation to moored flying boats in Darwin Harbor. The Western Australia Maritime Museum recently made a public call to find more photographs of the Broome attack, and further test this predictive methodology, in order to locate the final remaining undiscovered aircraft, the B-24A.[143]

4.1.3 Deconstruction Site Mapping

Deconstruction site mapping is popular for aircraft remains underwater as a way to quickly and accurately map wrecks. The methodology involves using the blueprint plans for an aircraft, assuming standard measurements for aircraft based on manufacturing specifications, and then 'deconstructing' it based on site formation. Popularized was by Jung in 2007, this method has been used in some archaeological publications, for example, the US Navy's UAB on a recent survey of WWII aircraft remains in Florida.[144] Deconstruction site mapping is also taught in Maritime Archaeology Survey Techniques courses in University of Hawaii, although one of the professors expressed concerns that shortcuts in site mapping may represent details on site that are not accurate, if alternative site mapping methodology is not already known.[145]

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[142] Jung 2013.
[143] McCarthy 2018; Croy 2017.
[144] Jung 2007b; Brown 2014.
[145] Hans Van Tilburg personal communication 2013.

4.1.4 Feasibility of Recovery Survey

Close to Rottnest Island, near Perth, Western Australia lie the remains of five scuttled Catalina wrecks in about 200 m of water. These wrecks are of interest enough to the local community to engage the services of the Western Australian Maritime Museum to report on the feasibility of their recovery.[146] Four of these aircraft are 'Black Cats', a distinct group of flying boats that completed highly dangerous and important Royal Australian Air Force missions such as the 'Double Sunrise' service, and can be celebrated as representative of historical achievement.[147] The Catalinas were scuttled using explosives and gunfire, and although one witness claims to have seen an aircraft blown to pieces, the general condition of the remains was unknown. Wreckage in pieces in a high-energy environment is far more likely to corrode and suffer component and skin loss, as well as have undesirable structural instability at the weight-bearing areas, creating hazard for lift and support structures.[148] The report did not recommend recovery.

4.1.5 Criteria for Rating Potential Archaeological Significance

In his dissertation on underwater aviation archaeology in Malta, Burgess included an innovative set of classification methods for submerged aircraft remains in terms of their viability for research and display.[149] This guide helps categorize archaeological significance based on criteria such as rarity, condition, association, and potential for display. He notes that each aircraft or site can change over time and due to future artifact-limiting events, for example, air show

[146] McCarthy 1997, 3.
[147] Wilson 2014.
[148] McCarthy 1997, 12–3.
[149] Burgess 2013, Appendix L.

crashes. This type of grading system is extremely useful as a pre-survey tool to guide methodology and reporting priorities.

4.2 Project Planning and Skills

Aviation archaeology is a subfield of archaeology and specialized skills exist that can help an aviation archaeologist effectively plan successful projects. Most of these skills are based on adapting archaeological methodology to suit the requirements of a particular environment, similar to the evolution of underwater archelogy from traditional archaeology. Some of the specialized skills in aviation archaeology are based on adapting methodology to suit the requirements of the socio-cultural environment of aircraft wreck treatment and display. An aviation archaeologist is, above all, an archaeologist, and as such should have competency in field methods, theory, critical thinking and research skills, analytical and interpretive skills, a code of ethics, and knowledge of artifact conservation requirements. Aviation archaeologists should have the ability to influence the development of the field; this can be through the standardized practice of well-planned projects and the refinement of archaeological techniques that increase our ability to preserve sites and information. With these skills, aviation archaeologists and their projects remain relevant to the overall field of archaeology.

4.2.1 Research and Records

Aviation archaeologists usually benefit from the pre-existing wealth of information on aircraft history, technology, fabrication and materials, as well as associated historical landscapes. In some research areas a large amount of information on aircraft, aerial battles, and significant aviation events has already been collated, and in most cases summarized, by historians. In most military losses the type of aircraft and military mission records relating to the wrecking event are well documented. It is becoming increasingly rare that the people who used the artifact (pilots, airfield workers, etc.) are still alive and able to provide information about the use, life story, or wrecking event of the aircraft. An aspiring aviation archaeologist should endeavor to discover every avenue of research that might lead to better understanding of the site. In addition to the obvious historical research, they should be well versed in locating well-known items like crash reports, missing air crew reports (MACRs), land use documentation, or flight routes, and then supplement these studies with oral histories, verifiable internet sites, or even urban legends. Research tools are available, such as the recently published guide for defining sources for US Naval Aircraft.[150] This guide can serve as a starting point for sources on US Air Force, or other military or civilian aircraft. Other guides, even in limited form, may be available for research in other countries.[151] Currently, an extremely valuable resource are the historians and aircraft experts on internet forums such as www.warbirdinformationexchange.com and the Key Publishing forum.

4.2.2 Collaboration

Archaeologists should include specialist support whenever performing site surveys or excavation on aircraft wrecks. Given the technical complexity of the aircraft and the vast number of types, even an aviation archaeologist cannot expect to become an expert on more than one aircraft, if any at all. Specialization of that kind would make an aviation archaeologist's knowledge base so niche as to make them un-employable, while collaboration leads to more well-rounded surveys that require less research time. Aspiring aviation archaeologists should recognize the strength in an aviation historian, whether enthusiast or trained, because that person

[150] McKinnon and Pruitt 2016.
[151] Wessex Archaeology 2008.

has spent as much time as the archaeologist perfecting their knowledge set. Collaboration is also valuable when federal, state, or CRM resources are stretched thin due to staffing or budget constraints. Project cooperation and collaboration also creates transparency and may give the archaeologist the ability to inspire adoption of a shared set of aviation archaeology standards. Engaged enthusiasts, amateurs or avocational stakeholders often perform the equivalent of monitoring surveys lacking only the formatted final report. Partnerships of this nature encourage innovative and shared solutions for artifacts as well as public concerns:

> Win-win partnerships, to be successful over the long term, must engage in approaches that objectively assess specific resources and resource sites, assess alternative uses and management approaches, and empower stakeholders to contribute as well as receive benefits.[152]

The most well-rounded projects are those where collaboration proves essential to posing challenging research questions and positive site stewardship practices that are relevant to all stakeholder groups.

4.2.3 Determination of Project Goal Based on Desired Result

The survey of aircraft archeological sites should, first and foremost, aim to identify the type, provenance, and if possible even the aircrafts' serial number. This identification will help in narrowing the field of research, the materials study for site formation processes, and deposition information. US Army Air Force aircraft have serial numbers (S/N), US Navy aircraft have Bureau numbers (BuNo). Identification of at least the type of aircraft can be made by diagnostic areas of body design or serial numbers on most associated parts, either stamped or

[152] Vander Stoep 2000, 229.

etched on a data plate or printed on the part itself. Confirming an aircraft's identification requires evidence in the form of a data plate, a serial number that can be linked to associated weaponry or engines in a report, or a BuNo or S/N painted on the aircraft's tail or fuselage. Without one of these highly informed speculation is possible; for example if no other aircraft of the type are known to have been lost in the area where a reported crash took place, or if the squadron paint colors are present on an example where no other aircraft in the squadron are known to have been lost the area.

After identification, the goals of an archaeological survey on aviation remains should be planned in anticipation of the desired end result. If the desired end result is to determine site formation and deterioration, then an archaeologist should undertake a survey including an aircraft materials specialist and accommodate limited strategic removal of marine growth. In cases where the desired end result is to have a baseline survey for future comparative or heritage maintenance reports, then survey planning should include HD video and photo imaging for 3D modeling and parts identification. Surveys that precede excavation, or are completed on aircraft after excavation but prior to restoration work, should be detailed enough to be able to refer to them when the site is destroyed or if the original parts are removed. Surveys designed to engage the public should concentrate on obtaining exciting data visualization products and disseminating those results in an effective way.

4.2.4 Determining Archaeological Significance

In the vast majority of submerged aircraft cases, the archaeological value of the site may not always be readily apparent. Mostly this is because of the seemingly complete supply of historical information about aircraft types, military operations, and deposition information:

> Given the vast amount of documentary source material available from contemporary blueprints, servicing manuals, photographs, film and even sound recordings, it might be expected that early C20th military aircraft represent an extremely well defined and understood phenomenon. As with many other aspects of archaeological or historical study, closer analysis suggests otherwise.[153]

In most underwater cases, WWII era, or earlier, aircraft have been in situ for some seventy years. Normally the life span of these aircraft prior to deposition did not exceed ten years, and some not more than a few months. Archaeological surveys have the ability for archaeologists to shed light on the timeline of events since the last known moments of the aircraft's existence above water. Site formation studies can inform records on the wrecking event, battle damage, or the aircraft's final location, Pattern recognition after multiple single-site surveys can allow for maritime landscape or airscape-type studies.

Archaeological significance should be determined on a case-by-case basis, rather than assigning a value to a site that it cannot fulfill. The case studies presented as later chapters of this dissertation show a range of values for underwater aircraft sites.

4.3 Survey Techniques

Archaeological methodology on terrestrial aircraft or aviation heritage sites (buildings or foundations, airfields, route markers, etc.) differs only slightly from traditional site survey methodology in historical archaeology in that often the artifact partially remains above the surface in situ. Also like other historical archaeology sites, this may not always be the case and gridded excavation is required. An aviation archaeologist must be able to adapt documentation

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[153] Holyoak 2001, 265.

and mapping requirements for large objects that have several flat and/or vertically tall parts that may extend from the site in various directions. Aircraft sites on land have a greater chance of being spread out due to a crash event; an aviation archaeologist should anticipate this and plan for location efforts to accurately establish site boundaries, which is most often achieved more successfully with a metal detector than a trench.

In underwater aviation archaeology most methodology reports appear in theses.[154] A non-disturbance survey on aircraft in terrestrial and underwater sites can most often provide information about site formation, and it is also likely the archaeologist can perform a visual deterioration study on the remains. Underwater sites often present more unique challenges to aviation archaeologists due to the relative difficulty of working underwater. Comparable challenges for shipwreck sites underwater are from either the Polar Regions, the Black Sea, or the Baltic Sea, where ship structures remain intact above the seafloor, requiring adaptations in site mapping methodology beyond the adaptations normally required for underwater work.[155] Of course, efforts to standardize documentation methodologies on metal shipwrecks from similar time period to aircraft also evolved in the past 20 years as well.

4.3.1 Data Visualization

Digital data visualization methods in archaeology have developed with the pace of new technology to create high-impact images, most notably in the form of advanced sonar imagery, high definition 2D photomosaics, and 3D point clouds or models. Three-dimensional modeling of underwater archaeological sites has been popular for the past few years. Archaeologists have

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[154] Bell 2010; Burgess 2013; Pruitt 2015.
[155] Eriksson 2015, goo.gl/sSYZZh, goo.gl/EknfCd.

been experimenting with 3D point cloud site documentation with data from sonar and photogrammetry.[156] Many archaeologists prefer diver-acquired photographs on shallow sites and processing with Agisoft Photoscan. On deepwater surveys, however, still photography is time-consuming and often an objective that is trimmed during planning. Stills from ROV video can be used as 'photographs' of the site which may take the place of diver-acquired images. Creating a model from video gives researchers the ability to interrogate the model directly instead of spending hours viewing footage, and the model serves to illuminate larger objects that would not otherwise be seen whole in the dark depths.

In 2008 a magnetometer and high-frequency sonar were used simultaneously to document a German Dornier Do 17 site in the Goodwin Sands for the RAF Museum, and in 2009, a hydrographic survey vessel surveyed the aircraft using multi-beam sidescan sonar to document bathymetry (Figure 4.1). The results are comparable to those achieved during shipwreck survey and in some cases exceeded expectation. The sonar data suggested a debris field and a scouring pattern, and sonar pictures from 2008 and 2009 show remarkable detail. In 2011, just before the RAF Museum announced their intentions for recovery, the Port of London Authority performed a sonar scan of the site and returned enhanced imaging (Figure 4.2). In the Dornier recovery's case especially, the use of sophisticated imagery of the wrecks caught the attention of the news media and the public, providing a positive attention base for the museum and numerous crowd-based opportunities for advertising their activities. RAF Museum was able to broker this interest and received a massive following for the 2015 excavation.

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[156] McCarthy and Benjamin 2014; Basta et al. 2015; Eriksson 2015; Van Damme 2015; Edwards and Cooper 2015; Yamafune 2016; Delgado et al. 2017.

 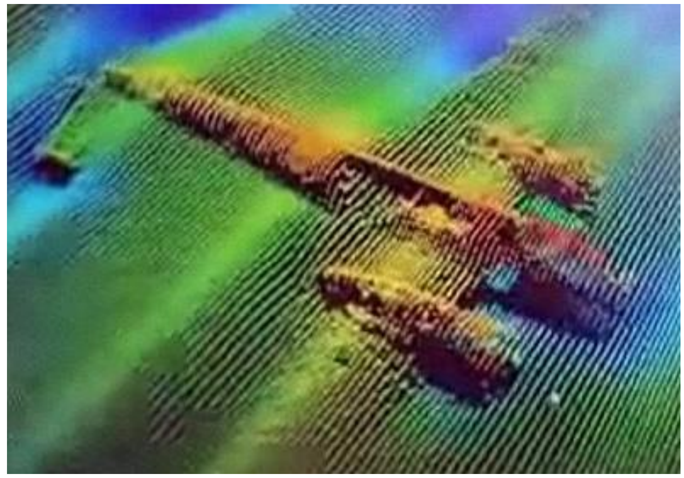

Figure 4.1 (L) and Figure 4.2 (R)- Sonar images of the Dornier Do 17 aircraft found on the Goodwin Sands, UK. Reprinted from (L) Wessex Archaeology 2011, (R) London Port Authority/Reson, reprinted from Thirsk 2013.

Aviation archaeology 3D modeling projects provide both documentation for the sites as well as a potential display unit to engage public interest. For example, a team of Norwegian technology students who discovered a WWII Halifax bomber off the coast of Trondheim in 300 m in 2016 created a 3D model from the ROV video and sent the information to Norsk Luftfartsmuseum in Norway.[157] As part of 2017 fieldwork in Saipan, East Carolina University's Maritime Studies Program and contractor Kota Yamafune created 3D models of several deteriorating aircraft sites in shallow water (Figure 4.3).[158] An archaeologist for a collaborative University/State Government survey effort in Sweden reported baseline condition assessment on a rare Arado 196-3 aircraft off Karlskrona, including a 3D model of the site (Figure 4.4) in order

[157] NRK 2014.
[158] https://sketchfab.com/jenmck13.

to see both an overall picture and detail, which would have otherwise been impossible in the poor visibility area.[159]

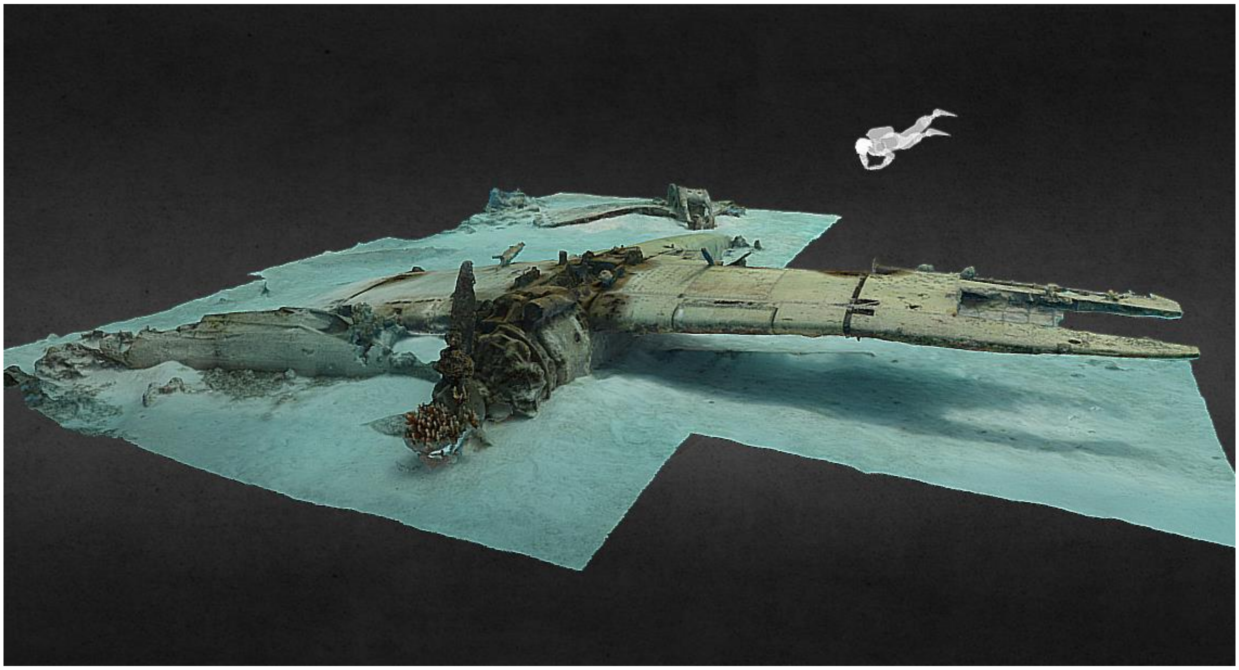

Figure 4.3- An Aichi E13A "Jake" floatplane 3D model for the East Carolina University (ECU) Maritime Studies Program Saipan Field Season 2017. Photo courtesy of Ships of Exploration and Discovery; Model by Kotaro Yamafune.

[159] McWilliams 2017.

Figure 4.4- Data Visualization of an Arado 196-3 aircraft, Sweden. Model by Ingemar Lundgren, Ocean Discovery, photo courtesy of A. McWilliams.

Archaeologists should continue to employ digital visualization techniques as they develop, not to replace standard archaeological practices, but to enhance survey timeliness and relevance of the report products. Data visualization products that are useful for archaeological documentation and research also are beginning to resonate with the public as well, and garner more public interest in projects.

4.3.2 Excavation Techniques

A large number of aircraft have been recovered from oceans and lakes but seldom are the projects archaeological in nature, or contain advanced documentation. Partial and full excavations have showed that a wealth of artifacts that convey significant information can be found on aircraft wrecks. Some methods of excavation on submerged aircraft sites have included the water dredge in circumstances ranging from the removal of sterile overburden down to the uncovering of fragile items including human remains. Traditional cofferdamming techniques have been used in shallow water to recover human remains and ordnance. While improper recovery methods (such as poorly slung crane or incorrectly-calculated lift bag examples) have resulted in damage to a number of submerged aircraft, the expert application of cranes, lift bags, baskets and other devices can result in successful recoveries.

4.4 Case Illustration, B-29, Saipan Channel

Myself and a number of other stakeholders in aviation archeology were invited to participate on a recent deepwater survey on a WWII-era B-29 aircraft wreck at 370 m in the Saipan Channel. The survey was part of NOAA's CAPSTONE project to investigate deepwater Marine Protected Areas, including submerged cultural heritage.[160] NOAA's research vessel *Okeanos Explorer*, and its ROVs *Deep Discoverer* and *Seirios*, carried out the seven hour non-disturbance survey dive, covering a range of over 200 m and several distinct areas of wreckage. It was broadcast live over the internet and to the general public via NOAA's website. The project's objective was to confirm the presence of WWII aircraft remains, and to determine the aircraft type if possible. A secondary goal was to study site formation processes. Because of time constraints, project planning did not include complete site mapping or the investigation of a secondary set of sonar targets close to the primary targets.

Stakeholders were invited because of their respective specialties and their ability to provide live insight and direction to the survey team, and also because the site represented a new set of concerns for the study of aviation archaeology. Each stakeholder brought to the project

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[160] Cantelas et al. 2017.

different research strengths and priorities concerning archaeology, history, federal policy-making, MIA crew affairs, and museum concerns. Since the area is part of a Marine Protected Area, NOAA has the responsibility to monitor and protect associated submerged cultural heritage, as well as an agreement with the US Navy under the Sunken Military Craft Act to monitor and protect military craft in its jurisdictional areas. No B-29s have been discovered in deep water in the Pacific Theater, so the wreck site is of particular research value to archaeologists as well as museum curators and historians. The consideration of the preservation of any associated MIA remains have the potential to affect site management procedures and federal policy if an identification of the specific aircraft and its wrecking event is possible.

The wreck site is largely disarticulated and is missing several sections. The first wreckage group seen on camera was the inverted center wing section of a B-29-type airframe, three engines attached to the wing, and an associated debris pile of large and small objects directly aft of the wing (Figure 4.5). The second grouping located was the forward gunner's turret surrounded by parts from that section of the fuselage (Figure 4.6). The third group of wreckage was the horizontal stabilizer and some small deteriorated pieces (Figure 4.7). In between each group were several smaller pieces of wreckage, one of which was the pilot or co-pilot's seat next to a flak jacket. Organic remains from the wreck also include two parachutes and some remnants of the doped fabric on the flight control surfaces (Figure 4.8). Most of the thin aluminum surface skin has been scoured away by sand movement. Site formation, including the separation of the wreckage groups, missing sections, and damage to the engines' nacelles and turbochargers suggested a catastrophic surface impact and breakup, with possible fire and loss of life.[161]

[161] Lickliter-Mundon et al. 2018.

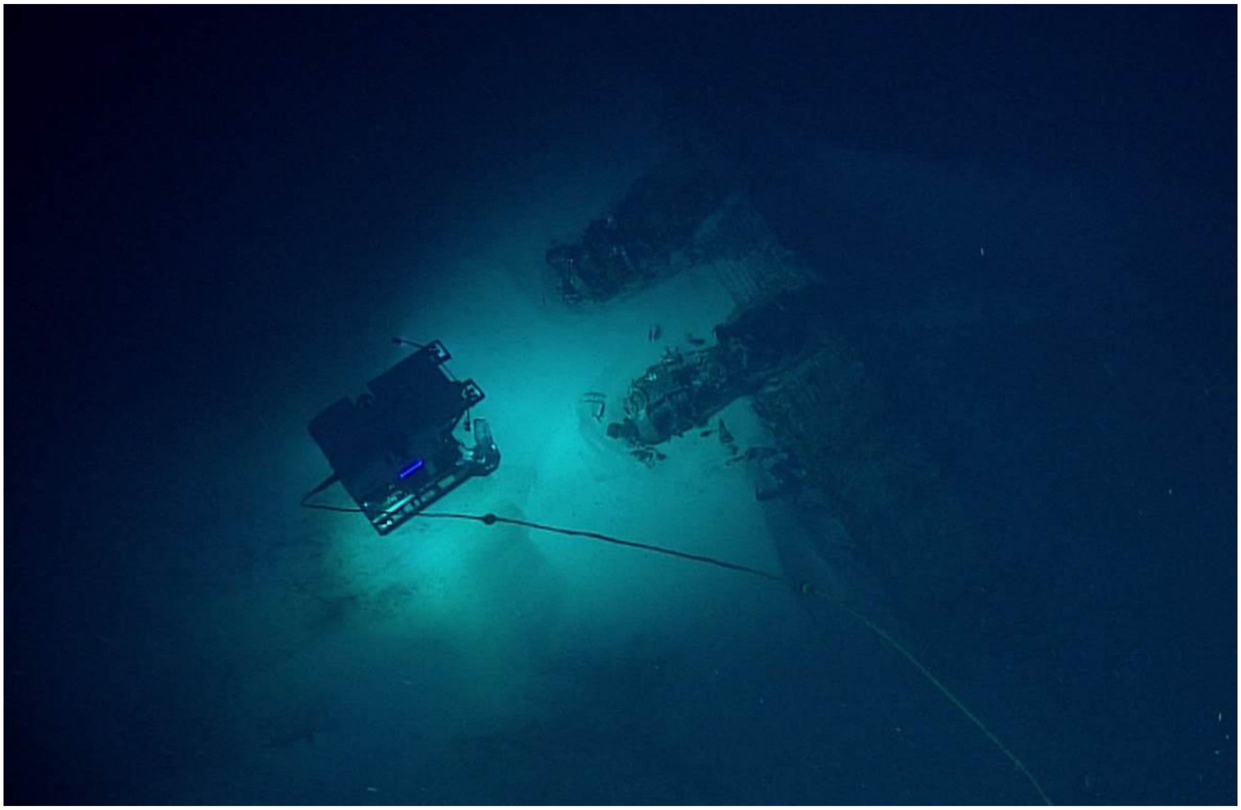

Figure 4.5- ROV *Deep Discoverer* imaging the B-29 wreck site as seen by ROV *Seirios*. Photo courtesy of NOAA Office of Ocean Exploration and Research, 2016 Deepwater Exploration of the Marianas.

Figure 4.6- Remains of the top turret and the navigator’s instrument panel and window. Photo courtesy of NOAA Office of Ocean Exploration and Research, 2016 Deepwater Exploration of the Marianas.

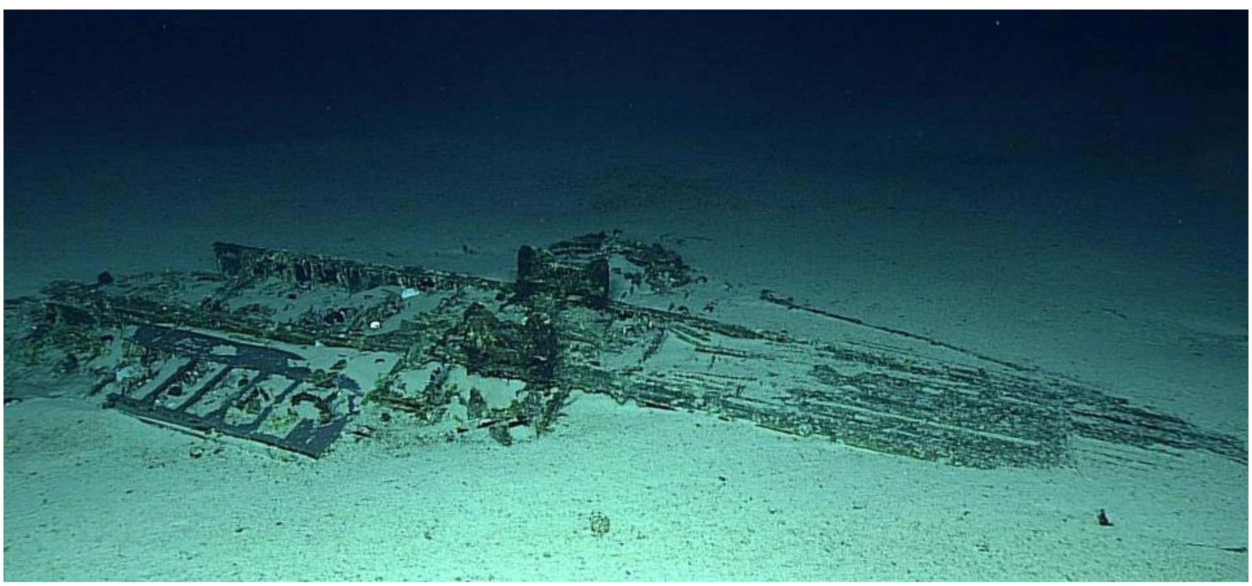

Figure 4.7- The horizontal stabilizer of the B-29 site. Photo courtesy of NOAA Office of Ocean Exploration and Research, 2016 Deepwater Exploration of the Marianas.

Figure 4.8- One of the parachutes on the B-29 wreck site, aft of the wing. Photo courtesy of NOAA Office of Ocean Exploration and Research, 2016 Deepwater Exploration of the Marianas.

The B-29 dive did not include planning for 3D modeling, but I experimented with the video in order to obtain stills for post-processing with Agisoft Photoscan (Figure 4.9). The resulting 3D model proved what could be achieved from minimally acceptable conditions. The ROV's survey flight path of semi-circle travel and extreme camera zoom caused several breaks in the overlap of images (Figure 4.10). The 3D model, as a result, has a currently unmeasurable margin of error. Despite this, the model can be easily serve promote NOAA's public engagement through its publication on a website or in museum display. The model is also an excellent tool for researchers to study a site that cannot be fully seen otherwise at that depth at once due to the limited illumination from the ROV. I also used it to create the site map for the B-29, which I drew through a combination of deconstruction mapping and tracing the model (Figure 4.11).

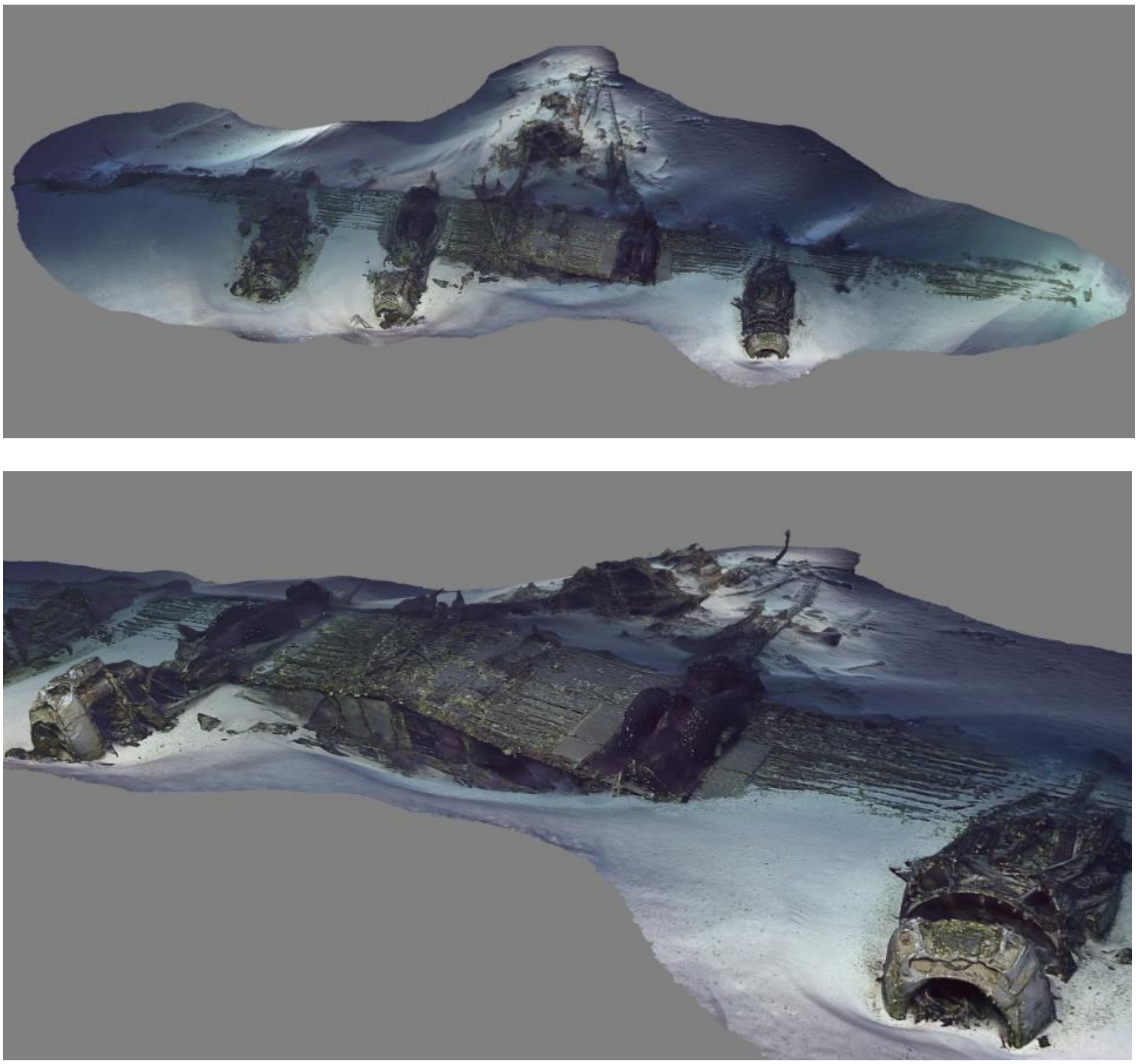

Figure 4.9- Two views of the B-29 3D model showing the excellent coverage and illumination that a model can provide for a deepwater site. Model by the author from Agisoft Photoscan.

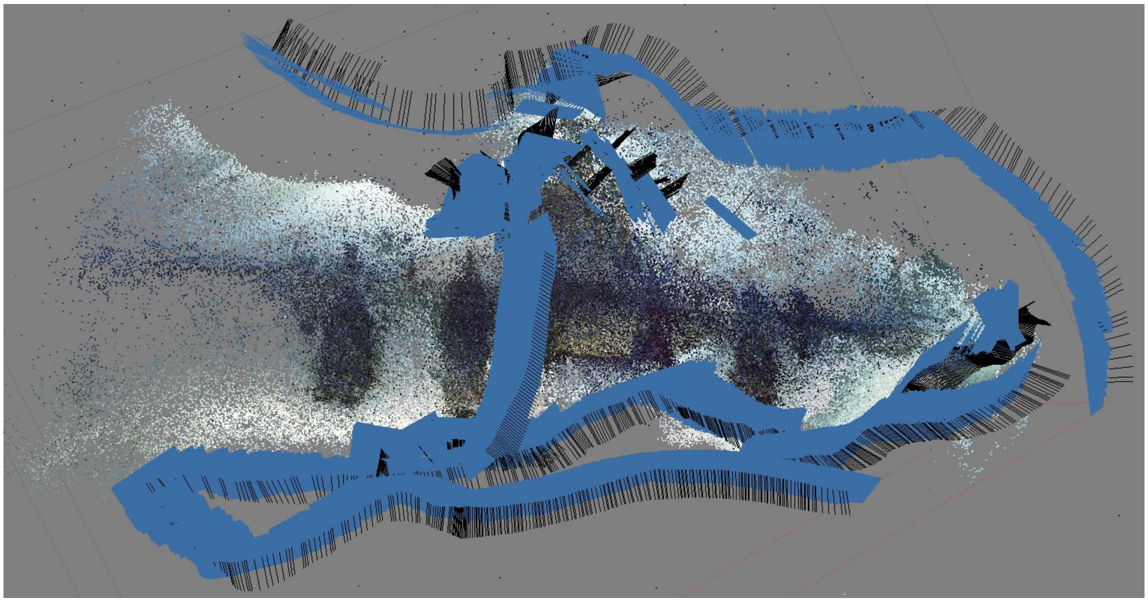

Figure 4.10- The flight path in camera stills from the ROV video. Each blue square and accompanying line of sight represents one still. Model by the author from Agisoft Photoscan.

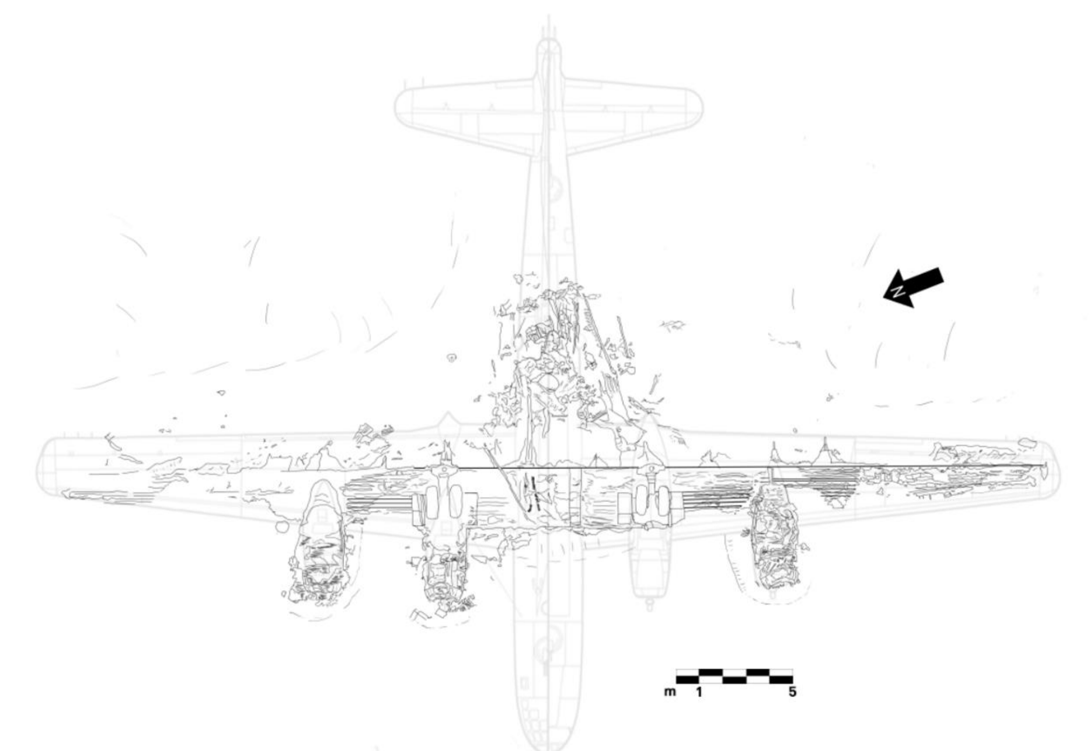

Figure 4.11- Site map of B-29 site, Saipan Channel. Site map drawn by the author.

Our study of site formation processes provides a starting point for comparative identification efforts. The post-survey site formation researched as part of the survey report focused on identification of the individual aircraft, which to date has been unsuccessful. Comparison of the site formation to Missing Air Crew Reports (MACRs), Air Force Accident Reports, witness statements, rescue logs, and other primary sources only served to eliminate proposed aircraft candidates. An example of site formation for B-29 downed in fresh water was also used for comparative research.[162] Missing information, or inaccurate or incomplete statements and reporting errors may be partly to blame. Still, the information gained from the research and interrogation process proved extremely valuable.

Scientists onboard the NOAA research vessel *Okeanos Explorer* were joined by several scientists on shore and members of the general public online via telepresence technology, allowing for live research and reaction by both researchers and public viewers. Telepresence delivers surveying activity and scientist commentary live to the general public, potentially via broadcast into museums, classrooms, meeting spaces, or to private homes. If set up in advance, some ships have the capability of taking and answering questions from remote audiences. Telepresence enables the live interpretation of the survey and the showcasing of different methodologies, explaining tools and techniques, and effecting interest in the action of archaeological survey itself. Members of the public have the ability to become engaged in the process of archaeology, rather than just the outcomes.

The 2016 NOAA B-29 project is an example methodology for surveying and reporting on an aircraft in deep water, inaccessible to divers. This survey was heavily dependent on

[162] Chenoweth et al. 2006.

technology. The sonar targets were faint but delineated as probable by an expert, and now represent the deepest aircraft to be found by hull-mounted sonar. ROV survey is a proven tool for archaeological inquiry both in non-disturbance and excavation surveys.[163] In this case, the desired outcome was an identification of the site type and possible specific aircraft. Project planning should consider the desired outcome, but one might be able to get more out of the survey results than previously thought possible. Ideas and collaboration by multiple stakeholders illustrate an ideal process for the research of aircraft sites; future studies of this type can build a database of better research reports.

4.5 Section Discussion

There are a number of options to consider when planning for an aircraft survey or recovery project. Planning methodology will understandably vary given the type of project, but must also vary with consideration of the outcome of the work. Planning to search for a site differs greatly from a maintenance survey for example, as does a project designed to engage the general public. Similarly, aircraft present with different challenges in shallow water and deep water, necessitating a range of adaptations to research methodology and goals. Ideal methodologies in aviation archaeology are research goal-based, well-rounded, multi-disciplinary, include multiple types of documentation, and can sometimes incorporate expertise, tools, and technologies developed for other fields but adapted for aviation sites. Successful project planners not only will anticipate the types of interpretations that might be made from future research on present site surveys and include baseline, accessible information in site reports, but they will also recognize the present needs and best interests of the site or artifact.

[163] Adams 2007; Horrell and Borgens 2014; Delgado et al. 2016a.

From the examples presented in this dissertation, it is evident that collaboration and accessibility of results is key for a meaningful research project. A particular site's value might not always be purely archaeological and may be recreational, as a tourist facility even. A site or object's significance and needs will change over time, as well as their recommended treatment. Many underwater aircraft sites will already be known to local divers and enthusiasts, and their input and historical knowledge will aid any site survey project. Enthusiast and archaeologist cross-fertilization and collaboration can prove a useful training opportunity aimed at developing an organized group of dedicated maintenance survey divers. Failure to cater for those already accessing sites in a recreational or tourist context can be to the site's detriment.

ROVs, AUVs, and other deepwater technologies are allowing for advanced archaeological methodologies to be possible on deeper aircraft sites. New data visualization techniques, like 3D photogrammetric site mapping, can make the product of visual surveys both interesting and helpful for present and future archaeologists. Used as tools for museum and public outreach, 3D models and advanced sonar bathymetry models can excite and engage the public.

5. CONSERVATION

Aircraft materials recovered from submersion in water require treatment to stabilize the material. Without treatment, aluminum will suffer from pitting and exfoliation corrosion and ferrous material will rust, the effects continuing until the material has decayed to dust. Conservation treatments and prevention of exposure to humidity can extend the life of any aviation artifact for storage or display.

5.1 Research History

Conservation of aircraft aluminum and artifacts from underwater has evolved slowly. Treatments differ based on whether the aircraft was removed from fresh or salt water, with more aggressive treatments needed for saltwater-submerged material. The first non-contemporary recovery of an aircraft from salt water was of a WWII Hellcat off the coast of California in 1970, after it had been submerged for 35 years. The aircraft was rinsed in fresh water and sent to a dry climate in Arizona, but prior to restoration in the 1990s the aluminum had deteriorated dramatically in appearance and strength in the intervening years. Freshwater recoveries were favored in the 1990s and early 2000s when several US Navy aircraft were salvaged from the Great Lakes. These aircraft were also rinsed with fresh water as a primary means of conservation prior to restoration work. Aircraft salvaged from the Great Lakes and placed on display without restoration appear to be in good condition, although artifacts from the aircraft sites appear to be actively corroding (Figure 5.1). Conservation procedures for freshwater-submerged aircraft have developed largely in museums from restoration practices. Conservation practices and publications for saltwater-submerged aircraft and components closely follow the early 1990s rise in theory publications in the aviation archaeology field, with most of the experimental research on aluminum desalination and corrosion stabilization taking place in Australia under the direction of the Western Australian Maritime Museum's (WAMM) lead conservator.[164] Experimentation led to the initial development of two methods for the treatment of submerged and corroded aluminum, which were used by museums successfully but somehow never gained much popularity.[165] Publications on aluminum conservation have been sparse since 2006 and while most museums and archaeologists know that citric acid-based submersion treatment produces good results, the treatment method is still not widely used and most conservators are still experimenting with alternative options.

Figure 5.1- Deteriorated pieces surround artifacts recovered from aircraft sites in Lake Michigan, on display at the National Naval Aviation Museum. Photo by the author.

[164] MacLeod 1983; 2004.
[165] Adams 1992, Bailey 2004, Degrigny 1995.

5.1.1 Methodologies

Within the field of archaeology there are two well-known treatment methodologies for recovered vintage aircraft metals. MacLeod, a conservator from WAMM, began experimenting with treatments in the early 1980s. Degrigny began trials on aircraft aluminum and engines in the mid-1990s. MacLeod's method is a washing procedure that uses an ammonia-ammonium sulphate solution at a higher-range pH 9.6 in order to remove copper metal precipitates and copper corrosion products from the surface of the object whilst also removing aggressive chloride ions.[166] MacLeod's method was proven effective but not efficient- it took roughly three times the amount of time and chemicals that Degrigny's method used. Degrigny's electrolytic method was developed while experimenting with composite metal artifacts and has been used on large aircraft engines and frames.[167] The portion concerned with aluminum alloys involves mechanical cleaning, electrolytic reduction in a citric acid and sodium hydroxide solution, and application of a protective wax. Bailey's treatment of an entire fuselage planned for museum display showed that the electrolytic process is more efficient that washing alone.

More recent projects, like the Sola Heinkel and the F-1 engines, show a crossover in the influence of both traditional aircraft corrosion inhibitor products and museum conservator treatments. Corrosion inhibitors that have been specifically developed for aircraft should prove effective in treatment, and it seems like they are effective at chloride removal as well.[168] Treatment methods, especially on modern aviation materials, will benefit in development with collaborative efforts from conservators, industry, and museum personnel (Figure 5.2).

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[166] MacLeod 1983; 2004.
[167] Bailey 2004; Degrigny 2004.
[168] Mardikian et al. 2015.

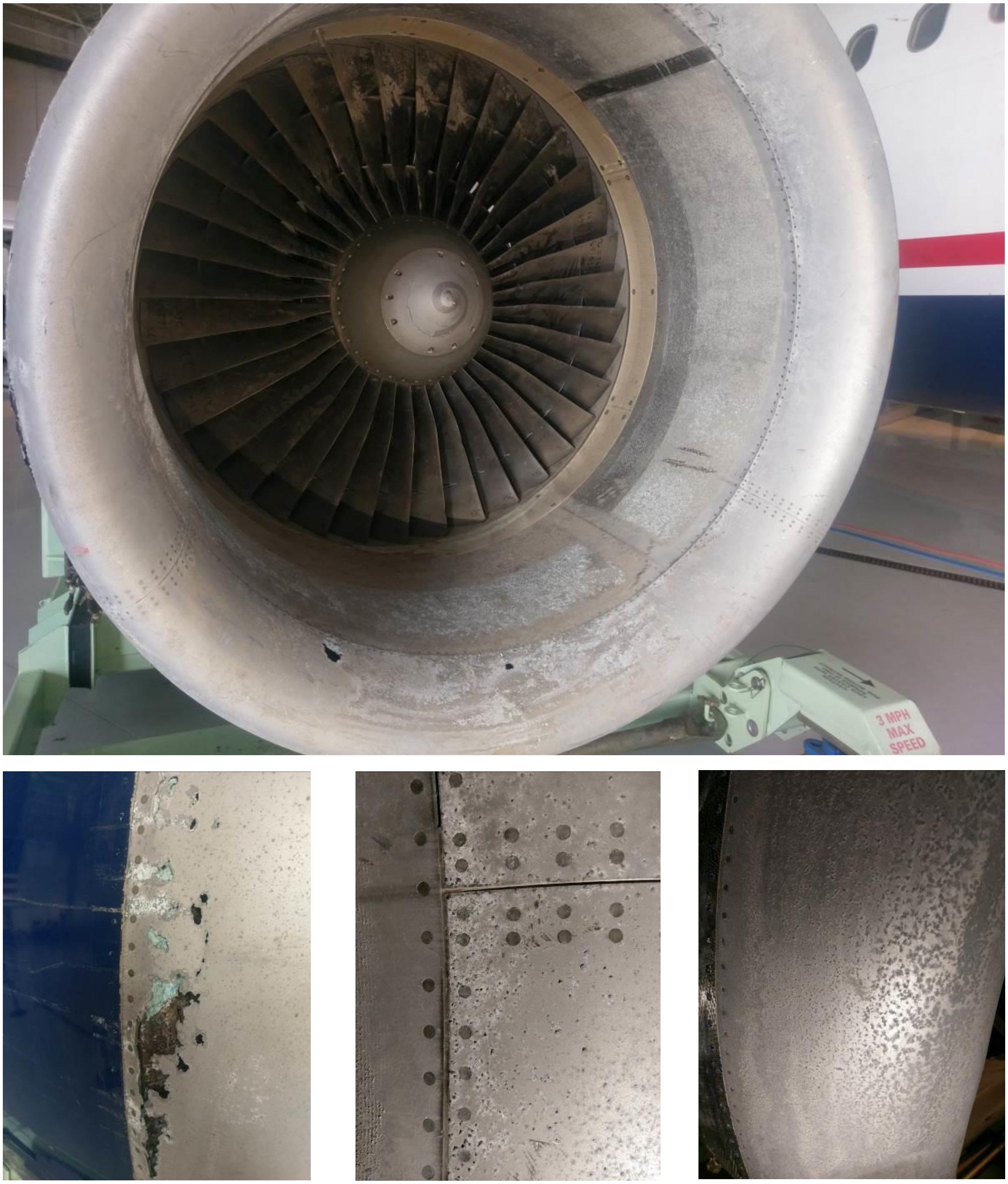

Figure 5.2- An interesting set of corrosion products appear on the two GE CFM56-5B4/P turbofan engines of the 'Flight 1549' Airbus A320-214 aircraft that crashed in the Hudson River in 2009. These engines were only submerged for a few days in brackish water, but did not undergo any conservation treatment and have consequently developed a range of issues. These engines will be treated in 2019 by a team of archaeologists, conservation specialists, museum professionals, and airline maintenance professionals. Photos by author with permission from the Carolinas Aviation Museum.

Aviation conservation study and experimentation necessitates knowledge of the metal compositions. One of the easiest and least destructive methods is X-ray fluorescence (XRF) analysis. An XRF machine sends an x-ray beam to the artifact in order to excite atoms in its material makeup. When that atom then releases an electron, the tracer machine measures the resulting energy transfer. The information obtained from all atom energy transfers is plotted and the graph and shows the chemical make-up of the object. XRF analysis on aircraft and corrosion products is in use on several archaeological projects and in museums like the National Air and Space Museum and the Navy's Underwater Archaeology Branch.[169]

Aluminum conservation research produces a growing body of metal signatures, to which future researchers can compare results from their studies.[170] Other studies, such as weight and thickness loss, electron microscopy, and x-ray diffraction also can be valuable to the field. More research is needed specifically on submerged or recovered aircraft, and the results made available to CRM managers, museums and contractors who will both deal with the deterioration effects of and preserve these artifacts before after recovery.

5.1.2 Recovered Aircraft Conservation Projects

The most notable aircraft conservation projects in the past two decades have all been in cases where the final product is for museum display. The Sola Aviation Museum in Norway recovered a German Heinkel in 2012 and, with funds from the museum friends' group, built their own submersion tank for the conservation procedure after fully documenting the aircraft.[171] The aircraft, along with a number of associated materials, is currently undergoing conservation

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[169] Shackley 2011; Mirambet et al. 2016.
[170] Degrigny 1995; Gujarathi 2008; Richards and Carpenter 2012.
[171] Sola Museum 2012.

treatment for display. As of 2017 the tail section has completed a dry-ice cleaning and lanolin-preservative treatment.[172]

Canadian conservation efforts have developed experimental methodologies for submerged aircraft material, but no project has progressed past the initial recommendations. One study proposed the treatment of the steel-tube structure and other remains of some of the oldest aviation material ever found underwater.[173] Parts of this aircraft were recovered and are in storage without receiving treatment. In 2014 private conservators prepared a report commissioned by the Yukon government on the proposed conservation treatment of a B-26 nose required after its illegal salvage from a freshwater lake.[174] The report suggested washing with a corrosion inhibiting detergent and manual brush removal of corrosion products, before the final application of an oil-based inhibitor. This aircraft is also in storage but will soon undergo treatment in preparation for display.

The Royal Air Force (RAF) Museum recovered the Dornier Do 17 in the summer of 2012. Upon consultation with materials scientists from the Imperial College London the RAF Museum decided to develop a conservation plan, which uses Degrigny's citric acid chemical base but houses the artifacts in a fog tunnel in which they are sprayed almost constantly.[175] The fog supposedly penetrates the space between metal pieces and removes corrosion products as if the objects were submerged. This treatment method is attractive from a cost standpoint, and time will tell if it is effective as well. As of 2016 the large fuselage and tail sections have completed treatment and are in storage awaiting display.

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[172] Aarebrot 2014.
[173] Binnie 2006.
[174] Sembrat 2014.
[175] Ryan et al. 2013.

One of the most recent projects is the conservation of several Saturn V Rocket F-1 engine parts from the Apollo 11, 12, 14, and 16 missions.[176] The project first focused on materials identification in order to develop a treatment plan, using several analysis methods including XRF, scanning electron microscopy, and Raman spectroscopy, among others. Removal of sediment was followed by the use of a 0.1% solution of a commercial corrosion inhibitor in a submerged tank for chloride removal for composite metal parts that were primarily non-copper based. Final cleaning was with dry ice blasting. Some of the engine material is now on display at Seattle's Museum of Flight in Washington.

In terms of aircraft that remain submerged, Australian researchers are studying aircraft wrecks in situ to create a database of aluminum deterioration rates and active vs passive decay status.[177] This method of studying corrosion potential for aluminum was developed from the same methodology for iron-hulled shipwrecks. Corrosion potential of a metal can be measured if in an electrolyte, and the results graphed on a Pourbaix diagram to show the decay status. Salt water is the electrode in the case of submerged aircraft, and meters measure the metal voltage and pH.

5.2 Corrosion Study and Stabilization of Saltwater-Submerged Aluminum

Aluminum or aluminium is a widely used metal first isolated in 1827. Methods of extraction became cheaper after 1900 and several alloys were developed that made aluminum stronger, more corrosion resistant, or more flexible. Known for its strength and lightness, it has been used in aircraft construction since the 1920s. Aluminum naturally and preferentially forms a

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[176] Mardikian et al. 2015.
[177] MacLeod 1989; 2003; 2006; Richards and Carpenter 2012; MacLeod and Richards 2014.

passivation layer of aluminum oxides, which protects it somewhat from its environment. Salt water can damage this protective layer, and the removal of the object from salt water can exacerbate the process, forcing the production of aluminum hydroxides which are highly corrosive.

Aircraft aluminum is derived from an early alloy called dural, or duralumin, which is a heat treated, 4% copper alloy. It is 30% less dense than steel but comparative in strength. Aircraft aluminum 2024, or 24ST, is the modern aluminum/copper alloy most used in aircraft, although aircraft can also have wrought or cast aluminum. Aluminum alloys are organized into series based on their alloy material and properties (Table 5.1). Alloying and heat treating aluminum gives the metal strength, but limits its natural corrosion-resistance. Alclading, anodizing, painting, or applying a primer to aluminum are ways in which the level of corrosion resistance can be raised. Alclad is a thin layer of pure aluminum added to the outside of an alloy. Anodizing is a form of plating for aluminum surfaces, and consists of an aluminum oxide layer.

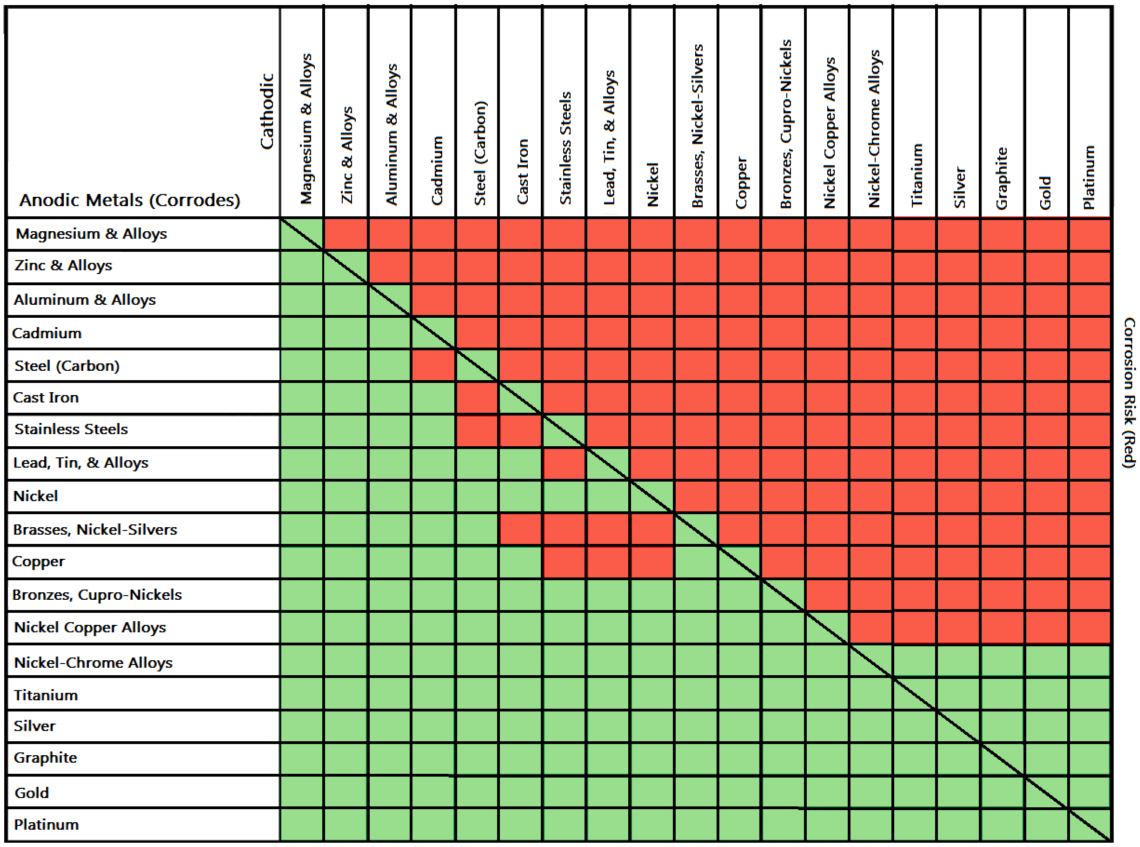
Table 5.1- Aluminum Series Table of Examples.

Aluminum Series	*Common Alloying Elements*	*Example Alloys*	*Properties*
1xxx	Mg, Li, Zr, Mn, Sc	**1050** (99.5% Al)	Usually pure aluminum sheets or drawn tubes
2xxx	Cu, Mn, Mg, Ti, Si, Fe, Ni, Cr	**2024** (4.4 % Cu; 0.6 %Mn; 1.5% Mg)	Aircraft aluminum in sheets, rivets, bars, wires, plates, etc.
3xxx	Mn, Mg	**3004** (1.2% Mn; 1% Mg)	Sheets or work-hardened bars, aluminum cans.
4xxx	Si, Fe, Mn, Mg, Ni, Cr, Cu	**4043** (5.2% Si)	Rods, sheets, cladding
5xxx	Mg, Mn, Cr, Ti, Cu	**5052** (2.5% Mg; 0.25% Cr)	Universal uses including marine and aerospace, welding, and automobile.
6xxx	Si, Mg, Mn	**6101** (0.5% Si; 0.6% Mg)	Some aerospace use, mainly architectural and structural
7xxx	Zn, Mg, Cu, Zr	**7065** (7.7% Zn; 1.6% Mg; 2.1% Cu; 0.1% Zr)	Aerospace in plates, foils, extrusions, etc.
8xxx	Fe, Si, Mg	**8176** (0.6% Fe; 0.1% Si)	Wire, aerospace

Corrosion occurs as a result of unstable metals being affected by environment, and is almost always electrochemical in nature.[178] In an electrochemical process, electrons are transferred from the original metal to either another metal or an oxidization process that will result in some corrosion process. Aircraft aluminum corrosion processes are problematic because of the use of alloys and other metals in the same structure. Iron and steel compounds (stainless steel) are protected at the expense of aluminum and most magnesium and copper alloys degrade extremely quickly. Different aluminum alloys will also corrode preferentially in the presence of one another, such as aluminum rivets on an aluminum structure (Table 5.2). The availability of oxygen also affects aluminum corrosion, and this can relate to either physical space in creation of a concentration cell, biological organisms or a biofilm attaching to the exterior surface, or the presence of mud or silt.[179]

[178] Selwyn 2004.
[179] Nelson et al. 2017.

Table 5.2- Galvanic Reaction Risk in Sea Water



Note: These metals are arranged according to their risk for reacting with each other. Table reprinted from StructX 2014.

Pitting corrosion is a type most widely found on aircraft underwater, although it is often as a result of galvanic corrosion. Pitting corrosion begins in compromised areas of aluminum, which could be imperfections in the alloy compositions or the passivation layer, and results in a hole or pit in the metal surface, which can grow if the corrosion is not treated and the compromised area sealed (Figure 5.3). A galvanic reaction, sometimes causing corrosion, can exist when metals are in contact with each other and an electrolyte, and one metal gives up electrons preferentially to another, resulting in the loss of stability in the first metal. Often a prevalent form of corrosion on aluminum alloys is intergranular corrosion, often due to the presence of copper precipitates. Pitting, galvanic, crevice, filiform, and exfoliation corrosion are often seen in museums on aircraft that have been exposed to humidity or water (Table 5.3).[180]

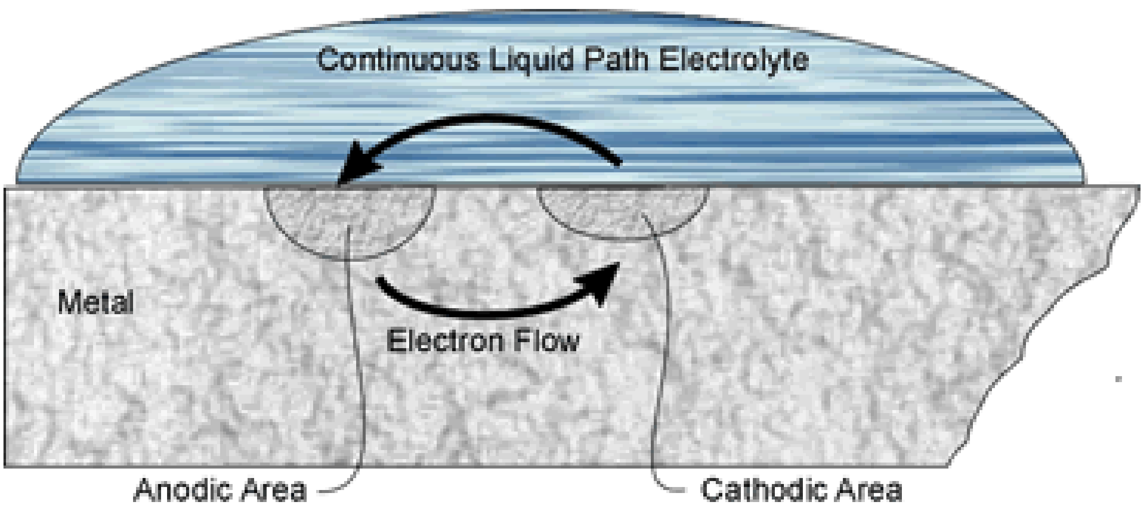


Figure 5.3- A diagram of a corrosion cell in salt water. "Four conditions must exist before electrochemical corrosion can occur. They are:

1. A metal that is going to be subject to corrosion (Anode) must be present.
2. Another dissimilar conductive material (Cathode), which has fewer tendencies to corrode, must be present.
3. There must be a continuous, conductive liquid path (Electrolyte).
4. There must be electrical contact between the anode and the cathode (usually in the form of metal-to-metal contact such as rivets, bolts, wire, etc)."

Photo and text reprinted from RAF Museum Cosford Michael Beetham Conservation Centre 2011.

Aluminum or other aircraft components will require stabilization treatment once removed from water. Treatment will rid the artifact of corrosion products and, in aluminum samples, should seek to restore the protective passivation layer prior to sealing the metal from humidity.

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[180] RAF Museum Cosford Michael Beetham Conservation Centre 2011.

Restoring stability to an aluminum artifact will stop further pitting corrosion, but further galvanic, crevice, or other physical space-based corrosion may occur if the metals remain in contact in any humidity. Sealing the copper precipitates will elongate the life of aircraft aluminum alloys on display.

Table 5.3- Presentation of Corrosion or Compromised Aircraft Metal

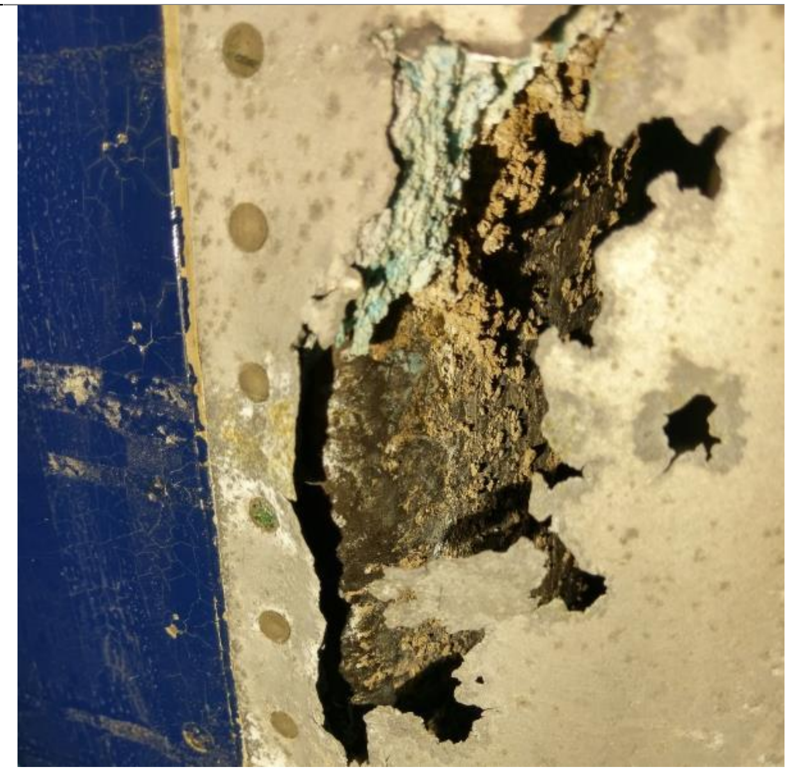
Pitting corrosion	

Table 5.3- Continued

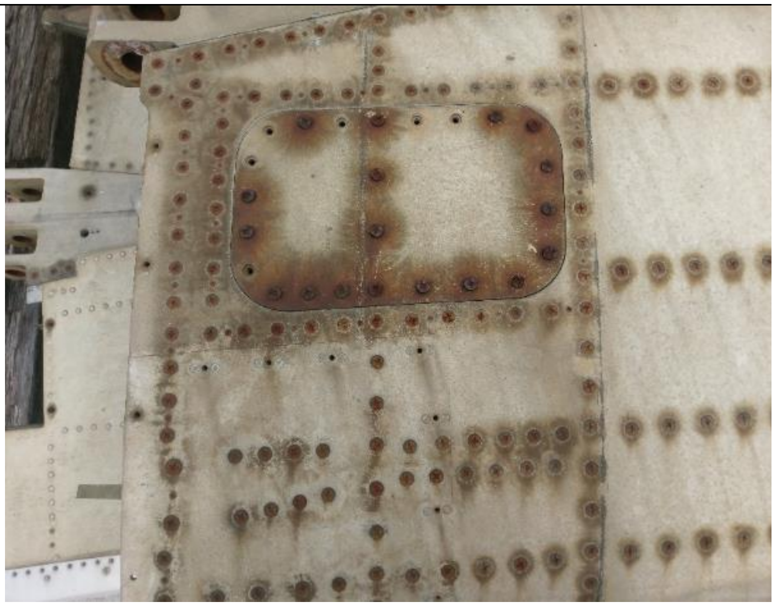
Galvanic Corrosion	
Exfoliation Corrosion	

Table 5.3- Continued

Filiform or Crevice	
Fire Damage	

Table 5.3- Continued

Rust	
Humidity Oxidization	

Table 5.3- Continued

Active Corrosion	
Combat Damage	

Note: All photos by author, various aircraft skin and structures.

5.3 Experimental Studies on Aircraft Aluminum[181]

In 2013, as part of this dissertation, I proposed a pilot study into the crossover between modern museum aircraft conservation techniques and two known modern metal conservation methods for submerged material. From 2013 to 2018 I acquired samples of aircraft aluminum from various museums and organizations.[182] I wanted to investigate non-intrusive elemental analysis to determine the effects of submersion in sea water and fresh water. In 2013 I received a grant from the Center for Maritime Archaeology and Conservation at Texas A&M University for aluminum conservation research, which encompassed composition investigation, materials science, conservation treatments, and preservation treatment. These studies are meant to add to the data pool for identifying the characteristics of vintage aircraft components and their treatment for preservation and display. The following are selected examples that received treatment as well as diagnostic analysis, the rest of the examples appear in Appendix A.

From the RAF Museum I acquired three pieces of Do 17 aluminum for conservation experimentation (RAFMDo01-03) (Figures 5.4-5.6). The samples of Dornier Do 17 material show a range of corrosion products and decay rates, including pitting, rust and exfoliation. They also represent a collection of treatment considerations including original paint, ferrous rivets, and one sample, RAFMDo02 appears to have a leather covering glued to the aluminum.

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[181] The results from the USS *Macon* materials which are a part of this pilot research are discussed in the complete case study in Chapter 9 of this dissertation.

[182] I experimented with artifacts currently in the collections of the US Navy History and Heritage Command, Moffett Field Museum, the Royal Air Force Museum Cosford, Norsk Luftfartsmuseum, the Carolinas Aviation Museum, and private individuals. Artifact images and descriptions in Appendix A.

Figure 5.4- Sample RAFMDo01 is a fragile piece if stringer material that is pitting and exfoliating extensively. Photo by the author.

Figure 5.5- RAFMDo02 is also long and thin, but is in a much better state of preservation that RAFMDo1. There are remains from a suspected leather covering, which was glued to the piece. The leftover glue covers the piece. There are rust spots from iron rivets, and a small amount of blue copper corrosion product. Photo by the author.

Figure 5.6- RAFMDo03 is a cast aluminum curved object with four aluminum rivets and one ferrous rivet. The ferrous rivet is surrounded with rust. The object was painted with a light blue paint and remnants of it remain on the surface along with dirt. Photo by the author.

In late May 2012 the Naval History and Heritage Command's Underwater Archaeology Branch (UAB), in cooperation with the U.S. Navy's Military Sealift Command (MSC) and U.S. Navy Mobile Diving and Salvage Unit TWO (MDSU-2), completed a survey of a Helldiver SB2C-type aircraft at 56 m off the coast of Jupiter, Florida.[183] Navy divers training on a technical dive mission located and recovered a data plate and a small piece of metal, most likely broken off the starboard wing. I received the smaller wing piece (UABSB2C01, Figure 5.7) as part of this experimentation with the aim of determining the correct conservation method for both pieces.

[183] Brown and Lickliter-Mundon 2013; Brown 2014.

Figure 5.7- UABSB2C01 aluminum sample outward side. It appears that the outwards angled side of the metal sample is plated with a thin layer of metal that is different from the structural metal; i.e. a laminate, or alclad. Photo courtesy Kate Morrand, NHHC UAB lead conservator.

5.3.1 XRF Analysis[184]

All of the samples I obtained are aircraft aluminum from around the WWII era, but also represent a diverse range of site formation processes, all which will reflect in the XRF readings. Differences include:

- Samples are from various areas of the aircraft
- Samples have different fabrication techniques, like casting or heat-treated rolling among others
- Samples were from different countries of design and manufacture, including US, UK, and Germany

[184] Individual sample site and readings are in Appendix B.

- Samples were found in a range of environments, such as beach, mud, shallow water, swamp, and land, and from all over the world

I present below a series of examples showing different metal XRF readings from Bruker Tracer III SD (Figure 5.8-5.10, 5.12).[185] A full XRF readings analysis of my 16 aluminum samples is available in Appendix B, and serves as a database of comparative vintage aluminum signatures. I chose to have the settings at 40k volts and 11.5 micro amps in order to excite the electrons of the heavier elements; consequently the readings reflect lower peaks in the lighter elements than normal, although they would still read much lower because of the distribution scale of return being centered near to copper. Aluminum, being a light metal, in some cases does not show well on the reading and only the alloy elements do. Copper will show in relatively high amounts because of its visibility to the sensor. Analysis on XRF machines will also register trace peaks from the anode material; this particular Bruker shows trace peaks of Rhodium and Nickel.

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[185] The voltage, amps, and time for all samples is shown in each. All samples were shot by me or Dr. Chris Dostal, Texas A&M Maritime Archaeology Conservation Lab, with a yellow filter unless otherwise noted.

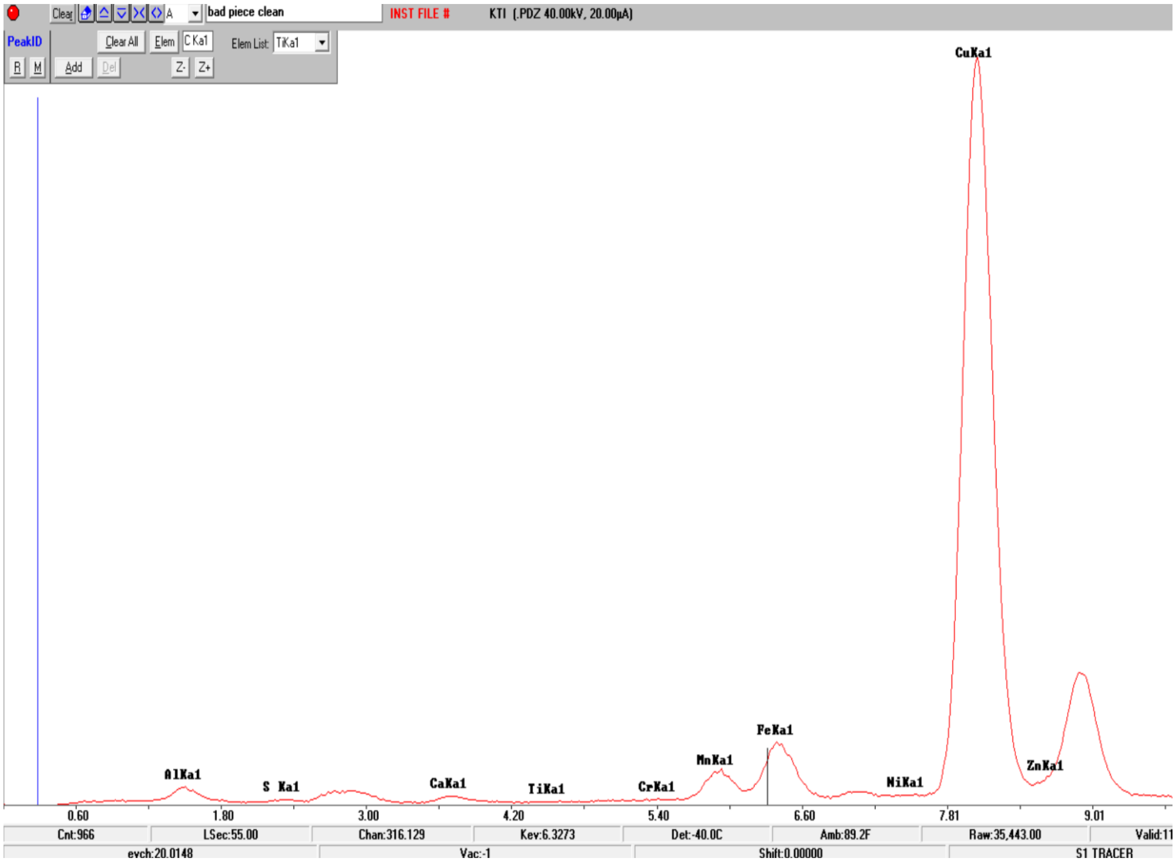

Figure 5.8- RAFMDo01 shows evidence for being a typical duralumin alloy. A small spike for aluminum and magnesium, and a large spike for Copper characterize this alloy's XRF reading. Notice also the small prevalence of calcareous growth and silicate, typical for underwater growth.

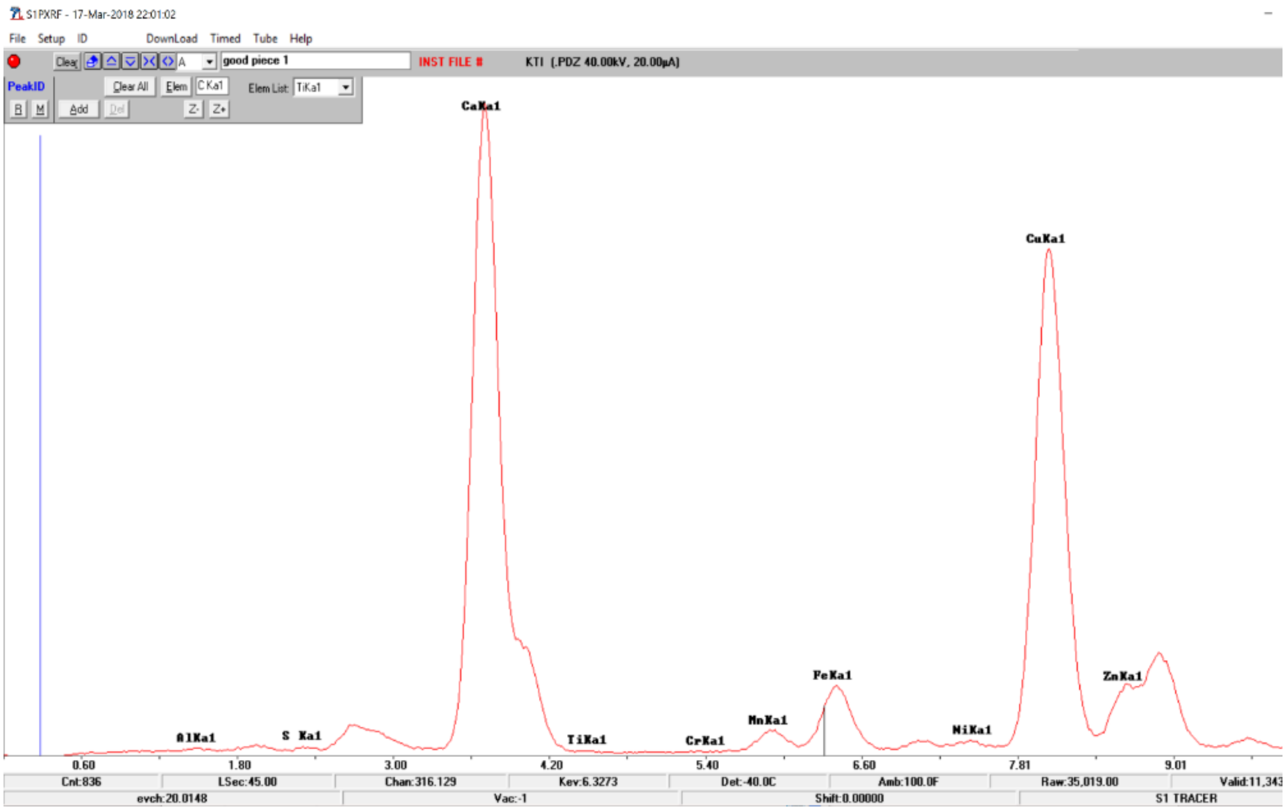

Figure 5.9- RAFMDo02 presents with a large calcium reading, probably from a nodule of calcareous growth. This alloy appears to have a slight amount of iron and nickel as well as the Copper and Manganese, making at a different type of 2xxx series alloy. The small bump in Zinc is likely evidence of a primer coating.

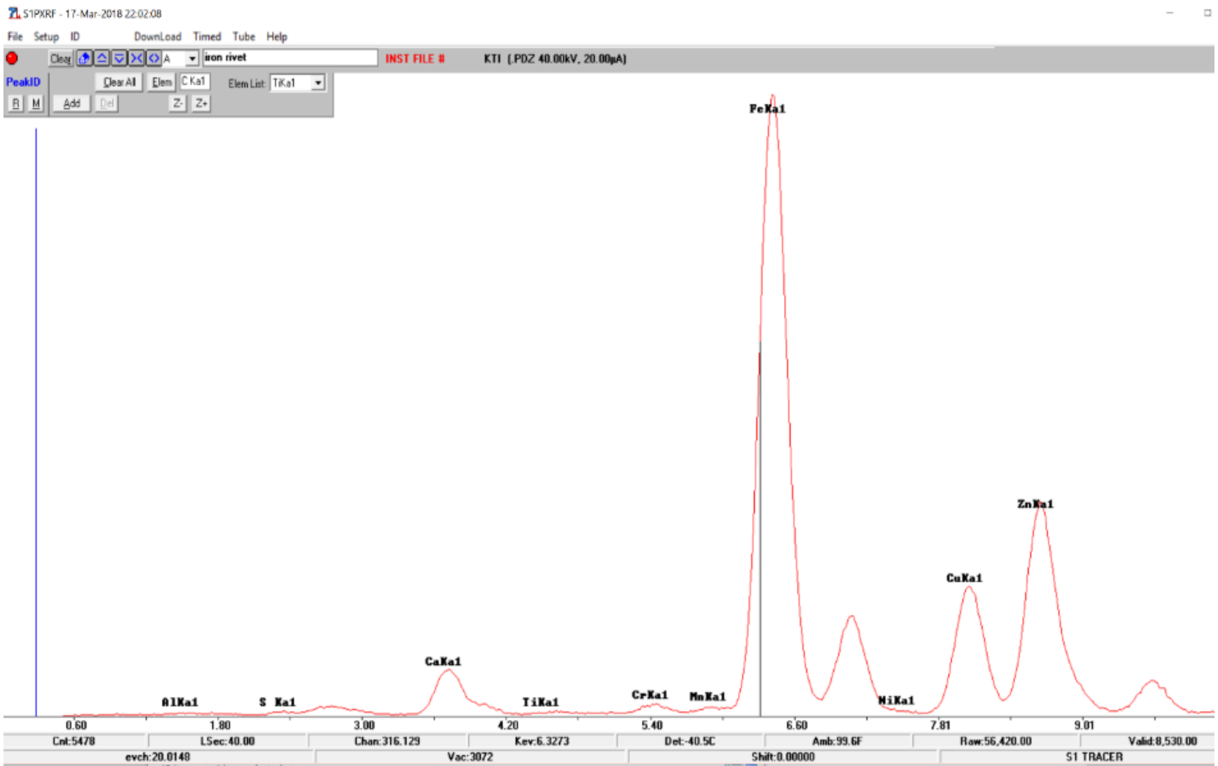

Figure 5.10- RAFMDo03 reading on top of the iron rivet. The zinc primer is a higher peak because of the intact level of the paint.

The XRF reading will vary according to where on the artifact you place the sensor (Figure 5.11). I used a vacuum on three different samples areas on UABSB2C01 in order to check the difference in peak height, and the difference is apparent in sample areas 1, 3 and 4 (Figure 5.12).

Figure 5.11- XRF sensor locations on sample UABSB2C01. Photos by the author.

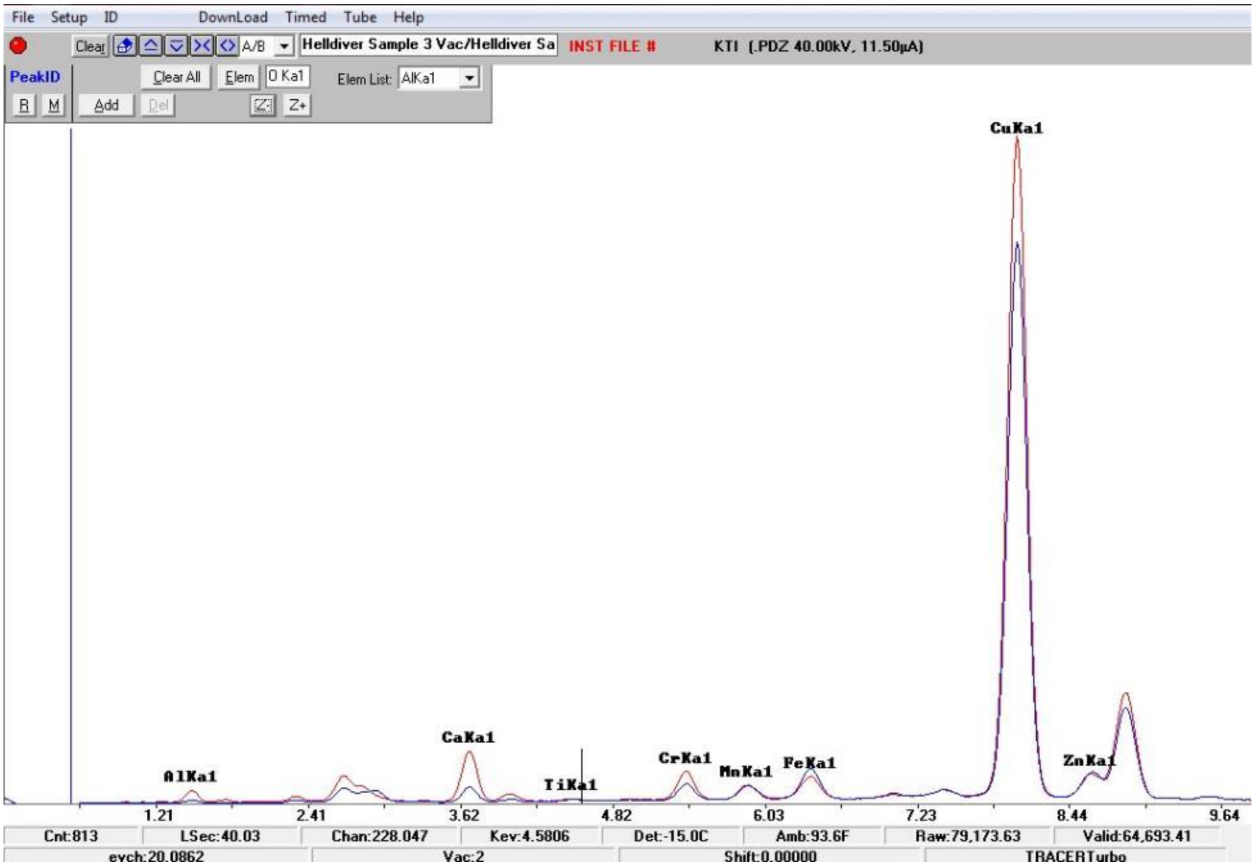

Figure 5.12- UABSB2C01 with and without vacuum. XRF analysis confirms the presence of Aluminum in all sample locations, as well as the presence of alloy metals common to Aluminum 2024: Manganese, Magnesium, Silicone, Titanium, Iron, and Copper. The presence of Calcium was also detected in varying levels, most noticeably in sample areas 5-6, which were shot through uncleaned portions of the wing sample. Chromium and Zinc were present in some sample areas, which is a hallmark of zinc-chromate primer, as well as a trace of either lead or molybdenum.

5.3.2 Sample Preparation and Treatment[186]

As part of my research into conservation methods, I wanted to test the most well-known archaeological methods for treating recovered aircraft aluminum. These experiments were

[186] Full preparation and treatment details of these artifacts is in Appendix C.

primarily to prepare for the conservation treatment of a sample acquired in the 2015 USS *Macon* survey, and to discover a viable method for treating the UAB SB2C Helldiver data plate. I experimented on the RAFMDo01-03 pieces, a sample frame from the USS *Macon*, and the UABSB2C01 piece. Initial visual documentation of all samples was completed with a microscope and with general observation.

The RAF Museum had originally sent skin pieces from the Dornier Do 17 to London Imperial College for element analysis through electron microscopy. The alloy supposedly contained no copper and was similar to modern 5xxx series. The samples I obtained were not skin pieces and present with clearly visible blue copper corrosion products, some maroon discoloration, and relatively shiny aluminum, as well as register as a common aluminum alloy in XRF readings. Under a microscope the surface of the Helldiver wing sample (UABSBC201) in sample areas 2-3 shows a delamination of green material over a metal surface with colors of black, silver, and the salmon pinkish color of copper. During preparation I removed a conical metal piece from the inward side of the wing sample, and noticed that it was filled with a gel-like white substance. This gel is indicative of aluminum corrosion and has hardened slightly in the time I was experimenting on the sample.[187]

As they are copper-based aluminum alloys, I planned for all samples to undergo treatment methods based on MacLeod, Degrigny and Bailey's research.[188] Given the fragility of RAFMDo01 and the relative integrity of the other two Dornier samples I chose to alternate the treatments on both pieces, so two of the four sections of the first piece would be washed and the

[187] Totten and MacKenzie 2003; Degrigny 2004.
[188] MacLeod 1983; Bailey 2004; Degrigny 2004.

other two conserved in ER. All work was completed at the Conservation Research Laboratory at Texas A&M University in 2014.

In the samples showing advanced exfoliation and pitting corrosion, such as RAFMDo01 and UABSB2C01, those areas most affected were lost during treatment. Maroon, blue, black, or green corrosion present on submerged aluminum may indicate areas where the corrosion has already deteriorated the aluminum past saving. Delamination also indicates total loss: for this reason sample RAFMDeH01 was not treated because it had already lost its original shape.

In my experience, ammonium-based treatments were less than ideal, while the citric acid treatments produced desirable color restoration and marine growth removal. The samples I processed with an ER method did not have a good outcome in terms of visual appeal. I checked all of the samples for corrosion products upon completion of the conservation process and they presented with none. In some of the samples now, four years later, dusty white copper corrosion is barely visible but is present in the pits, indicating either an inadequate sealing process or the continued presence of chlorides. I suspect that without microscopic cleaning tools, or perhaps sonic or laser cleaning, the corrosion products inside the pits cannot escape and are actually sealed into the sample. I would recommend this type of cleaning, as well as aerospace maintenance-grade corrosion inhibitors for sealing, as well as a low-humidity display environment.

5.4 Section Discussion

Aviation material recovered from terrestrial or submerged sites will require conservation treatment, in almost all cases, in order to be or remain stable. An aviation archaeologist must have a working knowledge of the types of material associated with aircraft sites, and an understanding of how aluminum especially reacts to humid, saline, or underwater environments.

This knowledge will not only lead to the ability to interpret site formation processes but also to determine the conservation, preservation, or other needs of the artifacts on site. At a minimum, an aviation archaeologist needs to be able to recognize the different signatures of corrosion and why they are, or are not, present. The effects of site formation on structural stability of the aircraft, and anything that might affect the longevity of the remains in situ also need be understood. Because aircraft are mostly metal, a working knowledge of galvanic reactions between different kinds of metals is also required, especially on underwater sites.

A literature search indicates that aviation archaeologists will find that conservation studies on aviation artifacts and aircraft recovered from a saline environment total relatively few, due to the limited number of excavations where conservators able to take and interpret corrosion and treatment data were present. Most aircraft recoveries do not originate from saltwater environments and the few reports on methodology have been largely experimental.[189] The citric acid treatment method has proven an effective means to treat complete WWII airframes. Alternative methods that include museum or industry-grade treatment products are also effective. Choosing a conservation or stabilization method requires an understanding of the desired display technique or future use of the artifact. Treatment methods on either fully exfoliated, delaminated, or corroded aluminum may include consolidation and sealing for display, for example. Museum restorations will often choose to replace damaged material entirely, or marry original, albeit compromised material to new metal to retain the original component shape or to provide an element of ‘authenticity’ to the exhibit (Figure 5.13). As the field develops, aviation archaeologists should design projects to either inspire, borrow from, or conduct more studies into

[189] MacLeod 1983; Adams 1992; Degrigny 1995; Hallam et al. 1997; Bailey 2004; Tengnér 2009.

conservation of submerged aircraft artifacts in order to move the field forward. Conservation treatments should cross over between archeologists and museum conservators as museum pieces will display similar issues on stability and require similar treatments.[190]

Figure 5.13- This Wellington bomber was recovered from Loch Ness in 1985 and is on display in Brooklands Aviation Museum, UK. It has been restored by placing compromised material on top of new material to retain the original shape. Burgess notes: "in this example, a middle ground was found between the competing demands of archaeology, which requires material to be kept in an 'as is' condition, and those of aircraft enthusiasts who wish to reconstruct aircraft to an 'as new' condition."[191] Photo by the author.

[190] Rocca et al. 2010; Horelick et al. 2014.
[191] Burgess 2013, 20.

6. INTERPRETATION AND MUSEUM DISPLAY

Aviation artifacts in western cultures are a contested heritage resource. Stakeholder groups argue over the correct preservation and presentation of aviation artifacts. Aviation museums arose during the lifetime of the individuals who used aircraft as everyday objects, and the associated early display theory was based on object-as-new presentation. During this time crash sites, which all have the potential to lend important historical and technological information, were simply used as a pool of scrap material. This chapter outlines well-known aviation museum display methodology and includes a discussion of alternative display theory based on using aviation archaeology as an access point for visitor engagement.

6.1 Aircraft Display Trends and History

The National Air and Space Museum in the US was created after congress passed the National Air Museum Act in 1946. The museum opened in its Washington DC location on the National Mall in 1976. The US Air Force Museum and the National Naval Aviation Museum opened in 1952 and 1963, respectively. With the retirement of pilots from WWII came several other aerospace museums in the 1960s and 1970s. "The desire to preserve the aircraft and equipment involved in the air war and to honor the service and sacrifice of the aircrews provided opportunities for the growth of existing institutions."[192] These museums tended to focus on the celebration of advanced technology and the power of aviation in times of war. Museum display often included artifacts and personal stories of the pilots and crew associated with the different aircraft. Display trends in most aviation museums showcased a hangar-style room or rooms full of static aircraft with little interpretation beyond a label with design or powerplant specifications.

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[192] Crouch 2007, 22.

Smaller aviation museums, largely personal collections of wealthy individuals-turned tax havens, sprang up all over the country during the 1970s-1990s. Aviation museum visitors in the 1990s closely followed trends of other national museums in terms of ethnicity, gender, and income.[193] Visitors came to these museums to revere large aircraft and receive information on significant events and achievements as curated by the museum staff, in an effort to inspire, as Fix notes, "further discovery and exploration of their nation's aviation heritage."[194]

Aircraft were displayed in factory-fresh condition and the impetus was on having as many aircraft as possible: "there should always be examples of a wide range of airplane types that will portray how improvements were conceived and then evolved throughout the years since man took to the air."[195] The amount of remaining original material on restored examples of aircraft was of relatively little concern versus the outward appearance.[196] This trend has received some lip service but relatively few changes. Most notably are the articles that extoll the virtues of some documentation of original components for storytelling ability, such as pencil marks, battle damage, and other evidence of human interaction. [197]

This type of memorializing priority in exhibit design, heavily reliant on large objects and the visitor's pre-disposition to nationalistic feelings concerning WWII, may be becoming outdated.[198] Similar to maritime museum evolution, aviation museums are beginning to understand the pressures of visitor numbers: "the ability of a museum to attract the crowds ensures continued funding for research, design, conservation and acquisition of museum display

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[193] Purtee 1998.
[194] Fix 2011, 993.
[195] Mikesh 1997.
[196] Tidwell 2000; Schwarz and Fix 2010.
[197] Stafford 2008; Editors 2015.
[198] Whitmarsh 2011.

material."[199] Curators are pushing boundaries of exhibit content and new interpretation ideas. Exhibits that critically examine aircraft in the context of wartime loss may be less difficult to undertake and defend at this time as opposed to the late 1990s. Current aviation museums are undergoing changes in visitorship as we lose members of the generation who first used these objects, and with them our direct links to commonly understood interpretation of aviation artifacts.

6.1.1 Restoration Terminology and Choices

Aircraft and aviation material in storage or display in museum collections are treated in one of four ways; they are either stored with no other action, stored with some level of preservation, restored, or conserved. Any four of these treatments can occur in the lifetime of the artifact or airplane. Storage without any preventative maintenance, cleaning, environmental mitigation measures, or pest control will contribute to the quick deterioration of the aircraft.

- Preservation processes are methods that slow down the natural aging process of a stable aircraft without altering original parts. This can mean displaying an aircraft without a full restoration, in order to show original features or the true age of the aircraft. Preservation can also include any preventative, protective, or maintenance measures that do not significantly alter the originality of the artifact.
- Aircraft that are deteriorating because of an unsuitable environment should be stabilized by conservation treatments. For example, if an aircraft was recovered from underwater or out of another high humidity environment such as a swamp or

[199] Hosty 2006, 160.

ice, the metal and other components need to be returned to a stable condition to make sure it does not deteriorate further.

- Partial or full restoration can include repainting, repairing damage, or replacing parts on a vintage aircraft in order to make it serviceable or appear a certain way. Usually, the goal of restoration is to bring the aircraft back to a certain point in its life to show that history to the visitor. Restoration includes the use of either newly fabricated parts or appropriate parts derived from another aircraft. Restoration, conservation, or preservation processes can be completed on an aircraft prior to storage.

Display techniques and preservation philosophy has evolved since museums began displaying aircraft. Planning for the restoration of a 40 year-old aircraft in the 1980s and 1990s now differs from the planning for a similar project with a currently nearly 80 year-old aircraft. As time passes since the aircraft was used, some museums place more emphasis on historical or original appearance versus the aircraft seeming to be factory-fresh. Guidance for preservation comes from a collection of established aviation museums, with an accepted standard generally following the Smithsonian guidelines for preservation and restoration.[200]

6.2 Aviation Archaeology in Museums

An archaeologist should plan documentation from aviation sites to help make the history of that site relevant and interesting to the general public, as well as future research possible by both amateur enthusiasts and academics alike. One expected medium is by showing results either online or in an aviation museum. Many small aviation museums in the UK show, or have

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[200] Mikesh 1997.

included in the past, exhibits on the collections of wreckage donated by various avocational groups after digs in the 1970s-1990s. In some cases, exhibits include even the archaeological report on the excavations, which have proven to make the wreckage more relevant to visitors in some circumstances.[201] Aircraft museums are relatively consistent in terms of displays, space, and appearance, and a visitor usually traces historical events as tied to aircraft examples.[202] Some personal stories are linked to those events in time, and aircraft are rarely placed in context. Aviation archaeology gives an opportunity to expand on historical knowledge on an event by providing significant further details of a historical event or a tangible artifact that has historical relevance, giving authority to the exhibit.

6.2.1 Artifact Treatment and Interpretation

Aviation museums were born partly from the ideals and values of the pilots who used the objects, or those with a direct link to them. These museums usually showcase aircraft as factory-fresh as a means to inspire pride and reverence. Aircraft are meant to stir the visitor, and generally museums believe that is done by producing the best physical representation of the aircraft as possible. In the case of WWII, the aircraft are meant to serve as the memorializing object of event; the aircraft's value is seen as an object that defines a part of our culture.[203] This value is usually something that the museum assigns and that the aviation heritage object then assumes. When museums make the conscious decision to restore aircraft, sometimes even different aircraft, to a representation of a famous warbird they are leading the public in deciding how to best preserve aviation heritage. Museums sometimes assert that the display theory is

[201] A recent news story highlights how recovered wrecks impact visitors in Fenland Aviation Museum: http://www.wisbechstandard.co.uk/news/cousin-of-flight-sergeant-visits-wreckage-at-museum-1-5512743
[202] Dechow and Leahy 2006.
[203] Dechow and Leahy 2006.

publically-motivated, but museums should be responsible for driving conceptual learning of history. Often, aircraft are not considered museum-worthy unless fully restored, and only recently have aviation museums begun to exhibit permanently un-restored war planes.[204] Display theory evolution will continue as we move further away from the period of the aircrafts' use.

The choices of restoring, conserving, preserving, or storing aircraft or aviation artifacts will not be consistent in every case. There is no 'one size fits all' solution; the best treatment for one aircraft might not be the best for another, based on a multitude of factors. Museums, which have the responsibility as caretakers of aviation relics, also have the responsibility to educate themselves about the role of aircraft in exhibits, and what they can do to make an airplane teach the most people in the best way possible. This statement resembles a museum mission statement in many ways, but after justification the generality of the statement becomes clear. In order to do due diligence in educating themselves and the museum's board, caretakers should ask these questions when planning for exhibits, recovery projects, maintenance, or treatment:

1. What is the role of the aircraft on display?
2. What can you do (as curators and educators) to make an airplane teach communication objectives? (What are its access points?)
3. What is the best way to display *THIS* aircraft?

First, museum curators and educators should critically examine the role of aircraft in exhibits, and the different opinions on conservation and restoration. An accepted curatorial viewpoint is that aircraft inspire reverence, and the aircraft itself is enough to engage visitors and lead them to understanding history and a communication objective that the aviation museum is

[204] Tengnér 2012. Sola Museum 2012. Bailey 2004. MacLeod 2004.

trying to pass on. Communication objectives can relate facts about history or people, or to abstract ideas about sacrifice or freedoms, for example. In some aviation museums, like the Smithsonian National Air and Space Museum (and especially the Udvar Hazy Center), which has over 7 million visitors per year, the Pima Air & Space Museum in Arizona, and the US Air Force Museum in Ohio, the approach of having an overwhelming number of aircraft in one place with minimal interpretation works to draw massive visitor numbers. For these museums, the aircraft's role is to serve as an example airframe at a particular point in history. Again, though, not all aircraft should have the same role, and an aircraft's role in museum display may change over time. At a smaller museum, for example, the aircraft might require interpretation in order to connect with visitors. The aircraft's role might change to being an illustrator for a much larger communication objective.

One commonly accepted idea in aviation museums is that visitors only wish to see restored aircraft. Aviation museums have been conveying the idea that anything less than a factory-fresh example of an aircraft is a lower-quality display. Do the public indeed only want to see fully restored aircraft, or do they want this because museums have been telling them they do for 40 years? Aviation museums have long relied on the aircraft's ties to the original users of the objects both for relevance and perspective. Modern museum visitors are increasingly disconnected from these people and ideals. Aviation museum caretakers have the responsibility to determine whether or not they want to challenge these long held perspectives. One way could be by audience research and reaction. Curators and educators should make decisions based on what is best for the organization at the time, but creating museum policy should only be done after careful and informed consideration.

If an aircraft's role in a museum is to teach the public a communication objective, the museum should decide what that is, keeping in mind that it is possible to change the teaching or communication objective without changing the illustrator, or aircraft. Using the aircraft as a tool, or as the illustrator of a story, it has the potential to capture the interest of as many people as possible when the display incorporates different access points. An access point is any interpretive information, even from relating or peripheral subjects, that creates relevance in the artifact to the visitor; it can be seen as a 'hook'. An access point can focus on history, science, art, or a number of subjects important to visitors today. Access points come from documentation and associated information about the aircraft, but are more effective when they elicit and emotional response.[205] For example, an exhibit at the Australian War Memorial Museum of a Lancaster bomber 'G for George', called *Striking by Night*, explores the 1943 bombing run over Berlin through an unexpected perspective; it is understood that the aircraft is making a bombing run from the theater-style light show, but the narration consists of a letter written by an Irish nurse to her mother describing her fears of the war and her hopes for the return of her boyfriend, a crew member on the Lancaster (Figure 6.1). The letter and the situation create an emotional connection with visitors.[206] The Lancaster in this case is the largest object in the room, but it instead of the story of the aircraft dominating the space, it is used as an illustrator of a communication objective, in this case the emotions of people peripheral to WWII and how the war affected everyone.

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[205] Suchy 2006.
[206] Ryan, Stephen, Director of FRD. Interview by Megan Lickliter-Mundon May 3, 2015.

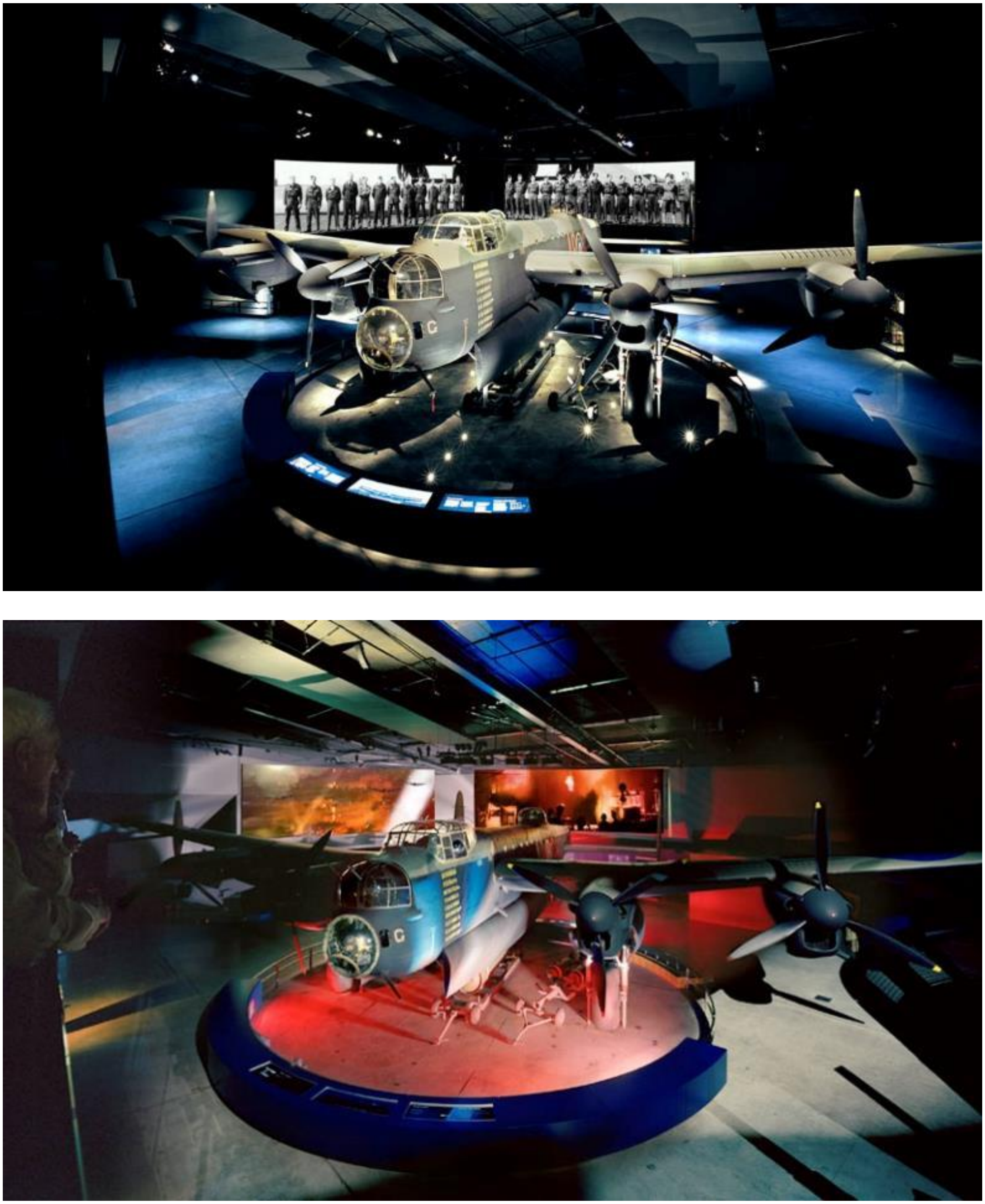

Figure 6.1- Two views of the ‘G for George’ Lancaster bomber exhibit at the Australian War Memorial Museum. Theater-style lighting can introduce multiple storylines, interpretations, and access points. Photos and exhibit design courtesy of FRD.

Museum curators and educators should consider the display purpose and power of each individual aircraft and the strengths or weaknesses of the rest of the collection and space. For example, surplus DC-3s at Pima Air & Space Museum are of no use in the exhibit, which already displays other examples, and are not currently valuable for sale or trade, so the museum offered them to be painted by local artists and used as art pieces (Figure 6.2). The paint did not affect these DC-3s' originality and actually served as a protective measure from the elements. The DC-3s' roles as art pieces created access points for a number of visitors in the community, and can easily be changed in the future.

Figure 6.2- A painted DC-3 art piece at Pima Air & Space Museum, AZ. Photo by the author.

6.2.2 Submerged Aircraft in Museums

The natural post-excavation environment for a submerged aircraft is a museum. Some aviation museums, however, are notorious for favoring a final-appearance based reconstruction processes that strip damaged original or historical material off the airframe and replace it with new material. This restoration ethos was popular in the early days of aircraft salvage for museums, and seems to largely ignore the long-term management of the objects.[207] Aircraft that have been submerged, of course, present a unique set of challenges and requirements in terms of effort, time, and costs associated with conservation and preservation. Naturally, a museum would have to prioritize the historical accuracy of the displayed aircraft over the cost and time it takes to present it as conserved in order to consider these requirements.

The National Museum of Naval Aviation in Pensacola, Florida has the longest history with the treatment of submerged aircraft. In the 1990s they contracted a company for the salvage of a number of aircraft in Lake Michigan. The history of these aircraft was relatively insignificant; they represent either missed training landings on a lake-based aircraft carrier or post-war dumping activities. The museum felt, with these particular aircraft, no need to maintain the original, partly corroded skin and structural components and usually made the decision to completely restore the airframes to factory-fresh quality.[208] The resulting displays are representative of a particular type of aircraft and interpret general historical information and concepts. These aircraft are restored in house or loaned to other museums who complete restorations as well.

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[207] Schwarz and Fix 2010, 1.
[208] Stafford 2008, 35.

There are several examples of exhibitions that have chosen to display the aircraft in unrestored states. The best example of this approach is the previously discussed Swedish 'The Catalina Affair' DC-3 exhibit. The RAF Museum in Hendon, Sola Museum in Norway, and Pima Air & Space Museum in Arizona all display conserved examples of recovered aircraft that convey simple historical stories.

6.2.3 Display Alternatives

Not every submerged aircraft should be treated or displayed in the same way. In some cases, access points that archaeological documentation and alternative display can provide include the fact that the airplane came up out of the ocean, the tools used in the excavation or recovery process, seeing the conservation in action, seeing the dive site in VR, or seeing the writing still intact on the aircraft from the woman who put it together. Museum aircraft caretakers must recognize that every aircraft could have a unique way to engage the audience, which might not be limited to the aircraft itself as an object. In the case of submerged aircraft, archaeology can create access points but can also be used to get as much information as possible from a wreck during recovery, as well as ultimately serve to clarify the limitations of a particular aircraft once recovered. Museum curators and board members should educate themselves on what is possible now in imaging, and should also understand deterioration processes and future display concerns. This can be understanding the basics of how metals react in water so planning can take into account the structural stability of a potential submerged aircraft. For example, will it be able to withstand the recovery without disintegrating, or will it be able to sit on its gear once displayed, will the paint remain intact, etc? These questions raise another point: whether to consider the value of having the original artifact versus a reproduction, or whether the display requires the submerged aircraft to be brought up at all?

A TBD Devastator survives in good condition off the Marshall Islands in Oceania, which, if recovered, would be the only example of its kind on display in the world (Figure 6.3).[209] Any future museum tasked with its care will be required to decide the treatment of the wreck for display, whether conserved and displayed in its wrecked form for the history of the individual aircraft, or restored to its original form as a representative example of the aircraft type. In this case, the value of the aircraft and its role to convey history might be greater in its restored state. Archaeological documentation, however, could serve to both capture the originality of the aircraft prior to restoration and provide access points to complement the eventual display; with a 3D model both the data and the context of the site is preserved for the archaeologist and the museum visitor. This requires a high level of detail in the photogrammetrical model, but with a fully HD-documented survey it's possible to build that as an exhibit component at any point in the exhibit's lifetime, or for use in another museum.

[209] TBD Devastator Project, Air Sea Heritage.

Figure 6.3- Shot of a TBD Devastator during survey work. Photo by Brett Seymour and courtesy of Air Sea Heritage.

Alternatively, for example, imagine a hypothetical museum that has collected nine out of ten carrier-based aircraft and tells the Pacific Theater history of WWII. The museum receives visitors who understand the communication objectives of the display. This museum then finds a submerged example of the tenth missing aircraft. The museum now has a choice; spend millions to recover, restore, and display the aircraft to tell exactly the same story to the same visitor base, or use it strategically to provide access points to engage a different, and potentially additional group of visitors. This can possibly be achieved by recovery, conservation, a technology component such as a small ROV or dive tools, and interpretation of the deterioration process or conservation process. The exhibit could easily incorporate STEM initiatives and educational programs and most importantly, provide multiple access points for visitors, potentially expanding the visitor base.

6.2.4 Case Illustration, Norseman, Norway

In 2016 I created the interpretation for a recovered and partially-restored aircraft in the Norsk Luftfartsmuseum's civilian collection while contracting for the exhibit design firm FRD. Museum curators, educators, restoration volunteers, and our design team all saw different values for the aircraft's display. This particular aircraft, Norway's first civil registered Noorduyn Norseman Mk. VI, was registered in the Narvik-based airline Polarfly on 17 July 1947 as LN-PAB. Various use of this aircraft included normal passenger flights, cold war spy missions, abandonment, rescue, and restoration, which is similar to many museum aircraft. This Norseman was coming in for a landing in 1952 and hit an object in the water, causing it to flip over. Fifty years later, in 2002, the Norsk Luftfartsmuseum and Bodø Luftfartshistoriske Forening (BLHF) were permitted to recover the aircraft for display. The wood and fabric parts had deteriorated off the metal frame, which was lightly pitted but otherwise intact.

Since the museum's opening the BLHF has restored, or in some case, fabricated replicas, of several aircraft on display including a replica Sääski, a C5 Polar restoration, and a Junkers Ju-52. The cooperation between the museum and BLHF has resulted in several projects in the military gallery as well. The oldest aircraft in the museum's civilian collection is 75 years old. The restoration of the Norseman had begun, but was not finished by the time of the installation of the new exhibits. One of the curators even suggested that the best case display scenario was to undo the restoration work and return the aircraft to the wreck. It was an impossible in this case, as the restoration work was largely without documentation the process irreversible, but the sentiment was raised and considered by staff who will be involved in future recoveries. The education staff use the aircraft as a tool to teach, and as a design team we wanted to provide access points for alternative communication objectives.

We decided to display the aircraft as is, in consideration of where it is located in the museum: in its current state it is the last near-complete aircraft the visitor sees before exiting, and immediately before a space dedicated to interpreting various functions and systems (Figures 6.4 and 6.5). So in a sense this exhibit sets up the visitor to engage and ask questions. Displaying a partially-restored aircraft is not a profound concept, as many exist in exhibits all over the world. In creating the interpretation, however, I included both the history of Norseman aircraft in Norway, this particular Norseman, and then also highlighted the history of the restoration team and their contributions to the museum over the years (Figures 6.6-6.8). I used the narrative to point out which aircraft in the exhibit were restorations, as well as their in situ environments and conditions. The interpretation then expanded even further to discuss the differences in the aircrafts' conservation, preservation, and restoration, and what various aircraft components look like prior to restorative work.

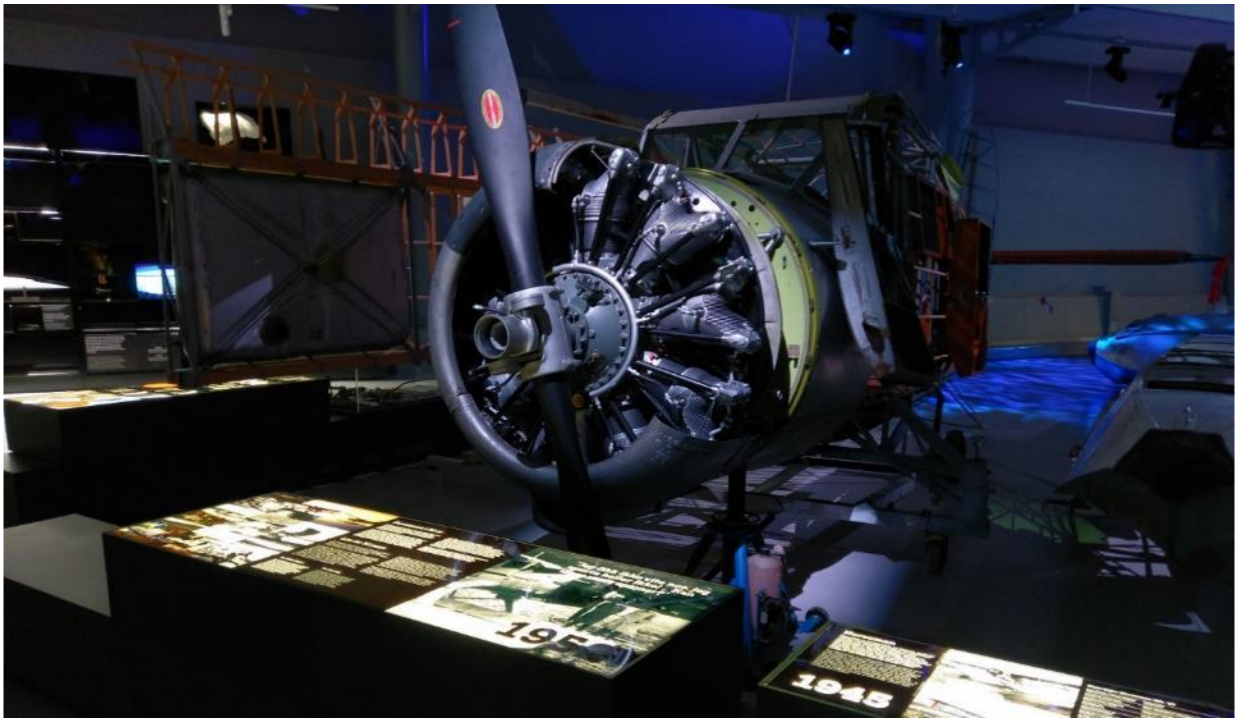

Figure 6.4- Front view of the Noorduyn Norseman LN-PAB as displayed in the Norsk Luftfartsmuseum. Accompanying the technical panel is the aircraft's history. Photo by the author.

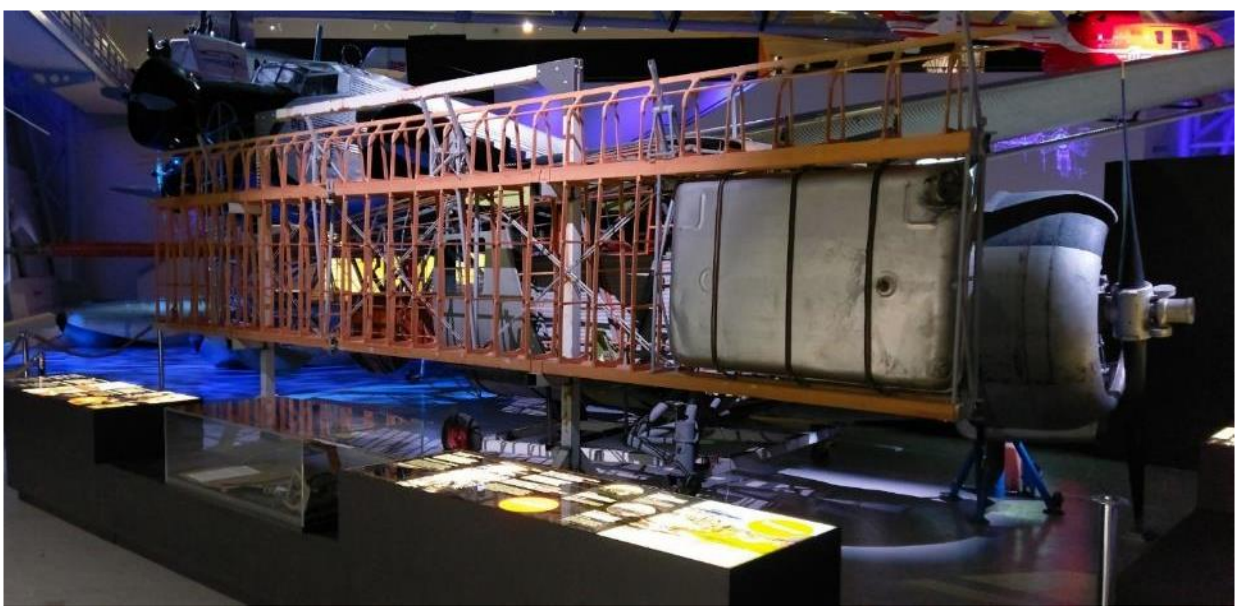

Figure 6.5- The side view of the Norseman exhibit, showing the wing construction details. Interpretive panels show information on display ethos and examples of pre-restored artifacts. Photo by the author.

Figure 6.6- This interpretation panel provides the aircraft's history. Text by the author, graphic design by FRD.

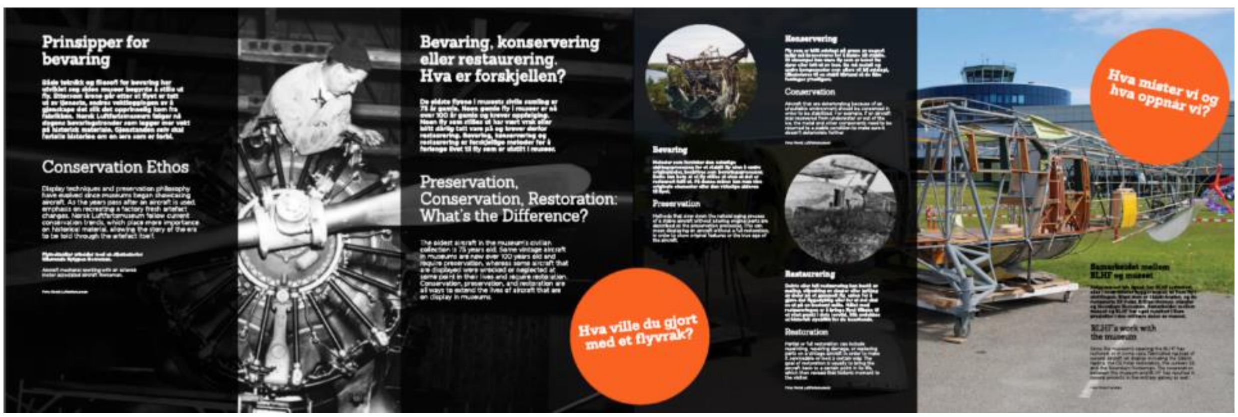

Figure 6.7- This interpretive panel highlights preservation and restoration terminology. Text by the author, graphic design by FRD.

Figure 6.8- This panel introduces the restoration team at Norsk Luftfartsmuseum and highlights other restored aircraft in the collection. Text by the author, graphic design by FRD.

6.3 Public Engagement Using Artifacts In Situ

Given the space, funding, and effort involved with raising submerged aircraft for display one can safely anticipate that most underwater aircraft will remain in situ. The impetus will remain, however, to find and visit these sites, as is seen today. Management of underwater aircraft sites, besides restriction of access, must be standardized in order to address concerns from interested parties as well as federal and state managers. Dive sites can increasingly be seen as a type of heritage park, and underwater aircraft dive sites as a possible choice for heritage management. Archaeological sites, and even aircraft sites as part of underwater heritage areas, are known entities for management and public outreach efforts in government and academia.[210] Increased diver stewardship of wreck sites is one possible benefit of a management plan that focuses on the value of submerged aircraft sites as part of a cultural heritage trail.

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[210] McKinnon and Carrell 2014; Delgado et al. 2016c.

6.4 Section Discussion

Aviation heritage is a relatively new concept, but like other traditional heritage beliefs that include associated values, its meaning has changed over time and across cultures. Aviation is a technology, arguably one of the more iconic technologies of the 20th century. In terms of recognizing aviation heritage, we are distinguishing technological achievements and nostalgic or national events, such as war in the air. Value was usually assigned by the group of people who used the artifact and these values often guided heritage preservation decisions for the majority of cases in the past half-century. Since the 1970s there has been a struggle between stakeholders arguing which presentation of the object is the most valid. As with other heritage values that change over time, however, with the loss of the portion of the population with direct memory of the artifact in use will come a shift in preservation behavior and attitude.

The use of archaeology and the personal stories most often associated with aircraft wreck sites can challenge the visitor's expectations of what comprises an aircraft exhibit, for an exhibit can (and perhaps should in some cases) provoke emotion, discussion and inspire further learning. Aviation exhibits, in order to be relevant, must be able to provide multiple access points for visitors and one point of access and interpretation is archaeological information. The potential for conflict about the exhibit also needs be recognized. Conflicts between the academic interpretation of historical themes and cultural memory, especially in the case of WWII history, can often arise when people who lived through that time, or their next generation descendants, may not be amenable to accepting interpretations, including those that question acts of war. The most widely documented case of this was the Enola Gay exhibit, which was well planned and executed but had to be cancelled after public outcry.[211] The exhibit included a small section that focused on the value and morality of strategic bombing during WWII. Likewise, the Canadian Bomber Museum was required by Parliamentary Act to change wording on a similarly-focused exhibit.[212] Clearly, archaeology and associated museology dealing with military aircraft and the wars in which they took part will often include research on the use of a particular aircraft in events that to some are unpalatable, or will become so. Increasingly, these critical questions will be a part of the research and display process. Museums must make provisions for conflicting viewpoints and, where possible, these should be acknowledged.

Aviation museums should choose display methods and treatment for aircraft after fully considering their roles, potential access points, and the information they should convey. There exists no one correct manner to display an aircraft: any decision can be correct if fully researched and justified. Recovery of a submerged aircraft will not definitely attract new or different visitors to a museum, but it has the potential to. An aircraft recovered in an archaeological manner provides an enhanced access point, given the required diligence in documentation prior to irreversible change. Museum staff should educate themselves on the possibilities as well as their responsibilities as stewards for the artifact, and undertake treatments with a well-considered institutional ethos firmly in mind.

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[211] Capaccio and Mohan 1995; Goldberg 1995; Schofield 2009.
[212] Dean 2009.

7. CASE STUDY- THE TULSAMERICAN

A B-24J Liberator bomber aircraft named *The Tulsamerican* is the first case study in this dissertation. *The Tulsamerican* has been under 39 m of water near Vis, Croatia since 1944. This case study is an example of primary project planning and archaeological survey methodology. I chose this aircraft because of its proximity to other known B-24 wrecks, its outstanding community ties and history, and its overall visual impact as a wreck site. In 2014 I began planning a survey project for this aircraft and two other partial B-24 sites. I will address the survey goals more specifically in section 7.2 below, but they included 2D and 3D mapping of the site and surrounding environment, site formation study, corrosion potential measurements, and museum display of digital data visualization products and conserved artifacts. The Tulsa Air and Space Museum and I expect the survey to help integrate *The Tulsamerican*'s memory into the Tulsa area community and provide the museum with opportunities to honor its history.

I provided the results from this survey to the Defense POW/MIA Accounting Agency in 2016. This led to the excavation of the wreck site in October 2017 using a dredge recovery method with ship-based artifact recovery.[213] The excavation recovered remains of one of the three crew members who died in the crash, the pilot Lt. Eugene Ford. The site will continue to remain open as a DPAA case for future recovery missions focusing on the remaining two MIA crew.

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[213] Foley 2017.

7.1 Background History

7.1.1 The Adriatic During WWII

US Air Forces closed in on Axis fronts first from Tunisia, and then Italy as WWII progressed. In 1943, the US established the 15th Air Force in Italy as their second strategic division in the European Theater. The 15th Air Force operated bombing squadrons of B-17 and B-24 aircraft, and fighter squadrons of P-38, P-47, and P-51 aircraft. By 1944, American forces used B-24s heavily for strategic bombing runs over oil fields in Romania and Poland.[214]

Vis, off the southern coast of present-day Croatia, is one of the country's many islands in the eastern Adriatic (Figure 7.1). In 1941 Italian forces occupied this island, then a part of Yugoslavia, after the Axis powers invaded the rest of the country, with Germany holding major control of the mainland areas. In 1943 after the Allies signed an armistice with Italy, Vis became a base for Yugoslavian partisans led under General Josip Broz Tito. Even though Germany still occupied the main land, German forces never took Vis and it remained in partisan control for the remainder of the war. Early in 1944, Allied forces began using the island to support aerial campaigns into Eastern Europe.[215] British forces built a short runway, designed for crippled fighter aircraft, that the Allied Air Forces immediately used as an emergency option (Figure 7.2-7.3). Cargo transport aircraft, such as the C-47, would use Vis to deliver spare parts to repair damaged aircraft and also ferried crews back to Italy. Soon after the airfield's establishment, large American bomber aircraft also began using it if they could not make it across the Adriatic to their bases in Italy and required emergency landings (Figure 7.4).

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[214] Dorr 2000.
[215] Freeman 1997.

Later in 1944, as Allied and partisan action pushed Germany away from Yugoslavia, bombing mission paths over the country towards Germany and Poland increased. Vis was strategically employed as part of these flight paths; during Allied bombing missions the airfield was used heavily, some days seeing nearly 40 emergency landings.[216] Badly damaged or aircraft low on fuel would sometimes ditch, or the crew members would sometimes bail out, near the island and await rescue. Sometimes PBY aircraft helped rescue air crews who ditched in the surrounding sea but mostly partisans in small local vessels rescued stranded crews.

Figure 7.1- The island of Vis, Croatia, in the Adriatic Sea. Photo from Google Earth.

[216] Editor 2010.

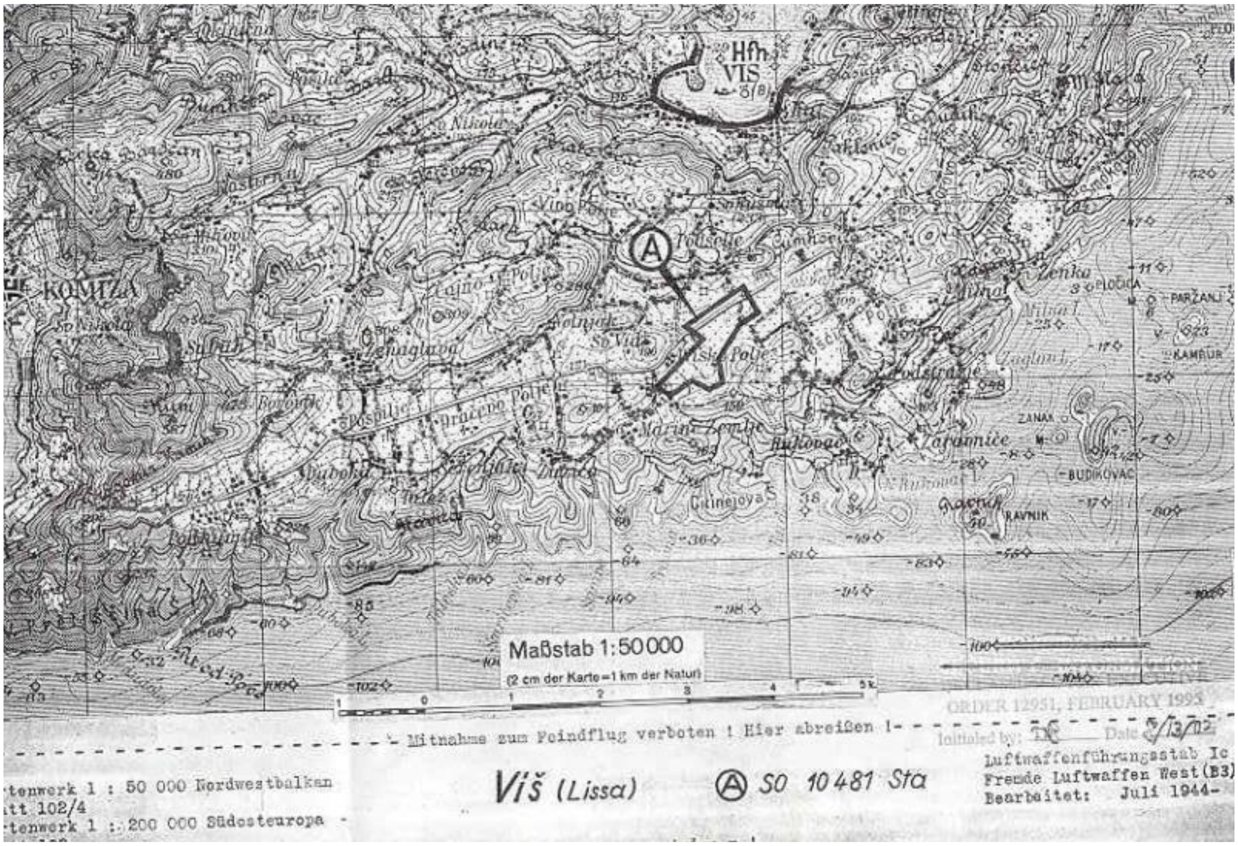

Figure 7.2- A German map from WWII shows the location of the air field on Vis. The field was known to the German Air Force but there were never and attacks on the aircraft or the island. Photo courtesy of Kevin Gray, Tulsa Air and Space Museum.

Figure 7.3- An aerial view of Vis in 1944, looking towards the southeast. Photo from the National Archives.

Figure 7.4- B-17s and B-24s bomber aircraft on Vis in 1944. Photo from the National Archives.

There are over 300 wrecks of allied aircraft in modern Croatia, with over 100 resting in the Adriatic Sea. Estimates for US aircraft in the general area of Vis number close to 20, with 11 of those being B-24s (Table 7.1) (Figure 7.5).

Table 7.1- US Aircraft lost near Vis, Croatia during WWII

A/C Type	*MACR #*	*DATE*	*SQDN*	*GRP*	*AF*	*AAF s/n*	*Nickname*	*Command pilot*	*MACR location*	*Crew members missing?*
B-24H	07144	440726	760BS	460BG	15	42-95366		Lee, John W	Vis- Land Crash	None lost
B-24G	05841	440531	764BS	461BG	15	42-78103	*Red Ryder*	Ryder, George N Jr	Vis-10mi SSE {43.02N-16.26E}	possible bail/empty plane
B-24J	09205	441017	515BS	376BG	15	42-51568		Kamps, Aloys L	she-3mi W of N {43.10N-16.20E}	10 crew MIA, 6 parachutes
B-24H	9931	441117	827BS	484BG	15	42-52774	*Lady Luck*	Mills, Henry T	Vis/ Bisevo	10 crew, 9 MIA - 3 drowned, one returned to Vis
B-24G	9938	441117	741BS	455BG	15	42-78397	*Organized Confusion*	Redding, Horace D	Vis	10 crew, 4 MIA
B-24J	9045	441007	722BS	450BG	15	42-51848	*Dragonass*	McCumsey, Louis M	Vis (43.02N - 16.15E)	10 crew all bailed, only 2 MIA
B-24J	9948	441120	776BS	464BG	15	42-51625	*Stevenovich*	Arlington, Matthew T	Vis- Ravnik	9 crew, 1 MIA down with A/C
B-24J	16507	441217	765BS	461BG	15	42-51430	*The Tulsamerican*	Ford, Eugene	Vis- near Ravnik	10 crew, 3 KIA (excavated 2017)
B-24H	6315	440530	723BS	450BG	15	42-95296		Morris, Jack C	Vis- Land Crash	10 crew 1 MIA
B-24		440423	767BS	461BG	15	41-28724	*Jizzy Outch*	Torres, Matias	Vis- bailed out near	10 crew, all bailed
B-24H	8747	440912	515BS	376BG	15	41-28762	*Tailwind*	Click, Dale W	Vis- 30 mi W	10 crew, all bailed, 4 MIA
P-38J-15	12533	441105	37FS	14FG	15	42-104117		Bach, Lawrence V Jr	Vis-N	Benkovac-E 44.04N/15.38E
P-51B-	06316	440524	309FS	31FG	15	42-106595		Mann, Harrison (NMI)	Island of Vis-nr	1 MIA
C-47A		440709	28TCS	60TCG	12	42-23515		Cook, Robert E	Vis Is/ 1 1/2 mi E	unknown
P-38J		440917	71FS	1FG	15	43-28276		Dunne, Thomas M	Vis Is/ADR	unknown
B-17G		441106	340BS	97BG	15	44-6630		Emerson, Irving	Vis	Near *The Tulsamerican*
0A-10		440912	(ERS)		1				Vis, Svetac	Lee side

Note: Table compiled by Danijel Frka and the author.

Figure 7.5- Locations of aircraft and partial aircraft sites- yellow is unknown location according to MACR, red is locations found. There are two known aircraft around Svetac, an OA-10 and a B-24. Photo from Google Maps.

7.1.2 B-24 Liberator Aircraft[217]

Early in WWII the US Army sought an alternative for the B-17 bomber that would have a longer range, higher speed, and greater ceiling. Consolidated won the contract and began producing B-24-type aircraft out of five factories in the US from 1939-1945. Its design included four engines, the modern Davis wing, a flying boat twin tail, and a fuselage that was built around two bomb bays forward and aft, each the same size of the B-17's single bay (Figure 7.6). The B-24's central compartment was a box-like structure with a catwalk through the bomb bay, which

[217] Complete specifications and plans in Appendix D.

was opened with a set of tambour-panel "roller-type" bomb bay doors. B-24 aircraft could carry eleven crew members- a pilot, a co-pilot, a navigator, a bombardier, a radio operator, gunners in the nose, ball, and top turrets, two waist gunners, and a tail gunner. Often B-24s flew with a crew of 10 and the flight engineer served as the top turret operator (Figure 7.7).

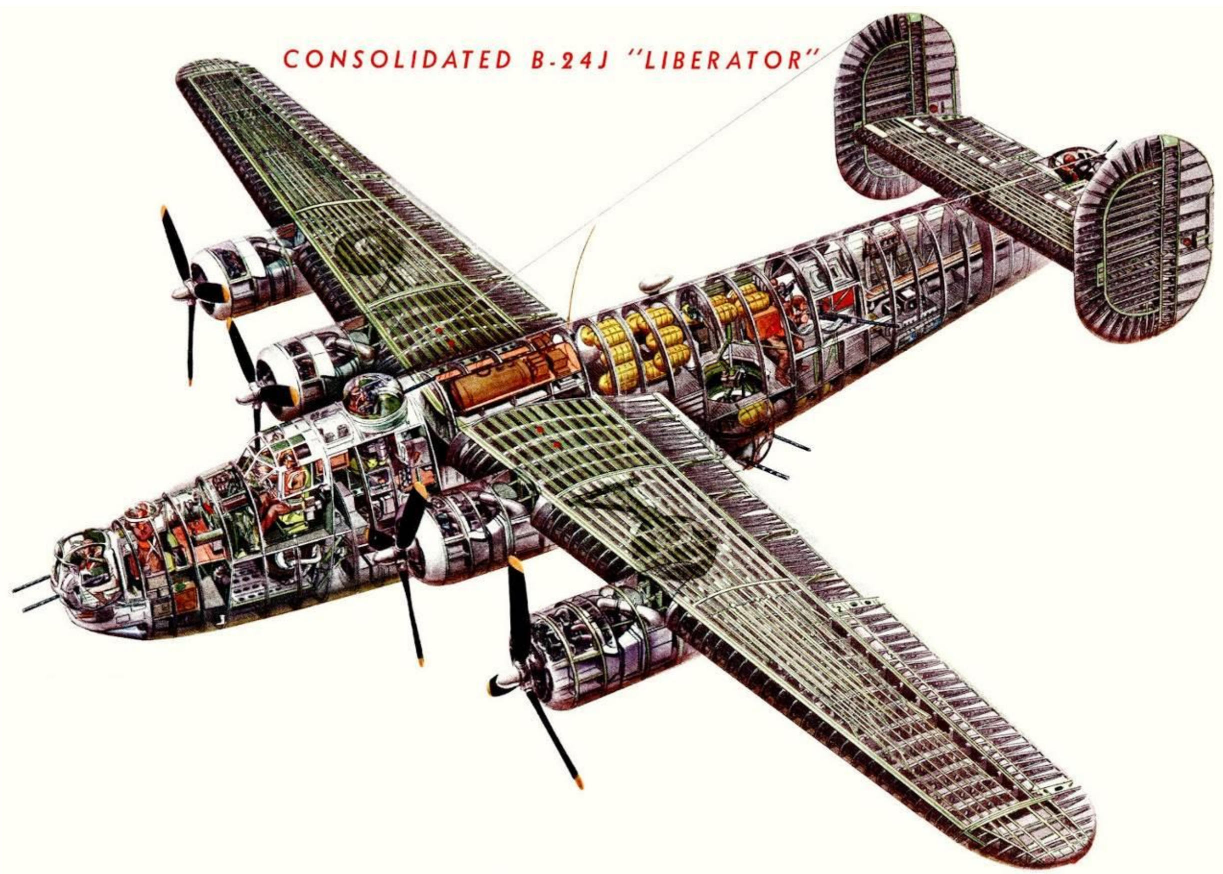

Figure 7.6- B-24 cutaway revealing structural details. Reprinted from *Industrial Aviation* 1944, reprinted from Scorza 2017.

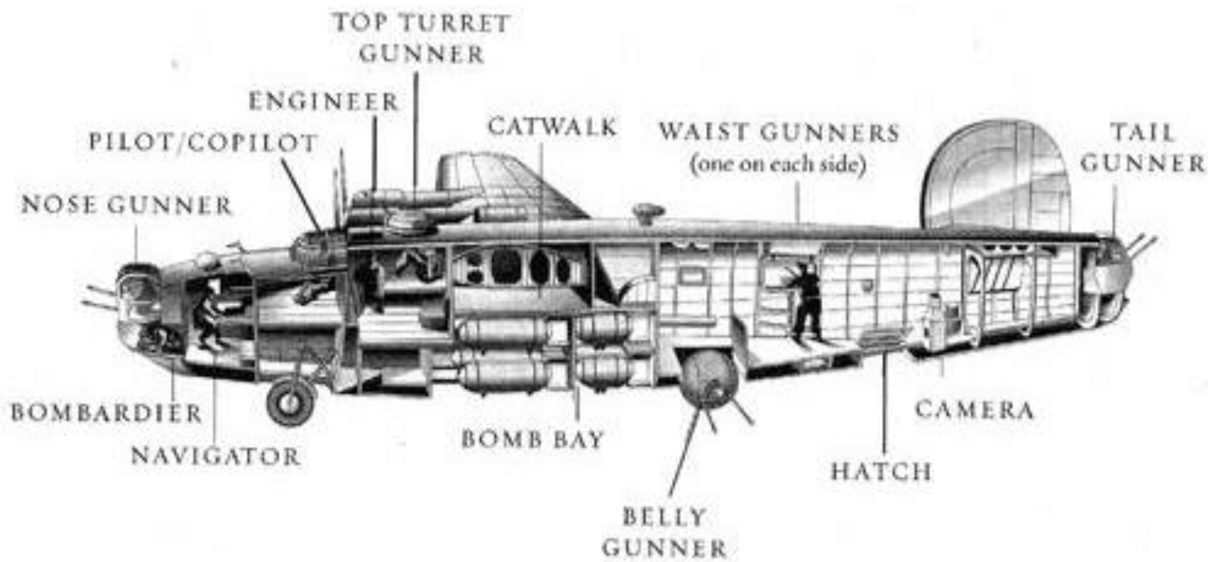

Figure 7.7- Crew positions in a B-24 Liberator. Reprinted from Stekel 2017.

To meet the foreseen large demand for the B-24, the government set up a consortium of aircraft manufacturers and plants to build the plane. Factories were built in interior US states due to the threat of coastal bombing. The Ford factory at Willow Run, MI built most of the B-24s of the war effort, but also sent finished parts to other plants for final assembly. The Douglas Aircraft factory in Tulsa, OK was one of those plants, producing just under 1000 B-24s from 1942-1944.

7.1.3 *The Tulsamerican*, Crew, and History

The city of Tulsa, OK was chosen to host a new factory for aircraft assembly in April 1941. The US war department promised financial aid for infrastructure and housing to support an increased worker population.[218] The factory began production on B-17s by June 1941 and B-24s

[218] Editor 1944 (June 21).

and A-24s soon after. In order to make room for the production of A-26 aircraft the US Army terminated all other contracts by July 1944.

The last B-24 bomber produced by the Douglas Aircraft Factory in Tulsa, OK was number 952, an aircraft purchased with war bonds by Tulsa factory workers. Douglas was determined to create excitement about the final B-24 and instigated a number of promotions supporting the purchase of the war bonds (Figure 7.8). War bond purchasers were allowed to sign their names and write messages on the fuselage. They were also entered into a raffle for a ride aboard the completed aircraft. A contest for the name of the last B-24 was held for bond purchasers, sponsored by Douglas Airview News, the Douglas company newsletter. On July 25th 1944 *The Tulsamerican* was reported as the winner, a name entered by H. W. Addington of Jigs and Fixture Fabrication.[219] *The Tulsamerican*'s name and nose art were painted on the fuselage, and a scroll with names of all the bond holders was placed in a leather pouch, also bearing the nose art, behind the pilot's seat (Figure 7.9-7.10). Marcus Johnson of Development, a WWI vet, also won a raffled ride and happily took it days after (Figure 7.11).[220]

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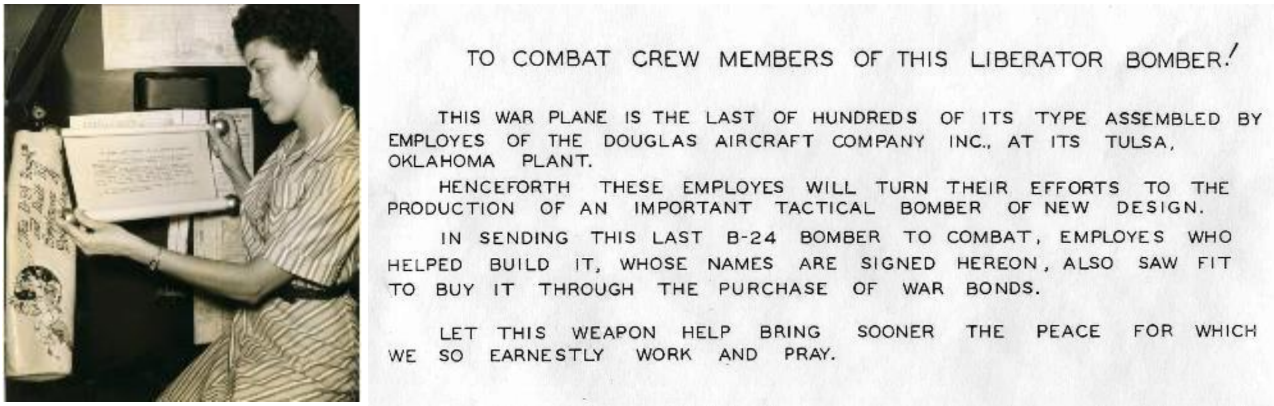
[219] Editor 1944 (June 28).
[220] Editor 1944 (August 4).

Figure 7.8- Douglas Aircraft factory workers pose for publicity photos of *The Tulsamerican*. Photo courtesy of Kevin Gray, Tulsa Air and Space Museum.

Figure 7.9- (Top) A Douglas Aircraft factory employee inspects *The Tulsamerican* nose art. Note the signatures and messages on the fuselage. When a person purchased war bonds they were able to sign their names to the aircraft (L). Photos courtesy of Kevin Gray, Tulsa Air and Space Museum.



TO COMBAT CREW MEMBERS OF THIS LIBERATOR BOMBER!

THIS WAR PLANE IS THE LAST OF HUNDREDS OF ITS TYPE ASSEMBLED BY EMPLOYES OF THE DOUGLAS AIRCRAFT COMPANY INC., AT ITS TULSA, OKLAHOMA PLANT.

HENCEFORTH THESE EMPLOYES WILL TURN THEIR EFFORTS TO THE PRODUCTION OF AN IMPORTANT TACTICAL BOMBER OF NEW DESIGN.

IN SENDING THIS LAST B-24 BOMBER TO COMBAT, EMPLOYES WHO HELPED BUILD IT, WHOSE NAMES ARE SIGNED HEREON, ALSO SAW FIT TO BUY IT THROUGH THE PURCHASE OF WAR BONDS.

LET THIS WEAPON HELP BRING SOONER THE PEACE FOR WHICH WE SO EARNESTLY WORK AND PRAY.

Figure 7.11- The scroll of factory worker's names also included this message of peace. It was placed behind *The Tulsamerican*'s cockpit when it was ferried to Europe. Photos courtesy of Kevin Gray, Tulsa Air and Space Museum.

Figure 7.10- *The Tulsamerican* as pictured during one of its publicity flights. Photo courtesy of Kevin Gray, Tulsa Air and Space Museum.

The Tulsamerican left Tulsa for a modification plant in Birmingham, AL; factory workers knew this because an employee at the plant wrote to one of the addresses written on *The Tulsamerican*'s fuselage.[221] A similar letter notified factory workers that the aircraft had reached Tunisia on its way to Italy, this time from an Oklahoman pilot who related seeking out names on *The Tulsamerican* when he felt homesick.[222] In Italy, Oklahoman air force pilots, officers, and crew posed for pictures in front of the aircraft. Crew members also report heightened interest over women's names and addresses written in lipstick (Figure 7.12).[223] For the factory workers and more than 50 native Oklahoman officers and enlisted soldiers in Italy, *The Tulsamerican* was a community icon.

[221] Editor 1944 (August 11).
[222] Editor 1944 (October 6).
[223] Editor 1945 (January 19).

Figure 7.12- Crew members inspect *The Tulsamerican*'s signatures and messages. Photo courtesy of Kevin Gray, Tulsa Air and Space Museum.

By October 1944 *The Tulsamerican* was ferried to Europe and assigned to the 15th Army Air Force, 49th Bombardment Wing (H), 461st Bomb Group, 765th Bomb Squadron at Torretta Field, Cerignola, Italy. The initial crew for the transfer to Italy consisted of Lt. William Donald, Pilot; Lt. Smith, Co-Pilot; Lt. Stuart Lefkowitz, Navigator; Lt. Everett Lorenzo, Bombardier; Sgt. Russell Walling, Flight Engineer; Sgt. Cleo West, Gunner; Sgt. Vernon Miller, Tail gunner; Ernest Balent, Gunner; Sgt. Lick; and Sgt. Marino. Once in Italy the normal crew was S/Sgt. John Toney, S/Sgt. Wallace McLemore; T/Sgt. Charles Priest, Sgt. Spaulding Tukey, Jon Wroclowski, S/Sgt. James Hazel, Lt. Vincent Ecklund, Lt. Leo Cooper, and Lt. Russell Landry

(Figure 7.13).[224] The aircraft flew eighteen bombing missions over France, Italy, Austria, Germany, Yugoslavia, Hungary, and Poland.

Figure 7.13- *The Tulsamerican*'s regular crew. Photo courtesy of Kevin Gray, Tulsa Air and Space Museum.

[224] Landry 2011.

7.1.4 The Wrecking Event[225]

On Dec. 17, 1944, the 15th Army Air Force launched a strategic bombing assault on the oil refineries at Odertal in Germany with 527 B-24s and B-17s, along with 300 P-38s and P-51s.[226] The 461st BG had 32 aircraft in this mission- three formations of six B-24s and two with seven. *The Tulsamerican*'s crew on this day was Lt. Eugene Ford, Pilot, on his first mission with *The Tulsamerican*, Lt. Vincent Ecklund, Co-Pilot, Lt. Russell C. Landry, Navigator, Lt. Val Miller, Bombardier, T/Sgt. Charles E. Priest, Flight Engineer, S/Sgt Wallace H. McLemore, Ball Gunner, S/Sgt John F. Toney, Nose Gunner, S/Sgt Casimir Walenga and S/Sgt Edward F. Steelandt, Side Gunners, and S/Sgt James Hazel, Tail Gunner. The flight path took them over Yugoslavia, through Austria, and up into present day Poland.

In its last mission *The Tulsamerican* led a box formation of six B-24s through heavy clouds. In the clouds the formation broke to avoid collision with each other, and when the aircraft came out of the clouds they were immediately set upon by German Me109s and Fw-190s. The German fighters shot down four B-24s in Ford's formation within 10 minutes. *The Tulsamerican* sustained heavy damage, losing one engine, the hydraulic system, and taking a hit in a fuel tank. Enroute back to base in Italy, it lost another engine from flak batteries and was flying low and slow due to loss of fuel and the bomb bay doors being jammed open. The crew conferred about whether to parachute out over German-occupied Yugoslavia, but decided to try for the Allied airfield at Vis. The loss of the hydraulic system required a crew member to manually extend of the landing gear, and Lt. Ford flew an orbit around the island to give the

[225] *The Tulsamerican*'s aircraft record card and MACR are in Appendix E.
[226] Mahoney 2013.

flight engineer time to accomplish this. On approach for landing both of the remaining engines cut out due to fuel loss. *The Tulsamerican* plummeted 30 m and hit the water at an angle at a speed of 150mph. The pilot, Lt. Eugene Ford, the navigator Lt. Russell Landry, and flight engineer T/Sgt Charles Priest were killed upon impact and sank with the aircraft. Most of the surviving crew swam to safety during the resulting breakup of the aircraft. S/Sgt Edward Steelandt received the Soldiers Medal for saving injured S/Sgt James Hazel on his way out of the sinking aircraft.[227] The surviving crew members were picked up by local partisans and ferried to hospitals for treatment.

7.1.5 Discovery and Jurisdiction

In 2002 Kevin Gray, a volunteer historian for Tulsa Air and Space Museum, began to research the whereabouts of the wreck together with Gerald Landry, nephew of navigator Lt. Russel Landry, and sent information to a group of Croatian divers. In 2009 an unrelated Croatian diver discovered an unknown B-24 at 40 m deep in the appropriate general area, and divers from the Croatian Conservation Institute and partner organizations dove the site to identify the wreck in May of 2010. The site was positively identified through recovery and conservation of the serial data plate from the cockpit area (Figure 7.14).[228] The data plate remains in the care of the Croatian Conservation Institute.

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[227] Landry 2011.
[228] Frka and Mesić 2013.

Figure 7.14- (L) Croatian divers Gabrijel Hrovat, Zeljko Bocek, Danijel Frka, and Marino Brzac hold *The Tulsamerican*'s data plate (R) after completing initial dives on it in 2010. Photo (L) courtesy of Danijel Frka, photo (R) by the author.

The Croatian Ministry of Culture immediately placed the aircraft under protection when it was discovered, and allowed the Croatian Conservation Institute to recover some small artifacts that would be easily removable by looters. *The Tulsamerican* remained a war grave, whose three missing persons fall under the jurisdiction of the Defense POW/MIA Accounting Agency, and the aircraft itself belongs to the US Air Force, protected also by the Sunken Military Craft Act. The Croatian Ministry of Culture kept *The Tulsamerican* as a closed site until 2014, when they opened the wreck to recreational divers. It remains a popular dive site to this day, seeing over 50 divers a day on its busiest days.

7.2 Project Planning, Methodology

Although the wreckage of *The Tulsamerican* is a popular site, is well photographed, and is the subject of an artist's rendering, scientific documentation for a baseline of the wreck site's condition had never taken place. The 2015 investigation serves as the first of several monitoring surveys designed to report of the wreck's overall site formation. It also served as a preliminary archaeological survey of the wreck prior to the 2017 excavation.

7.2.1 Collaboration and Outreach

This project benefits from the ideal collaboration between several groups of stakeholders in aviation archaeology, including enthusiasts, historians, policy makers, and archaeologists. Members of the original dive team who identified the site were gracious with their assistance in time, expertise, and support of the project. Danijel Frka and Gabrijel Hrovat's familiarity with the site, their diving experience, and their local knowledge served as a valuable asset to the project. Kevin Gray, historian from the Tulsa Air and Space Museum and a non-diving member of the team came equipped with research materials and was an in-field asset for wreckage queries. Their prior knowledge of the site and *The Tulsamerican*'s history was essential for team operation. Avocational researchers Andreas Sannerman, Mark Petersen, and Russ Matthews provided systems and parts identification knowledge, as well as technical and dive assistance. Anthony Burgess, MA and Bridget Buxton, PhD assisted in directing support divers in archaeological duties. Collaboration proved key for identification and interpretation of research materials and wreck debris, while insightful team research discussions helped to create a consensus among contributors regarding the baseline site formation.

The project was funded in part by the Institute of Nautical Archaeology (INA), who also hosted a blog site for our project. We provided daily updates explaining different aspects of the survey highlighted by images from the field. I was not able to track our visitor numbers or statistics, but several team members shared the blog link on their social media pages.

7.2.2 Research Goals

This survey's primary purpose was to fully document the complete wreckage of *The Tulsamerican* through site mapping and video. Visualization of the resulting data supports the exhibit materials interpreting this particular aircraft's cultural importance in a museum setting, which will include its history, its present state, and an indication of what might happen to it in the future. A secondary goal of the project is to understand the decay rate of aircraft aluminum in this area. To complete these goals I designed *The Tulsamerican* project to include several avenues of research:

1. A thorough and accurate documentation of the wreck site

First and foremost this project created a 2D bird's eye site map and 2D renderings of the wreck site's two major fields. We also video documented the site in its entirety with divers and a remotely operated vehicle (ROV).

2. A conservation assessment prior to recovery and treatment of artifacts

To support the future display goals of the Tulsa Air and Space Museum, the proposed survey sought to determine the viability, and assess the condition, of small artifacts for possible recovery, conservation, and museum display. A full recovery of the aircraft is not feasible but the Tulsa Air and Space Museum has expressed interest in acquiring some physical remains for interpreted display. Although a visual survey alone cannot fully determine site integrity, a condition assessment should indicate enough information about the aircraft remains to either encourage or discourage recovery attempts.

3. Visual modeling of the wreck site

Data visualization goals of this project were to produce a 3D model of both major areas of wreckage. We used the photos and videos from the divers and ROVs to create a 3D model of the entire site using Agisoft Photoscan software. The model, when built into a new exhibit discussed below in section 7.5, will allow the Tulsa Air and Space Museum to enhance their current historical artifacts display to allow the general public to understand the wreck site in its present state.

4. Study of corrosion potential

Building on studies from Saipan, the project will also attempt to verify the aluminum alloy and create a baseline of aircraft metal deterioration for this area.[229] This non-disturbance experiment allowed us to develop a method for in situ conservation using the appropriate anode. Future research using these results would prove extremely valuable for culturally important underwater aircraft wrecks that require preservation rather than excavation.

7.2.3 Logistics, Methodology

The Tulsamerican wreck site, being a tourist destination, has a line down for divers that attaches to the propeller hub shaft of Engine 2. Our project team included 4-8 divers on any given day, and divers worked in pairs to accomplish daily tasks. We had six advanced divers on air surveying the shallower site, and one rebreather diver and one trimix diver for the deeper site. Our team dived six out of ten days.

One of the earliest tasks was to drive two rebar poles into the seafloor on opposite quadrants of the aircraft to serve as datum points on the shallower site. One pole was placed forward of Engine 3 and one aft of the wing near the raised landing gear. For reconciliation, as well as providing a known scale, we laid a set of 13 mm alignment markers randomly generated from Agisoft Photoscan. We laid three markers around each datum pole to make a meter square

[229] MacLeod 2003; Richards and Carpenter 2012; MacLeod and Richards 2014.

box, and laid the rest around both sections of wreckage about 1-2 m apart in random locations (Figure 7.15). Paired divers made triangulation measurements between the two datum points and several points on the wreck. Survey plans called for measurements along the entire center section of the B-24, but weather days forced a time constraint on the project and we measured only the starboard wing side.

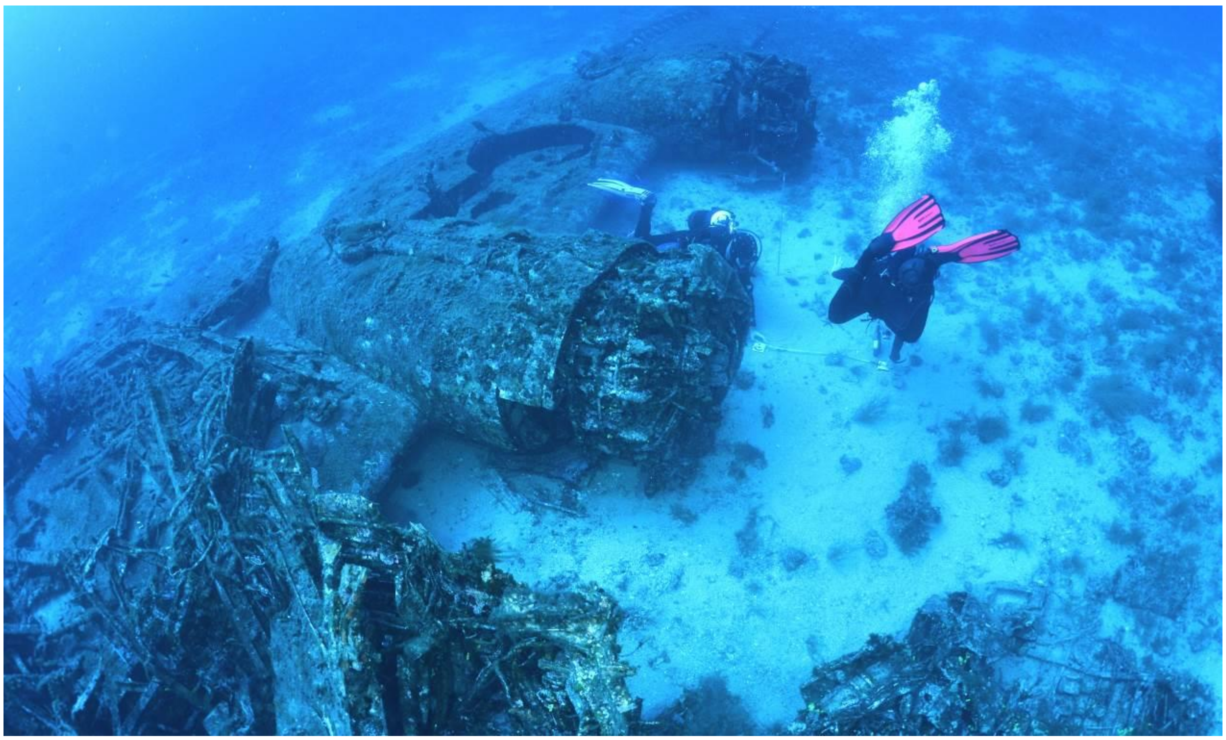

Figure 7.15- Anthony Burgess, L, and the author, R, lay alignment markers and measure a 1x1 m box in front of the starboard wing datum point. Photo by Danijel Frka.

In a reconnaissance survey performed on the wreck in 2014, I processed images taken with a GoPro Hero 3+ camera with Agisoft Photoscan Software for 3D modeling experimentation. We tested image acquisition methodology using primarily the VideoRay Pro4 ROV flying a pre-determined pattern while setting the camera to take two photos per second. We then tested a second model of flying independently using the video function, and then a third model using a diver-held GoPro camera. I used these results to plan the 2015 survey.

In 2015 we again used a VideoRay Pro4 ROV flown by a professional pilot. We equipped the ROV with two GoPro Hero 3+ cameras and lights, one on an adjustable mount on the top and one facing down on the bottom. The top-mounted camera captured imagery for 3D modeling and we positioned the bottom camera to allow for a 2D photomosaic. Divers also used hand held GoPro Hero 3+ cameras to video the site. The methodology of image acquisition on aviation sites requires an adaptation from the mow-the-lawn pattern for nearly flat or slightly concave shipwrecks; an aircraft’s vertically protruding propellers or landing gear, raised wings, and often convex surfaces create backs, corners, caves, and undersides which require modeling from many different angles. We flew the ROV in a circling pattern, concentrating on smaller areas of wreckage to make a series of overlapping ‘chunks’. We filmed the majority of the wreckage with an ROV, while divers supplemented the video by acquiring film of difficult-to-reach spaces, such as the wheel well of the center section, the underside of the wing edges, or the interior of the tail section. I considered these patterns while processing the model and focused on accurately marrying the separate sections together.

7.2.4 The Survey Area

The Tulsamerican sank in the Adriatic Sea near Vis island at N43° 1' 59.99", E16° 15' 56.7". The site is separated into two distinct areas by a shear drop-off ridge, the shallower portion in around 40 m and the deeper parts lie in a range of 52-55 m (Figure 7.16). The wreck's arrangement, with the deeper section north of the shallow section, is due to the small islands surrounding the southeastern part of Vis (Figure 7.17).

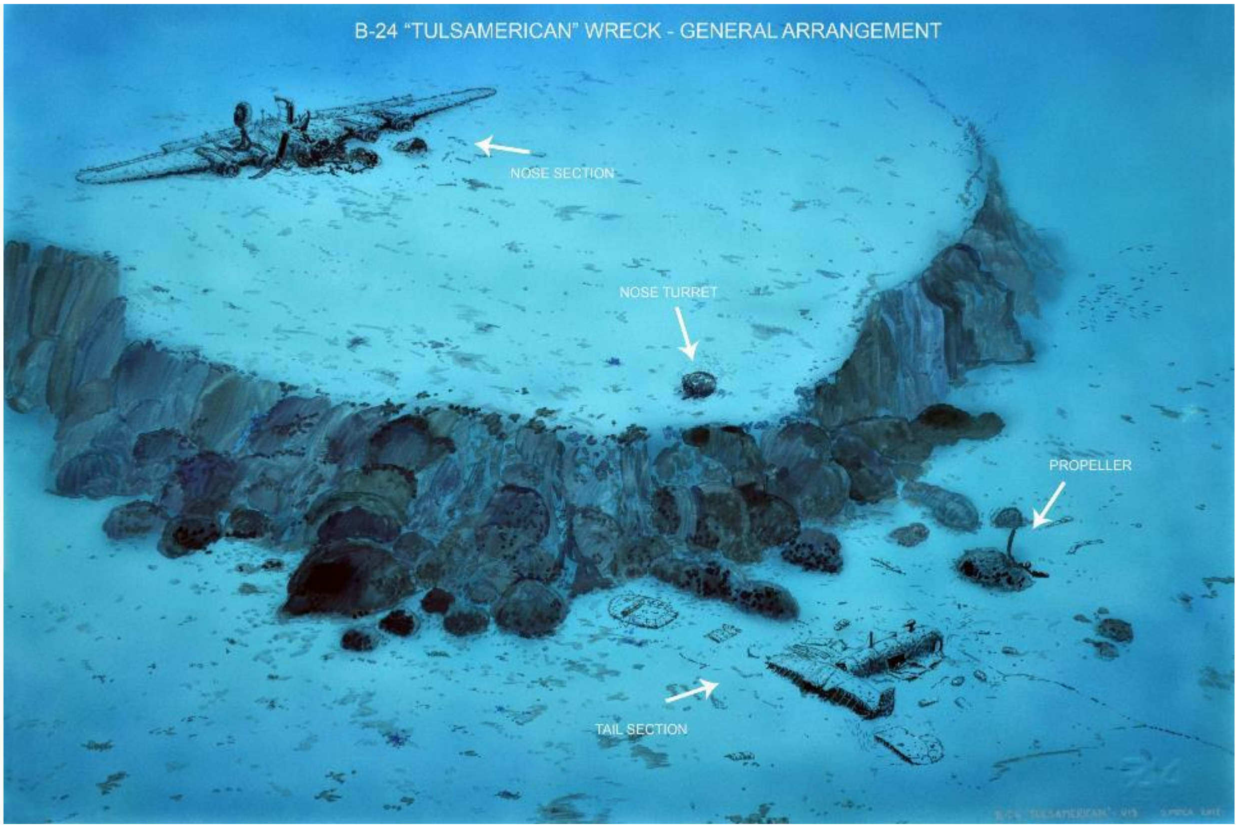

Figure 7.16- An artist's rendering of *The Tulsamerican* wreck site. Rendering by Danijel Frka, reprinted from Frka and Mesić, 2013.

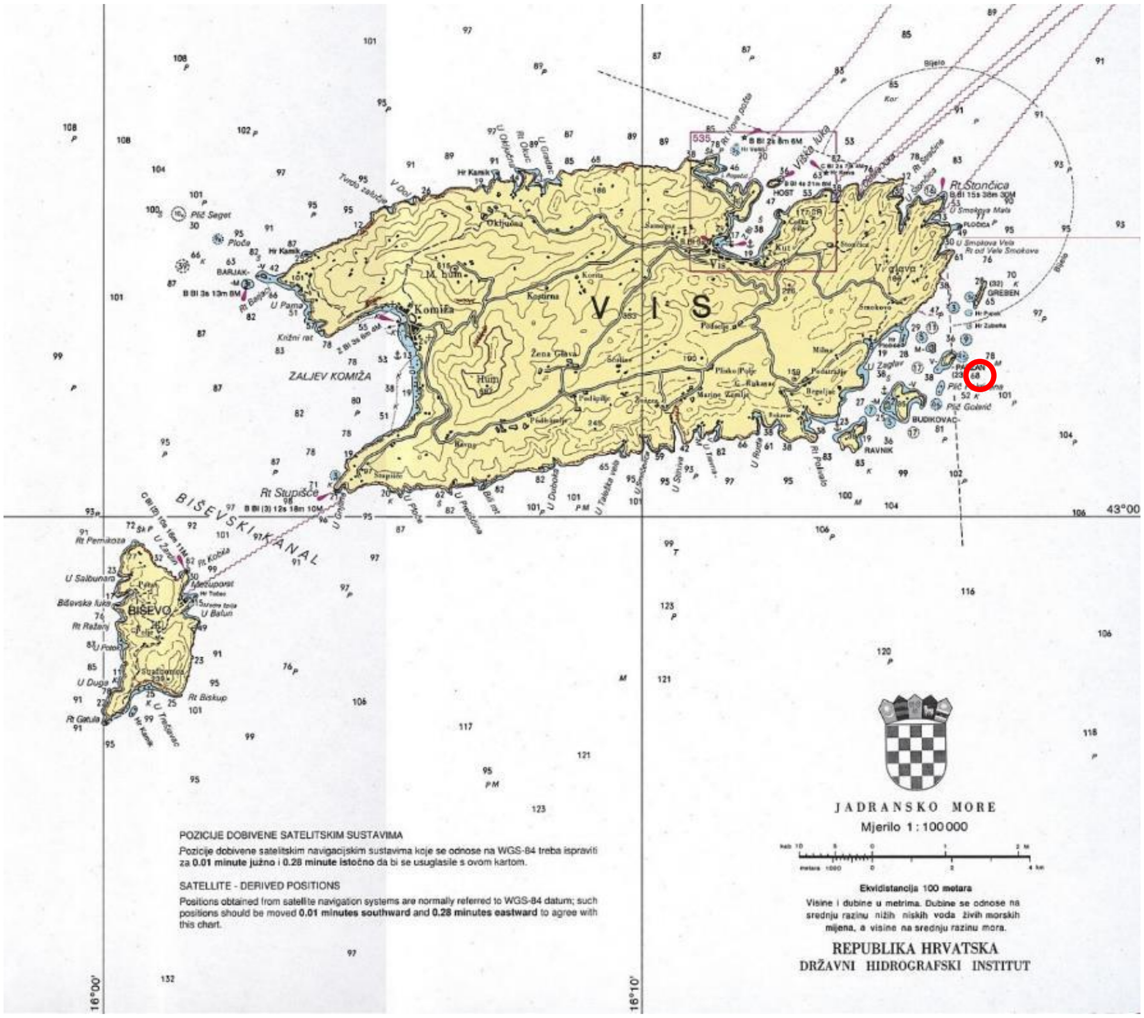

Figure 7.17- Depths around Vis and the location of *The Tulsamerican* wreckage. Map Republika Hrvatska Hidrografski Institut.

The bottom is sandy with rock outcroppings and varied marine life. A thin layer of marine growth covers all exposed aluminum surfaces with both green biofilm and calcareous white and orange patches. There are a few yellow corals growing on the shallow wreckage.

The Adriatic's surface temperature usually ranges from 22° to 24 °C (72° to 75 °F) in the summer, with the first thermocline at the depth of 3 to 5 m, the next one at about 12 m, another at

18 m, and below 30 m the temperature is mostly constant throughout the year. In September 2015 the water temperature at depth was between 17° and 18° C. The Adriatic's salinity ranges between 38 and 39 PSUs and the current ranges from .5 to 4 knots around Vis. We did not experience currents of more than 2 knots on site during the project. Visibility was in excess of 20 m on most days.

7.3 Survey

7.3.1 Site Description and Maps

As previously noted, the wreckage of *The Tulsamerican* lies in two major pieces separated by about 50 m. The forward half of the aircraft lies inverted on a flat seafloor at 40 m depth about 30 m away from a ridge that drops to 52 m and then slopes north to sea. The center wing section of the aircraft is largely intact, but there is crash damage to both wing tips and the starboard aileron is missing (Figure 7.18). The flaps are in the down position. Virtually nothing remains of the forward section fuselage, and all that remains of the bomb bay compartment is the ceiling and one upright central bomb brackets, while another bracket lies collapsed into the aircraft. The center section breaks cleanly at the bulkhead directly aft of the flap root. The port-side landing gear is lowered and locked in place with the tire intact, while the starboard gear assembly and tire are missing.

The engines all remain in place, but each propeller assembly save one lay scattered at varying distances from the tail section. Pieces of cowling appear damaged and/or missing from each of these three engines, while the engine with the propeller in place retains most of the cowling. As expected, each engine suffers from corrosion damage and the aluminum/magnesium alloy pieces are missing.

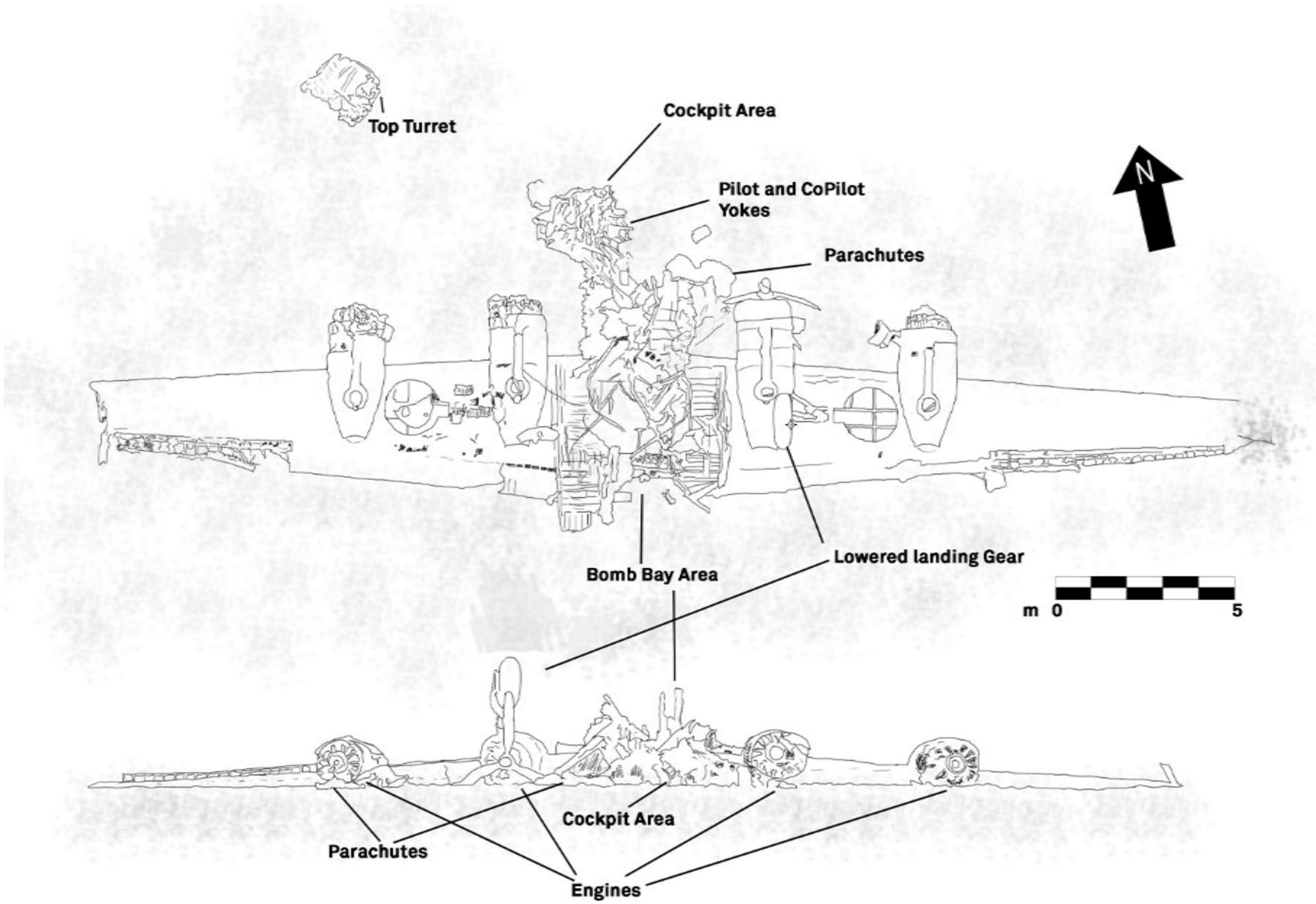

Figure 7.18- *The Tulsamerican* center section site map at 40 m. Drawing by the author.

The wrecking event heavily damaged the rest of the fuselage in the forward section and almost completely detached it from the wing section. The flight engineer's compartment remains attached, but the floor and some side fuselage have been ripped away. The cockpit's instrument control panel and yokes connects to the rest of the fuselage by a small area of skin, but the assembly lies open and away towards the starboard inboard engine (Figure 19). There is no evidence of the navigator's compartment, except for a small piece of skin and structure around 3-4 m in front of the cockpit area. The nose gunner's turret lies around 30 m south of the wing center section, near to the ridge drop-off (Figure 20). The nose guns were removed in 2010 by the Ministry of Culture.

Figure 7.19- *The Tulsamerican* center section. The cockpit lies in the front right. Photo by Danijel Frka.

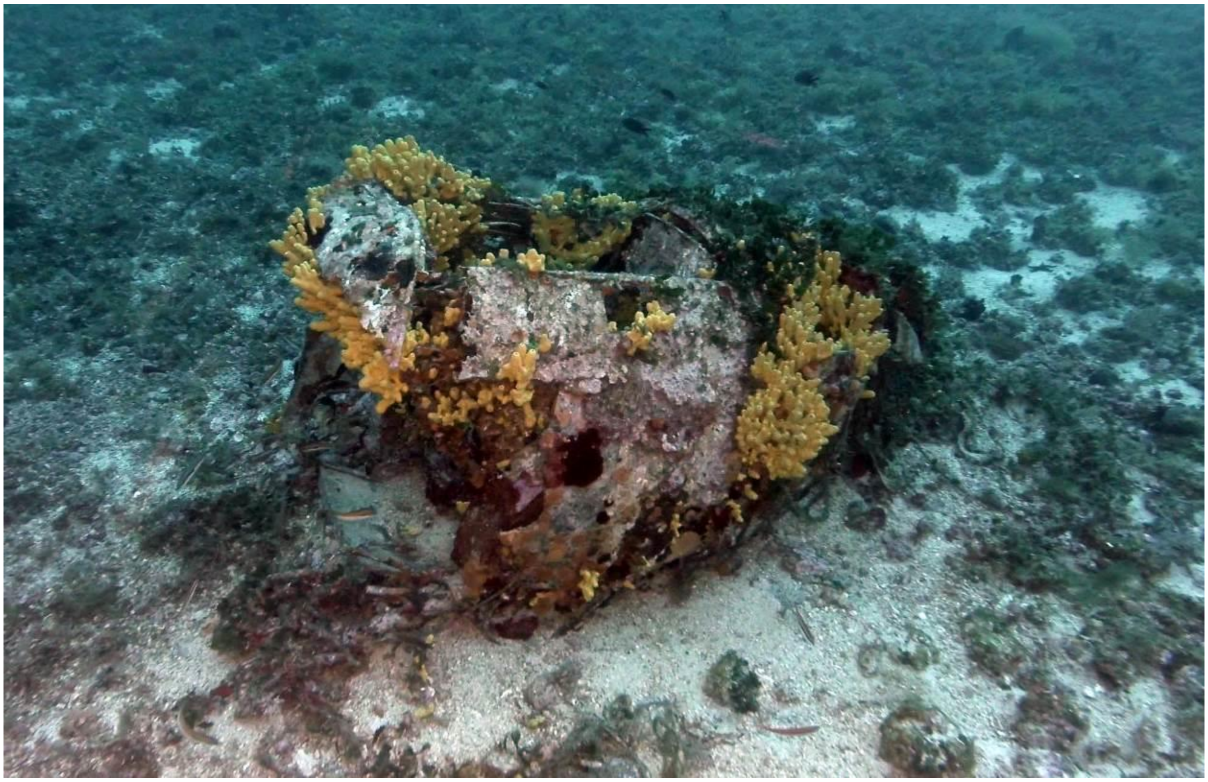

Figure 7.20- *The Tulsamerican*'s disarticulated nose turret. Photo by Danijel Frka.

The tail section of *The Tulsamerican* lies upright to the north of the center section just beyond the ridge drop-off at 52 m (Figure 21). The tail fuselage appears largely intact but somewhat flattened in the lower belly (Figure 7.22). Several oxygen tanks remain inside the tail, both pressurized and unpressurized, while more lie scattered in the vicinity. The ball turret fills the interior of the forward tail upper compartment and its transmission assembly juts out of the skin through a hole. Both machine guns in the side windows remain mounted in place. There is heavy damage to the tail assembly and the horizontal stabilizers appears broken. Both of the vertical stabilizers broke off either in the wreck or at deposition; the starboard one lies immediately off to the side of the tail while the port-side stabilizer lies close to the ridge drop-off in a pile of loose items. Only half of each vertical stabilizer remains.

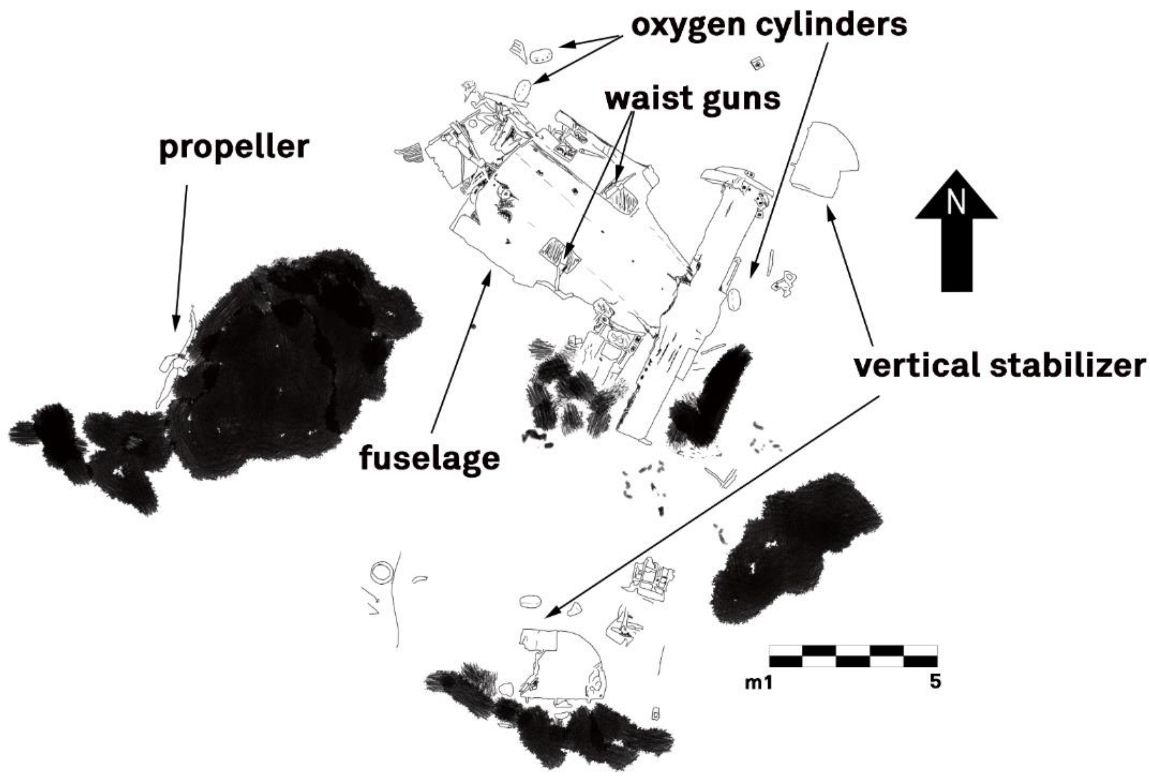

Figure 7.21- *The Tulsamerican* tail section site map at 52 m. Drawing by the author.

Figure 7.22- *The Tulsamerican* tail section. Note a propeller propped up against a boulder in the left part of the image. Photo by Danijel Frka.

Small, disarticulated pieces of the wreck lay scattered at this lower depth, the largest of which is a propeller laying propped up on a rock to the east of the tail section (Figure 7.23). A large sheet of bomb bay door lies nearby and closer to the ridge. Our team found two other propellers and more metal debris within 200 m of the tail section.

Figure 7.23- A propeller propped up against a boulder close to the tail section, which is visible in the far left. Photo by Andreas Sannerman.

On dives completed in September 2014 and 2015 I documented an overall fair-to-good condition for the metal on the B-24 wreck with lower than expected levels of marine and coral growth. There appears to be more coral growth on the tail section at the lower depth, and there is abundant yellow coral growth on the nose turret, a level unseen on the other wreckage. Items such as oxygen cylinders and tires appear to be in excellent condition. Flat surfaces, such as the wing and tail, suffer from some pitting corrosion resulting in small patches of skin loss. Our team was determined that paint from the nose art remained on the fuselage near the shear point of the cockpit area. We observed an unexpected number of surviving organic pieces on the site, given the shallow depth of the site, such as three silk parachutes and several shoes. In addition to these, the CCI recovered a canvas flak jacket in 2012.

7.3.2 3D Mapping of the Site[230]

I wanted to be able to perform the visual documentation portion of the survey quickly and accurately, but also show the resulting site map to members of the non-academic public. This meant the site map had to be both interesting and interpretive. One of the best ways to achieve this is through the use of 3D mapping. Since *The Tulsamerican* is an aircraft with a unique and important cultural tie to a specific area and group, the visual survey and 3D documentation of the site will be extremely valuable to that community, in addition to serving as archaeological documentation. Due to limited dive times at the 40 m depth, technology helped create a site map that not only interests the general public, but benefits the Defense POW/MIA Accounting Agency, who used the interactive model to plan an excavation for servicemen remains in 2017. Our team obtained images for the experimental version of this model on a few short dives in 2014 and processed it through readily available software. It allows for the general public to experience the site in a more intuitive way than solely through pictures and video.

The methodology of acquiring images for 3D modeling on shipwrecks has, over the past year, been modified for maximum efficiency.[231] Many aircraft wrecks present as dissimilar in deposition to shipwrecks and may contain upright or tall features perpendicular to the sea floor. Because of this, we used both divers and a mini VideoRay Pro 4 ROV equipped with GoPro 3+s and 4s to fly specific patterns over the wreck (Figure 7.24). For 2D photomosaic mapping, I

[230] Models on the author's sketchfab page: https://sketchfab.com/mlickliter.
[231] Yamafune 2016.

instructed our ROV pilot to perform a modified mow-the-lawn pattern at different heights above the wreck in order to have good lighting for all areas and not cut off areas that were taller than the ROV was flying. This pattern was successful on the center section, but unreliable in terms of blurry photos on the tail section, usually because of the current (Figure 7.25). For the tail 2D photomosaic, I asked one of our project divers to swim the modified mow-the-lawn pattern, this time including a circular pattern around the propeller up against the boulder while switching camera angles to capture all surfaces with adequate lighting (Figure 7.26). The 2D models are impressive and provide measurable context for the wreck, but, as suspected, this pattern resulted in a loss of detail on the sides of the aircraft (Figure 7.27).

Figure 7.24- A VideoRay Pro4 ROV with GoPro cameras attached. Photos by the author.

Figure 7.25- 2D view of the center section, *The Tulsamerican* wreck site. Model by the author.

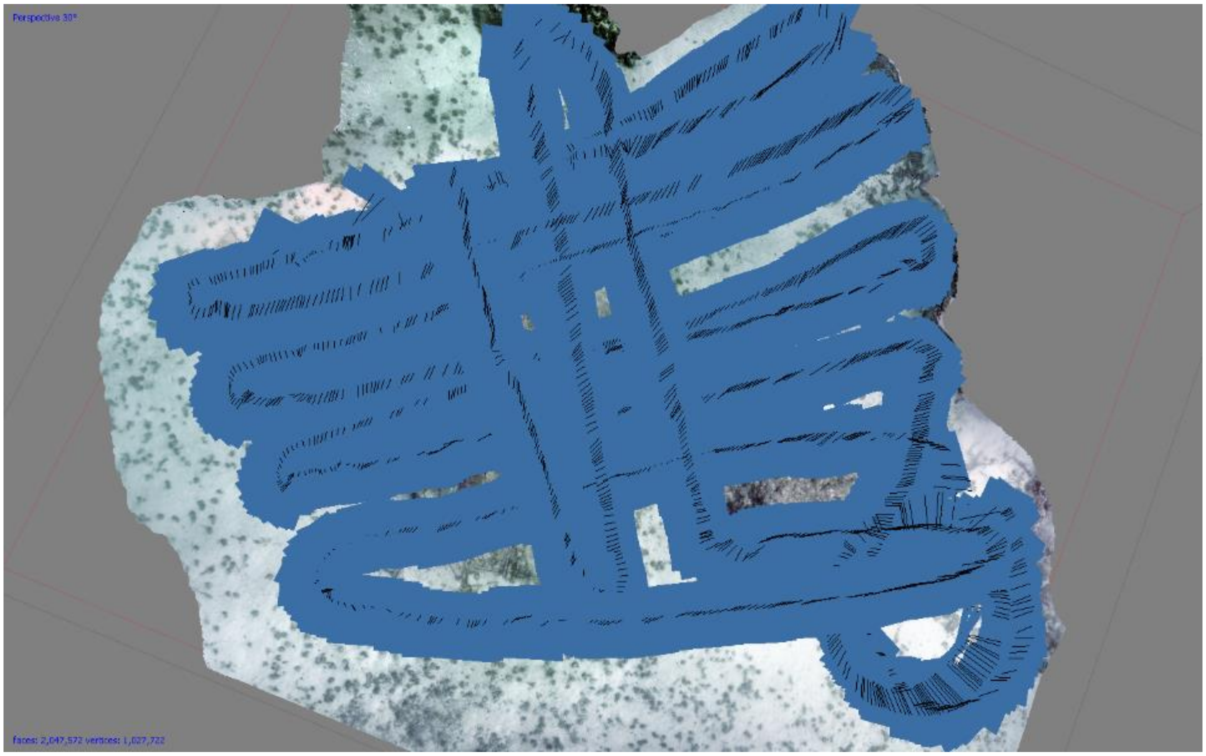

Figure 7.26- The diver swim pattern as taken from video stills. Model by the author.

Figure 7.27- Bird's eye view of *The Tulsamerican* tail section site. Model by the author.

For the final, display quality 3D model of both sections tail sections, my best procedure in terms of video and model processing time, and quality of the mesh and texture was to use color-corrected images from the mow-the-lawn pattern and marry higher detail ‘chunks’ of wreckage sections into those prior to meshing the model (Figures 7.28-7.32). The higher detail ‘chunks’ I obtained by adding both diver and ROV video into Photoscan by area, creating an array of random images that surround the desired subject. Prior to exporting stills I color corrected the video to achieve greater clarity in detail and to make a more interesting final product. We used the software-provided alignment targets on site but Photoscan seemed to accurately determine alignment well without recognizing them. The measurements to the datum points as well as the size of the tiles allowed for accurately sizing the 3D model and taking measurements from it.

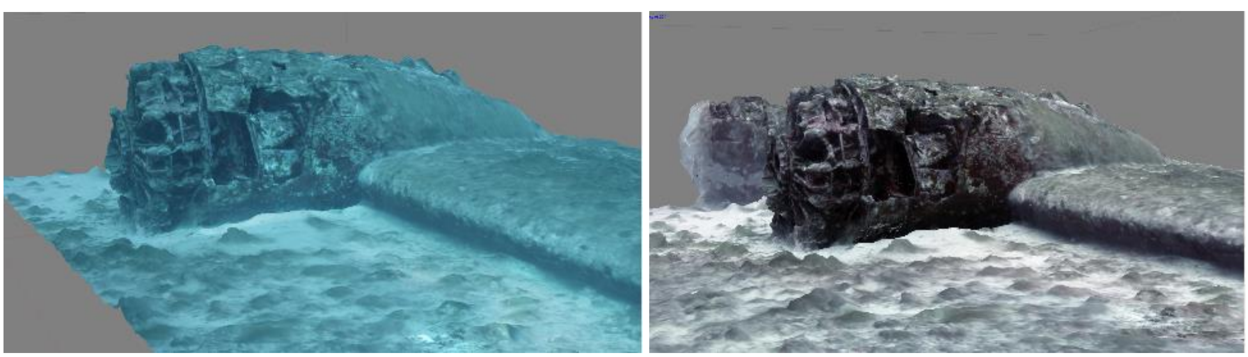

Figure 7.28- The original (L) and color correction on the model of *The Tulsamerican*’s engines (R). Models by the author.

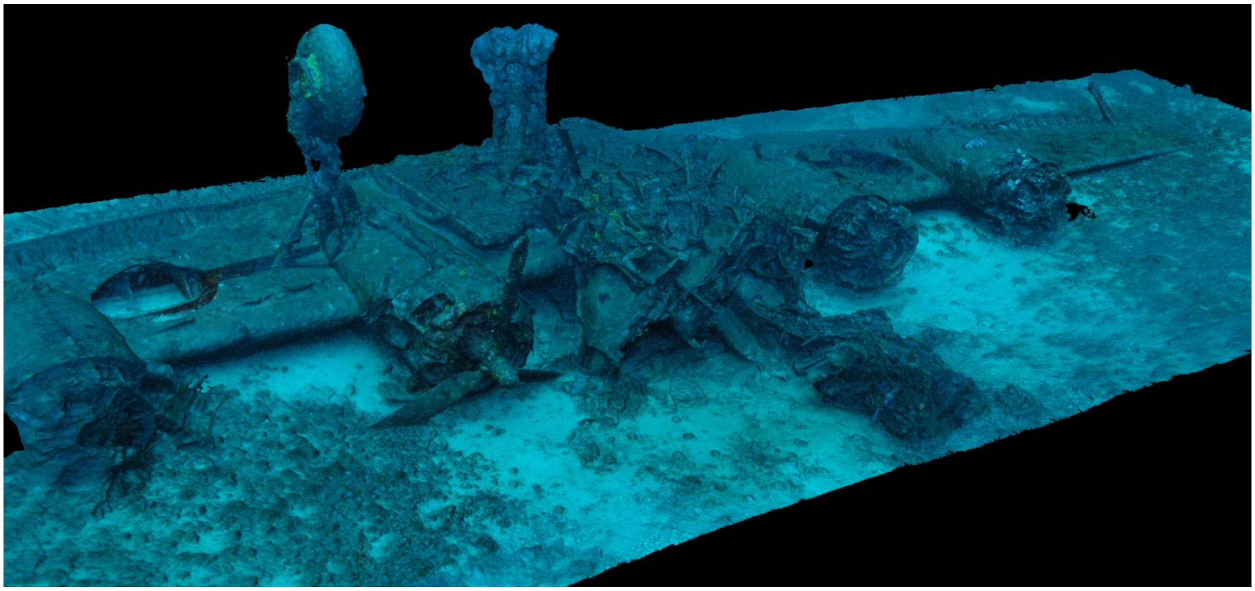

Figure 7.29- A test model of the 3D mapping methodology from ROV and diver footage taken in 2014 shows accuracy with some holes (mainly hidden in this view). The lack of color correction on this model shows benefit in contrast and shadow but hides some detail and the correct scene impression. Model by the author.

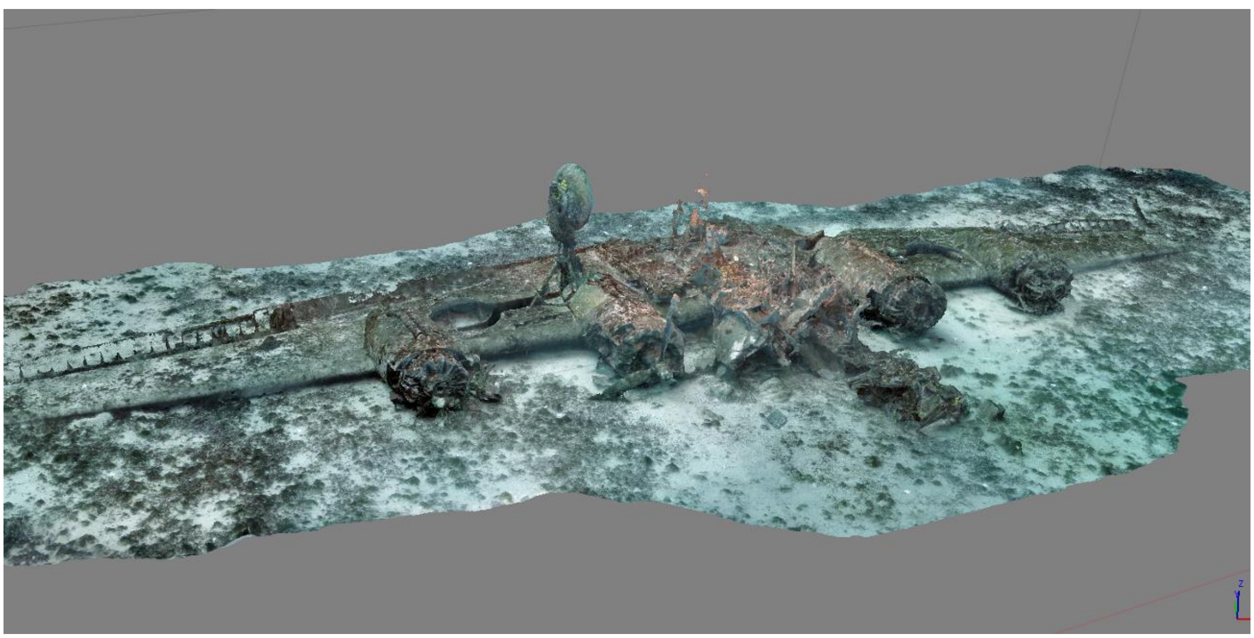

Figure 7.30- A color-corrected 3D model of *The Tulsamerican* center section at 40m, missing some elements such as the bomb bay brackets. This model, processed with ROV and diver footage from the 2015 field project, is a more accurate representation of the wreck. Model by the author.

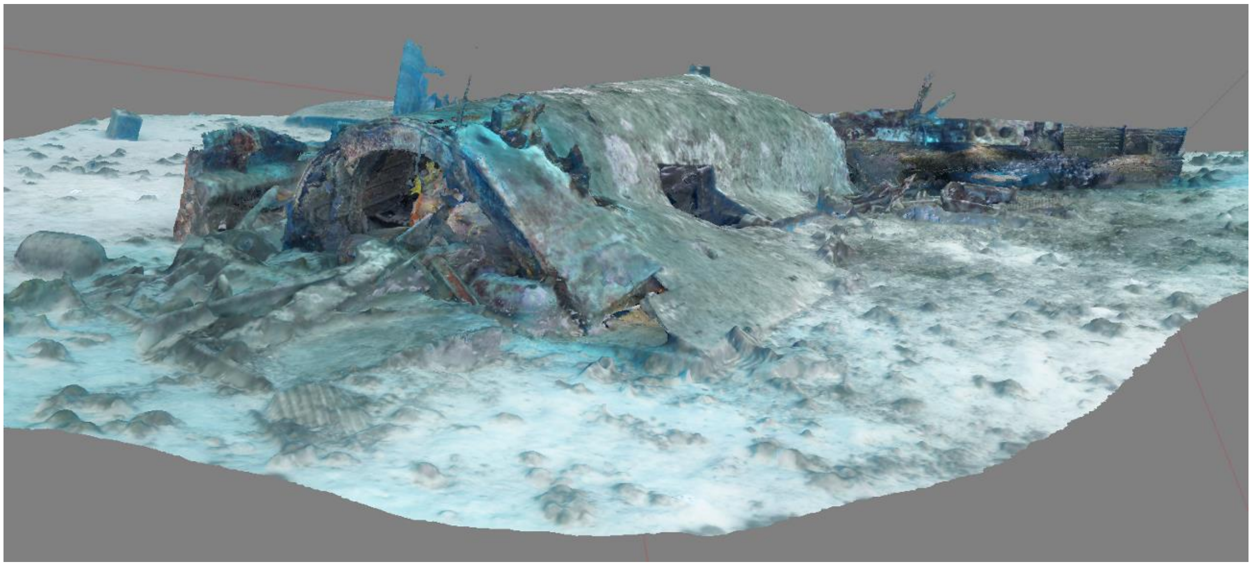

Figure 7.31- The tail section of *The Tulsamerican*. It was processed in several 'chunks' and then stitched together. The interior sections were lit with diver-held lights. Model by the author.

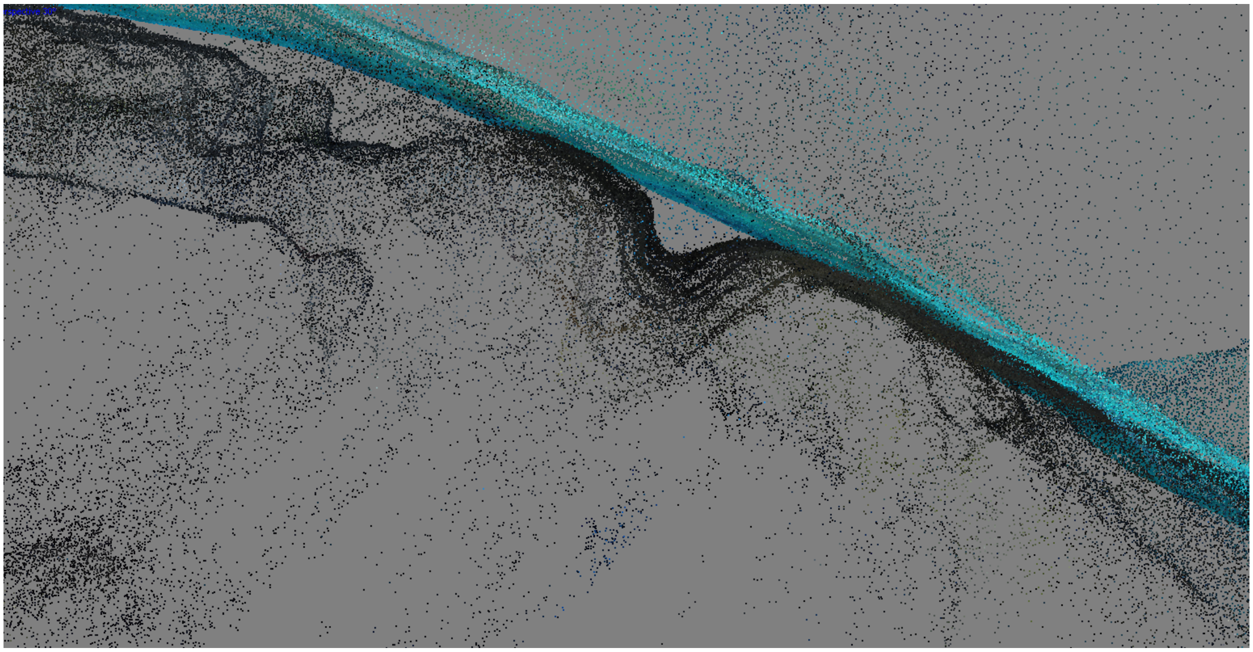

Figure 7.32- The 3D models give the opportunity for greater understanding of the interior and exterior surface areas. In this view, the exterior skin in blue lays above the interior skin, which is corrugated. Model by the author.

7.3.3 *The Tulsamerican* Site Formation

Site formation research begins with an analysis of the crash report for clues as to how the aircraft broke apart, looking first at two test ditches for information on the B-24's structural breakup. On September 20, 1944 experimental researchers at the National Advisory Committee for Aeronautics (NACA) at Langley, VA watched as two pilots ditched a B-24 in the James River north of Newport News.[232] Researchers reinforced the belly of the B-24 steel plating and minimized the weight of the aircraft to slow sinking time. The pilot performed a controlled ditch, hitting the aft fuselage first at around 100mph. Even with reinforcing, the aircraft broke at the bomb bay, just aft of the cockpit seating. The report states extensive damage, with several tears in fuselage skin, missing flight control surfaces and a completely warped tail structure.[233] The research lab completed this test, and another similar one a few months later on a different B-24, mainly to resolve the known failure of B-24s when ditching and the resulting high crew loss. From March to September 1944 fifty B-24s were ditched while on combat missions, with the loss of 24 percent of their crew members. Thirty-one of those aircraft broke into two or more pieces during the crash.[234] The experiments would not alter WWII use, but results from several aircraft and physical modeling tests would later result in modern ditching procedures used today, most notably with the 'Miracle on the Hudson' Airbus 320 that ditched into the Hudson in 2009.[235]

In the case of *The Tulsamerican*, MACR 16507 reports the wreck but read as largely incomplete, notably without the aircraft's serial number listed or witness reports from surviving

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[232] Long 1944.
[233] National Advisory Committee for Aeronautics 1944.
[234] Johnsen 1999.
[235] National Advisory Committee for Aeronautics 1957.

crew members. The majority of the pages consist of a general statement and letters to family members. Gerald Landry, nephew of the navigator Lt. Russell Landry, collected crew member witness statements years after the accident. In the statement of Lt. Val Miller, he described several crew members' situations and the impact:

> I was on the flight deck, seated immediately behind Lt. Ford. The co-pilot, Vincent O. Ecklund, and Russell C. Landry, Navigator, and Charles E. Priest, engineer, were with me on the flight deck. This is a small area and I could have reached out and touched any one of them. We were flying at approximately 100 feet above the water, when suddenly two more of the plane's engines cut out. Lt. Ford said "We're going in". Because of the loss of power, the plane fell over on its side and crashed into the sea. It was a tremendous impact. Somehow, I did not lose consciousness and was able to inflate my Mae West and somehow shot out through the wreckage and was able to come up out of the water.[236]

S/Sgt John Toney had been in the rear compartment of the fuselage, behind the bomb bay. He recalls:

> With the bomb bay doors open, gear down and no power we really hit the water hard. The plane broke up and I was under water when I came to. We were always instructed not to open our Mae West inside the plane, but since I couldn't swim a lick and I was still in the plane underwater, the first thing I did was to inflate that

[236] Landry 2011, 9.

> Mae West. I don't know how I got out. I was knocked unconscious when we hit, but do remember coming out a hole in the plane.[237]

The Tulsamerican hit the water at an angle at high speed with the bomb bay doors open with the nose gear and one center landing gear down; it is unknown if the other gear was partially down but it is likely due to the complete loss of the starboard landing gear structure and wheel. This impact caused the fuselage to wrench apart into two sections, the aft and tail section sinking into deeper water. The forward center section remained intact at the wing except for the light supports for the bomb bay doors. It is likely the plane hit the water at a downwards angle on the nose and starboard side, given the loss from that side of the landing gear, both propeller assemblies, and some of the outermost wing section. The impact was hard enough to detach the plexiglass turret from the nose and completely disintegrate the navigator's area. The lowered forward landing gear may have ripped a hole in the bottom of the plane as it wrenched away on impact with the surface. It may also be likely that there was a hole in the top part of the cockpit area, through which Lt. Miller and other survivors in that area escaped. The aircraft broke on impact and the center section sank due to the loss of the nose and the weight of the engines. It inverted on its way to the seafloor. S/Sgt. Toney probably inflated his vest and shot upwards through the hole created in the tail by its separation from the bomb bay. Loss of metal since deposition is mainly from areas compromised during the wrecking event.

Several B-24 wreck sites in Croatia display the same site formation, one of these is a B-24J lost near Hvar on November 20, 1944. *Le Petite Fleur* was returning from a bombing run over Blechhammer, Germany with one damaged engine when the pilot decided to ditch after fuel

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[237] Landry 2011, 10.

loss. The bomb bay doors were open and the gear up and the crash resulted in almost exactly the same site formation as *The Tulsamerican*: the center wing section inverted and separated from the tail section at the rear of the bomb bay, with the cockpit area mangled and the nose missing (Figure 7.33).[238] The tail section is upright and near to the wreck.

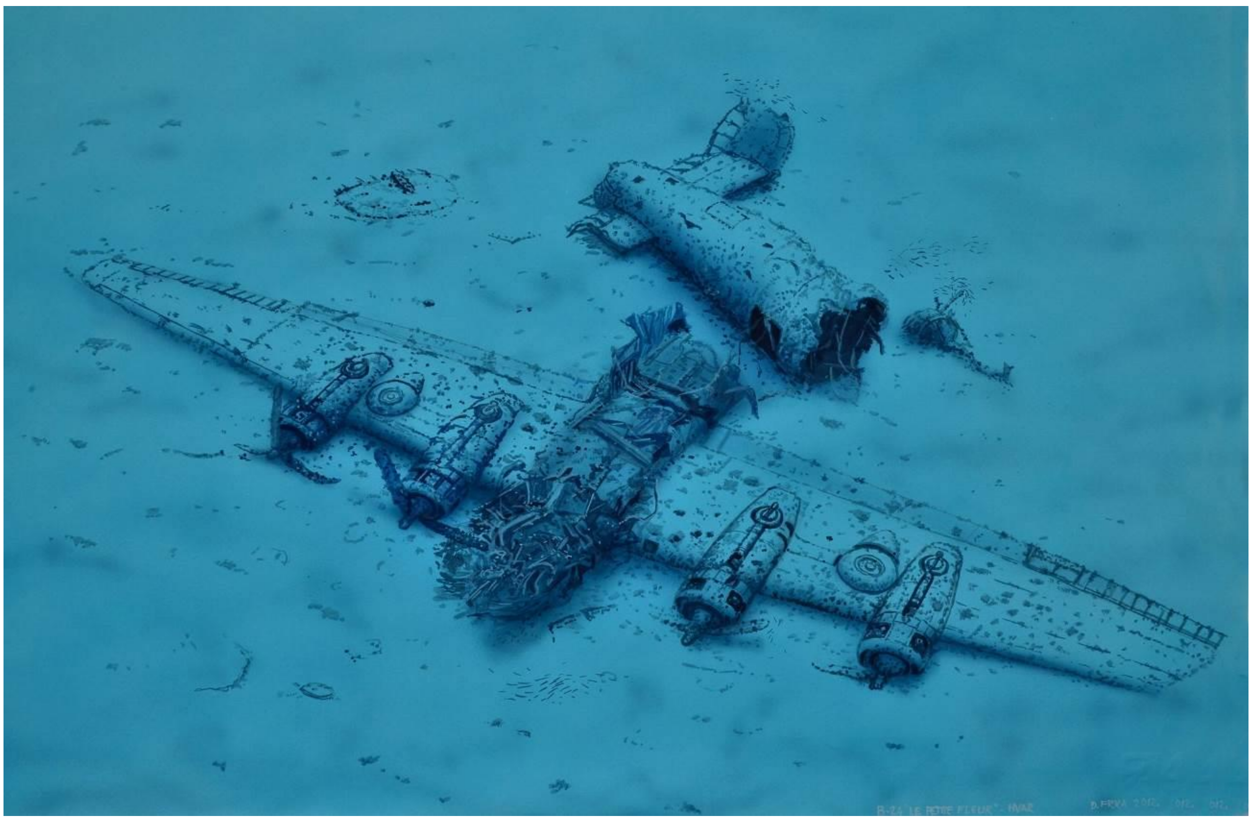

Figure 7.33- The B-24 *Le Petite Fleur* wreck site. The current wreck site presents as slightly different due to a fisherman's trawling net overturning the tail part onto the center section. Rendering by Danijel Frka, reprinted from Frka and Mesić 2013.

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[238] Frka and Mesić 2013.

In 2016 Croatian divers found and identified a B-24, S/N 42-52774 *Lady Luck*, resting at 90 m near Vis off Bisevo island. In the MACR, the sole survivor states that the aircraft engines failed close to the island, leading to a controlled crash resulting in the aircraft breaking in two and the rear section sinking immediately. There is no information about the status of the bomb bay, but this wreck presents as a similar site formation as *The Tulsamerican* and *Le Petite Fleur*. The inverted center section separated from the tail section aft of the wing's trailing edge. In this case, the tail remains close to the center section and might continue to be partially attached to it. This wreck presentation suggests a crash event similar to *The Tulsamerican* and *Le Petite Fleur*, which suggests a correlation between wrecking event and site formation in B-24 aircraft.

B-24s have also been located in the South Pacific, and I studied these for similar site formation comparison. An unknown serial number B-24 that completed a controlled ditch in 22 m depth in Tomini Bay in the Togean Islands shows a different site formation. Here the pilot successfully ditched the aircraft with no breakup on May 3, 1945; the aircraft remained floating for over an hour after the landing.[239] In this case, the pilot ditched the aircraft with the gear up and the bomb bay doors closed. This wreck appears upright and intact on the seafloor, but with the nose crushed and three out of four propellers missing. One of the landing gear has since collapsed into the sea floor. Two other B-24 sites in the South Pacific present as disarticulated wreckage over wide areas; B-24 S/N 42-41216 crashed in Papua New Guinea and B-24 S/N 42-73453 in Palau, both in 1944 due to combat damage.[240] B-24 42-41216's tail section broke apart from the fuselage at altitude and the rest of the aircraft crashed in the ocean nearby. The wreck

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[239] According to the 307th Bombardment Group website: http://www.307bg.net/images/crews/ethridge/index.asp
[240] Project Recover Reports B-24_42-73453 (JPAC CIL 2008-014), and B-24_42-4126_TENNYSON.

sites, two main areas at 53 and 65 m and over 300 m apart, represent the majority of the wreck. The crash of B-24 42-73453 was due to the complete detachment of the port wing and the breakup of the fuselage at altitude. The wreckage was completely demolished and found in four large sections at 12-22 m depth; two 80 m apart and smaller pieces up to 200 m away.

In Croatia, a B-24 crash event scattered the remains of S/N 42-51559 off the coast near Zadar, Croatia in 23 m depth. The crew of this B-24 bailed out on October 16, 1944 as a result of fuel loss. The aircraft presents as completely disarticulated in several large and small parts over a 100 m area. This site formation is similar to the uncontrolled crashes in the South Pacific. Similar site formation, regardless of area, may suggest that B-24s wreckage could be compared based on the crash event. In future research, an interpretation of crash event for unknown sites may be possible based on this dataset. More research is needed to formulate a hypothesis on wreck event effects on B-24 site formation, but given the number of B-24 off the coast of Croatia as a result of ditchings, controlled crashes, or uncontrolled crashes, this area would be a good place to begin.

7.3.4 In Situ Preservation Survey

In 2015 I conducted a field survey to visually document *The Tulsamerican* and determine the rate of its decay, as part of a larger goal to determine site formation of B-24s in a regional area. *The Tulsamerican* is not an isolated find, however, and, therefore, I also documented and sampled two other B-24 wings, dumped in local harbors at varying depths. Our survey permit was for non-intrusive work, and, therefore, I did not take samples of B-24 aluminum for XRF analysis. Following MacLeod's research, the goal was to take corrosion potential and pH readings of the bare metal at three different depth sites of B-24 wings in order to create a baseline of aircraft metal research for this area.[241] This non-disturbance experiment could determine the rate of decay given known depths and conditions and allow for developing a method for in situ conservation using the appropriate anode. Future research using these results could prove extremely valuable for culturally important underwater aircraft wrecks that require preservation rather than excavation. Museums, in particular, could benefit from the knowledge of how long aircraft wrecks will continue to remain in salt water. If a museum had a particular historical wreck in mind for future recovery given present restraints of funding, they could refer to documentation of this nature to help them create an appropriate timeline, or consider in situ preservation. In the case of *The Tulsamerican*, results will either encourage or discourage the Tulsa Air and Space Museum, who are looking into the feasibility of recovering small metals finds.

Natural decay of aircraft will occur in any body of water (the rate of decay is based on depth, salinity, oxygen, temperature, and water movement, among other considerations). For this survey I wanted to test the hypothesis that natural decay will be accelerated if the aircraft was broken up upon impact as the result of a high speed crash, namely because any warping, tearing, or fire compromises aluminum strength. Controlled aircraft water landings, such as ditching or dumping, usually result in the aircraft's overall integrity preserved intact.[242] Alternatively, an aircraft that has fully crashed into water is usually in two or more pieces or entirely disarticulated (incidentally and interestingly the Swedish DC-3 wreck is a rare exception). I based my hypothesis on the observation that aircraft metals decay faster underwater when they are

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[241] MacLeod 1997; MacLeod 2003; MacLeod 2006; MacLeod and Richards 2014.
[242] Smith 2002.

compromised. Coral growth on aircraft skin inhibits oxygen exposure, and allows for pitting, which accelerates decay. This suggests that at least in regard to Croatia, wrecks will be found in better states of preservation at depths up to 80 m, and that the torn edges of aircraft aluminum will read as active in the corrosion diagram.

Currently, there are three other B-24 starboard wings in known locations around the island that are under 40 m depth. Divers discovered two other complete B-24 wreck sites in 2016 near Bisevo at 90 m and Svetac at 110 m depth. For the experiment I took corrosion readings from, and performed visual analysis on, two of the aircraft wings- one at 14 m and the other at 31 m, and *The Tulsamerican*'s wing. Each of these single-wing sections were netted and carried into shallow bays by local fishermen, where they were dumped prior to 1970 (Figures 7.34-7.35).

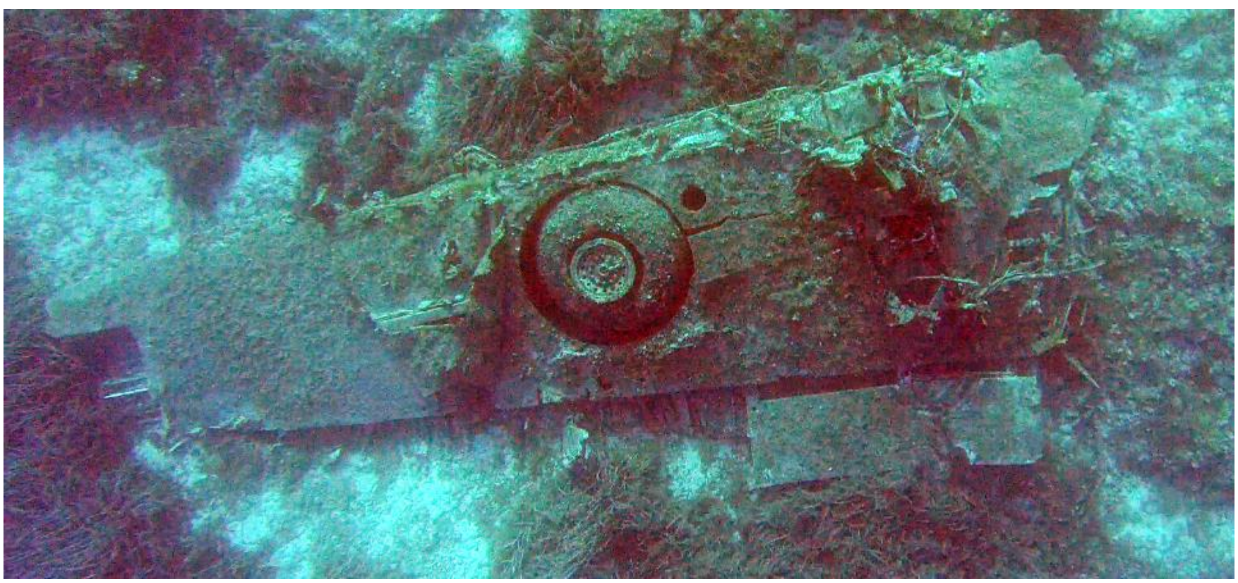

Figure 7.34- This B-24 starboard wing is located in a shallow bay on the northwest side of Vis at 14 m. It presents visually as intact except for either wreckage or drag damage, with almost no pitting loss or encrustation and only a thin layer of marine growth. Photo by Dr. Bridget Buxton.

Figure 7.35- This B-24 wing lies close to the shore in the harbor of Komiza at 31 m deep. It was difficult to visually survey this wing as it is almost completely covered in netting. This starboard wing is missing both the leading and trailing edges, the tire, and the engines. Our team, the author on the right, is taking images for a 3D model and performing the corrosion potential analysis. Photo by Danijel Frka.

Methods and Readings

I used a corrosion potential measurement device loaned from the Department of Materials Conservation at the Western Australian Maritime Museum. The device comprises two meters, a pH reader and a voltage reader, combined in a deepwater housing. The pH meter has a flat-surface measuring electrode with a rubber cuff and the voltage meter has a seawater reference electrode and a platinum pointer for metal contact. I took corrosion potential readings on multiple points on the skin and light structural areas of three starboard B-24 wings and pH readings from two (Table 7.2) (Figures 7.36-7.38).[243] I took the readings by placing the pH reader against a freshly scraped small surface area, followed by the tip of the voltage meter electrode. The next year, I observed that marine growth had reappeared over the scraped areas.

I converted these readings in reference to the electrode and plotted the results on aluminum's active vs passive Pourbaix diagram (Figure 7.39). In 2015 and 2016 I took water samples from the measurement areas in order to duplicate pH readings and also to check salinity and dissolved oxygen. The samples were lab tested from the sealed sample containers, as opposed to measured at depth, which may have skewed results in and unknown way, however the uniformity and the variation in yearly data suggest the readings are valid (Table 7.3). I plotted one reading from the B-24 wing in Komiza Harbor on the Pourbaix diagram using a mean pH value as corrected from the 2015 water sample data.

[243] Unfortunately, the pH-measuring electrode abraded prior to taking readings on the last B-24 wing, so these measurements are listed as N/A in the Table.

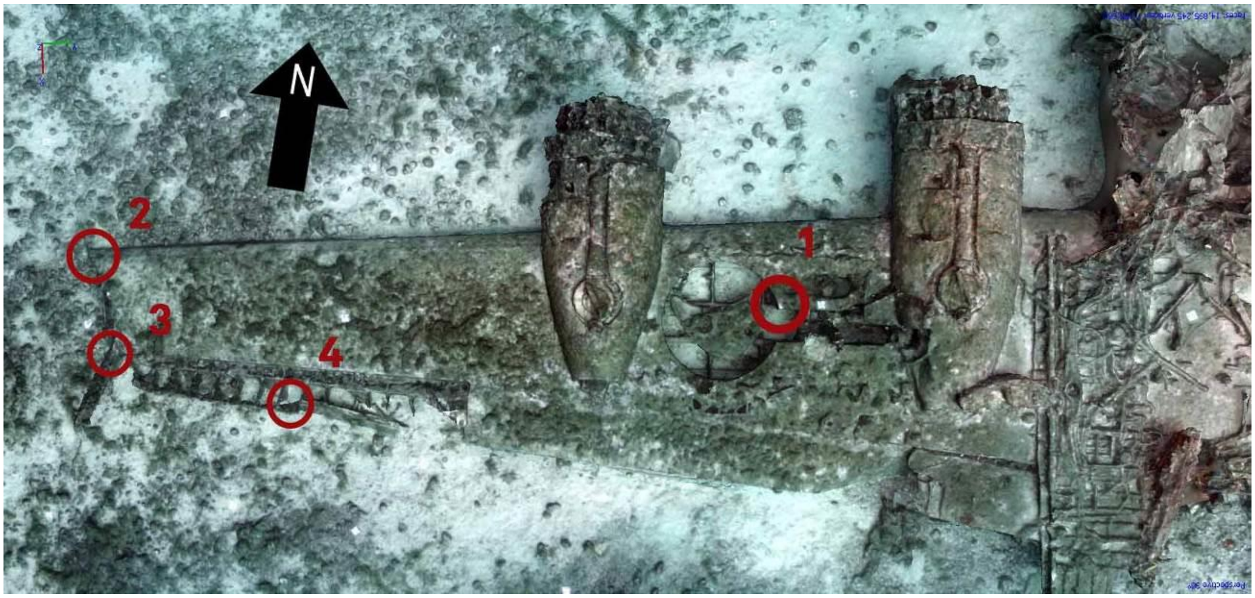

Figure 7.36- *The Tulsamerican* measurement points. Photo by the author.

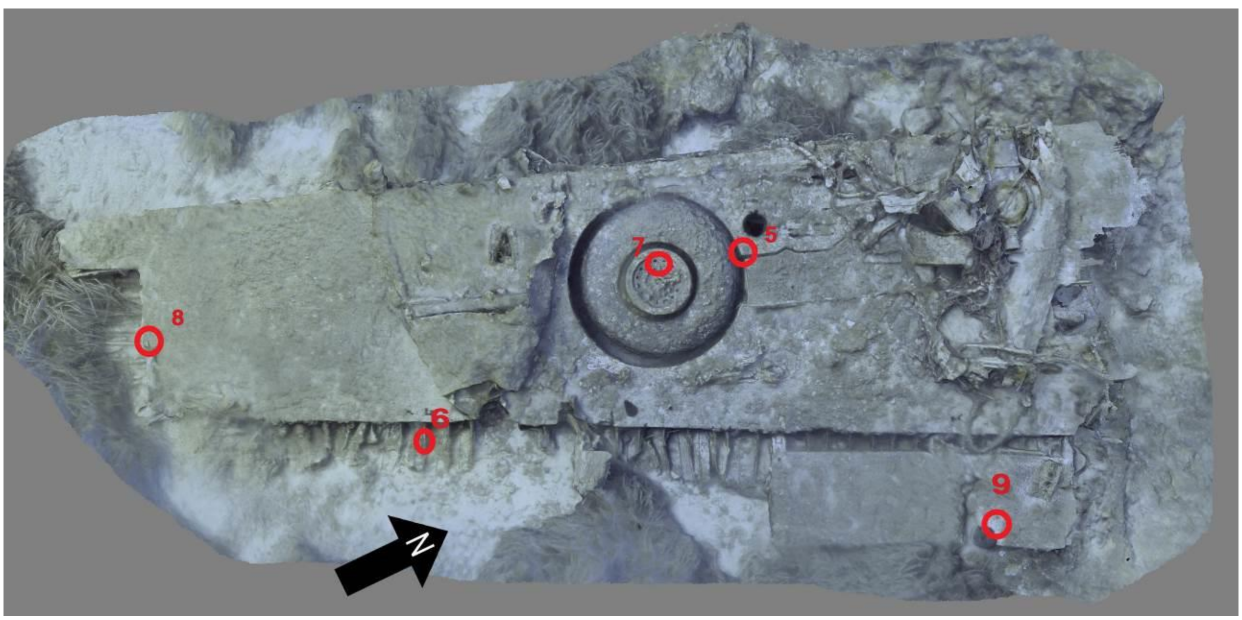

Figure 7.37- B-24 Wing, Shallow Bay measurement points. Photo by the author.

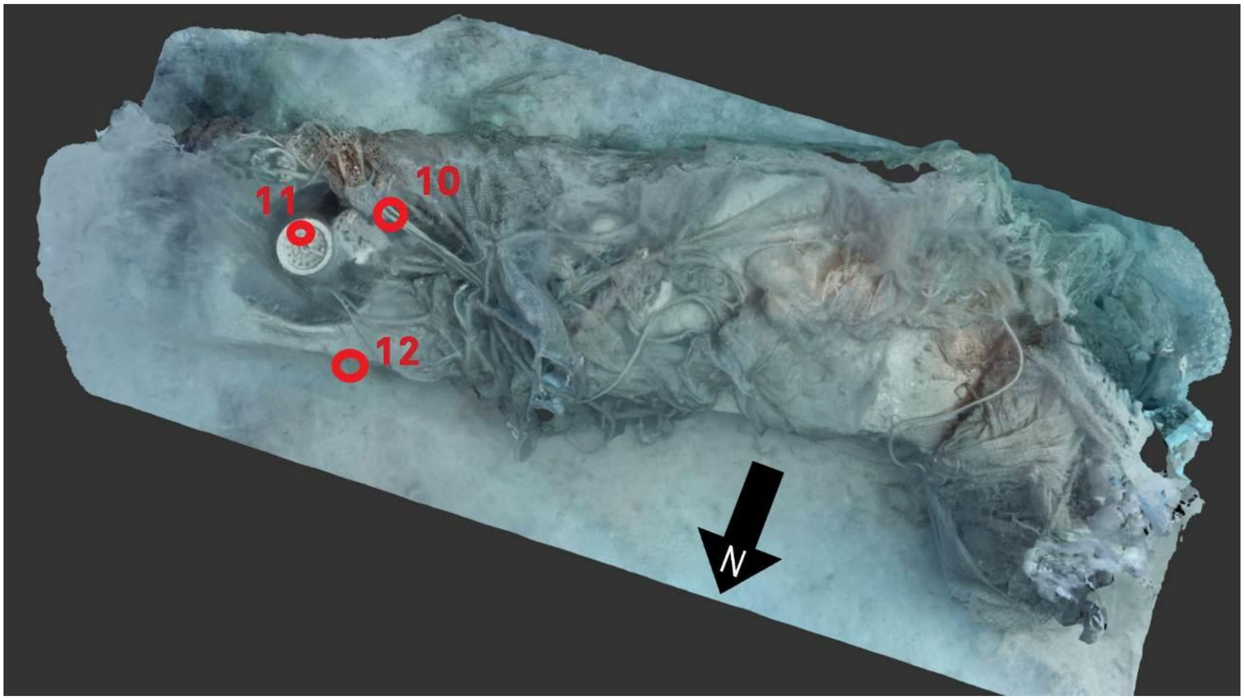

Figure 7.38 Measurement locations on B-24 Wing Komiza. Photo by the author.

Table 7.2- ECorr Measurements for B-24 Starboard Wings near Vis, Croatia

Identification	*Measurement Location*	*pH Reading*	*ECorr Reading*	*ECorr ref-Ag/AgCl/sea water electrode (.4365V) rel. to NHE*	*Depth*	*Location Reference in Figures*
B-24 The Tulsamerican	Starboard wing, near wheel well and landing light	6.09	-.721	-0.2845	39.6m	1
B-24 The Tulsamerican	Wing edge, Corner	6.18	-.720	-.2835	40.5m	2
B-24 The Tulsamerican	Aileron, Starboard	6.23	-.720	-.2835	40m	3
B-24 The Tulsamerican	Wing edge, broken	6.20	-.695	-.2585	40.8m	4
B-24 Wing Shallow Bay	Starboard wing, near wheel well and landing light	6.50	-.729	-.2925	13.7m	5
B-24 Wing Shallow Bay	Aileron, Starboard	6.38	-.728	-.2915	13.7m	6
B-24 Wing Shallow Bay	Metal wheel	6.47	-.728	-.2915	14m	7
B-24 Wing Shallow Bay	Wing edge, broken	6.00	-.728	-.2915	14.8m	8
B-24 Wing Shallow Bay	Painted piece of flap	5.95	-.729	-.2925	14m	9
B-24 Wing, Komiza	Starboard wing, near wheel well and landing light	N/A (6.53)	-.728	-.2915	31.3m	10
B-24 Wing, Komiza	Metal wheel	N/A	.728	-.2915	31.5m	11
B-24 Wing, Komiza	Wing edge	N/A	.728	-.2915	31.9m	12

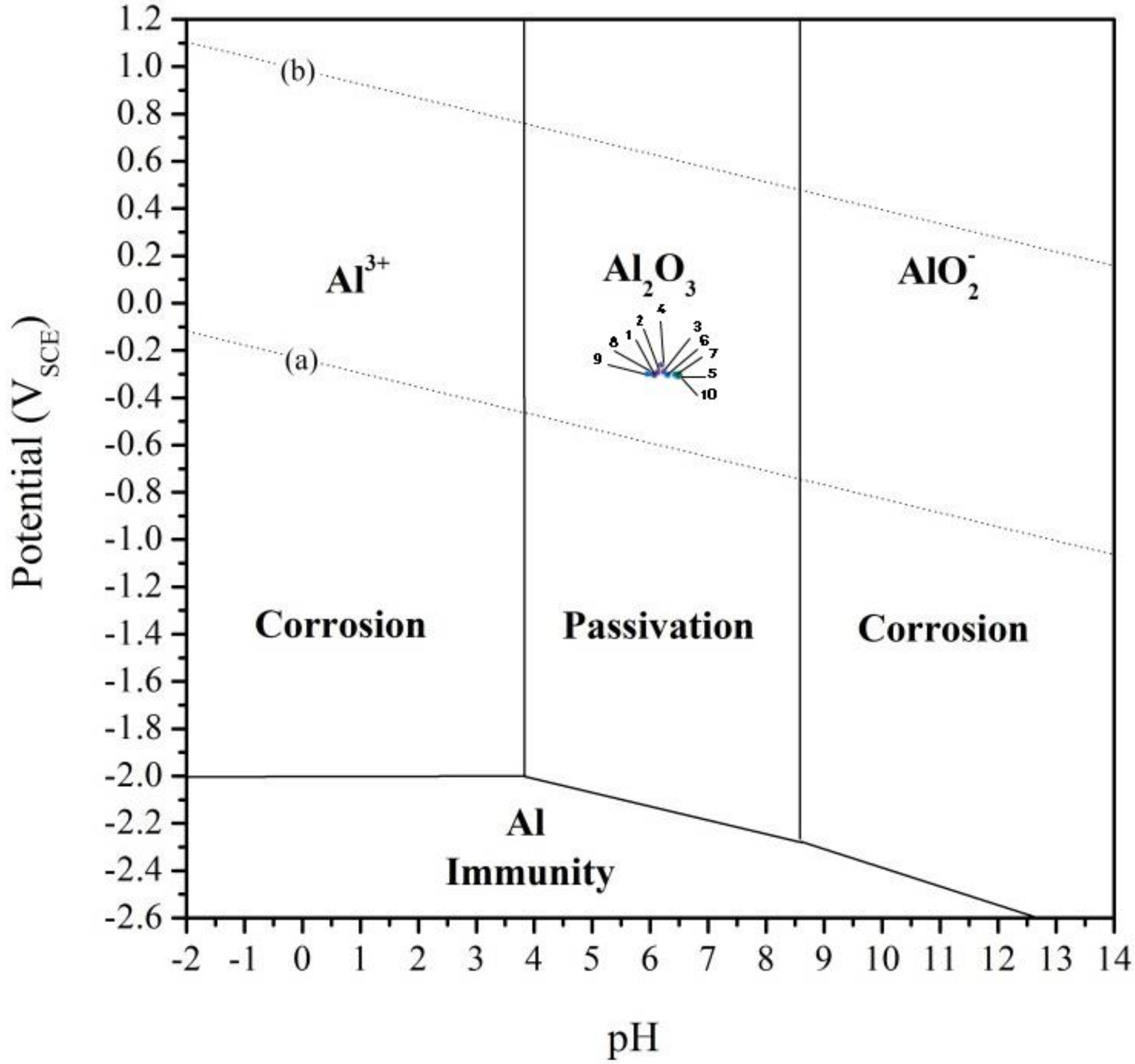

Figure 7.39- A Pourbaix diagram for Aluminum in Seawater at 25°C with plotted points from Table 7.2, showing all the metal to be in similar states of passivity. Produced by the author.

Table 7.3- Water Quality Measurements for B-24 Sites near Vis, Croatia

Identification	*Collection Date*	*Depth in m*	*Dissolved Oxygen (DO) in mg/L*	*pH*	*Salinity (S) in ppm*	*Temp at Depth*
B-24 The Tulsamerican	9/26/2015	39	8.13	7.76	40,900	17.2°C
B-24 The Tulsamerican	9/28/2016	39	10.7	7.45	38,900	20.0°C
B-24 Wing Shallow Bay	9/25/2015	14	7.46	7.81	42,500	20.0°C
B-24 Wing Shallow Bay	9/29/2016	14	10.4	8.04	39,100	22.8°C
B-24 Wing, Komiza	9/30/2015	31	ND	7.45	42,200	18.9°C
B-24 Wing, Komiza	9/29/2016	31	10.6	8.06	39,500	23.3°C

Conclusions

Initially I predicted that the corrosion potential readings as plotted against a Pourbaix diagram would show a difference in the corrosion potential of these three aircraft, and that the aircraft at shallower depths would be better-preserved due to less marine growth. Results have disproven my original hypothesis and in fact, the metal on all three sites is surprisingly well-preserved and has limited overall deterioration. *The Tulsamerican* site, despite its deposition damage, is not deteriorating at a higher rate than the shallower wing sections. The three B-24 sites are all relatively visually similar in terms of skin thickness and aluminum decay, and plot close together on the Pourbaix diagram. All of the samples plot well in the passive region for aluminum in sea water. This does not mean that corrosion cannot occur, but the passivation layer generally protects aluminum against uniform or partial corrosion, making localized pitting corrosion more common if any corrosion occurs.[244]

Readings for dissolved oxygen, salinity, temperature, and pH vary year to year, perhaps pH varying the least. Dissolved oxygen in the Adriatic, according to these readings, appears high when compared to data from other aircraft wreck sites, but these readings are not corrected for the 5-10° temperature difference in sampling.[245] The dissolved oxygen content might account for the strength in aluminum wrecks in this area, given aluminum's self-passivation in an oxygen-rich environment, but further tests should be made at depth. The Adriatic also is a region of high salinity, and it is generally agreed that higher salt content would increase corrosion, but this appears not to be the case with these aircraft wrecks. Based on the visual and ECorr data, one can predict that non-compromised metal aircraft wreckage as deep as 50 m in the Adriatic will remain in good condition with slow deterioration. Localized pitting corrosion is most likely in cases of missing metal. Fishing and diving activity, as opposed to environmental or decay, is likely the cause for any significant site disturbance after deposition.

Future study should extend research to include B-24 wrecks deeper than 50 m. Divers recently located wreckage at 90 m and 110 m and the wrecks visibly show more marine and

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[244] Sukiman et al. 2012.
[245] Richards and Carpenter 2012.

coral coverage. Readings for corrosion potential and water chemistry would serve to further correct this hypothesis and provide a more accurate chart for aluminum decay in this region.

7.4 Associated Artifacts[246]

The Croatian Conservation Institute removed several artifacts from *The Tulsamerican* site in 2010 prior to opening it for recreational diving. Ministry officials kept these artifacts in wet storage until 2013 when the conservation department of the Croatian Ministry of Culture was reorganized. Officials then removed the artifacts, except for one, from wet storage and placed them on a wood pallet in warehouse storage in Split (Figure 7.40). The artifacts consisted of a browning machine gun and shells, two aluminum radios, a wallet, a flak jacket, a signal lamp, an electric plug, and other unidentified debris. Unfortunately, the items are quickly deteriorating. Only one artifact, the data plate removed from the cockpit, received conservation treatment. I documented these artifacts in 2014, including photos for a condition baseline and for 3D modeling. Artifacts from this wreck also exist in private collections.

[246] Artifact descriptions and images are in Appendix F.

Figure 7.40- Artifacts removed from *The Tusamerican* site in 2010. Photo by the author.

7.5 Museum Display

The Tulsa Air and Space Museum in Tulsa, OK houses the current display of *The Tulsamerican* history and crew member stories. The museum has personal items from Val Miller, John Toney, Russell Landry, and Gerald Ford, as well as the scroll of war bond-purchasers for *The Tulsamerican* and its leather case, and a logbook for the pilot who ferried the aircraft across country and to Europe.

For the eventual display of *The Tulsamerican* history, I have been planning the surveys intending to show the results via a museum setting. The archeological community is embracing three-dimensional modeling, which is also the perfect tool to use for the non-academic public. A visual representation of the site, as well as being a fun interactive and providing information on how the site is deteriorating, will be exciting for visitors and help the museum raise funds for future recoveries.

Several smaller pieces of wreckage might, in future, be beneficial for the Tulsa Air and Space Museum to recover and conserve for display. In the deeper section near the ridge wall, the port vertical stabilizer appears to be wrenched into two pieces with only one remaining. The starboard vertical stabilizer is in almost identical condition near the tail and either should include the area on which the aircraft's serial number appears stenciled. Two propeller assemblies lay disarticulated from the wreck site and would serve as good display items. Also, a section of fuselage with the remains of the painted nose art could potentially could be detached, conserved, and displayed.

Working with the Tulsa Air and Space Museum I have proposed a set of interpretive renderings for a new exhibition which utilizes the historic artifacts and images, the new visual data from the wreck site, and future recovered items, if possible (Figures 7.41-7.43). This display's communication objectives will be the understanding of how the aircraft touched the lives of many people across several different communities. The display will explain the effect *The Tulsamerican* had on the community and what happened to the aircraft after the wrecking event, as well as what will happen to it in the future. The 3D models will allow for better representation of the wreck than a video or set of pictures, and the visitor will be able to understand the wreck and its surroundings. Using archaeological evidence to build a comprehensive history gives a museum better story-telling ability, which can ensure it remains relevant and sustainable.

Figure 7.41- This large-scale map display will place *The Tulsamerican*'s history in context with the places it flew and the objects associated with it. This area may also have room for artifacts recovered from the wreck, or a digital display of the wreckage against a full-size example, like the engine on the right. Rendering by Eve Bartolo, FRD, with direction from the author.

Figure 7.42- These showcases focus on the individuals associated with *The Tulsamerican*, and some of their personal artifacts. This exhibit will lead to the enclosed space discussing the wreckage. Rendering by Eve Bartolo, FRD, with direction from the author.

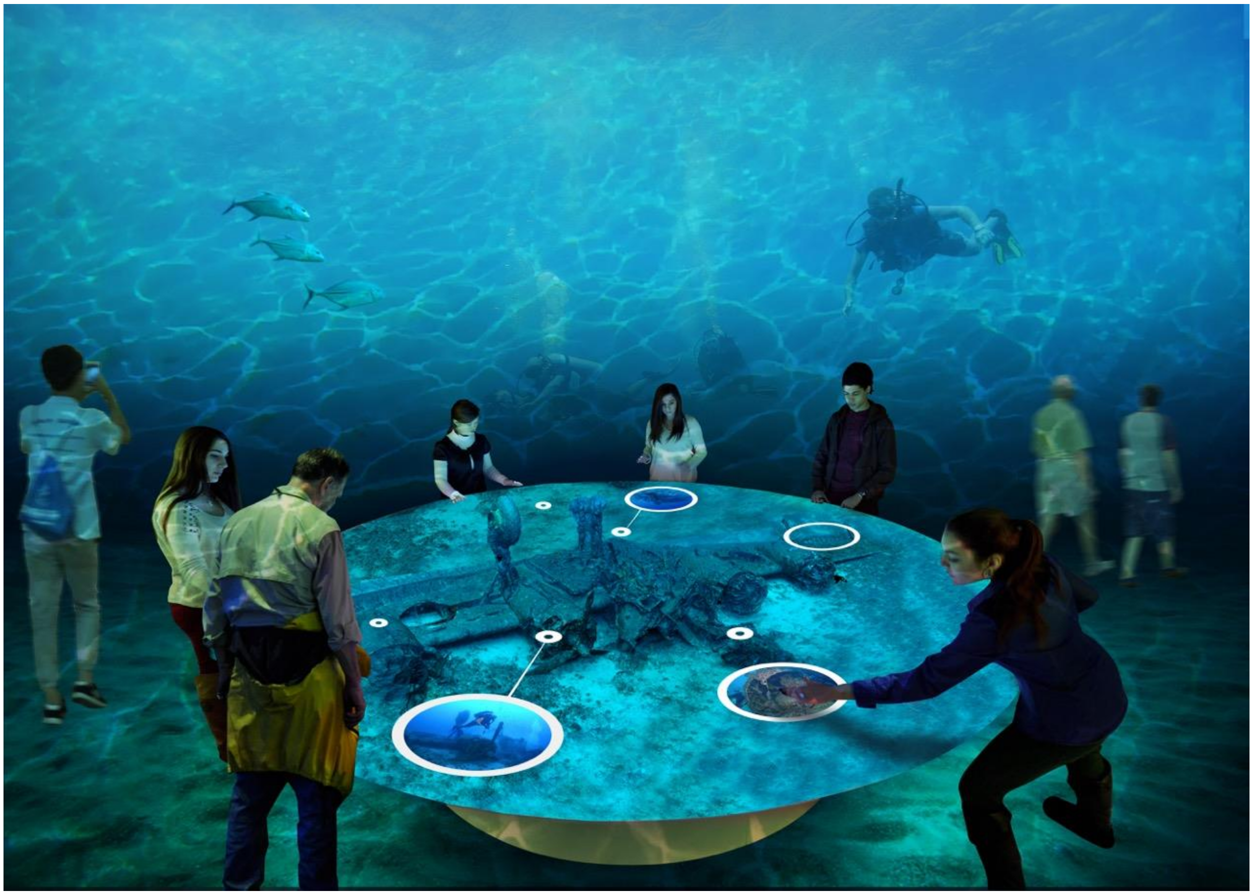

Figure 7.43- This touch table holds a 3D model of the site, and visitors can manipulate it, as well as interact with it by calling up alternative wreck images, historic photographs, or facts and other information. Rendering by Eve Bartolo, FRD, with direction from the author.

7.6 Case Discussion

Years of research and interest by American and Croatian stakeholders resulted in the 2010 discovery of *The Tulsamerican*. Our 2015 survey represented the first archaeological documentation of underwater aircraft in Croatia, and took place just after the first terrestrial documentation of an aircraft wreck in the country.[247] The survey created a baseline condition report on the visual condition and corrosion potential of the wreckage, and compared the results to other B-24s in the area at different depths. A 3D model of this site from 2015 will be available for comparisons to the site now that it has been excavated for human remains. Continued 3D modeling and other recording, corrosion potential readings, and water quality data can map any change in deterioration over time. This survey demonstrated an example of baseline research and data that can build into a maintenance survey whose results would be easy to acquire and valuable to the archaeological and regional community. This case study exemplifies an aircraft site with a strong community tie, in which partial excavation and alternative display methods would best serve museum display and convey authoritative, relevant communication objectives to visitors, without the expense and space requirements of raising and conserving the entire aircraft.

The Tulsamerican was a local community icon in WWII, and still remains important to several different communities today. Friends and family members of the crew members have been greatly impacted by the wrecking event, the discovery of the aircraft, and the recent excavation and recovery of remains. The diving community in Vis also consider the site to be extremely important in terms of tourism. Parts of other B-24s found either on the island or in the surrounding shallow water are currently in the museum on Vis island, but not on display. B-24J *The Tulsamerican,* the remains of at least eleven other B-24s, and an undocumented number of other WWII aircraft lie in various depths around the island of Vis, Croatia. Time and funding permitting, this project would benefit from a regional survey of underwater cultural resources,

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[247] Sinobad 2015.

which would contribute to the archival research being completed is the area. A critical site formation survey of identified B-24 wrecks and their wrecking event reports will enable future researchers to positively identify wrecks based on the breakup of the airframe.

8. CASE STUDY- USS *MACON*

The second case study in this dissertation focuses on the wreck site of the USS *Macon* and its four F9C-2 Sparrowhawk biplanes. This case study serves to showcase an example of long-term stewardship, visual deterioration analysis, and artifact conservation procedures. USS *Macon* lies off the coast of Point Sur, California, in around 441 m depth. Its remains constitute some of the oldest known aviation artifacts in salt water. Fortunately, interest in the wreck site has also led to multiple surveys, making the USS *Macon* and the associated aircraft one of the longest-monitored aviation sites anywhere underwater. In 2015 a collaborative survey with multiple stakeholders took place to monitor the physical deterioration of the wreck site and to recover samples for conservation study. The goals of survey are more specifically addressed in section 8.2 below, but included 2D mapping of the site and surrounding environment, 3D site mapping methodology experimentation, visual deterioration analysis, corrosion potential measurements, and an anticipated museum display of digital data visualization products and conserved artifacts. The results of the survey support federal and state ongoing stewardship of the wreck site, and engage public interest in cultural heritage resources under water.

8.1 Background History

8.1.1 USS *Macon* Design[248]

During the inter-war period the US Navy began its lighter-than-air program by researching and building airships. An airship is a natural development from a hot air balloon towards active control. Airships, dirigibles, zeppelins, and blimps are all aircraft that inflate and float with gas that is lighter than air, and they are powered and steerable. Rigid airships have a

[248] Full Specifications and plans are in Appendix G.

structural framework that maintains its shape even with loss of pressure, semi-rigid airships usually have a limited structure or a keel, and blimps inflate only because of gas pressure and have no internal structure; zeppelin is a type of airship manufactured by the Zeppelin Company.

Akron-class airships, named after *Akron* (ZRS-4), were commissioned to be the beginning of an airship fleet that would serve as 'an early warning defense line' on both coasts of the US.[249] At 240 m long with a 40.5 m beam and nearly 185,000 cubic meter capacity, they were the largest U.S. naval airships built to that time. They were also the first flying aircraft carrier and had the ability to carry five aircraft.[250] The ZRS airships were designed with three rigid keels, one at the top providing a triangle-like support strength for the two lateral keels, which allowed for mounting of four engines on each side. Having the third keel at the top meant that the bottom of the airship was open and could allow for the aircraft hangar inside the belly of the airship.

[249] Nye 1958.
[250] Smith 1965.

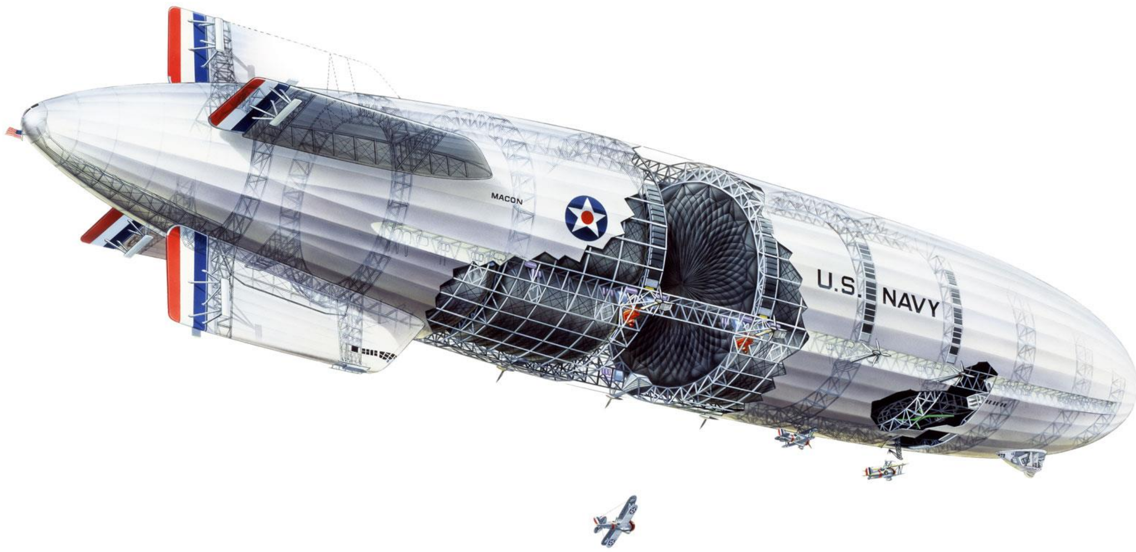

Figure 8.1- ZRS airship construction. Reprinted from Vaeth 1992.

The ZRS airships had twelve gas cells that held the helium lifting gas; USS *Macon*'s cells were made with cotton cloth that was impregnated with a gelatin-latex compound. This was a developmental upgrade over previously used ‘goldbeater's skin’, which was made from cow intestinal membranes. The bags had a valve venting system that officers on the bridge of the airship could manually or automatically control. Unique to the Akron-class airships was a ballast control system, presenting as external radiator-like racks running flush with the hull above each engine. These systems would capture exhaust from the engines and convert it to water. Dumping the water would change the ballast weight in the airship.

The airships were designed to be operated like ships, and as such had control and living quarters. There was a main control cab forward of the hangar which held the primary steering and communications gear. A backup control cab with steering gear was built into the forward end of the lower fin. The living areas consisted of seven bunkrooms, bathrooms, mess rooms, and officer’s areas (Figure 8.2). There was a galley, a radio room, and officer’s cabins. In order to save weight, all outfitting of airship spaces, e.g. furniture, desks, bunks, etc., were made of aluminum.

Construction on the USS *Macon*, ZRS-5, began in the Goodyear factory in Ohio on October 1931 and the new airship was completed in March 1933. *Akron* crashed on April 4, 1933 with the loss of 73 crew members. When *Akron* crashed it was not carrying any aircraft in the hangar, so the eight FC9-2 aircraft transferred to *Macon* (Figure 8.3).

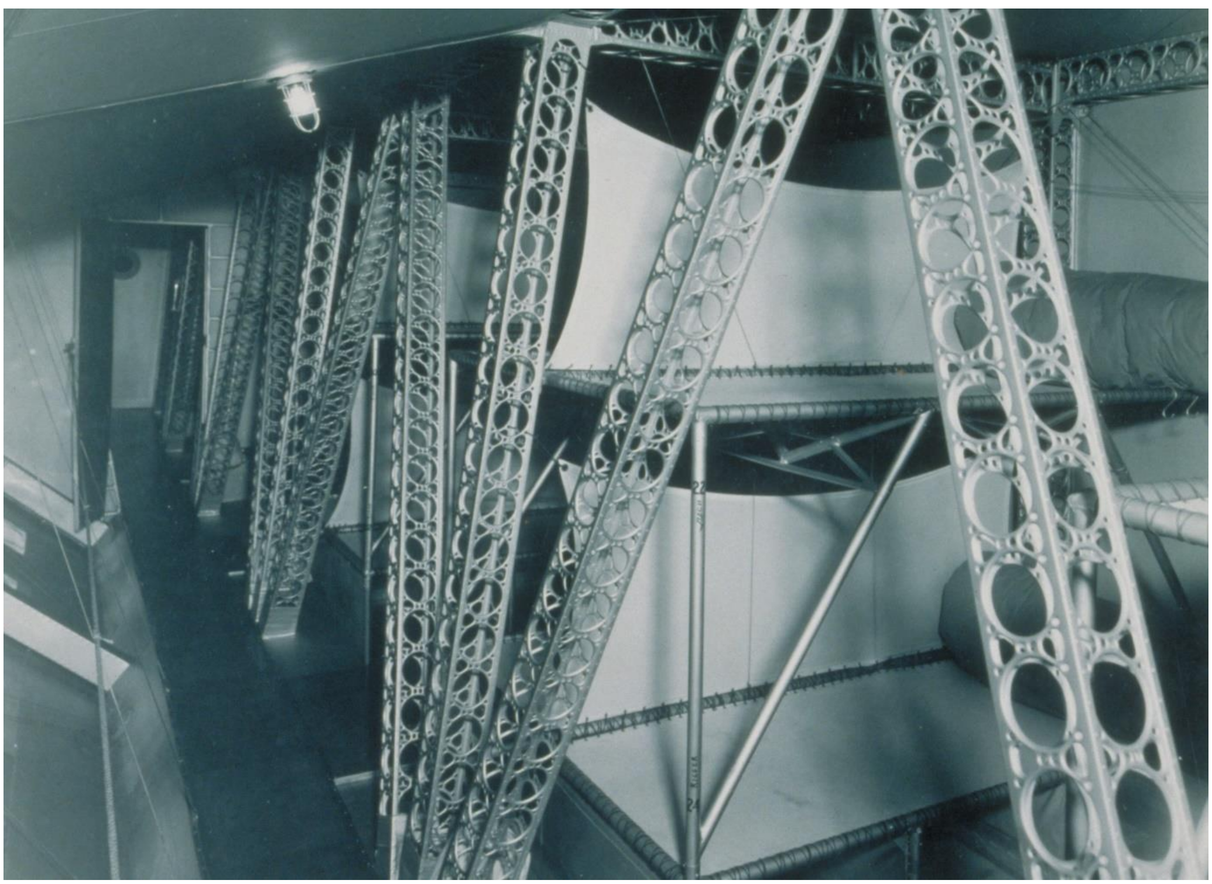

Figure 8.2- Bunk quarters for enlisted men in the USS *Macon* airship. Photo from the US Navy Archives.

Figure 8.3- USS *Macon* with two biplanes. Photo from the National Archives.

8.1.2 F9C-2 Sparrowhawk Aircraft[251]

The F9C type parasite aircraft is a light biplane with a steel and aluminum structure covered in doped fabric (Figure 8.4). The F9C-2s were designated ‘Sparrowhawk’ in keeping with the tradition of naming Curtiss fighters after hawks. F9C aircraft were planned to improve the scouting capabilities of the ZRS airships by the two working together in a mother ship/scout-type partnership. The US Navy chose them because of their small size, which allowed them to fit through the airship’s hangar door space, and low weight. The F9Cs were designed to launch, maneuver around the airship hangar, and ‘attach’ to the airship via a trapeze system lowered from the hangar (Figure 8.5). As such, the insignia for the aircraft was a stylized logo of a large circus performer man on a trapeze extending his arms to catch a smaller man (Figure 8.6).

[251] Full specifications and plans are in Appendix H.

Figure 8.4- F9C-2 Sparrowhawk aircraft flying in formation over USS *Macon*'s hangar at Moffett Field, CA. Photo from the Wiley Collection, NASM.

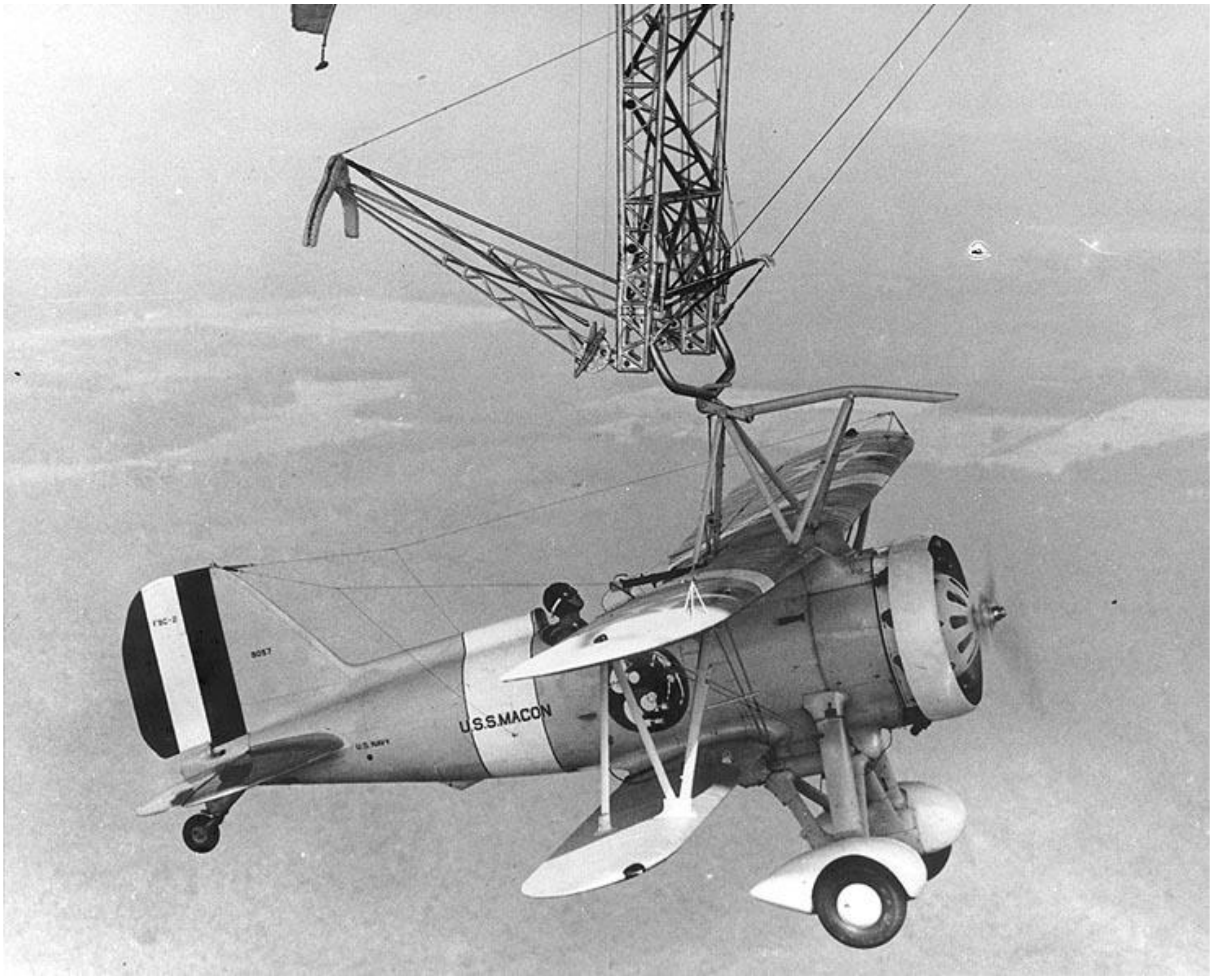

Figure 8.5- F9C-2 BuNo 9067 with white chevrons on the wings, a white band behind the fuselage, and white painted cowling and wheel pants, demonstrates the hooking mechanism that is attached to the aircraft. This allowed the biplane to hook on to the lowered trapeze from the airship's hangar. Once inside, each aircraft hung on a monorail system for storage and maintenance. Pilots could also remove the landing gear for some missions and replaced with an auxiliary fuel tank for extended range. Photo from the Wiley Collection, NASM.

Figure 8.6- The insignia on the fuselage of each F9C-2 aircraft. Photo from the Wiley Collection, NASM.

Curtiss Aircraft Company built the first experimental version of the aircraft, the XF9C-1, and delivered it to the US Navy in 1931. This aircraft was never intended to serve aboard either ZRS airship and was flight tested and modified throughout its life. X-F9C-2 began flight trials in September 1931 and the two parties soon after signed a contract for six aircraft. After their delivery to the US Navy in early 1932, the first three Sparrowhawk aircraft began training with *Akron*. The other three, delivered in September 1932, were outfitted and used as spares. Each aircraft was painted with squadron leader markings in a designated color on a top wing chevron, the engine cowl and the wheel spats. After the loss of *Akron* and the transfer of the airship to California, the four aircraft designated for routine missions on *Macon* were the final four F9C-2 aircraft delivered (Table 8.1).[252]

Table 8.1- F9C-2 Sparrowhawk Aircraft Data

Designation	*Serial #*	*Trials Begun or Date Accepted*	*Marking Color 1932-1934*	*Marking Color 1934-1935*	*Date Stricken*	*What Happened to it*
XF9C-1	8731	2/12/1931	None	None	1/31/1935	Scrapped
XF9C-2	9264	Spring 1932	None	None	11/16/1936	Combined with 9056 for donation to NASM
F9C-2	9056	5/5/1932	Royal Red	Royal Red	10/31/1939	Combined with 9264 for donation to NASM
F9C-2	9057	7/12-1932	White	White	11/30/1936	Scrapped after accident
F9C-2	9058	9/12/1932	True Blue	Royal Red	2/28/1935	Lost aboard *Macon*
F9C-2	9059	9/22/1932	Black	White	2/28/1935	Lost aboard *Macon*
F9C-2	9060	9/22/1932	Willow Green	True Blue	2/28/1935	Lost aboard *Macon*
F9C-2	9061	9/22/1932	Lemon Yellow	Black	2/28/1935	Lost aboard *Macon*

[252] Andrews 1987.

8.1.3 Operation History and Wrecking Event[253]

In October 1933 *Macon* transferred from NAS Lakehurst to a new hangar at NAS Moffett Field. During the transfer, while flying over the Rocky Mountains, the airship experienced damage to its upper tail fin. The damage was patch repaired, but not fully repaired. *Macon* performed poorly in several scouting missions, being discovered and 'shot down' on training missions. In July 1934, Lt. Herbert Wiley assumed command of the airship. He initiated strategic operational changes which had *Macon* serve as a mobile base while the Sparrowhawks performed many of the scouting operations themselves.

Macon was on the return leg of a multiple-day exercise over the Channel Islands on the night of February 12, 1935. The airship was flying through a storm near Point Sur, California when it experienced a significant gust of wind that tore away its already compromised upper tail fin. *Macon* immediately began to lose gas in the aft compartments resulting in a nose-high attitude. The crew began to drop ballast and heavy gear (and attempted unsuccessfully to jettison the F9C-2 aircraft), causing the airship to quickly rise above its ultimate pressure altitude. The pressure initiated release of the pressure valve system on the remaining gas bags, and with the loss of gas *Macon* began to float gently down to the ocean. As the airship sank tail first several crew members later recalled the groaning of the metal frame as it settled into the water. A gasoline fire broke out onboard *Macon* as Navy ships answering its Mayday call arrived to rescue the crew, of whom all but two survived.[254]

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[253] Aircraft Record and Event Cards are in Appendix I.
[254] Vaeth 1992.

8.1.4 Research to Date

In 1988 the US Navy first attempted to re-locate the remains of USS *Macon* and its aircraft with an unsuccessful sonar survey in the area of the recorded sinking. Soon after, an almost concurrent series of events led to the discovery of a piece of the airship from the wreck site and then to its origin.[255] Members of the National Museum of Naval Aviation Foundation in Pensacola, Florida, then proposed the salvage of the aircraft a potential project to the US Navy. In 1990-1991 the Monterey Bay Aquarium Research Institute (MBARI) coordinated with the US Navy to discover and characterize USS *Macon*'s remains at a depth of 441 m. This survey provided images for the first full color photomosaics of the biplanes, which showed an amazing level of preservation (Figure 8.7).[256] During these survey missions MBARI worked with the Navy to collect artifacts, which included a steel and brass trapeze hook from a Sparrowhawk, several duralumin frame pieces, plastic dinnerware, a glass Tabasco bottle, and a small aluminum pulley wheel. Conservators at East Carolina University completed stabilizing treatment on the hook, a frame piece, the pulley wheel, and a sheet of aluminum cowling in 1992. The US Navy planned to recover one of the F9C-2 Sparrowhawks, but ultimately a joint decision was made to abandon these plans.

[255] Grech 2007.
[256] Vaeth 1992.

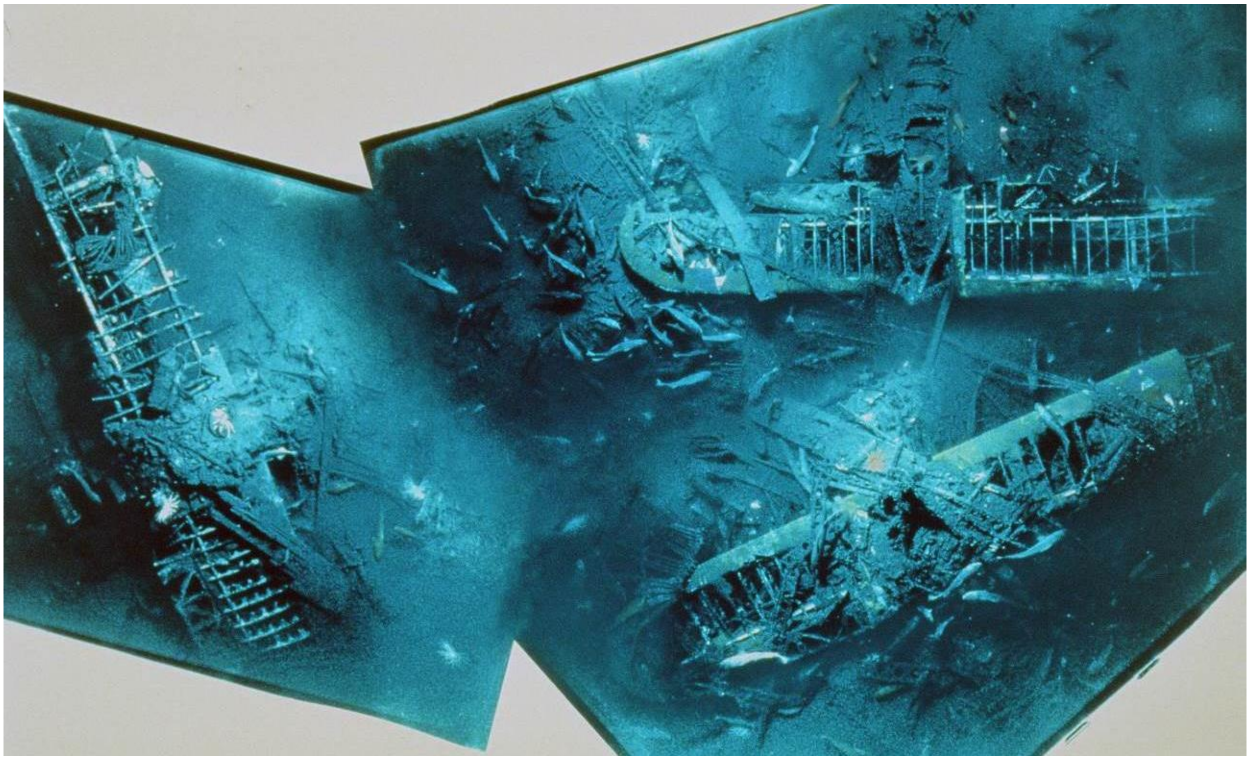

Figure 8.7- Photomosaic images of three biplanes on the USS *Macon* wreck site in 1991. Reprinted from Vaeth 1992.

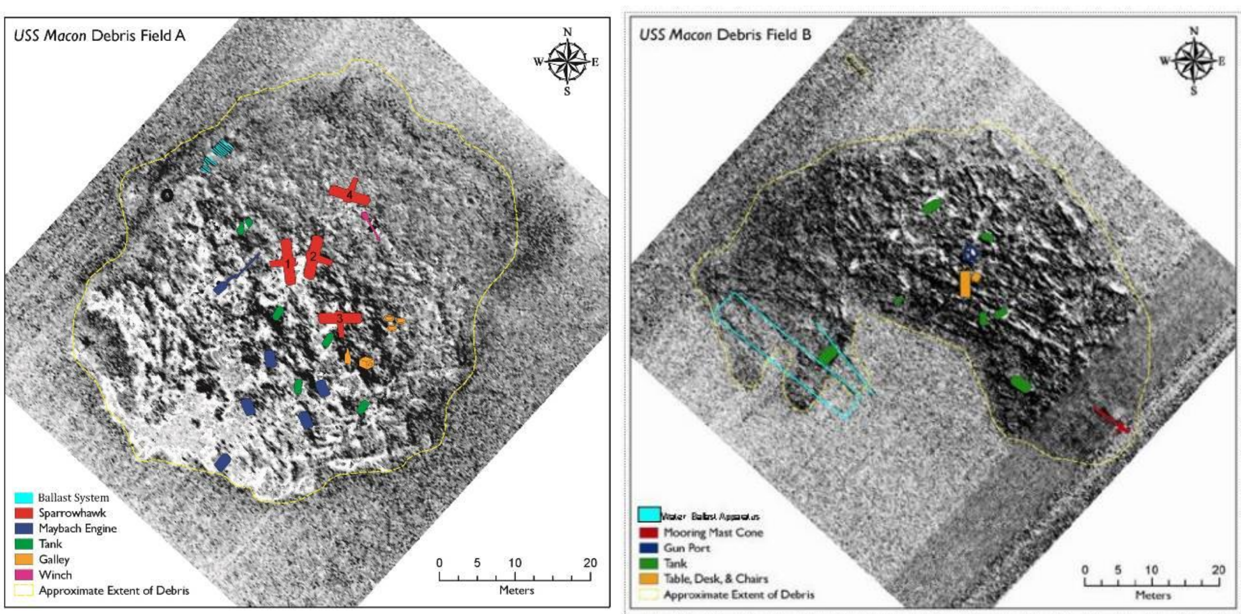

Figure 8.8- Sonar scan images from the joint MBARI/NOAA 2006 survey to discover the boundaries of the USS *Macon* site. Photo reprinted from Grech 2007, as corrected by the author.

The National Oceanic and Atmospheric Administration (NOAA) and MBARI conducted fieldwork for the survey to establish *Macon* as a National Register Site over a four-day period on September 19-22, 2006.[257] Primary goals of the fieldwork included photomosaic mapping of the primary wreckage area and a positive identification of its boundaries through sonar survey (Figure 8.8). The methodology involved high-resolution still photography and a mosaicking algorithm designed by researchers at University of New Hampshire (Figure 8.9). High-definition video used to document the site allowed for visual comparative analysis to the site integrity in 1990-1991.[258] NOAA archaeologists also used video from the 2006 expedition to identify several features and wreck components.

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[257] Terrell and Schwemmer 2006.
[258] Grech 2007; Geoghegan 2007.

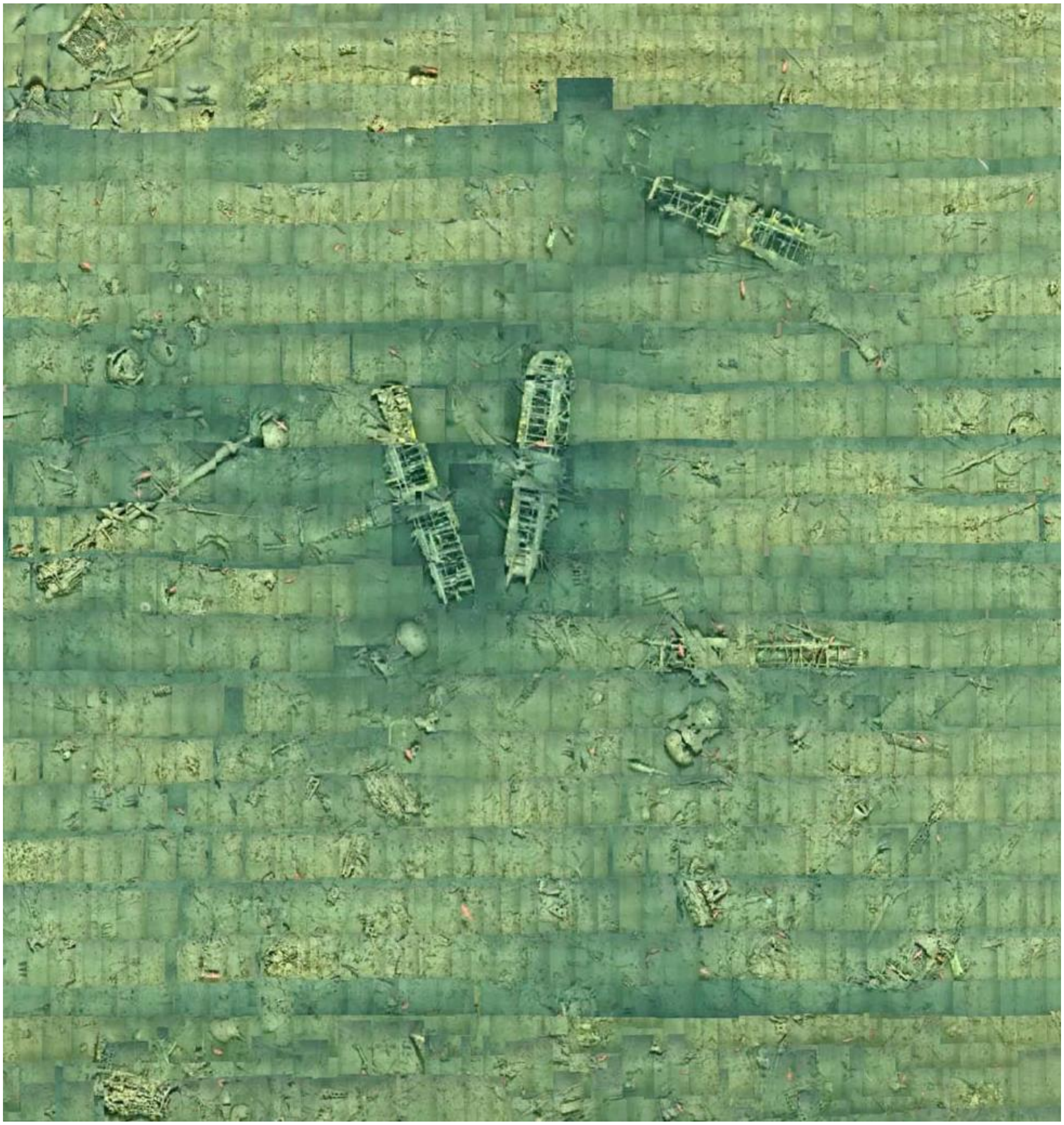

Figure 8.9- This navigation grade photomosaic of a portion of Field A was produced in real time during the 2006 survey. Data storage and processing requirements at the time made working with the 12,000 images difficult. Sparrowhawk F9C-2 biplanes 1&2 are in the middle of the image, 1 on the left and 2 on the right. Biplane 3 is to the northeast, and 4 to the southeast. Reprinted from Grech 2007.

Both phases of the survey assisted in meeting the mandates governing the wreck site. The National Historic Preservation Act (NHPA) directs Federal programs managing public lands to survey and inventory historical and archaeological properties and nominate them to the National Register of Historic Places. The National Marine Sanctuaries Act, which directs the Monterey Bay National Marine Sanctuary (MBNMS) to manage and protect archaeological resources it their boundaries. Using data acquired on the expedition, NOAA staff applied to list the USS *Macon* and the associated aircraft in the wreck site on the NRHP and the application was granted in February 2010, 75 years after its loss.[259]

8.2 Project Planning, Methodology

In 2013 I completed an internship with NOAA's Maritime Heritage Program working with Dr. Jim Delgado and Bruce Terrell researching the *Macon* wreck. When NOAA decided to collaborate with Ocean Exploration Trust (OET) for the 2015 survey summer on California-area submerged cultural resources, NOAA requested that I join the project as co-PI. We planned the 2015 USS *Macon* project to archaeologically survey the wreck site of the airship and its associated biplanes. The project called for both documentation and small item recovery. The survey of the airship site took place at the end of a longer, combined NOAA/OET survey of MBNMS's biological, natural, and archaeological sites. Documentation methods included creating an updated site map photomosaic, completing on-site photography and video, attempting post-survey 3D modeling, and a materials and samples study.

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[259] NOAA/Bruce Terrell 2010; For papers related to the nomination see http://www.nps.gov/nr/feature/weekly_features/2010/USSMacon.pdf.

8.2.1 Research Goals

MBNMS Final Management Plan 2008 emphasizes the systematic assessment and monitoring of archaeological resources as a sanctuary priority.[260] Since the discovery of the submerged remains of USS *Macon* in 1990, NOAA and MBNMS have designated personnel to develop a program to document its archaeological resources through survey and sampling. In the resulting *Oceanography* article, we succinctly defined the 2015 project goals that supported this:

> This project's primary goal was to provide ongoing stewardship of this wreck site by updating site documentation to supplement previous years' surveys. The secondary goal was to study and benchmark site formation processes for an early modern-metals aviation site….The survey's digital documentation methods included creating an updated photomosaic of the two areas of wreckage, on-site photography and video, and post-survey 3D modeling. A detailed study and comparison of the imaging results, along with a sample comparison to 1991 sampled metal, will inform general archaeological knowledge of the potential longevity of aviation sites in deep water. [261]

The imaging portion of the survey was to include enhanced images of the F9C-2 Sparrowhawk aircraft, in particular Biplanes 1 and 2, which are facing each other near the middle of the largest portion of wreckage.[262] The biplanes present a mapping challenge due to their structure and site formation process. Three of the biplanes have top wings that protrude

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[260] Office of Marine Sanctuaries 2008.
[261] Lickliter-Mundon et al. 2016, 44-45.
[262] Individual identification using video from previous years' surveys was not possible prior to 2015, so the aircraft were numbered 1-4. This dissertation retains original numbering to discuss site descriptions. A map is available in section 8.3.1.

from the seafloor, causing information loss for hidden structural areas without an alternate mapping technique. One of the biplanes also presents at a fairly extreme angle in the sediment, possibly due to a collapse. Creating a 3D map will allow for improved documentation and understanding of the aircraft on site deterioration process.

We proposed, but did not have time to complete, a limited but invasive excavation of an area 1x1 m using the ROV's brush tool in an area within the remains of the aircraft hangar, but at a safe distance from the aircraft. The purpose of the excavation would have been to determine the extent of small remains just below the sediment. A secondary purpose would be to determine whether anything remains of the monorail track-system that moved the biplanes inside of the hangar. Third, a strategic excavation would hopefully clarify whether the raised areas present on site are mounded wreckage or geological features.

The project planning called for the recovery of one piece of duralumin girder framework from the remains of the airship. *Macon*'s girders represent the most ubiquitous artifacts at the wreck site. Many present as disarticulated and reflect either the violent rending of the ship's structure during the crash or have fallen apart due to decomposition of the rivets. An acceptable piece would be no longer than 65 cm in length and should not require cutting or breaking. We planned to source this piece from anywhere on the site and focused on the outside edges of the debris field, but the recovery was planned to be entirely opportunistic based on our requirements. We planned to only disturb the area immediately surrounding the sample artifact, if not only the artifact itself.

8.2.2 Partners and Jurisdiction

The 2015 USS *Macon* survey was a joint-organizational project led by co-PIs from three of the stakeholder institutions in this project, NOAA, Naval History and Heritage Command

(NHHC)'s Underwater Archaeology Branch (UAB), and OET. Four different organizations manage the remains of the USS *Macon*. The location of the wreck site lies within California State waters and, therefore, any archaeological survey plan was subject to review by the State Lands Commission.[263] Because this wreck site is listed on the National Register of Historic Places, the Office of Historic Preservation (OHP) was involved in the process. OHP works with the State Lands Commission to issue a permit.

Macon's final resting place lies within the boundaries of the Monterey Bay National Marine Sanctuary, a federally-protected marine area administered by NOAA. The National Marine Sanctuary Act (NMSA) mandates that the National Marine Sanctuaries manage and protect submerged archaeological sites within their boundaries. And as a U.S. Navy craft, the airship and its aircraft remain the property of the US Government regardless of their location or the passage of time. All US Navy property, including the USS *Macon* wreck site and aircraft, is protected from unauthorized disturbance under the Sunken Military Craft Act (SMCA) of 2004 (Public Law Number 108-375).

In accordance with the SMCA, NHHC has established a permitting program, managed by the Underwater Archaeology Branch (UAB), to allow for archaeological, historical, or educational research on Naval submerged cultural resources. UAB also maintains the Archaeology and Conservation Laboratory for the stabilization, treatment, preservation, research, and curation of artifacts recovered from sunken US Naval craft.

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[263] The relevant statutes are codified at California Public Resources Code §§ 6301, et seq., and the regulations are at California Code of Regulations Title 2 §§ 2002, et seq. and 14 §§ 929, et seq. These laws declare that California's archeological resources are endangered by development, increased population, and natural forces and that preservation of these resources is important to illuminate and increase public knowledge of the state's historic and prehistoric past; Terrell and Schwemmer 2006.

8.2.3 Equipment

OET's ROVs *Hercules* and *Argus* conducted photomosaic and microbathymetric mapping from the Exploration Vessel (E/V) *Nautilus*. The ROVs operate in tandem during exploration dives with *Hercules* as the main ROV and *Argus* as both supplemental lighting, cameras, and stability. For the *Macon* survey mission *Hercules* was equipped with several HD cameras, an adapted GoPro camera in a deep underwater housing, sampling boxes, and a bathycorrometer (Figure 8.10). *Hercules* was also equipped with a navigation system capable of USBL mapping.

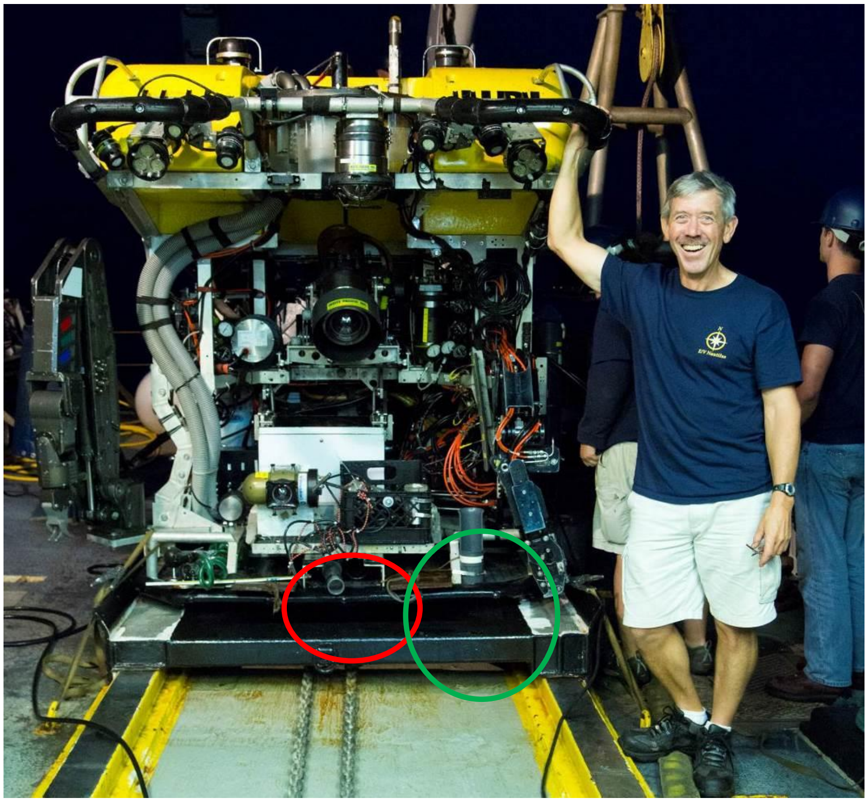

Figure 8.10- Sean Bercaw from OET stands in front of ROV *Hercules* at the end of the 2015 *Macon* survey dive. The GoPro camera is circled in red and the bathycorrometer is circled in green. Photo courtesy of Julye Newlin, OET.

8.3 Survey

The 16-hour survey took place on August 18, 2015 with co-PIs from NOAA (the author as a representative) and OET on board E/V *Nautilus*, and co-PIs from NOAA and NHHC, as well as representatives from MBARI serving as scientists on shore via multiple telepresence centers. Researchers from the University of Rhode Island's Roman Lab aboard *Nautilus* initiated the photomosaic mapping by first establishing a perimeter of the site and quadrants for USBL points. The photomosaic mapping portion was essentially repeating the 2006 survey but with highly-evolved technology and methodology. We mapped the aft portion of the wreckage first and then the forward portion (Figure 8.11). Mapping was planned to require only 8 hours but instead lasted 14 hours, limiting the available time to perform secondary goals.

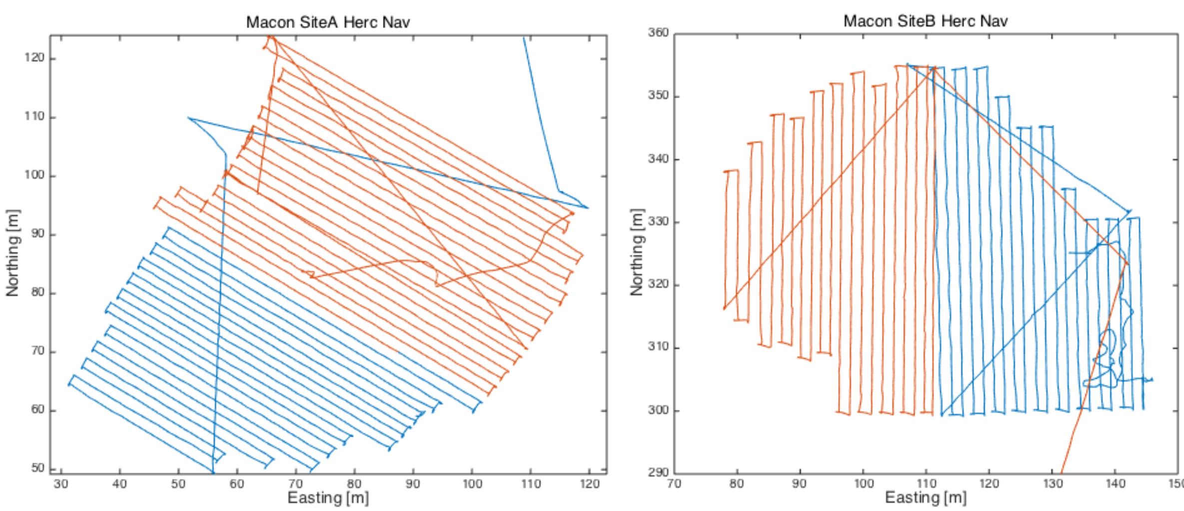

Figure 8.11- ROV path flown by *Hercules*. The diagonal paths are for alignment reference. Photo courtesy of Clara Smart and Roman Lab, URI.

After mapping, *Hercules* flew a pattern on Biplanes 1&2 using its forward-facing HD camera, which was set to a pre-determined tilt and zoom. The ROV filmed the two biplanes in situ in a circular, spiraling movement from left to right and made one pass over the two aircraft. We were only able to make one pass due to time constraints and, unfortunately, neither of the other two biplanes could be videoed for 3D modeling. Lighting on the site was also an issue, as by the time we could commence the 3D video spiral the current had picked up at depth, stirring up a great deal of sediment that showed on film.

We acquired water chemistry readings from the ROV's modified Conductivity, Temperature, and Depth (CTD) profiler for salinity, temperature, and oxygen levels at depth. In its on-board toolbox, *Hercules* carried a rigid ruler, which we used to test the depth of sediment on site. Using the bathycorrometer on the ROV's manipulator arm, we took corrosion potential reading on a disarticulated rib from the starboard wing of Biplane 4. We had endeavored to take one more reading from a disarticulated rib from the starboard wing of Biplane 3, but we eliminated this due to time constraints.

After taking the measurements we attempted recovery of an airship frame piece that we identified lying in front of Biplane 4. We touched the side of the girder piece to determine if sediment was obscuring any additional areas and the piece disintegrated, suggesting the metal was severely compromised. We identified another piece of framework, this one sticking up almost vertically out from the sea floor. The pilot used the ROV's manipulator to grip the piece and place it in the sample box for *Hercules*' return to the surface.

8.3.1 Site Description and Site Formation

The remains of *Macon* lie at 441 m deep approximately seven miles south of Point Sur, California and approximately three nautical miles west of the coastline (Figure 8.12). It is a sandy bottom with a significant amount of loose sediment and marine life. There is some small coral growth on the aluminum pieces but surfaces are mostly covered with a thin layer of marine biofilm or small biological creatures. Metal remains on site range from fragile and corroded to barely deteriorating. Stainless steel items, like the landing gear struts, the brass components of the trapeze hooks, and some aluminum pieces do not show any signs of decay while a large portion of aluminum aircraft and airship remains show exfoliation and pitting corrosion. Impressively, the doped canvas covering for the fuselage and wing surfaces remains present and visible on biplanes 1, 2, and 4, with Biplane 2 showing a clear partial US Navy insignia on the upper wing and Biplane 1 a clear marker band aft of the cockpit (Figure 8.13).

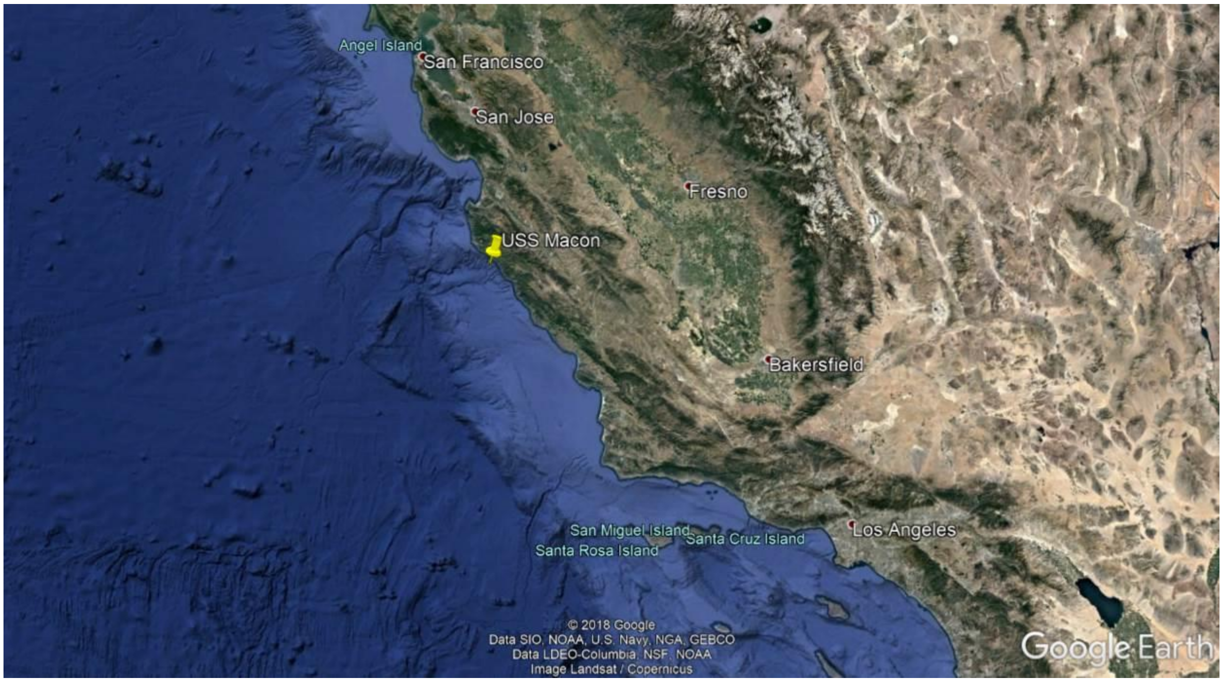

Figure 8.12- The location of the USS *Macon* off the coast of California, USA. Photo from Google Maps.

Figure 8.13- (L) Fabric skin and the remains of the US Naval insignia painted on the top of a F9C-2 Sparrowhawk wing, USS *Macon* field A in 2006. (R) Yellow wing fabric and blue fuselage skin on an adjacent biplane in 2015. Photos courtesy of NOAA/MBARI/OET.

The USS *Macon* wreck site is composed of two distinct areas; here I will continue to refer to them as Fields A and B as they were first identified as in the 2006 survey. A 250 m area devoid of visible wreckage separates the two fields. Field A is approximately 60 m in diameter and includes the aft portion of *Macon*'s remains, up to and including the hangar area and all four biplanes (Figure 8.14). It is a mound-like site elevated between 3-5 m at its center. In 2015 we measured sedimentation depth near to the middle of the mound to be 90 mm, suggesting compact wreckage lies under the top layer of sediment. We located all eight engines in this field, as well as large portions of the water ballast recovery system, some artifacts from the galley area, and several fuel tanks.

Field B is around 60 m x 50 m and resembles a kidney bean shape, wider than it is tall (Figure 8.15). This mound is similarly elevated although we did not perform any sampling of this area. The material in Field B corresponds to the forward section of the airship, containing remains from offices, fuel tanks, a section of water ballast recovery system, pressure control valves, and the bow anchor.

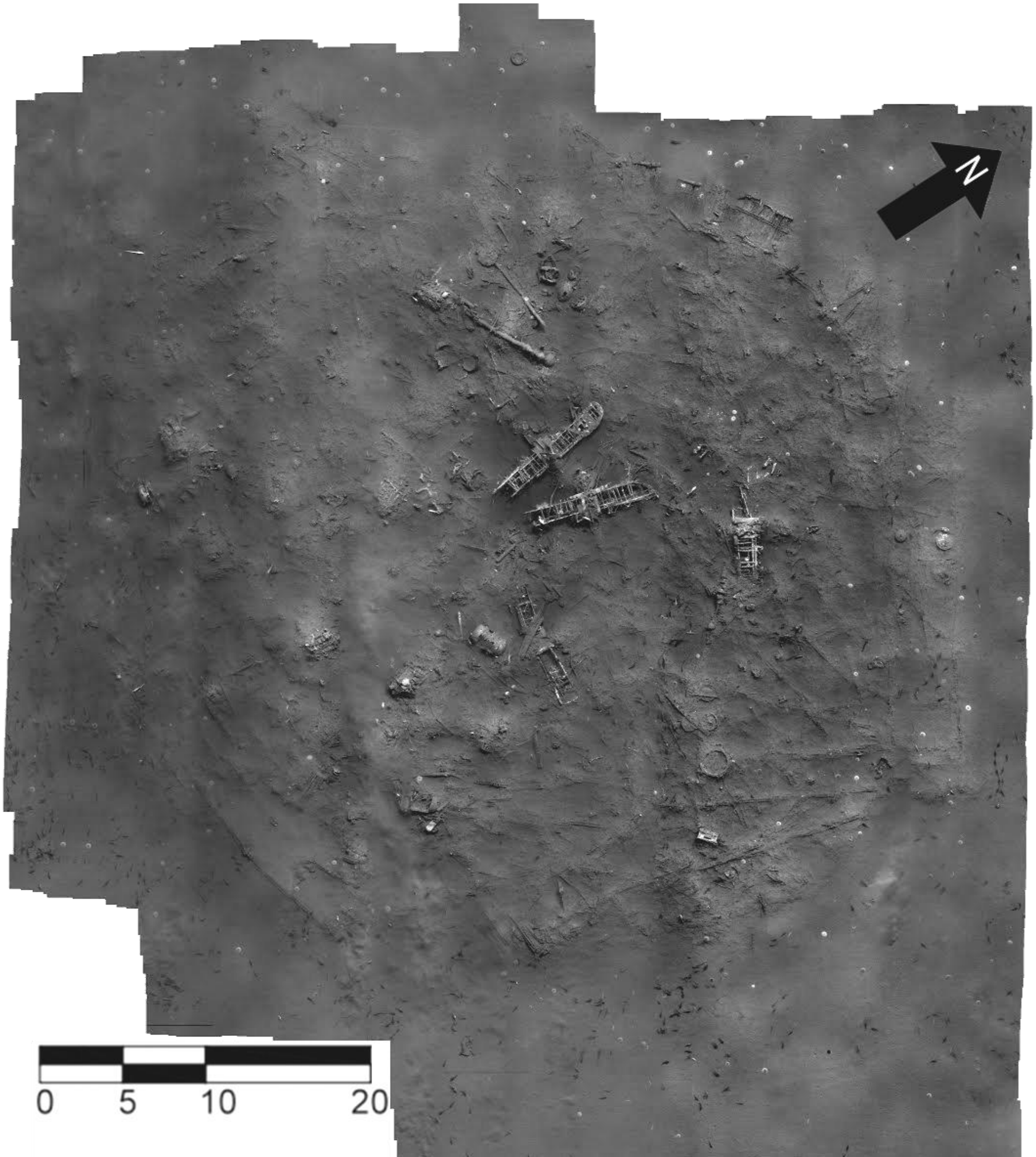

Figure 8.14- Field A of USS *Macon* debris and the four F9C-2 Sparrowhawk biplanes. Photomosaic courtesy of NOAA, OET, Roman Lab @ URI.

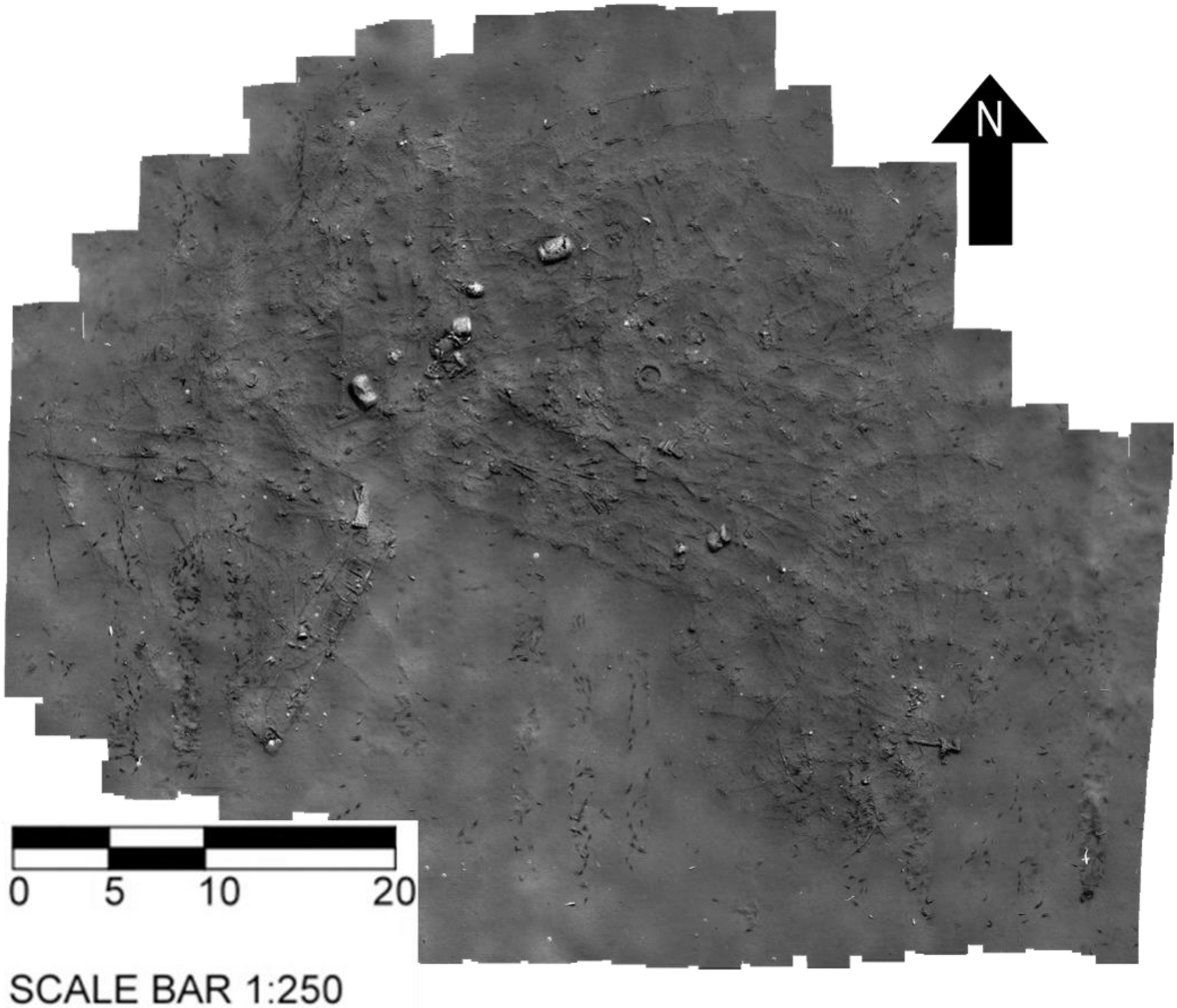

Figure 8.15- Field B of USS *Macon* debris from the forward part of the airship. The mooring mast is at the lower right of the image. Photomosaic courtesy of NOAA, OET, Roman Lab @ URI.

Site formation seems to suggest that during the wrecking event *Macon*'s tail section tore, but remained attached to the forward section just below the surface. As the tail sank, it pulled *Macon*'s nose into an upright attitude due to the remaining gas in the hull.[264] The aft section

[264] Hook 2001.

would have been hanging in an upright attitude as well, but broke apart fully from the forward section in the water column and descended to the bottom retaining this bearing. The aft section likely impacted the seafloor and folded like an accordion into the present mound structure with the biplanes on top. Over time the mound has settled, exposing the engines. On Field B the formation seems to suggest the forward section flattened out on the sea floor on its side; the 2015 photomosaic clearly revealed the aluminum ovoid, spider web-like frame structure of *Macon*'s bow (Figure 8.16).

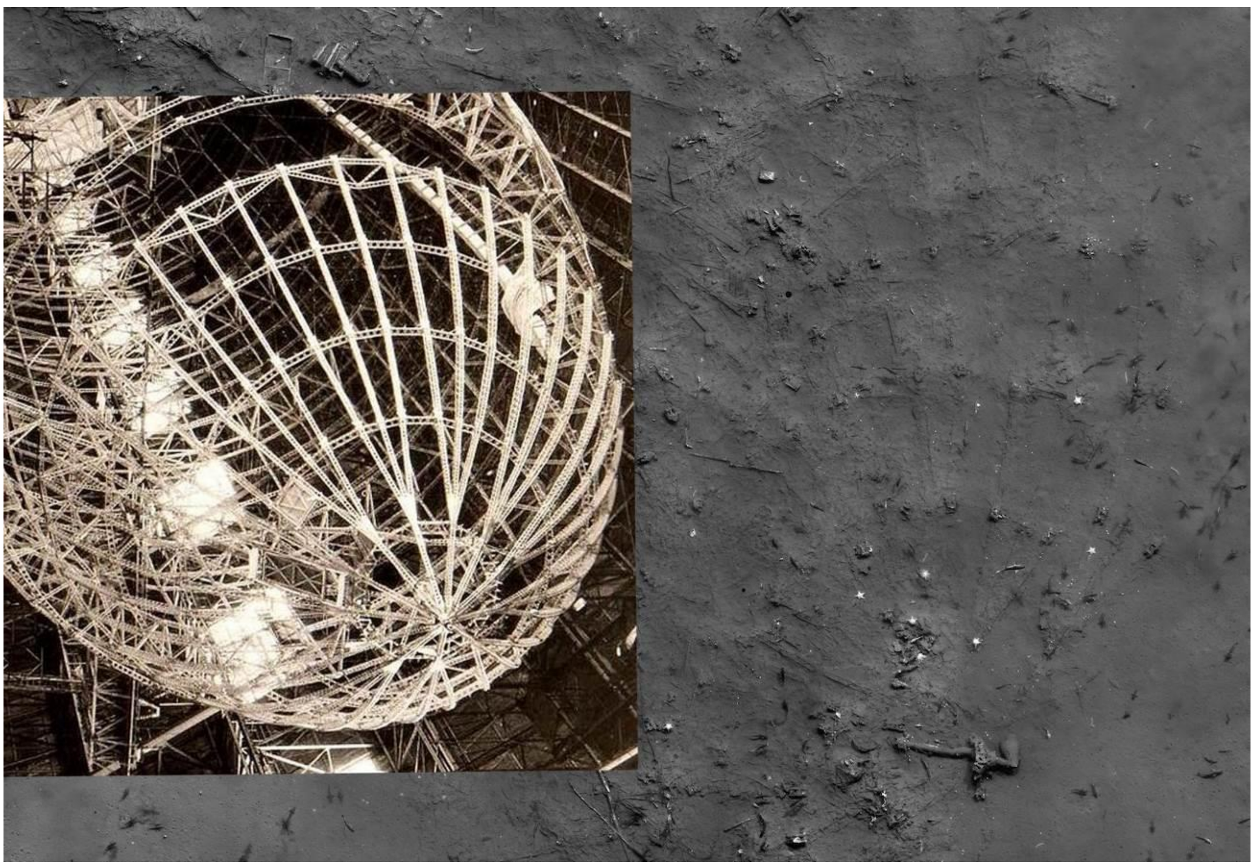

Figure 8.16- Field B with insert from the construction of USS *Macon*. The pattern of the frames is clearly visible below the sediment. Photo reprinted from Lickliter-Mundon et al. 2016.

8.4 Survey Results

The 2015 results serve to compare to data from previous years' surveys. Researchers can track the deterioration of the site easily through the changing visual appearance of the aircraft.

8.4.1 Aircraft Identification

Individual identification of each aircraft is not essential for understanding site formation and will not change any historical record, but adds to our further understanding and correct characterization of the site. Using video from both surveys, I made positive identifications of each aircraft by discerning the different squadron leader color worn by the aircraft on its wings, fuselage, and engine cowling (Figure 8.17).

Figure 8.17- The markings of the F9C-2 Sparrowhawk aircraft. Photos courtesy of NASM.

Biplane 1

Biplane 1 is located near the middle of Field A facing slightly northeast. In 2006 remains of the starboard wing fabric had almost completely deteriorated, but the port wing fabric retained an amazing level of preservation. Still, a piece of wood debris covered the exact area where the wing chevron would be. In the final hours of the 2006 project the ROV pilot moved this debris and exposed the wing surface. A light line demarcated an area of faded yellow paint (Figure 8.18). None of the aircraft were wearing squadron leader colors in yellow, but F9C-2 9061 had been repainted from yellow to black in 1934. The paint chevron has faded substantially, likely from being in contact with decaying organics and as a result both layers of chevron paint are nearly gone. Only the bottom, yellow layer remains visible on the wing, but a medium-sized area of the fuselage aft of the cockpit can be seen on the port side and it appears black. This aircraft can be positively identified as Serial Number 9061.

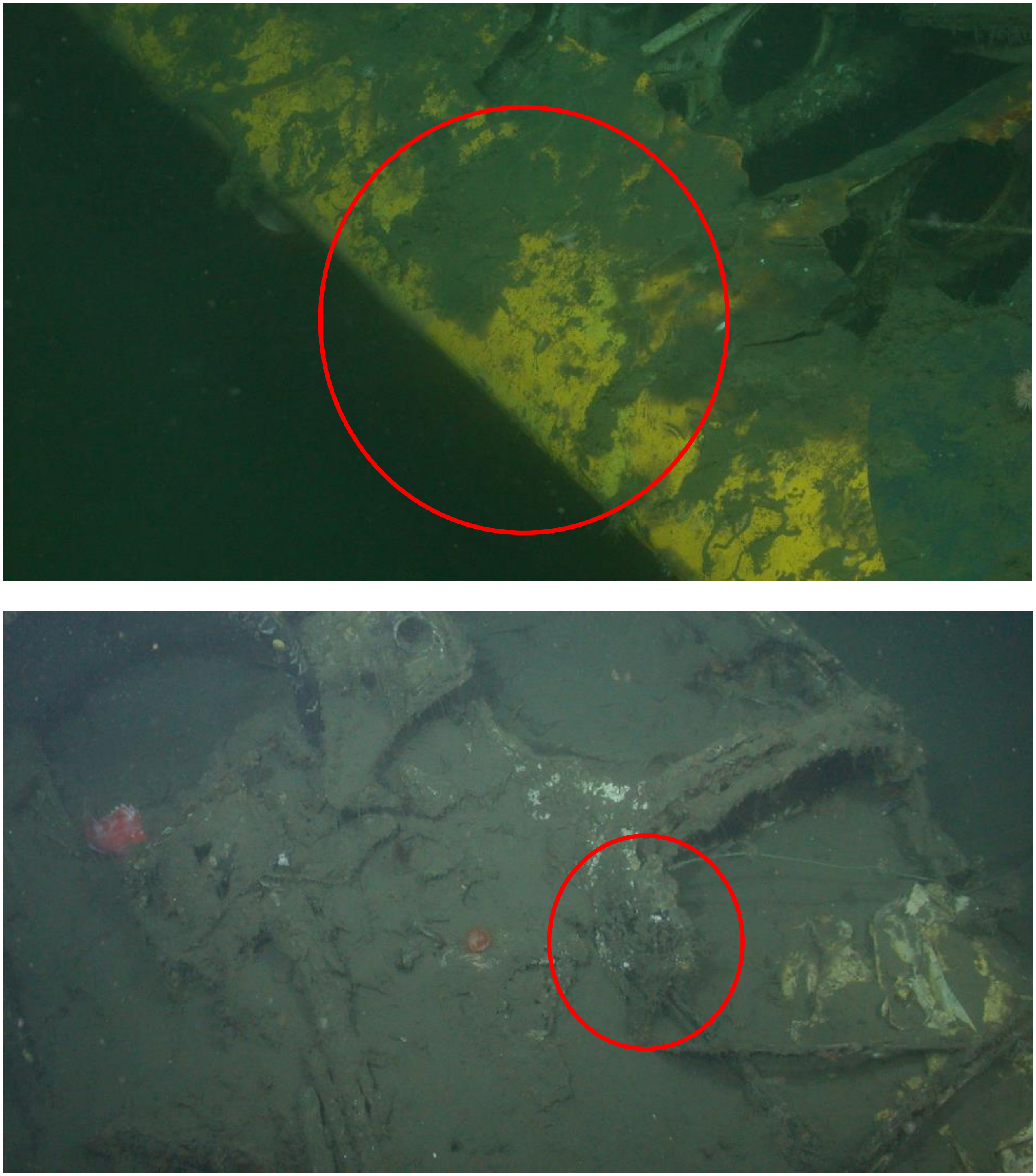

Figure 8.18- (Top) A faint yellow line on the wing top indicates the yellow chevron of 9061. (Bottom) Black paint is visible in the band behind the cockpit. Video stills courtesy of NOAA/MBARI.

Biplane 2

Biplane 2 is next to Biplane 1 with its wings aligned to face slightly to the northwest (Figure 8.19). In 2006, during the NOAA/MBARI survey the leading edge of the starboard wing was visible and the forward end of a blue wing stripe could be seen. The 2015 survey revealed a striking blue color band visible on the fuselage aft of the cockpit. This aircraft can positively be identified as Serial Number 9060.

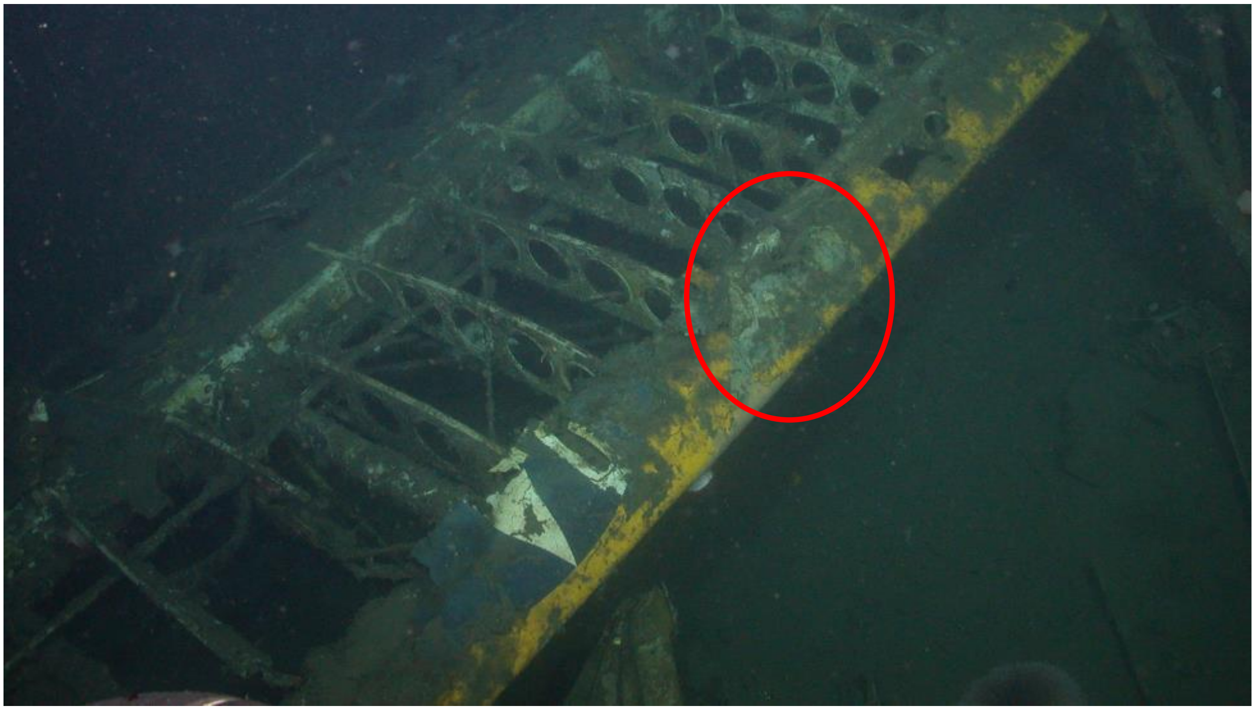

Figure 8.19- A faint blue line on the wing top indicates the blue chevron of 9060. Notice that the color of the chevron is fading faster than the bright blue and white of the nearby naval insignia. This indicates a different type of paint used and supports the idea that the black chevron faded off the yellow chevron of 9061. Video still courtesy of NOAA/MBARI.

Biplane 3

Biplane 3 is located southeast of biplanes 1&2 and is facing north. Like Biplane 1, there is a piece of wooden debris draped over the port wing section. Unlike the other biplanes, however, Biplane 3 is the most deteriorated and shows little evidence of wing fabric remains. The engine cowling and fuselage appear to be either crushed or buried deep underneath sediment and cannot be seen in both surveys. In the 2006 video one scrap of wing fabric with white paint remains visible in the chevron's location on the port wing (Figure 8.20). The rest of this chevron has disappeared with the fabric. Unfortunately, that scrap of fabric has also disappeared in 2015. This aircraft can be positively identified as Serial Number 9059.

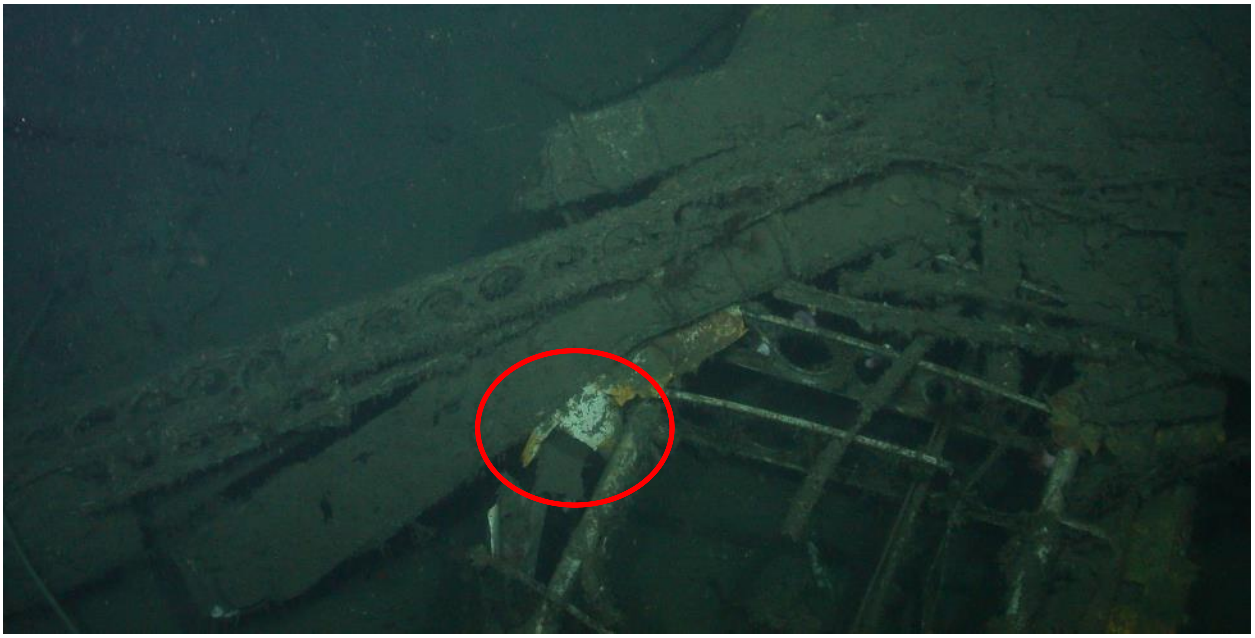

Figure 8.20- 2006 video of the NOAA/MBARI survey showing the port wing of Biplane 3, 9059, and the scrap of white chevron. Video still courtesy of NOAA/MBARI.

Biplane 4

Biplane 4 is situated to the northeast of biplanes 1&2 and faces southwest. This aircraft lists slightly upwards on its starboard wing and the port wing's outermost edge lies buried in sediment. In the 2006 and 2015 survey videos patches of bright red chevron can be seen on the port wing pull tabs and on the port leading edge (Figure 8.21). This aircraft can be positively identified as Serial Number 9058.

Figure 8.21- Biplane 4, 9058, with the remains of the red chevron visible on the wing edge. Video still courtesy of NOAA/MBARI.

8.4.2 Site Deterioration

Macon's wreck site has been photographed and filmed at three points over the last 25 years. These three surveys serve as points on a timeline of deterioration that we can track through the comparison of several smaller wreck section. Biplanes 1&2 are the most photographed area of the wreckage. In 1992 National Geographic published the first photomosaic images of Biplanes 1, 2, and 4.[265] The bird's eye images showed that the planes were intact, but associated with a large amount of various debris. It also showed that even though the aircraft were decaying, they retained some of the fabric covering the wing sections. A comparison of this same bird's eye view from photomosaics of 2006 images and 2015 images outlines the changes in the airplanes and surrounding area as well as highlights the development of camera technology and photomosaicking methodology over the same period (Figure 8.22-8.24).

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[265] Vaeth 1992, 124–125.

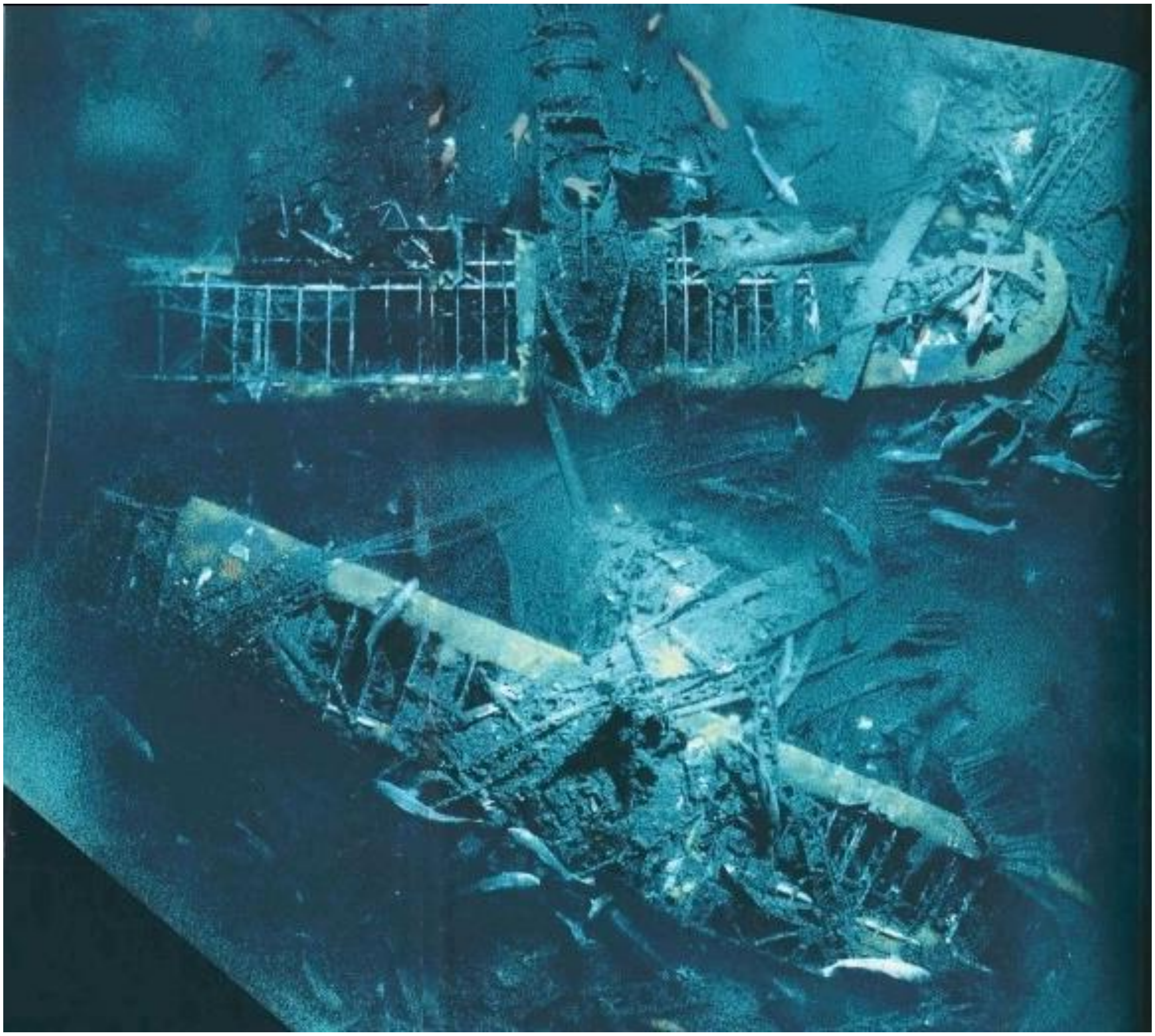

Figure 8.22- Photomosaic of Biplane 1 (top) and 2 (bottom) from the 1990-1991 MBARI/US Navy surveys. Reprinted from Vaeth 1992.

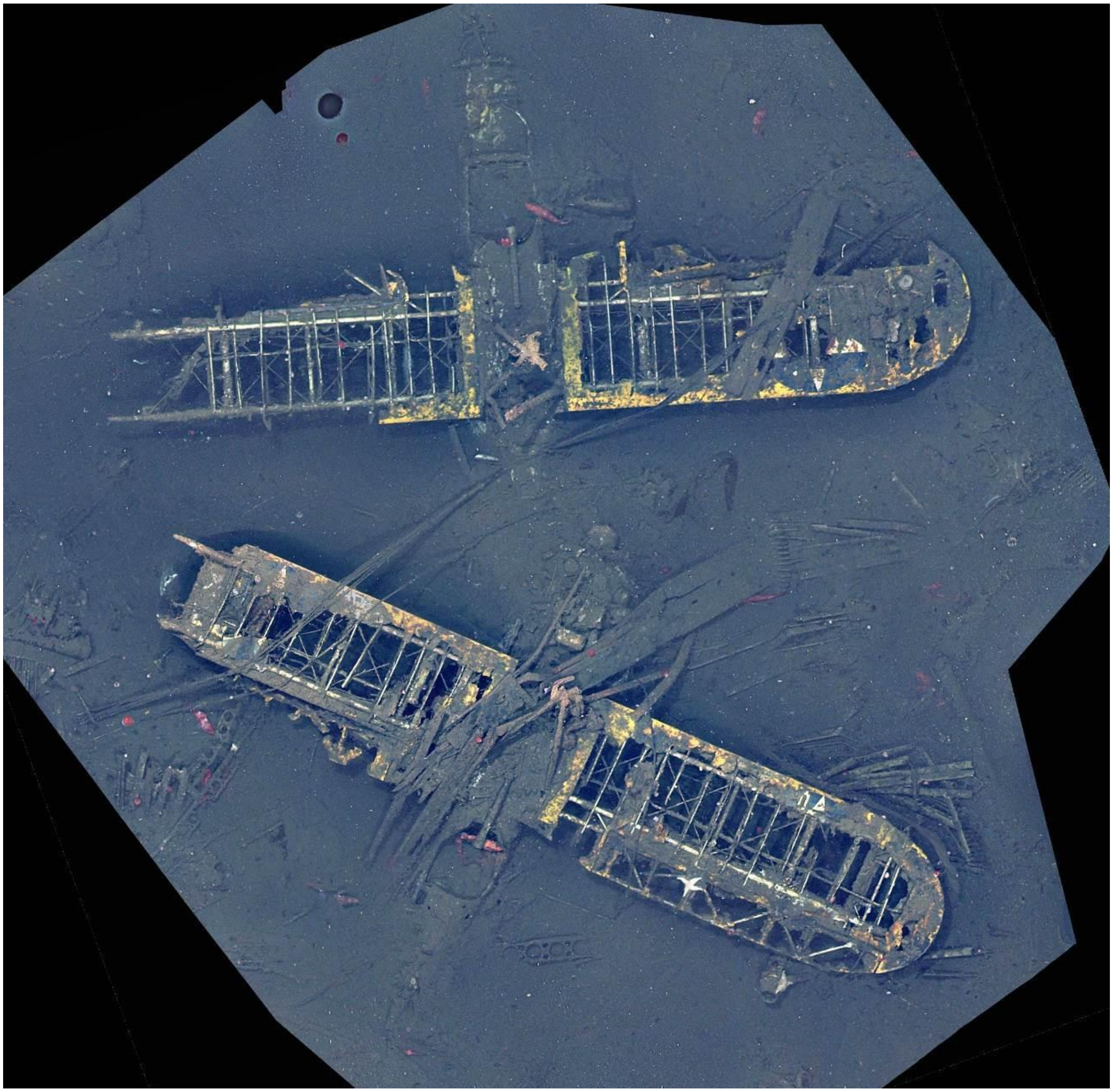

Figure 8.23- Photomosaic of Biplane 1 (top) and 2 (bottom) from the 2006 NOAA/MBARI survey. Photomosaic courtesy of Ken Israel and Chris Grech for MBARI.

Figure 8.24- Photomosaic of Biplane 1 (top) and 2 (bottom) from the 2015 NOAA/OET survey. Photomosaic by Clara Smart, Roman Lab @ URI for NOAA, corrected by the author.

Biplane 1

Biplane 1 was one of the most intact aircraft when first imaged in 1992. The Sparrowhawk's port wing had fabric on the leading edge, and the ailerons and naval insignia were almost fully intact. There was a long plank of wood, some wiring, and other metal or wood debris which had fallen onto the outer port wing obscuring some of the insignia and extending over a section of broken aileron. The aileron remained present but leaned down to the sea floor. The starboard wing presented as almost completely free of fabric skin except for an area from the leading edge to the first spar. Pieces of uncovered aileron frame lay on the sea floor below where they would have been attached to the exposed trailing edge spar. Nearly all of the ribs were in place on both wings, but the starboard wing had lost ribs 14-16 and the outer curved wingtip. The skyhook was in place, as well as the telescopic gunsight. The cockpit appeared to be filled with sediment and the skin on top of the fuselage had decayed or collapsed and had been covered in sediment, but the frames were upright and intact. In this image, we could see no tail surfaces. Relatively nothing can be seen of the sea floor except in the area of airship frame debris close to the port wingtip.

In 2006 Biplane 1 lacked its starboard wing ribs 12-16 and most of that wing's trailing edge. Sediment had covered up wing ribs and aileron frame that had fallen down to the sea floor. The leading edge appeared intact only up to rib 5. The port wing's broken aileron disappeared under sediment and more of the wing and aileron covering had decayed. The debris covering the insignia had moved or fallen through to expose a hole on the insignia fabric. Part of the red center circle, the upper half of the blue outer circle, and parts of three points of the white star were visible. Little change occurred to the cockpit and fuselage area except the ability to see a mass of yellow fabric in the fuselage, which is most likely the Sparrowhawk's life raft. The sediment seemed to have covered much of the surrounding debris, but the visibility issue might also have been due to the mosaicking method.

There is relatively little change in the starboard wing between 2006 and 2015 except for the loss and movement of several ribs. We suspect this is due to fish movement from our observations of their activity during the survey. Increased sediment can be seen on the wing roots but no changes to the skyhook or gunsight are visible. Removal of debris covering the port wing surface during the 2006 survey exposed more of the naval insignia, but increased deterioration since then decayed more of the insignia’s center. No ribs on the port wing are missing but a few appear to be jostled slightly out of place. The fuselage appears to be in the same condition as 2006, making this aircraft the most intact remaining today. The photomosaic is also the first that allows for studying the sediment’s color, texture, and items that are hidden but still outlined on the sea floor.

Biplane 2

In 1992 Biplane 2 appeared to be the most intact of the Sparrowhawk aircraft. The port wing’s fabric cover presented as near complete in the leading edge and naval insignia. The wing itself lacked ribs 14-16 and it appeared to be missing the entire trailing edge and aileron. There was wire, wood, and airship frame debris atop the aircraft at port wing ribs 9-12, the starboard wing root to port wing rib 4, starboard wing ribs 1-9, and a piece of ballast control system shutter had fallen over the starboard wing’s outer leading edge and onto the sea floor. This debris across the center section hid a mound where the engine would be, but on the aircraft itself the skyhook poked through the debris and remained intact. The starboard wing presented as structurally intact throughout but was missing the majority of the fabric covering on interior surfaces.

In 2006 Biplane 2 appeared not to have deteriorated significantly, with the most obvious change being the reduction in debris on top on the center sections and both wings. This port wing was missing two more outer ribs since 1992 and ribs 6 and 8 appeared to be loose. The naval insignia on the port wing has decayed further, but remained visible. One change from the 1992 photomosaic is the ability to see some frame from the aileron on the port wing, the telescopic gun sight, the cockpit area, and an outline of the fuselage. The breakdown of debris over the mound forward of the center section revealed the remains of the engine, cylinders, engine shutter, and propeller hub. The starboard wing remained unchanged in structure and was fully free of debris. Ribs 1 and 11 appeared broken with half remaining of each, but were in place.

Biplane 2 has experienced a significant level of structural deterioration between 2006 and 2015. On the wings especially, we see direct evidence of a breakdown in the strength of the aluminum structure. The port wing's aileron frame and attachment spar have disarticulated from the frame, the trailing edge spar is broken, and the broken piece is hanging off it where rib 12 would have been. The port wing lacks the leading edge after rib 3 and ribs 8-16. One flap of leading edge skin with the naval insignia is clinging to the leading edge, but now below the wing structure itself. The center section appears to be the only area that has not deteriorated significantly. Less debris covers this area and the skyhook, gun, sight, fuselage, and engine all remain intact. In the 2015 photomosaic the blue band aft of the fuselage appears visible, as well as the bright white of the engine shutter. Half of one wooden propeller sticks up out of the sediment. The deterioration of Biplane 2's starboard wing is also substantial, with a structural failure in the leading edge spar causing the collapse of the outer wing at rib 11. The aileron frame is somewhat intact closer to the fuselage and is missing closer to the wing tip. The leading edge fabric is intact from the wing root to rib 5. A number of ribs appear broken and jostled out of place and ribs are missing on the collapsed wig tip.

Biplane 3

Biplanes 3 was not photomosaicked consistently so the following deterioration summary is based on video and photos from each survey. In 1992 Biplane 3's wings appear to be supported by their lower struts and elevated off the sea floor. The skyhook lay on top of the center section but the US Navy recovered it near the end of the 1992 survey. In 2006 the starboard wing's leading edge retains fabric but the wing tip was either missing or buried in sediment. A large piece of wooden debris and airship frame lay across the middle of the wing. The port wing had no fabric covering and lacked ribs closer to the wing root, while the outer ribs remained in place. In 2015 the remains of Biplane 3 are the most deteriorated (Figure 8.25). The wings appear to have collapsed and retain no fabric, ailerons, and only few ribs. In the 2014 photomosaic, mounds both forward and aft of the center section indicate remains of the engine and fuselage, but nothing is identifiable through the sediment. The rate of deterioration appears consistent throughout each survey.

Figure 8.25- Photomosaic of Biplane 3 from the 2015 NOAA/OET survey. Photomosaic by Clara Smart, Roman Lab @ URI for NOAA.

Biplane 4

Biplane 4 appeared to be at the same level of deterioration as Biplane 3 in 1992, but this is the only plane that has a slight list to starboard. The starboard wingtip was either buried in sediment or missing past rib 12. The ailerons and the leading edge fabric on that side remained intact but the wing fabric was decayed on the wing surface. A large wood plank draped atop the forward wing from rib 1-8, and a large amount of debris covered the center section and both wing roots. The port wing appeared elevated and had lost all the fabric skin, the aileron attachment point, ribs 11-16, and its wing tip. On the 1992 photomosaic there is a fire extinguisher across ribs 1-3, and a coiled piece of rope on ribs 7-9 (Figure 8.26). Remains of the first frame aft of the cockpit are visible, and a few cylinders are visible emerging through sediment. In the 2006 footage everything appears to be relatively unchanged except for the port wing, which is missing the tips of the trailing and leading edge spars past the support tube near rib 10. A number of other ribs are out of place on the port wing as well.

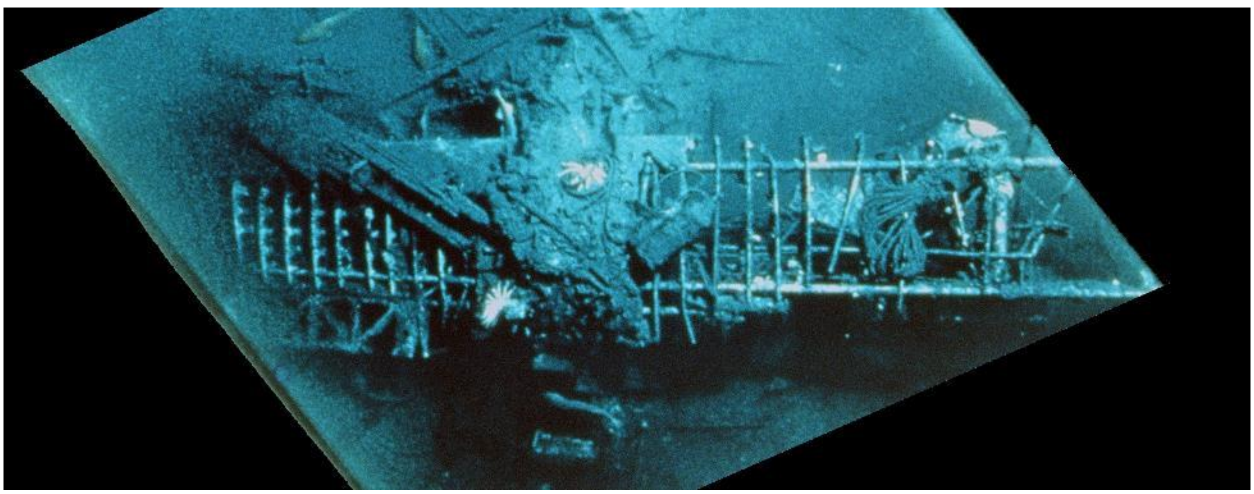

Figure 8.26- Biplane 4 from the 1990-1991 MBARI/US Navy survey. Reprinted from Vaeth 1992.

The 2015 survey showed a significant deterioration of Biplane 4’s port wing including a collapse of trailing edge spar and the loss of all of wing ribs (Figure 8.27). The leading edge piece remains at the original height. The outline and aluminum painted fabric of the curve of the lower port wingtip is clearly visible, as well as some ribs lying on the sea floor. The starboard wing shows little change from 2006 beyond a slight loss of aileron framing and some fabric from the leading edge that was formerly debris-covered.

Figure 8.27- Photomosaic from the 2015 NOAA/OET survey. Photomosaic by the author.

Airship Debris

The remains of several fuel cans are present in both areas of wreckage, in varying levels of deterioration. All of them show significant pitting corrosion and metal loss. The 1992 photomosaic shows a fuel can near Biplane 1, aft of the starboard wing, which is pitted to collapse throughout the middle section but the curved top is intact. This fuel can in 2015 has fully corroded on both its top and bottom. One fuel can aft of the port wing's trailing edge on Biplane 3 is nearly intact with only a few corrosion pits in the middle section in the 2015 photomosaic (Figure 8.25).

Likewise, there are several small pieces of airship frame that seem to show varying levels of deterioration; we can trace one frame, aft of Biplane 2's port wing trailing edge, throughout all three photomosaics. Whereas some airship frames have disappeared from on top of wings, this piece has remained in situ. We expect a similar case to be the small frame piece forward of Biplane 4's starboard leading edge- this frame piece disintegrated when we touched it with the ROV's manipulator arm.

Looking selectively at the aircraft and other aluminum finds on the *Macon* wreck site it appears that aluminum is one of the more actively-decaying materials on site, but at varying rates. It is unknown if the difference in rate is influenced by environmental factors. The current is relatively slack in the morning, but picks up in the afternoon, moving east to west. Sediment fall is uniform on site, as well as marine growth. In the 1992 video mussels and some other bivalve shell creature were present in large numbers, but we did not see these in the 2006 or 2015 surveys. Deterioration of Biplane 2 and 4 seems to have accelerated between 2006-2015, but Biplane 3 shows the most rapid rate of decay from 1992-2006. Biplane 1 shows a constant slow pace of decay throughout the 25 years period primarily to the starboard wing. Overall, the aircraft appear to be losing a protective cover of sediment and debris that interacts favorably with doped aircraft fabric. The loss of structural stability in the aircraft aluminum seems to accelerate as its covering of doped fabric disappears. Duralumin underwater will behave like other known examples of aluminum and display galvanic corrosion at attachment points with other aluminum or metal parts, especially if the metals are different. As mentioned earlier, marine life activity might further the visual decay process by bumping the compromised pieces. Some pieces, like the airship fragments that are horizontal on the sea floor and covered with sediment, might appear intact, but be fully compromised by internal corrosion.

By 1992, after the four F9C-2 aircraft has been underwater for almost 60 years, their structural stability was already compromised. This can be seen in the decay of the wings and fuselage in each aircraft. It can be assumed that the fuselage and wing areas covered by sediment remain intact, however, any entry point of sediment into interior structural aluminum spaces will result on the structural decay of the aluminum. These airplanes will likely continue to deteriorate quickly now that the fabric covering has almost completely disappeared from all the aircraft.

8.4.3 In Situ Corrosion Potential Study

Following the mapping portion of the 2015 survey, our investigations included making a conservation assessment based on the aluminum's visual appearance, voltage readings, and a recovered sample study of an aluminum airship frame fragment. ROV *Hercules* carried a CTD with temperature, salinity, and dissolved oxygen meters as well as a manipulator-held Polatrak Deep C Meter 3000 AD bathycorrometer, which is a voltage-reading probe designed for work-class ROV use (Table 8.2). We succeeded in taking one reading from an F9C-2 biplane wing rib, which will help determine whether the aluminum is in an active or passive deterioration stage (Figure 8.28). The Polatrak meter readings are calibrated to compare with other ECorr readings in this dissertation, but cannot be plotted on a known Pourbaix diagram due the extreme difference in temperature. Our reading was -0.597 +/- 0.003, which corrected to our reference anode relative to NHE is -0.325 +/- 0.003. Water chemistry readings showed that salinity and conductivity are consistent around the site. Temperature varies slightly, but the oxygen saturation on site varies from 6.50-10%, which is extremely low considering the amount of marine life observed at depth and by comparison to other deep-water sites in the Pacific.[266]

Table 8.2- Water Chemistry Readings on the USS *Macon* Wreck, May 2015

Reading Site	*Time*	*DO (mg/L)*	*Salinity (psu)*	*Conductivity (S/m)*	*Depth (m)*	*Temp (C)*
Beginning descent	11:17:06	10.63	33.05	4.16	3.634.19	15.9
Passing over Biplanes 1 & 2 during survey	16:30:15	1.1	34.19	3.45	436.9	6.81
Calibrating the bathycorrometer after mapping	00:25:03	0.99	34.20	3.44	437.2	6.71
Taking ECorr measurement on wing rib	01:23:11	1.14	34.19	3.46	439.6	6.90
Taking sediment depth	01:43:18	1.2	34.18	3.47	439.5	6.94
Acquiring aluminum sample	02:23:53	1.3	34.18	3.49	438.5	7.18
ROV surfaced	03:03:14	9.86	33.16	4.38	3.1	18.1

Note: For reference, data on the September 2006 NOAA/MBARI shows consistently slightly lower DO readings as 0.82-0.85 mg/L at depth, and slightly higher temperatures of 7.07-7.13 °C, with nearly the same salinity.

[266] Lickliter-Mundon et al. 2018.

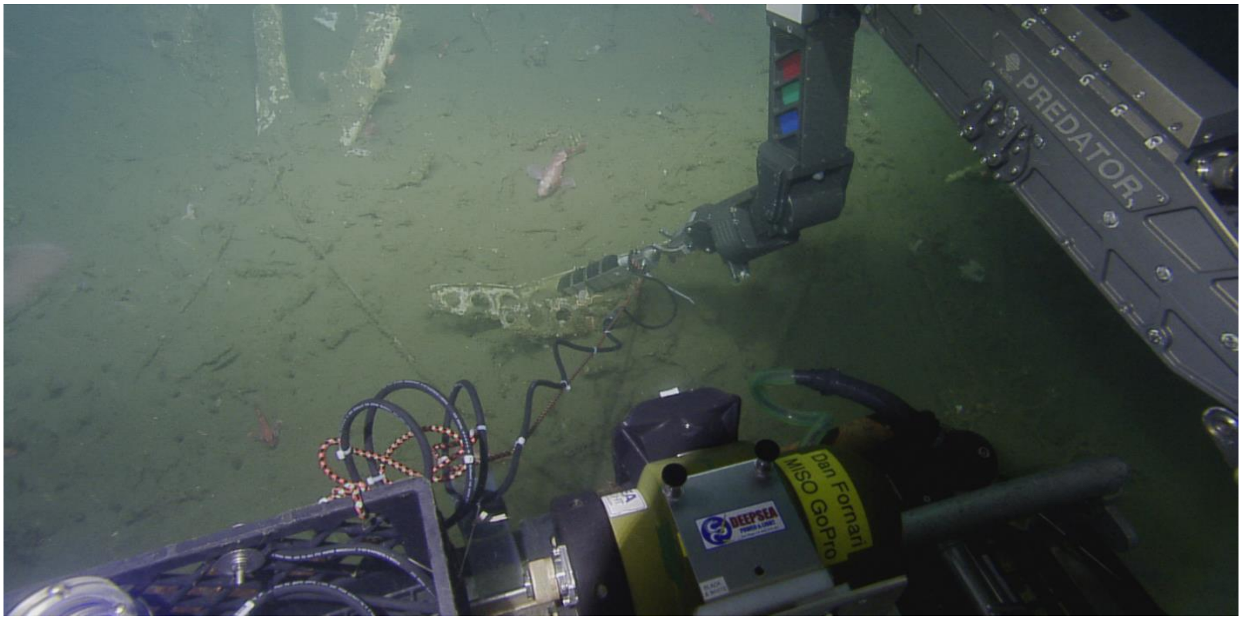

Figure 8.28- The Polatrak Deep C Meter 3000 AD bathycorrometer taking the reading from a starboard wing rig of Biplane 4. Photo courtesy of NOAA/OET.

8.4.4 3D Modeling Efforts

During my internship at NOAA's Maritime Heritage Program working on USS Macon material from the 1990-2006 surveys, I experimented with using video stills to create 3D models using Agisoft Photoscan. The video camera faced downwards from the ROV, but I was still able to capture depth on Biplane 4's raised wing (Figure 8.29). A full 3D mosaic of the wreck site may have been possible, but is currently beyond the limits of my computer.

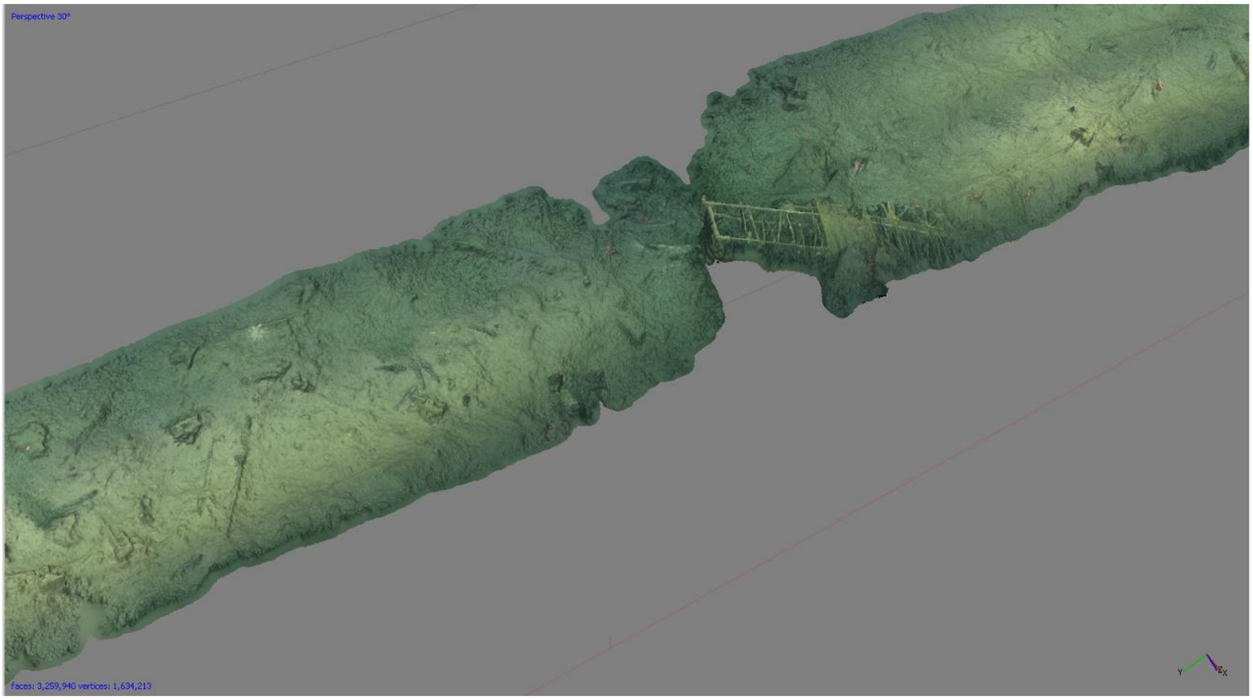

Figure 8.29- A 3D model of two ROV paths during the 2006 survey. Model by the author, video courtesy of NOAA/MBARI.

As part of the 2015 survey I planned for, and we executed, a close-range circle pass of Biplanes 1 and 2 to obtain video for 3D modeling. This model is an excellent example of what is below a minimum acceptable standard for 3D modeling conditions, as the resulting model is noisy and incomplete (Figure 8.30-8.32). Because we began the survey at 04:00AM PST, we experienced optimal visibility for the photomosaicking portion of the survey. By the time we began the 3D modeling, the current had increased on site, sending billowing clouds of sediment in a roughly east to west direction. This created unequal conditions on aircraft sides for our ROV path in terms of maneuverability and position in front or behind sediment movement. Our shortened time frame on image acquisition reduced potential circles to one, although the onboard GoPro added what the program viewed as another pass. Still, this was not enough to make up for the low light, high particulate matter in the water column, and our distance from the subject. The model presents as lumpy from the program's inability to register enough clean points per still image. For the USS *Macon* survey, 3D modeling was a secondary priority and our methodology reflected this. If undertaking a similar survey, I recommend finding the best window possible in terms of visibility for the 3D modeling portion. If the survey required image acquisition in low visibility conditions, it is necessary to either increase the light available, or fly the ROV closer to the subject, or both, and make more passes at higher and lower angle circles with no zoom. This will significantly increase the time it takes to perform this portion of a survey.

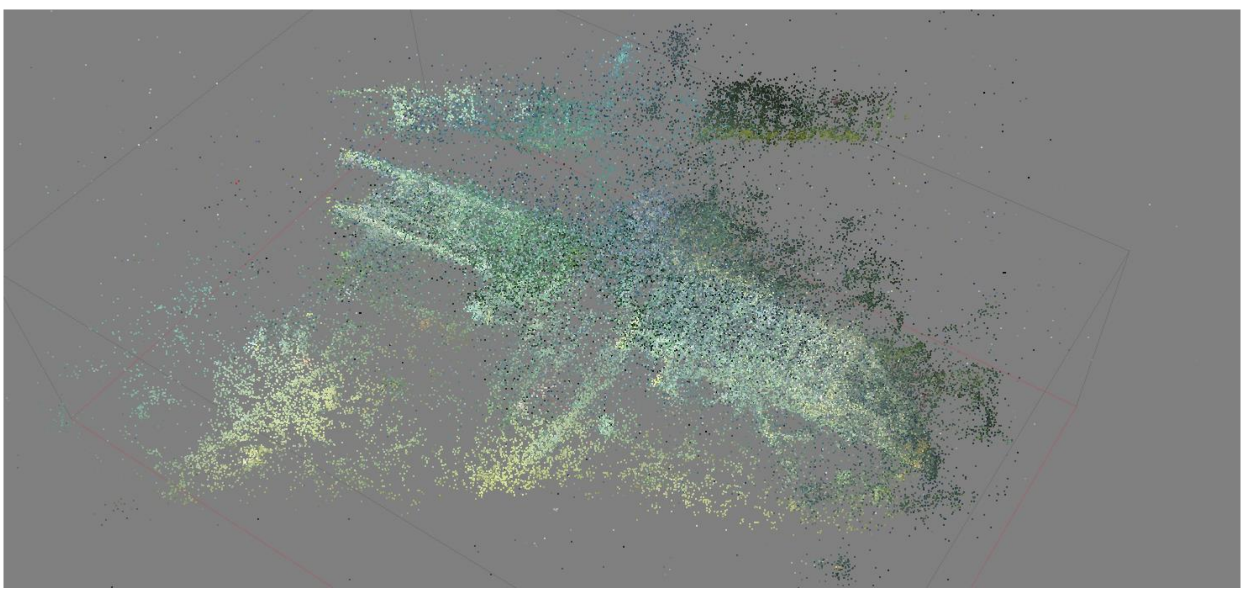

Figure 8.30- Sparse point cloud of Biplane 1 & 2, USS *Macon* site. This model has only 100,000 points in the dense cloud- a comparable model will have over 2 million. Model by the author, video courtesy of NOAA/OET.

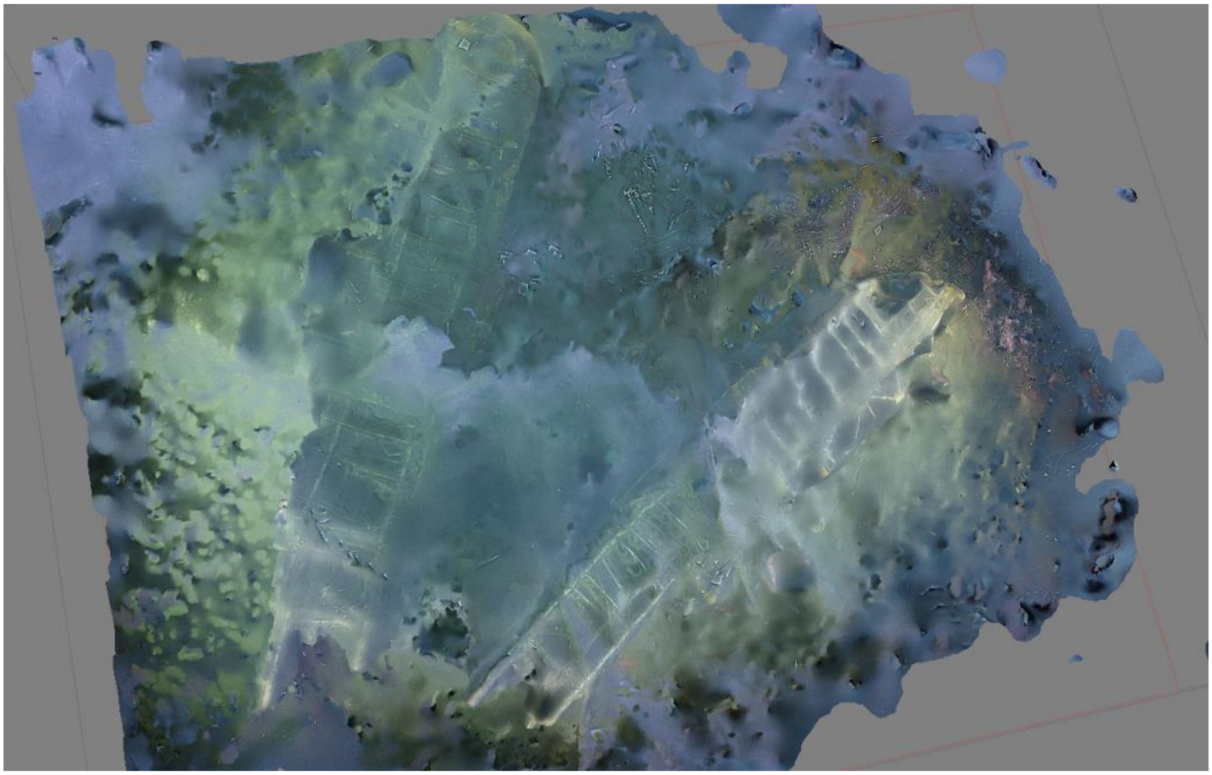

Figure 8.31- Model of Biplanes 1 & 2, USS *Macon* site. Model by the author, video courtesy of NOAA/OET.

Figure 8.32- Average image quality versus the resulting area of the model. Model by the author, video courtesy of NOAA/OET.

8.5 Artifact Assembly and Conservation

From 2014-2016 I conducted research on the artifacts associated with USS *Macon,* in either museum or private collections, recovered from the site in 1991 or our 2015 survey. I also did visual condition assessments and experiments on conservation methods for these recovered artifacts. Some of the recovered artifacts had documentation resulting from conservation treatments, but the treatment records were difficult to locate, and only photocopies with poor image quality were eventually found. The purpose of the research was to bring these important examples of the first real aviation archaeology project back into the light.

There are several artifacts associated with the US *Macon* and Sparrowhawk biplanes either donated as historical artifacts or recovered from the wreck in 1991 or 2015.[267] Tracing records for the location and treatment of recovered artifacts recovered during the 1991 survey proved difficult. The US Navy parted out these artifacts and sent them to various museums, gifted pieces to individuals, and some artifacts probably also exist in unknown archives. NOAA has a list from MBARI with general descriptions that had been written about 10 years after the recovery. An unreferenced rumor states that someone had discovered a *Macon* frame girder in a small museum serving as a plant holder. I began archival research at the NASM Mall and Udvar Hazy locations to supplement the historical research done by NOAA's Bruce Terrell and Lonnie Schorer. I located several items in the NNAM and at the Moffett Field Museum in California, and one in the possession of an individual. Moffett Field Museum's curator and the private collector both graciously allowed me to examine pieces of USS *Macon* framework; the individual loaned me an example recovered from the wreck site on 1991 that had not undergone conservation, and the museum loaned me a piece of frame allegedly taken off the airship during repair work done in 1934. In 2014 I documented eight recovered artifacts from the wreck site, and several associated historical artifacts, at NNAM and researched their acquisition records. Artifacts include a steel hook with brass components that the Sparrowhawks used to attach themselves onto the airship trapeze, several pieces of airship girder frame, several pieces of plastic galley ware, a glass Tabasco bottle, and an aluminum pulley wheel.

[267] A full list of associated artifacts and their descriptions is in Appendix J.

8.5.1 Artifact Visual Documentation and 3D Modeling

Funded by the Institute for Nautical Archaeology and Texas A&M's Center for Maritime Archaeology and Conservation, I was able to fully document several *Macon*-associated artifacts and perform X-ray Fluorescence readings on three pieces of USS *Macon* frame.[268] Visual inspection showed several differences in the material that proves useful for baseline treatment research. I will discuss some items of note below, and the rest of the items are in Appendix J.

I had the opportunity to study several artifacts, both recovered from, or associated with, USS *Macon*, at the National Naval Aviation Museum (NNAM) in Pensacola, FL and the Moffett Field Museum in Mountain View, CA (Figure 8.33). The Moffett Field Museum piece, supposedly salvaged from *Macon*'s 1933 accident over the Rockies, had been covered with aluminum paint at some point in its history. With good light and a microscope I was also able to see the piece that they sent me was surplus from the airship's construction in 1933, or so it said, rather than from the repair work.

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[268] Interestingly, XRF analysis helped me determine that one sample provided by Moffett Field Museum for research is likely not, in fact, from the USS *Macon* due to the presence of titanium in the alloy, which was not common in aerospace manufacturing use until WWII. XRF of the other *Macon* frame pieces shows no titanium.

Figure 8.33- A piece of surplus *Macon* frame. Photo and inset by the author.

I also studied three aluminum artifacts recovered from the wreck site during the 1991 survey (Figures 8.34-8.36). Two out of the three metal artifacts salvaged from the archaeological site in 1991 were conserved at East Carolina University and had been either on display or in storage at the NNAM since then. The artifacts included a piece of aluminum frame from the airship similar to the one from the private collection. As I examined the pieces and read the conservation reports of the piece conserved by ECU, it was obvious that in both cases, the conservation method was highly experimental and overall thought to be in the artifact’s best interests. Neither method had stabilized the artifacts nor protected them from further corrosion, but at the time (1991) there had only been one paper written on experimental methods.

Figure 8.34- This piece of cast aluminum, recovered from the *Macon* wreck in 1991 and conserved by ECU as well, displays the brown wax no continued corrosion. Photo and inset by the author.

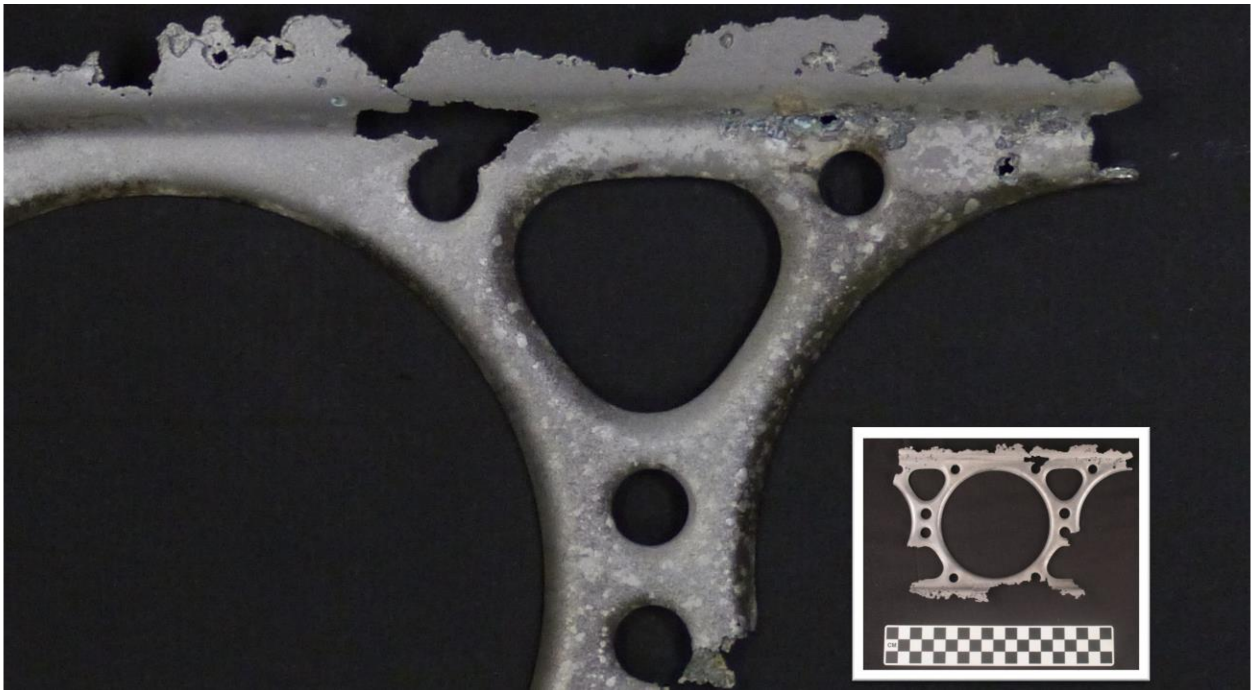

Figure 8.35- This piece, USMPC01, was recovered and given to a private collector in 1992 but did not receive any conservation treatment. It contains powdery blue copper corrosion products in its pits, but overall appears relatively unchanged since recovery. Photo and inset by the author.

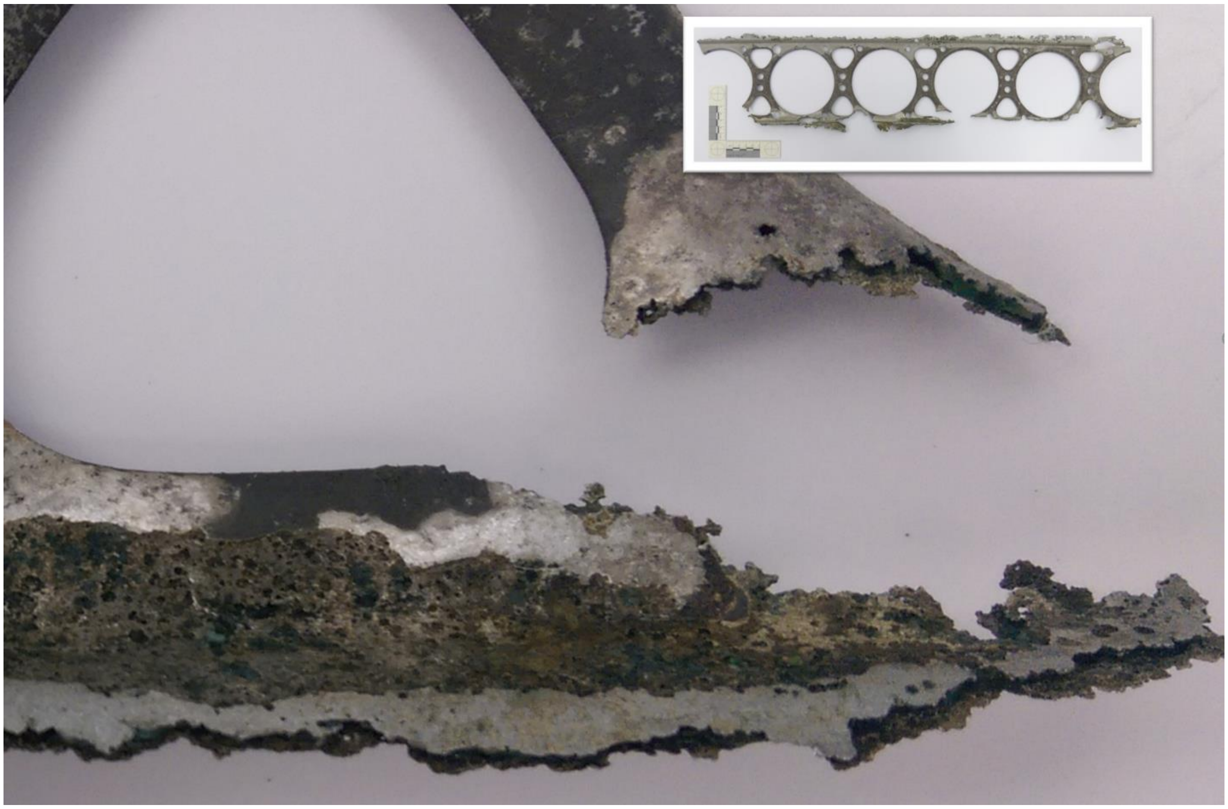

Figure 8.36- In this image the telltale brown microcrystalline wax indicated ER treatment common to iron artifacts at the time. The piece is currently also displaying green copper corrosion products, signaling continued pitting. Photo and inset by the author.

Documentation included visual assessment as well as digital-documentation methods, which served as experiments in 3D modeling methodology on clean metal artifacts. Along with physical documentation and determining the conservation issues, I wanted to test laser scanning on metal surfaces with a NextEngine HD and turntable versus taking images for photogrammetry using Agisoft Photoscan. Clean, shiny metal like aluminum or wax-coated steel will reflect light, making still photography in a light booth difficult, and with flash impossible. I experimented with a recovered skyhook, frame piece, and cast aluminum wheel in NNAM’s collections. Neither the laser scan nor photogrammetry would work with the frame piece, it picked up too much light during the photo-acquisition process. I discuss comparisons of the images below as dense point clouds without mesh or texture (Figures 8.37-8.39).

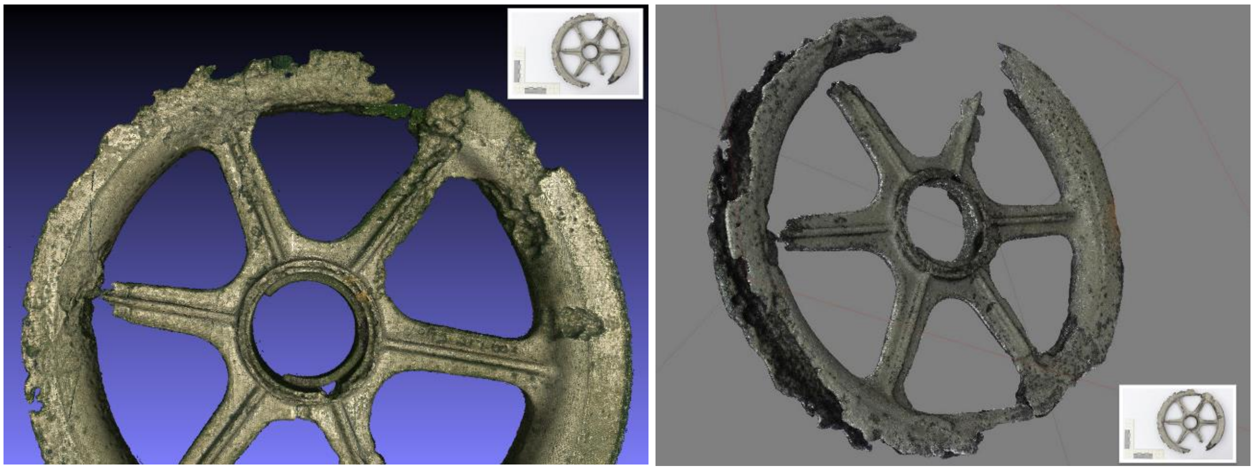

Figure 8.37- The laser scanner scanned the objects in a dark booth and produced an accurate structured point cloud of the hook and wheel surfaces (L). Photoscan produced slightly more problematic initial results but what I think is a better model in the end, composed of about 400 images (R). Models by the author.

Figure 8.38- On the skyhook, the laser scanner produced a uniform point cloud and a good result, but the model appeared to be of low quality in resolution (L). Photoscan software produced a simple point cloud of the hook from about 1000 images, which appeared to have more noise than the scanned model, but had a much higher level of detail (R). Models by the author.

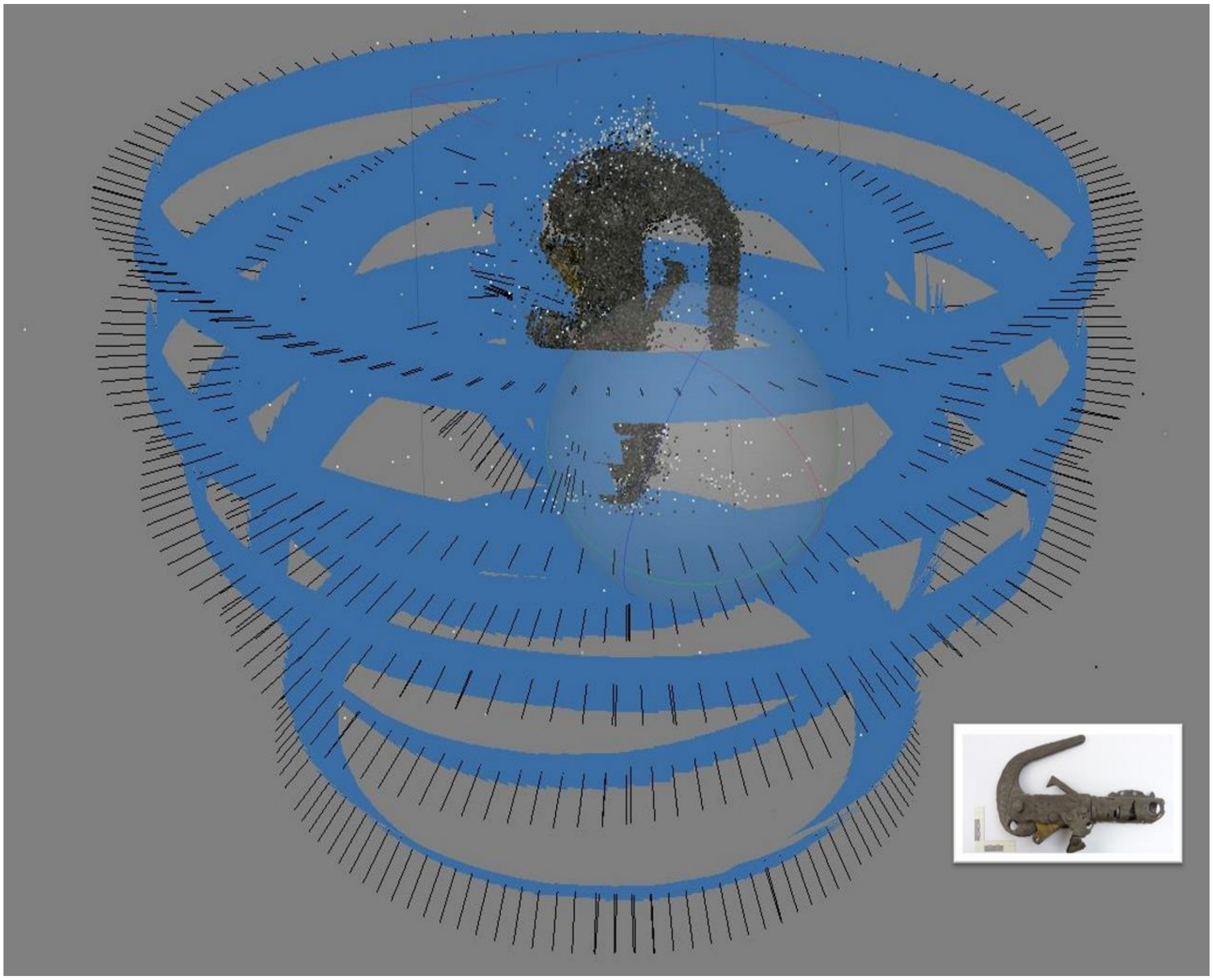

Figure 8.39- Photoscan methodology for the skyhook was to photograph each object using the laser scanner's turntable for precision in image acquisition. Model by the author.

8.5.2 Baseline Conservation Treatment Experimentation

In 2014 I was able to acquire a sample of duralumin framework from the USS *Macon* airship remains. The piece had been recovered in 1991 and minimal stabilizing efforts made on it. The piece had been in private collection ever since. After I observed and reported cupreous corrosion products to the owner, he directed me to conserve the frame piece. I performed experimental re-conservation of the 1991 frame piece from the private collection based on an adaptation of the prevailing knowledge of citric acid treatments.[269] The treatment involved submersion of the sample in a citric acid bath with no electrolysis, but a constantly maintained pH and water movement for about a week.[270] Spot treatment of corrosion products, ethanol drying, a benzotriazole (BTA) dip, and a renaissance wax treatment finished the experiment (Figure 8.40). I noted that the sample had lightly pitted on areas that were previously smooth, possibly due to improper mixing of citric acid into the solution to regulate pH. The method seemed appropriate for aluminum artifacts with limited conservation needs. I was also able to complete XRF analysis of the *Macon* sample to add to baseline aluminum reading research (Figure 8.41).

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[269] Degrigny 2004; Ryan et al. 2013.
[270] Treatment method followed the description of artifacts in Chapter 5 and Appendix C.

Figure 8.40- Frame piece USMPC01 after treatment to remove the powdery blue copper corrosion products, as seen in Figure 8.35. Photo and inset by the author.

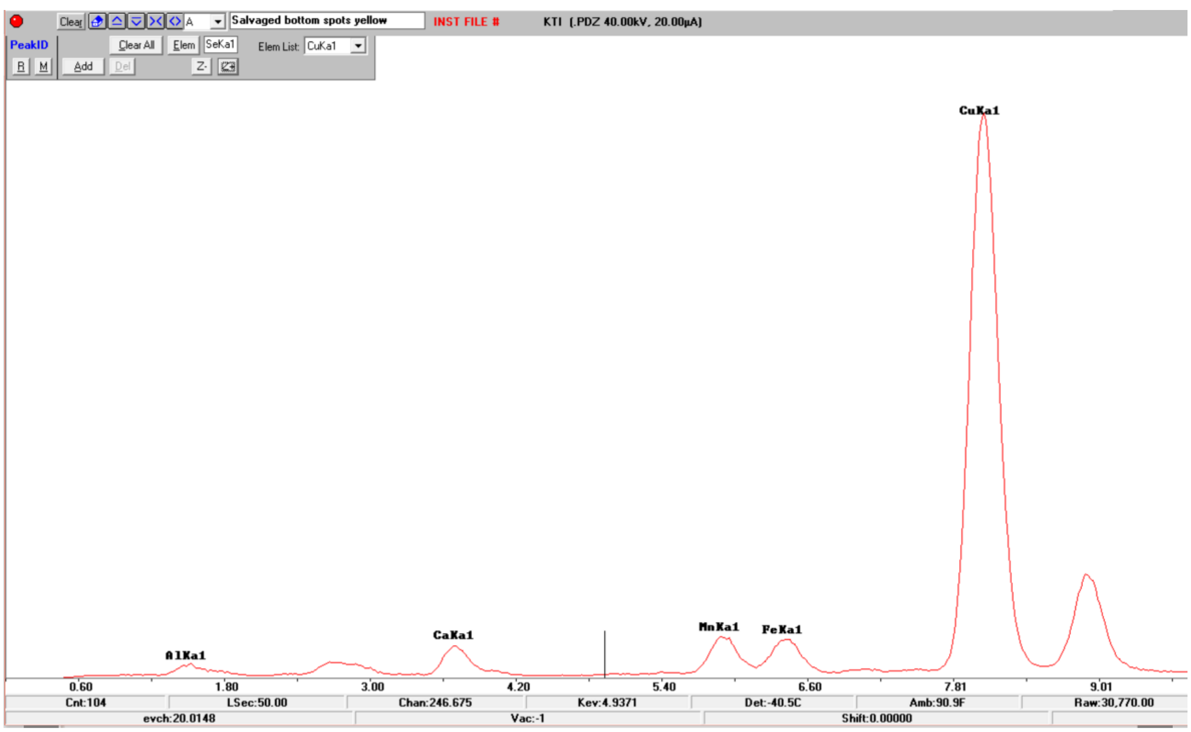

Figure 8.41- XRF analysis on USMPC01 shows a common 2024 alloy signature. Photo by the author.

8.5.3 Conservation on 2015 Recovered Sample[271]

The final goal of the 2015 NOAA/OET survey was to recover a piece of airship aluminum to conserve and compare to the 1991 examples. The frame piece we chose stood upright in the water column (Figure 8.42). Upon examination, it appeared to have been riveted to another frame piece to form a thin rectangular box. Two rivets remained intact, although the corrosion around the rivets appeared accelerated as compared to the rest of the piece. Pitting corrosion presented only in areas that were in contact with other metal frames, which is the same as in the samples recovered in 1991. The metal itself was discolored and covered with patchy sediment, marine biology, and calcareous growth, but after initial cleaning appeared no more deteriorated than the 1991 example (Figure 8.43-8.44). Based on the decay of the sediment-covered piece that disintegrated at touch, I theorize that a slower rate of decay occurs when bare duraluminum lays uncovered by sediment or marine growth.

[271] Conservation Notes in Appendix K.

Figure 8.42- The frame piece we recovered in 2015. Photo courtesy of NOAA/OET.

Figure 8.43- The demarcation line between the portion of the frame that was buried in sediment (L) and the side in the water column (R). Some pitted areas presented with black, maroon, and green corrosion products. Photo by the author.

Figure 8.44- A sample of marine growth on the recovered frame piece. Also note the dark brown color of the metal surface. Photo courtesy of Juyle Newlin, OET.

Together with Kate Morrand and Shanna Daniel from NHHC Underwater Archaeology Branch, I carried out the conservation at the NHHC Conservation Lab using the same methodology from my 2014 experiment. After receiving the frame piece at UAB's conservation lab, I placed it immediately into the citric acid solution. After a few days, the sediment and marine growth had been removed from the surface, and the metal was a lighter color. During these days, however, we noticed accelerated corrosion products present in the microscopic pits on the frame's surface (Figure 8.45). After being treated for about five days, the frame piece presented as closer to its original color, but with a series of stain patterns visible to the right side of the sample and black corrosion products surrounding larger pits (Figure 8.46). Two rivets appeared in corrosion products on the top side of the frame piece, but later fell out because the metal was completely compromised and disintegrated during the treatment process.

Figure 8.45- Soft nodules of corrosion products on the frame surface after a few days of conservation treatment. Photo by the author.

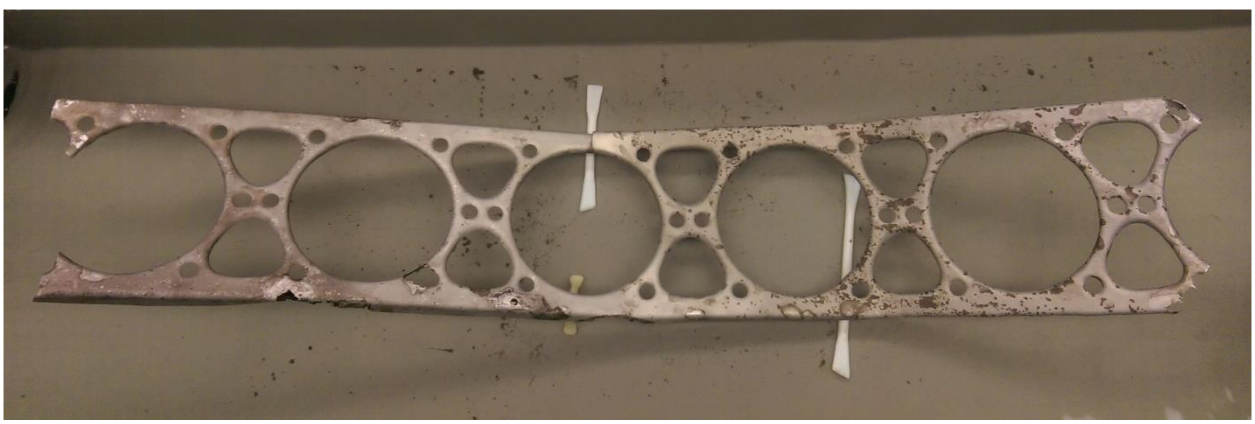

Figure 8.46- Staining appears on the frame piece during conservation treatment. Photo by the author.

Treatment continued for about 4.5 months, during which time the frame piece continued to brighten. In a few instances, UAB conservators noticed algae-like film growing on the metal surface, which they removed. At the end of the treatment process I washed, dried, dipped the frame in BTA, and then sealed it with renaissance wax (Figure 8.47). I placed the 2 rivets back into the corrosion pit hole and seated them there with microcrystalline wax.

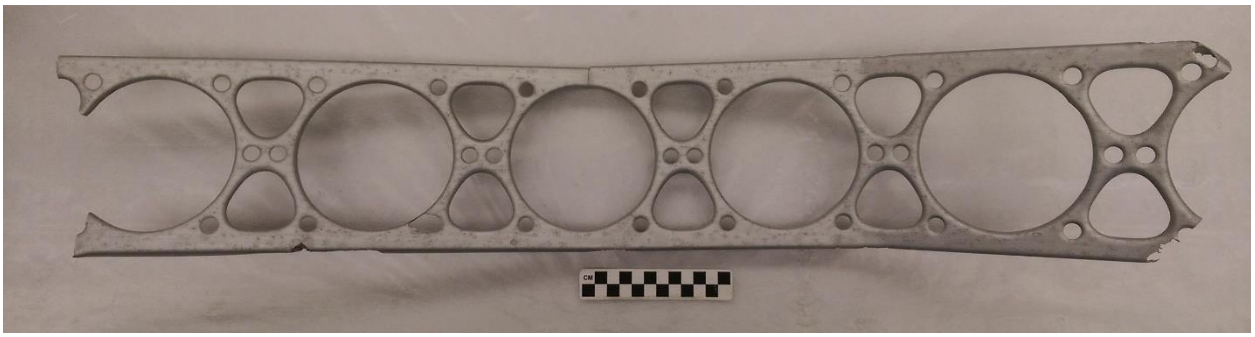

Figure 8.47- Final image of the *Macon* frame piece after treatment. Photo by the author.

While overall effective in stabilizing the artifact, the same pitting occurred on this piece as had on the 1991 piece although proper mixing of the solution had been done. My conclusion is that the duralumin alloy, which is an aluminum-copper-manganese-magnesium alloy, is more susceptible to damage from citric acid treatments than alclad aluminum, which is the same alloy with a thin coating of pure aluminum. Since the corrosion products on both 1991 pieces were solely on areas of metal that were compromised by pitting action, and the 1991 piece in private collection had originally only been washed in fresh water, I would propose that in the future duralumin finds undergo a staged freshwater desalination process for the entire artifact followed by a short citric acid treatment. This will reduce the overall pitting corrosion but ensure the metal returns to its original appearance.

Post treatment analysis on the frame pieces included XRF readings. The *Macon* frame registered as expected, with readings similar to aluminum 2024. The rivets, however, registered with a higher percentage of iron, signifying a different alloy. These readings confirm my suspicions on *Macon* site formation processes: pitting occurs as a result of galvanic corrosion localized around rivets, which are numerous in *Macon* framework. I can also infer that similar reactions are occurring in any location where two dissimilar metals touch. The frame piece we recovered was intact and attached to another, so complete structural stability had not yet been lost. In the future, breakdown of these interconnected pieces will result in a flatter site, and eventually the collapse of all F9C-2 upper wings.

8.6 Public Outreach

The 2015 survey had a public outreach component made possible by the telepresence capabilities of E/V *Nautilus*. Telepresence allows for scientists on-shore, museums, education facilities, and the public worldwide to participate live in the expedition. The projects outreach goals were "to highlight not the only history of the USS *Macon* and its four biplanes, but the current technology being applied by OET and NOAA to continue to conduct archaeological surveys over time, monitor change, and the continued protection and management of the historic remains of this unique wreck site."[272] I was able to discuss the site live with a curator and public audience at the Smithsonian National Air and Space Museum while the survey was taking place. Audience members were able to see the ROV's camera and ask questions about the site, the

[272] Lickliter-Mundon et al. 2015.

history, or the technology we were using to survey. On that day, OET's website NautilusLive logged over 70,000 viewers, and the YouTube video of highlights has over 40,000 views. The airship and biplanes, while it might never be a part of a museum collection, still have the ability to engage visitors in a way that fits into the mission of most museums.

8.7 Interpretive Display

Museums rarely interpret the lighter than air story because of the average visitor's expectation for the accompanying large aviation artifacts. In *Macon*'s case, there are no large airship remains to display; the crash event of this airship and USS *Akron* are the leading reasons why no rigid airships were developed after 1935 and none exist today. With alternative access points the wreck site can serve as the main interpretive artifact for any *Macon* story, and in this manner the museum does not require the actual airship. A combination of archaeological documentation and curated, conserved artifacts can provide the best access points to the wreck. I propose several displays of the site as it is today, focusing on the crash site and its associated biplanes, intact and with amazing preservation, along with associated artifacts from the crew members and from the crash site itself (Figures 8.48-8.51).

Figure 8.48- Two-dimensional archaeological data and history combined in one visual-touch tool can provide interactivity as well as knowledge. This is a touch table that can highlight and pull up images of the wreck with explanations, short videos, historical photos, etc. It would force the visitor to make the links between site and history, and provide detail on demand. Rendering by Eve Bartolo, FRD, as directed by the author.

Figure 8.49- An interactive station for ROV control, focusing on the technology of deepwater science. Rendering by Eve Bartolo, FRD, as directed by the author.

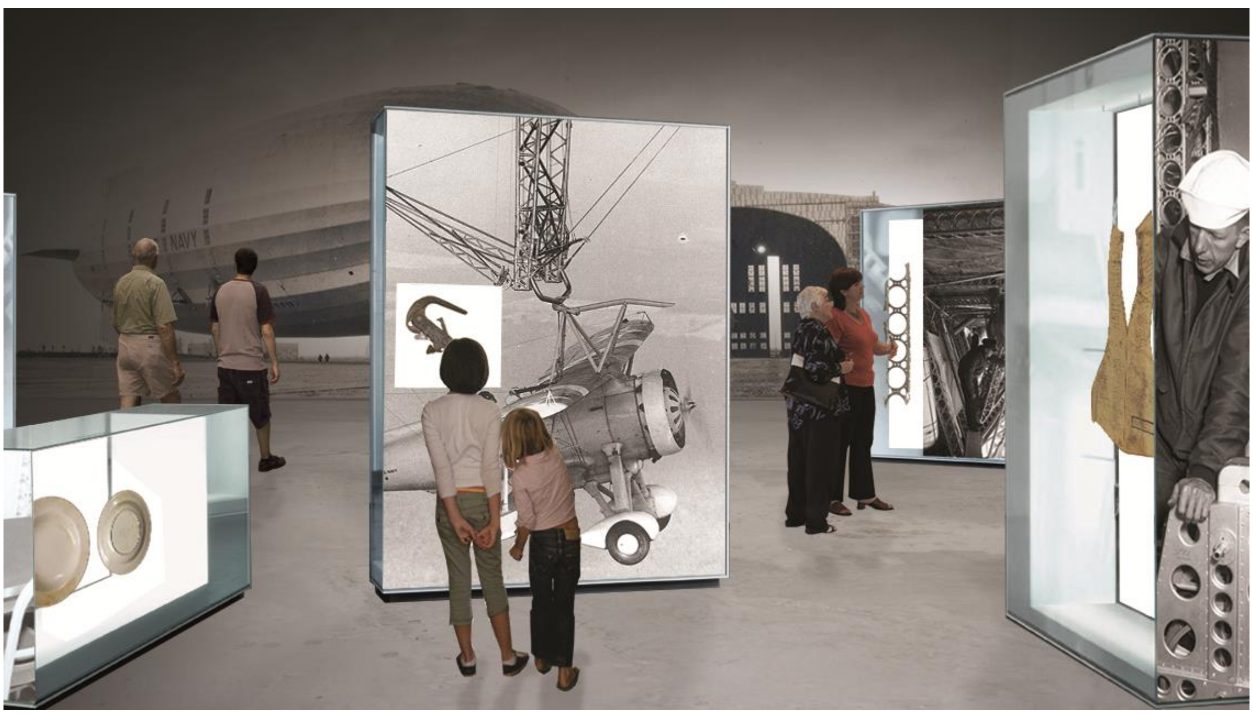

Figure 8.50- These displays convey the expected authenticity for museums by containing interpreted artifacts. For example, on the right is a life vest used during the rescue, after which it was signed by every survivor and illustrated with a picture of *Macon* sinking, which is a fantastic storytelling object. Rendering by Eve Bartolo, FRD, as directed by the author.

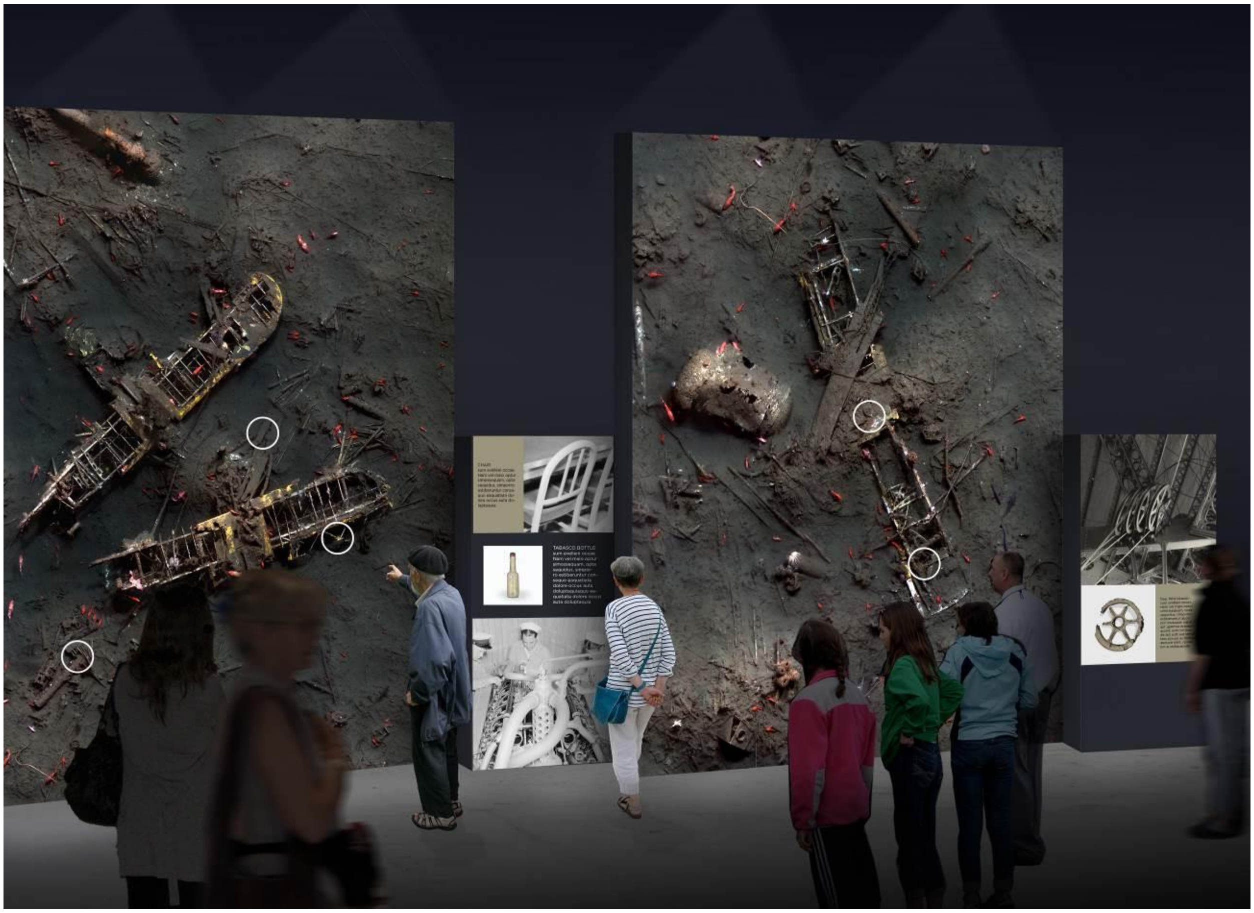

Figure 8.51- This display of the actual wreck site invites the visitor to engage in an object finding mission, reminiscent of a 'Where's Waldo'-style picture. On the right is a recovered pulley wheel, of which several still remain on top of Biplane 3. The visitor can not only find them aboard the wreck, but can see them in use in a photo of *Macon*'s hangar. Rendering by Eve Bartolo, FRD, as directed by the author.

8.8 Case Discussion

The USS *Macon* wreck site and the remains of the four F9C-2 Sparrowhawk biplanes represent a unique aviation cultural heritage site. The wreck site, protected by the National Marine Sanctuaries Act soon after its location in 1990, affords researchers the ability to study preserved airship and aircraft remains in situ over a long period. Several surveys over twenty-five years have shown incremental deterioration in the material components and a traceable decay timeline for the biplanes. Survey work in 2015 served to fulfill federal stewardship responsibilities for this National Register-listed wreck site, but more importantly, was the latest in a series of condition assessments that inform scientific and archaeological study on aviation sites and decay of aircraft materials.

Studies showed that some aluminum experiences advanced decay, especially where it either remains in physical contact with other metal or different aluminum alloy pieces, or is buried. The F9C-2 Sparrowhawk biplanes in situ will continue to break down, primarily because the aluminum structural support is decaying at the contact points (pieces that are riveted or bolted together). In contrast, pieces of doped aircraft fabric are decaying at a slower pace and will continue at that rate, especially if they remain covered in sediment and with relatively low oxygen on site. It appears that complete or partial recovery of aircraft or other large components will never be in these artifacts' best interests and will likely result in their destruction.

Because of this, the rarity of these artifacts, and also their ability to engage the public, any archaeological survey of this nature should include planning for virtual museum or online display, which allows, in this case, for the airship story to be told via this archaeological site at any number of aviation or other museums. Digital data visualization methods, for example 3D models, can serve as both archaeological recording and public engagement tools. This site should continue to be studied and documented into the future as a characteristic example of a range of fragile aviation remains on one specific site. WWII sites, in comparison, will deteriorate slower in similar conditions due to the improved strength of the metal.

9. CASE STUDY- PBM-5 BUNO 59172

The third case study in this dissertation focuses on the wreck site of Martin PBM-5 Mariner BuNo 59172. This case study serves to showcase an example of long-term community stewardship, visual deterioration analysis, and interpretive display methods for the archaeological site and artifacts. PBM-5 59172 rests in 24 m at the south end of Lake Washington in Seattle, WA. This PBM-5 Mariner presents as typical for the age and preservation of most aircraft in freshwater lakes and reservoirs in the US. The aircraft is atypical, however, in that it is one of few remaining underwater examples of the type, and only one remains of this particular type completely restored in a museum.

In 2018 a collaborative survey with engaged community stakeholders took place to serve as a collection of baseline-status data for the wreck, an experiment to streamline quality imagery for 3D modeling of a low-visibility site, and to test museum visitor reaction to an interpretive display using the 3D model. I address the archaeological goals of the survey more specifically in section 9.2 below, but they included 2D mapping of the site and surrounding environment, 3D site mapping, and visual deterioration analysis. I designed the survey to inform federal and state authorities of the condition of the wreck site, and to provide enough data visualization to help foster stewardship for Seattle's cultural heritage resources under water. This survey also illustrates an example of a successful collaboration between enthusiast divers, academic partners, and the museum community.

9.1 Background History

9.1.1 PBM-5 Martin Mariner[273]

The Martin Mariner is a large twin-engine flying boat with a twin rudder tail, a 36 m gull wing, and retractable floats (Figure 9.1). The US Navy invited bids for an improvement upon the well-known PBY Catalina in 1937. After the 4000+ manufactured PBY Catalina, PBM Mariners (variants 1-5) were the second largest produced military flying boat of any nation, at 1,366 total. PBM-5 59172 is one of 628 aircraft built of this specific variant. In WWII Mariners were used for cargo transport, search-and-rescue activities, air to sea warfare, and long-range reconnaissance missions. The Mariner was a versatile aircraft in the US Navy, and could be used on carriers as well as fitted with a jet-assisted-take-off system to allow operations in rough sea states. The Mariner was an improvement over the Catalina in many ways, but proved too expensive to order and maintain in large numbers.

[273] Complete specifications and drawings in Appendix L.

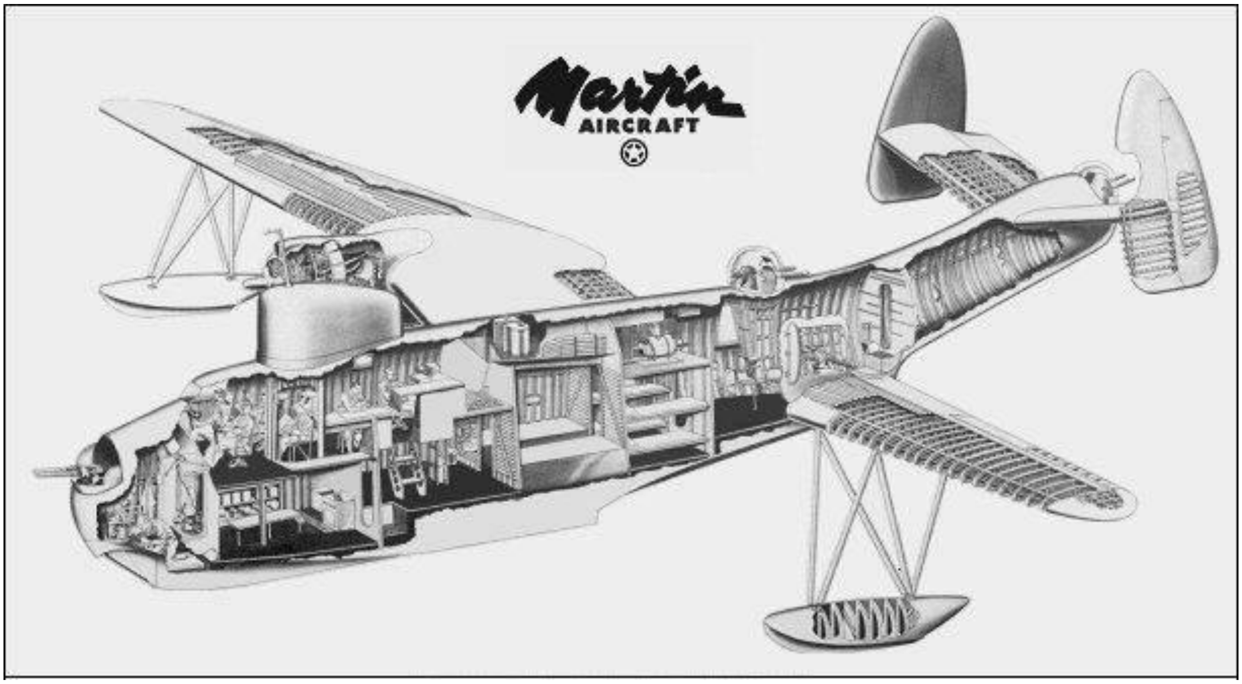

Figure 9.1- Cutaway model of the Martin Mariner aircraft. Reprinted from Industrial Aviation 1945.

9.1.2 PBM-5 59172 Seattle History[274]

In 1923 the US Navy completed construction on the first hangar on the newly established joint Army/Navy airfield at NAS Sand Point; it held six naval reserve aircraft and one Army ROTC Jenny biplane.[275] By the outbreak of WWII in 1939, the expanding city of Seattle was too close to Sand Point to make it effective for combat training with live weaponry, so the station served primarily for outfitting, servicing, and flight training. After the war ended Sand Point became a service center for US Navy flying boats stored in Renton, at the southern tip of Lake Washington. Naval Reservists continued to use NAS Sand Point until its closure in July 1970.

[274] PBM-5 59172 Aircraft history and accident cards are in Appendix M.
[275] Wilma 2000.

The US Navy's Mariner BuNo 59172 was taxiing to the Boeing-Renton seaplane ramp at Renton near the south end of Lake Washington on May 6, 1949, when strong winds forced it into pilings near the shore. One of the pilings knocked off the starboard float, causing the aircraft to list to the starboard side. The pilot recalled crew members climbing on top of the port wing in an attempt to stabilize the aircraft but to no avail; the pilot's logbook shows the note "Sank this one" next to the bureau number.[276] The crew escaped unharmed and the PBM slipped over on its back and sank to 24 m.

9.1.3 Salvage and Display

This aircraft has been subject to multiple unsuccessful salvage attempts and partial recoveries. Local divers rediscovered the site in 1972 after which, in 1980/1981, a concentrated effort by the Underwater Historical Research and Recovery Foundation (UHRRF) sought to recover artifacts from the site. No clear rules on permitting of activity on underwater aircraft existed at this time, and the National Naval Aviation Museum (NNAM) in Pensacola, FL, claimed the project as unauthorized recovery in 1981. UHRRF turned over all of the artifacts they had recovered to NNAM, after which they and the museum abandoned further plans to salvage the airframe.[277] After fruitless interest by several salvagers, in 1990 the US Naval Reserve Mobile Diving Salvage Unit One's Detachment 522 (NRMDSU-1 Det 522) of Naval Station Everett, Washington, made an attempt but after 10 days a diver experienced a fatal heart attack on-site due to a pre-existing heart condition and the project suspended further work.[278]

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[276] Grant et al. 1996, 95.
[277] Grant et al. 1996.
[278] Naval History & Heritage Command 2014.

In 1995 UAB archaeologists evaluated the wreck for Section 106 determination for the NRHP designation, and created a Memorandum of Agreement (MOA) between the Navy Historical Center (NHC), the U.S. Army Corps of Engineers (ACE), the Washington State Office of Archaeology and Historic Preservation (OAHP), and Advisory Council on Historic Preservation (ACHP) for a potential excavation. Using the site as a training ground for Naval Reserve Mobile Diving and Salvage Unit Detachments, the US Navy supported the excavation attempt in August-October 1996. The Naval Historical Center, the Mariner/Marlin Association, and the Boeing Corporation contributed financially and logistically to the 1996 project. Navy UAB sent an underwater archaeologist to document the wreck and the project during the project. The archaeological report notes the following:

> The documentation of BuNo 59172 was conducted in a manner which allowed for achieving, in some form, the fol1owing seven specific research objectives: (1) the gathering of historical research regarding the history of the boat, (2) the compilation of baseline site information, (3) documentation of the recovery activities, (4) registration and control of any disarticulated artifacts recovered, (5) documentation of the recovered aircraft structures, (6) assessment of the aircraft's relative state of preservation fol1owing recovery, and (7) compilation of a final report integrating all of this gathered data.[279]

US Navy MDSU determined and directed the manner in which the salvage proceeded. The Navy team first focused on removing the mud and silt that had accumulated in and on top of the aircraft. In October 1996 a failed attempt to pull the aircraft up resulted in the separation of the

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[279] Wills 1997b, 3.

rear fuselage and tail of the aircraft and a longitudinal splitting of the rest of the frame.[280] The project team members continued raising the broken tail section to the surface, cleaned it, and NNAM loaned it to Pima Air & Space Museum in Tucson, AZ for display (Figure 9.2). In the remaining wreckage, Navy divers closed egress into the aircraft with mesh screens covering hatches and the now-exposed hole in the aft section. The tail section and tail turret are currently on display in Pima. Pima is also the home to the only fully-restored Mariner on display, and the two exhibits sit side-by-side creating an interesting comparison.

[280] Barth 1996.

Tail section being raised less one stabilizer

Complete Martin twin .50 cal tail turret less glass

Figure 9.2- (Top) Images from the salvage of the PBM-5 59172 tail section. (Bottom) The tail assembly display at Pima Air & Space Museum. Top photos reprinted from Barth 1996, bottom photo courtesy of Pima Air & Space Museum.

9.2 Project Planning, Methodology

Plans for this survey originated from interest in a larger survey of submerged cultural resources in Lake Washington that would satisfy grant incentives from NOAA's Office of Exploration and Research. This smaller project instead focuses on the 3D modeling and site characterization of one aircraft out of nine in Lake Washington. I planned the survey to garner support from State Historical Preservation Office authorities and local community enthusiasts by including documentation products that would be beneficial for future management of the site.

9.2.1 Partners and Jurisdiction

This project benefitted from the kind assistance and enthusiasm of two local organizations. The Seattle-based Global Underwater Explorers (GUE) is a group dedicated to the responsible exploration and observation of Seattle and Puget Sound's submerged environmental and cultural resources, and Coastal Sensing Survey is dedicated to mapping and community stewardship of wreck sites in Seattle's waters. Both groups supplied access to in-kind support of ship time and costs. Members of this organization have been obtaining sonar and photographic images of wreck sites for decades, and more recently have been experimenting with 3D modeling.

PBM-5 BuNo 59172 is a Navy-owned aircraft and under protection by the Sunken Military Craft Act. Any intrusive survey or excavation requires a permit from the US Navy's UAB for SMCA compliance and the Washington Department of Natural Resources (DNR), due to the aircraft being on a lakebed under DNR jurisdiction. This project is a non-disturbance survey and, therefore, did not require a permit, but both the US Navy UAB and Washington DNR were notified about the project and will receive a report of the results.

The NHHC's UAB developed several option justifications for the future of this site, including recovery, preservation in place, or preservation and development into a community dive site, noting that exploring ways to develop the wreckage as a dive site may be the best option.[281] Project planning for this survey takes into account the ability to forge relationships between collaborators at the amateur and State level in order to promote this kind of development. It is possible that this survey work, and the resulting 3D model, can be the first of many project which promote collaborative management between divers and the State of Washington.

9.2.2 Research Goals

The archaeological component to this project serves as a means to provide both baseline and updated documentation to a historical submerged resource. This project focuses on one aircraft site in Lake Washington and allows for experimentation with all aspects of site documentation and display. This chapter summary and the ensuing report to the State of Washington includes background research, a current condition report, site mapping, and 3D modeling of the site, after which I hope a maintenance-survey program can be planned for future years. Future 3D models can be easily compared with this project's results and archaeology students, or the State of Washington, can monitor a timeline of deterioration. The Navy History and Heritage Command (NHHC) is supportive of non-intrusive research of its sunken military craft, and indicated they are appreciative of the survey results. I also provided the report and model to the Washington Department of Natural Resources (WDNR) and the Department of Archaeological Preservation and History (DAHP).

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[281] Naval History & Heritage Command 2014.

Site survey in Lake Washington itself presented the first challenge; this aircraft is within easy recreational dive limits but in extremely low visibility due to sedimentation in the water column and the resulting lack of light. 3D modeling of this site allowed for the ability to 'see' the wreck fully for the first time since its deposition. 3D models are often viewed online, but models of archaeological sites, especially underwater, have not been widely incorporated into museum display. As part of this dissertation I wanted to test the relevance of these models in a museum setting with accompanying interpretation.

9.2.3 Equipment

This project deployed a low-cost remotely-operated vehicle (Blue Robotics BlueROV II) customized for exploring and recording submerged archaeological material in low level light environments. Beyond the standard configuration supplied by Blue Robotics, the ROV hosted two HD cameras and auxiliary lights. Divers on this project used GoPro Hero 3+ Black cameras, and one diver used a Sony A7RIII with underwater housing. I discuss a comparison of results between the GoPro and the Sony camera in the modeling section 9.4 of this case study. Supplemental divers carried BigBlue 30k and 25k lumen lights.

9.3 Survey

Survey dives took place January-March 2018 and began with orientation dives and ROV practice runs on the wreckage. GUE divers made five dives on the PBM-5 wreckage to capture imagery for the 3D modeling and the visual condition survey. Divers made measurements of the aircraft solely to scale the 3D model accurately.

9.3.1 Site Description

The 1997 baseline report was one of the first documentation sources for the PBM site, described prior to the excavation attempt. The report notes the location, orientation, depth, and initial sediment overburden on the wreck. At that time, the hull projected approximately 12 feet above the mean bottom at its highest elevation (Figure 9.3).[282] The 1996 salvage attempt removed a significant amount of sediment from on top of the aircraft wings and around the fuselage (Figure 9.4).

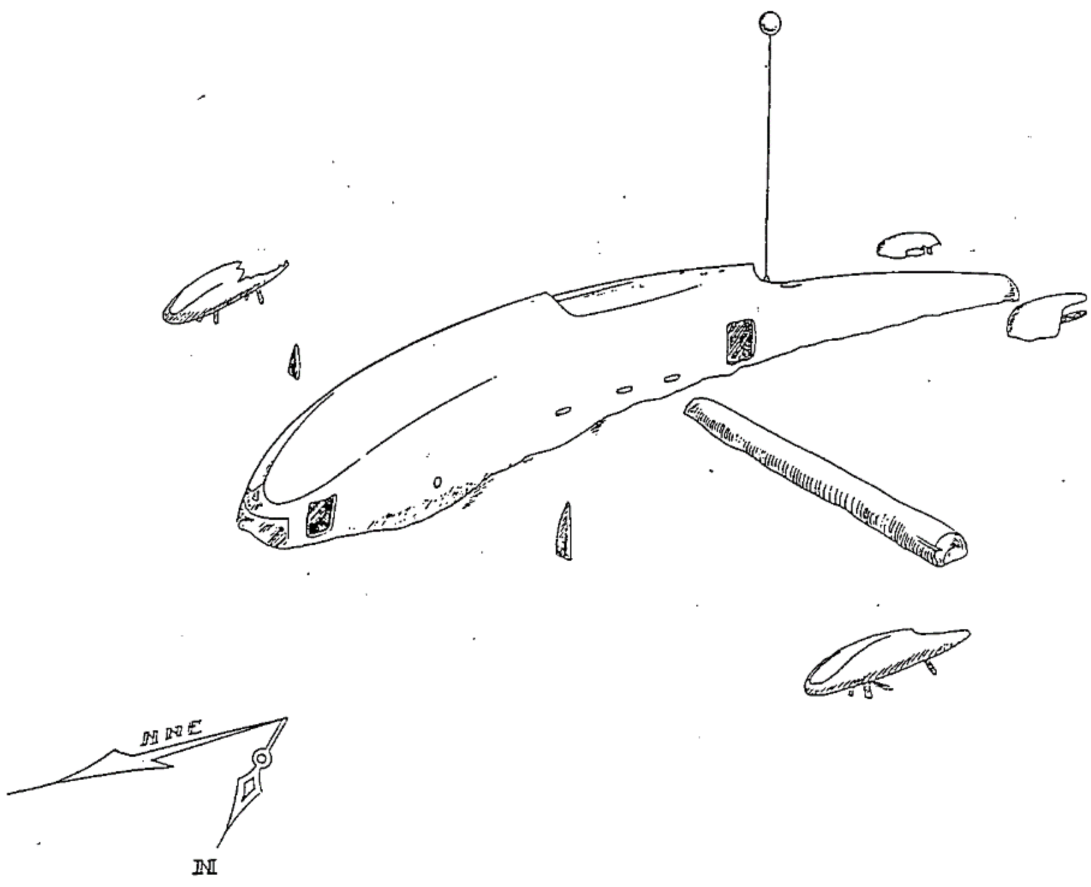

Figure 9.3- The PBM-5 59172 site as drawn in 1996 by Robert Mester. Reprinted from Wills 1997.

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[282] Wills 1997b, 22–23.

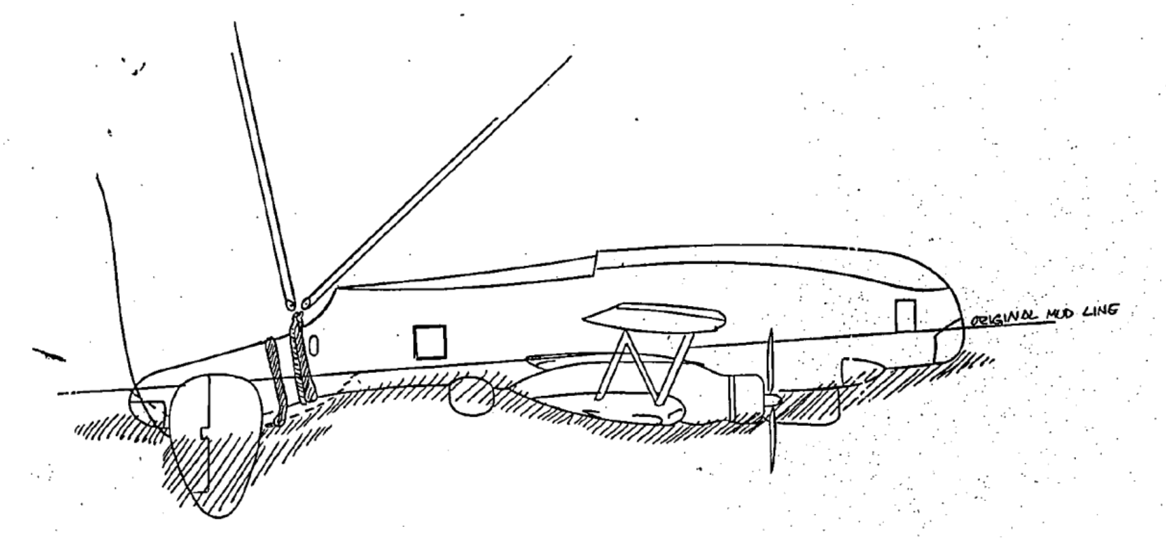


Figure 9.4- The PBM-5 site after sediment removal, Reprinted from Wills 1997.

The PBM-5 rests inverted and on an incline near the southern end of Lake Washington at 21 m (Figure 9.5). The majority of its aft and tail section was recovered from in between the step and the end of the afterbody of the flying boat hull, just forward of the rear exterior hatch. This resulting hole exposes the corresponding bulkhead and the interior compartment. A 3 m section of the ceiling compartment to the aft fuselage remains on the lake floor. The hatch doors near the cockpit are missing on both sides and there is a mesh screen bolted to the holes preventing access to the interior. Steel bars bolt in diagonally across some of the smaller openings on both sides of the fuselage. One mesh screen also covers the aft interior door of the aircraft. A mesh screen once covered the rear opening to the interior of the aircraft, but that screen disappeared after 1998.[283] Sediment covers most of the upper portion of the aircraft from the top side of the wing

[283] Wills 1996; 1997a.

surface. Both engines were used as attachment points during the recovery attempt, and now present as wrenched away from their mounts and angling slightly upwards and to the north. Half of both engines and two or more propellers on each engine show above the sediment layer. Engine 2 on the starboard side presents as intact with nearly all of three of the four propeller blades above the sediment level, pointing roughly at 300°, 30°, and 120°. The propeller assembly on Engine 1, port side, has been wrenched from its mount from the 1996 lifting attempt and only two propeller blades can be seen (Figure 9.6). Sediment covers the gull-type wing section outside of the inner-most part. The blue paint on the fuselage presents as a dark brown color on the fuselage, but the aluminum boat hull shines through patches of thin marine growth (Figure 9.7). The sediment layer ranges from a few millimeters to 0 mm on flat surfaces. The 1997 report records the port side pontoon float as in situ but damaged, and the starboard pontoon as missing (as well as the reported confusion in prior reporting for which float was missing).[284] The starboard float went missing in between 1990 and 1996. The port float remains in situ presently, and we recorded it to document any further deterioration (Figure 9.8).

[284] Wills 1997b, 13.

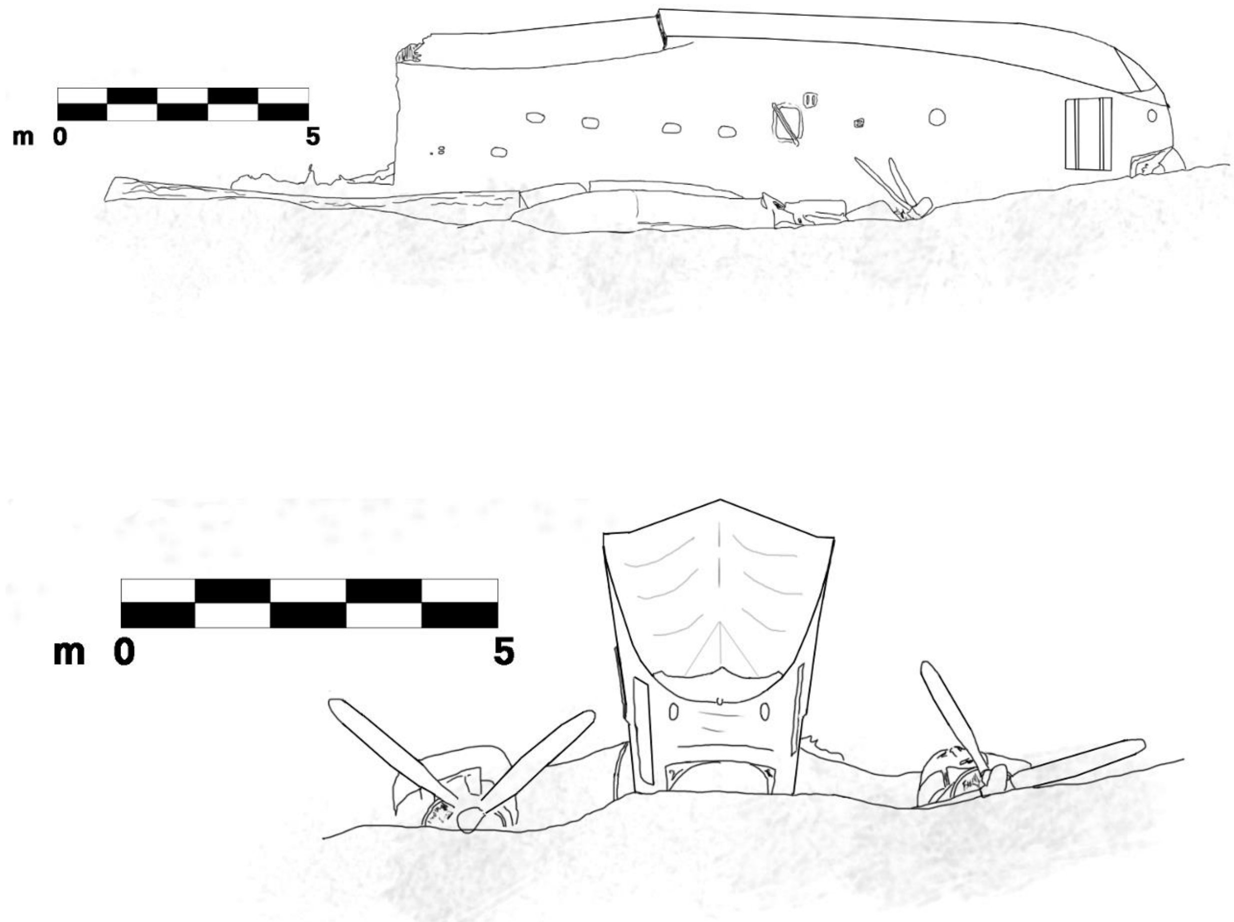


Figure 9.5 PBM-5 59172 Site map views. Drawing by the author.

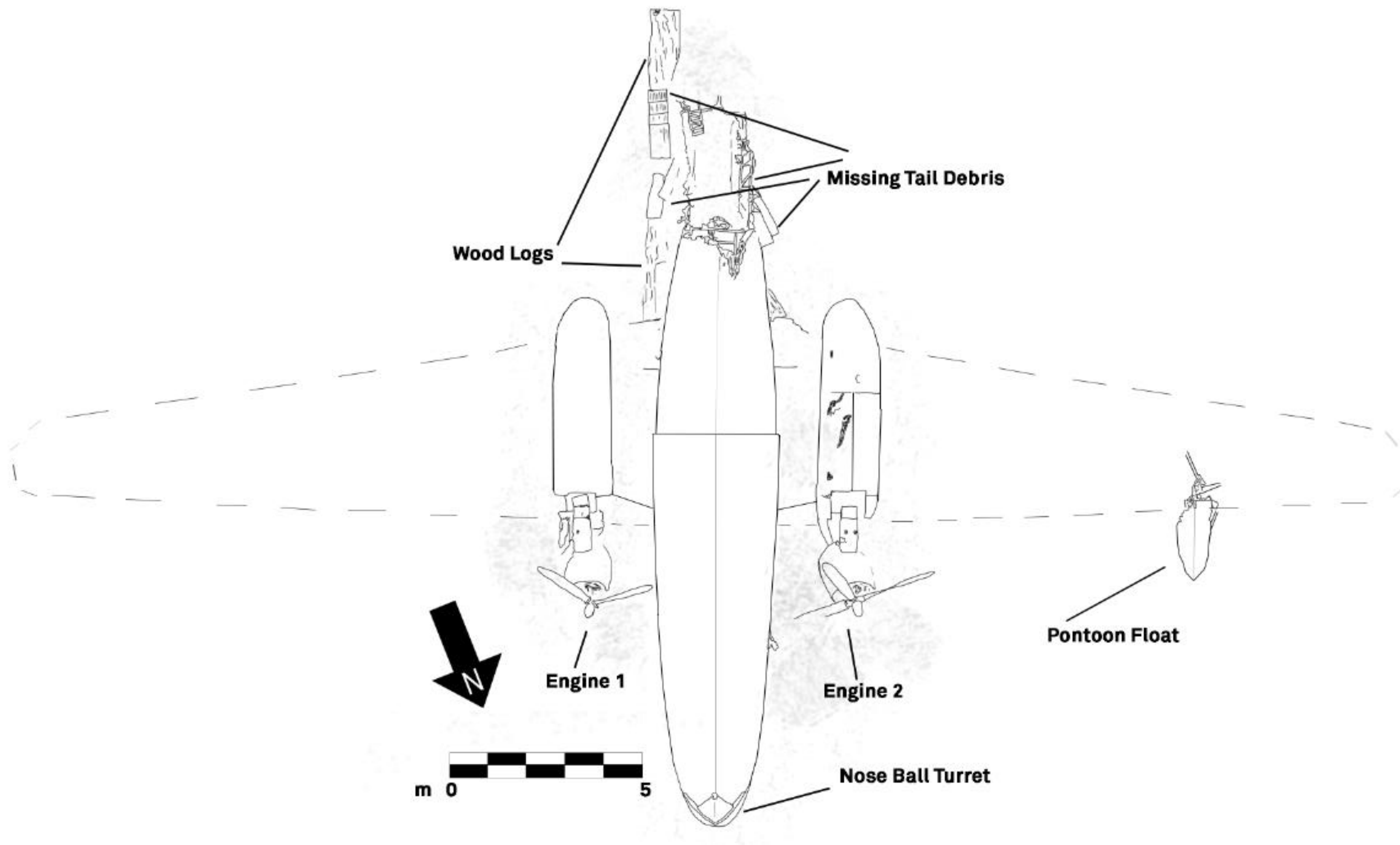


Figure 9.5 Continued

Figure 9.6- The port side engine cowling and propeller assembly of the PBM Mariner in Lake Washington. Photo by Kees Beemster Leverentz.

Figure 9.7- The PBM-5 nose and a portion of the nose ball turret above the sediment line. Sediment appears as lighter colored dusty patches on some vertical parts, and patches of aluminum shine from scratches. Photo by Kees Beemster Leverentz.

Figure 9.8- Part of the damaged port side pontoon float. Photo by Kees Beemster Leverentz.

While the majority of the aircraft still appears to be free from large amount of sediment, the wings are no longer visible except for an outline on sonar imagery (Figure 9.9). Damage to the airframe appears concentrated around the missing tail section, where several areas of fuselage skin are obviously torn. Several small holes puncture the bottom of the flying boat hull and the starboard wing. Damage to the starboard wing also includes a long gouge and an area of torn and buckled plating behind the engine on the bottom wing surface and leading edge. There are pieces of interior corrugated metal and some panels aft of both wing roots, likely from the salvage attempt. Some logs associated with nearby industry activity remain on site; one large log rests parallel to the remains of the missing tail section on the port side.

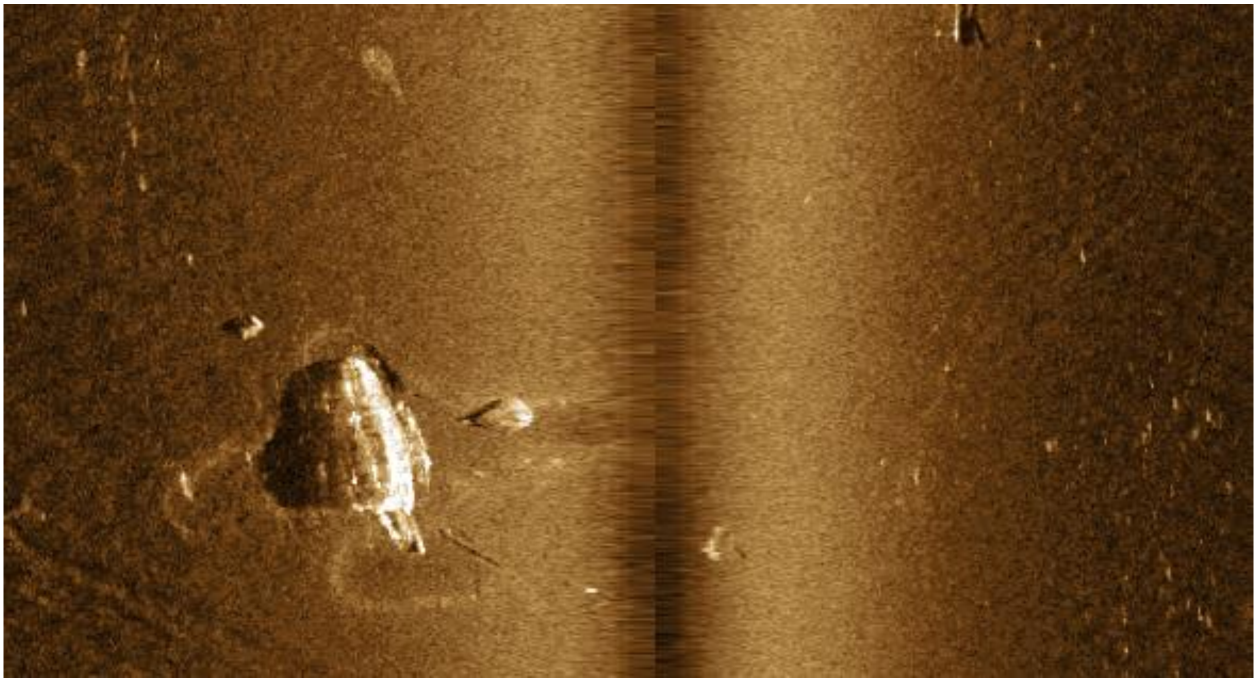


Figure 9.9- Sonar image of the PBM-5 in Lake Washington. Photo courtesy of Ben Griner and Mike Racine, Coastal Sensing Survey.

9.3.2 Site Formation Research

The damage from the salvage attempt is the most significant site formation event of the aircraft's history. Prior to the attempt, however, Wills notes several damaged areas in a physical condition report, such as perforations in the hull bottom, damage to the tail surfaces, possible shattering of plexiglass turret covers, and substantial damage to the starboard float attachment point in the underside of the wing.[285] In addition to these he states that several grappling hooks and boat anchors, causing perforation and tear damage in many points on the aircraft, had been

[285] Wills 1997b.

found lodged in the wreck itself and removed. During the recovery attempt Wills reports that separation occurred at frame 29 (station 647) at the forward extent and frame A34 (station 752 ½) at the aft extent, and the lifting straps had caused buckling damage to that section of hull.[286]

The salvage team recovered several metal objects in varying states of decay, and found several small shreds of doped fabric from the flight control surfaces around the site. In the photographs (unfortunately none appear of the recovered fabric) one can clearly see the dark blue color of the paint, as well as a medium blue color underneath in areas where the over layer had worn away (Figure 9.10). Wills concludes that, overall, the wreck was decaying at a slow rate, with accelerated rates seen around areas with magnesium, around areas which are joined or fastened together, in areas which experienced mechanical stress, or around metals not treated with anti- corrosive processes during manufacture.[287] In his report, he also notes that "exposed portions of the wreck may have suffered greater corrosion than portions which have remained buried in the sediment layer" (Figure 9.11).[288]

[286] Wills 1997b, 40.
[287] Wills 1997b, 45.
[288] Wills 1997b, 45.

Figure 9.10- Corrosion nodules, faded dark blue paint, and an under layer of bright blue paint from an areas of fuselage recovered in the 1996 salvage. Photo courtesy of NHHC UAB.

Figure 9.11- The recovered tail section of PBM-5 59172 (both side views) photographed on land in 1996 to show the areas of localized corrosion. The bottom part of the aircraft in the photo would have been exposed and the top part buried. The corrosion pattern shows the sediment line. Photos courtesy of NHHC UAB.

In 2018, more than a decade after the original research and salvage attempt, the PBM-5 presents as visually similar to the description in the 1997 report. Preparation for the 1996 salvage attempt included removing close up to 2 m overburden in some areas, which exposed up to 1 m of the wreck, especially in the wing and forward of the wing areas. PBM-5 59172 rests at the mouth of a river into Lake Washington, which continues to deposit silt and sediment on top of the wreck, but sedimentation has not appeared to occur at a high rate. Without clear images from after the salvage attempt, it is impossible to compare the current sediment level, but it appears to be extremely close. The wings and half of the nose ball turret remain exposed with a light sediment layer.

Each wing root has piece of stripping of an unknown material that is peeling up and away. Along this seam appears a band of pink discoloration in between the blue painted fuselage and the underwing area, which may have been painted white.[289] The unknown material is also present on a forward triangular area of the boat hull, and is also peeling up. Etched graffiti appears in several locations on the sides, and there are scratches on the aircraft sides from either careless divers or dropped marker weights.

Corrosion presents in a spotty pattern of white, tan, and brown colored nodules that present on every type of surface on the fuselage, boat hull, the aircraft's interior, and on access-limiting steel introduced to the wreck in 1996 (Figure 9.12). All corrosion nodules appear to be a similar height, and while some spots are singular, others have either grouped or expanded into larger areas. Mostly, corrosion patches are near to, or follow, riveted seams and openings, but does not uniformly affect these seams (Figure 9.13). Corrosion is mostly present on the corners of each side of the step, around most window or panel openings, and following the seam of the chine. In all other areas, corrosion appears to be random. There are fuselage skin panels that are corrosion-free, directly in between panel where corrosion follows the riveted seam; in these cases, the corrosion presents a straight edge (Figure 9.14). A large area of corrosion on the starboard side includes a pitted hole, but I was not able to see if other areas are pitting through the skin. There appears to be a slight discoloration along the fuselage that marks the previous location of the lake bottom. On the port side, it appears that the area buried in sediment prior to 1996 has less corrosion spots, but this is not the case on the starboard side.

[289] This pink discoloration is also visible on the displayed tail section, again in-between blue painted and non-blue surfaces.

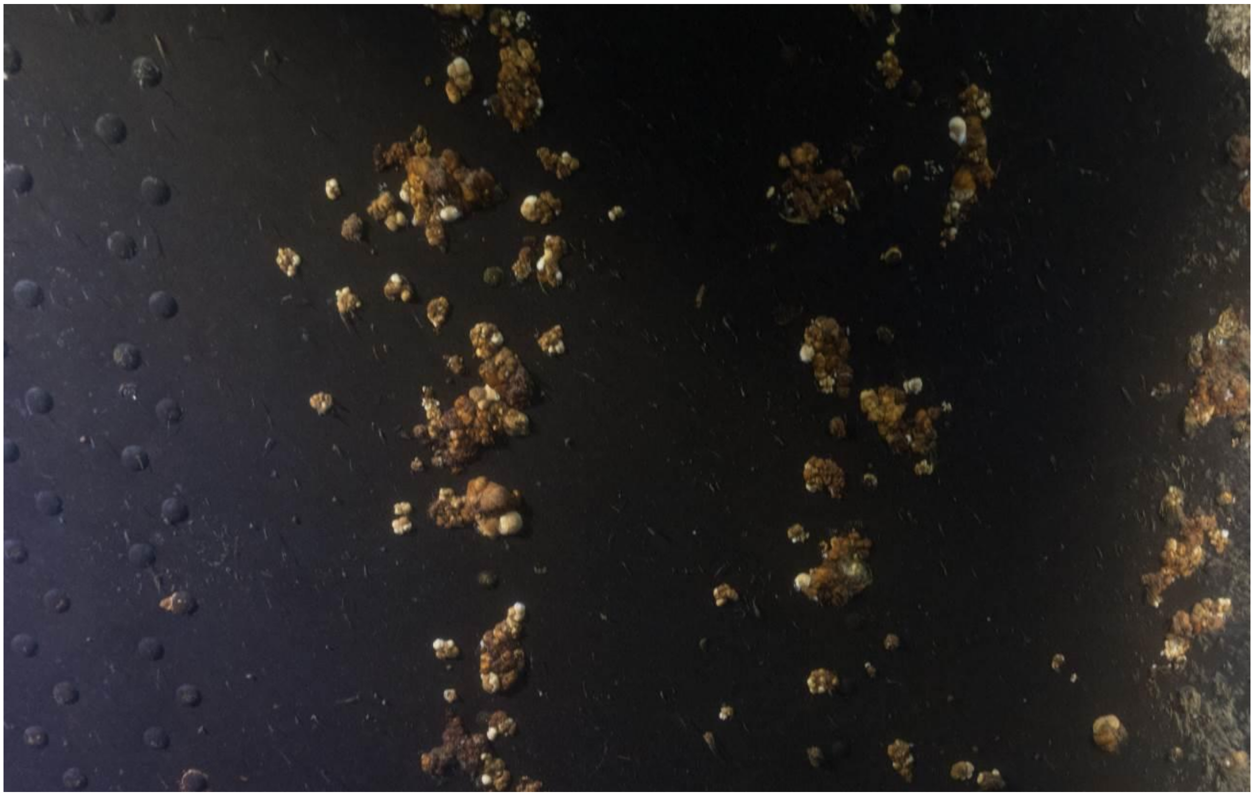


Figure 9.12- Corrosion nodules on the PBM-5 fuselage appear to be ferrous corrosion products. Photo by Kees Beemster Leverentz.

Figure 9.13- Corrosion patterns following rivet seams and the outline of a window, but does not affect every rivet seam. Note the graffiti on the top left. Photo by Kees Beemster Leverentz.

Figure 9.14- A panel with relatively no corrosion nodules in between areas with corrosion product patches. Note the straight lines following the seams. Photo by Kees Beemster Leverentz.

Several mollusks attach to the fuselage, mostly just below the sediment line, but a few are on the sides of the aircraft. They produce a stream of gas bubbles that float to the surface very near to the aircraft skin. In the path of the bubble stream, cellular chains of hair-like algae grow, feeding on the nutrients on the released gas (Figure 9.15). In these areas as well, corrosion appears in slightly greater amounts, although this is not necessarily correlated (Figure 9.16). This hair-like growth is most prevalent in the remains of the aft fuselage where there are more horizontal spaces to hang. The engines and propellers also appear to have nodules and the hair-like growth, as well as paint color deterioration. Stainless steel panels on both engines present as non-degraded, free from corrosion, and distinctly shiny (Figure 9.17).

Figure 9.15- An area of algae growth on the fuselage in the path of released gas bubbles (brightness adjusted to show the growth). Photo by Kees Beemster Leverentz.

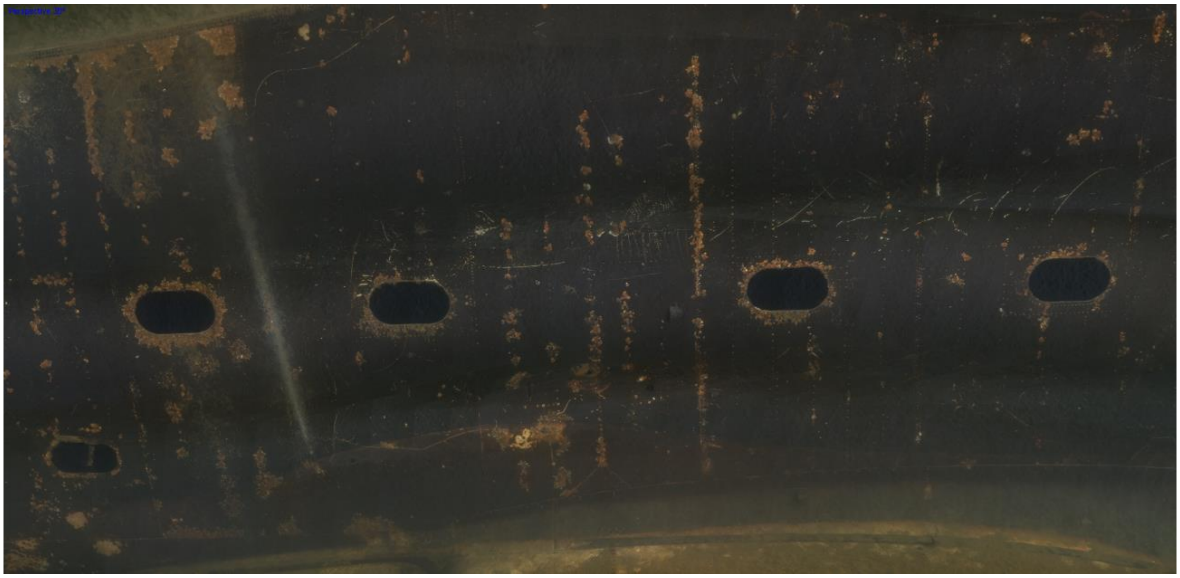


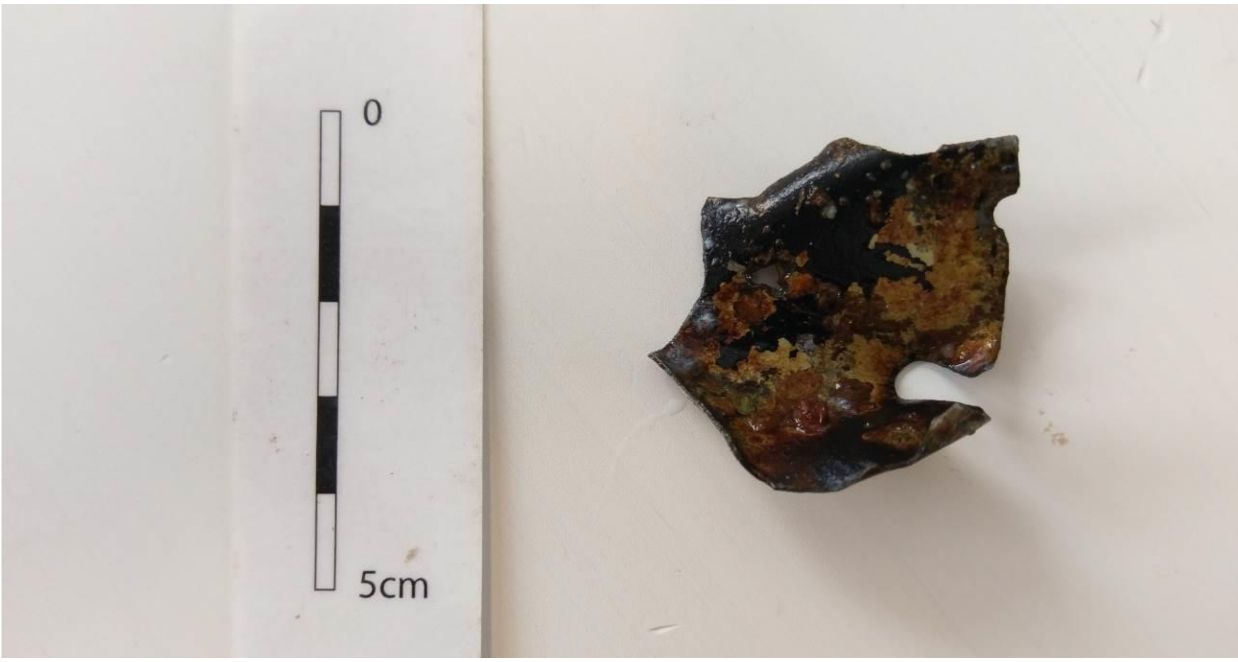
Figure 9.16- A mussel is attached to the side of the fuselage, in the lower left part of this image, that is emitting stream of bubbles. The hair-like growth follows and angle to the surface because the aircraft rests on a slope. Vertical corrosion on the center-right, however, follows the rivet pattern. Model by the author, photos acquired by GUE Seattle.

Figure 9.17- The starboard side engine with aluminum and stainless steel panels. Photo by Kees Beemster Leverentz.

Corrosion on the aircraft appears to be widespread, but does not completely cover the surface or disrupt the visual appearance. The corrosion does not seem to be threatening the structural stability of the aircraft, but further work should be done to help determine the extent of the pitting, if any, in interior or crevice areas. The steel access-limiting bars and screen bolt on to the aircraft so I anticipate some galvanic reaction at those points, but the edges of the screen lift away from the aircraft, so the extent of the reaction site may not be as large.

9.3.3 Sample Analysis

Working in partnership with the NHHC UAB Archaeology & Conservation Laboratory as co-PI on corrosion analyses, GUE divers and I acquired a sample of the PBM-5 59172 fuselage metal from the rear starboard side. GUE divers found it near to the sediment line on the starboard aft side of the aircraft where the tail was ripped from the fuselage. This metal shows both non-corroded areas and corrosion nodules (Figure 9.18). Side A is the exterior side facing the water column, side B faced the interior of the tail. I prepared the sample for initial visual analysis by scraping what appeared to be the back side of a nodule, which was the largest blemish on the less-corroded side (B). I could immediately feel that area had completely deteriorated into corrosion products and saw the telltale sign of blue gravely substance in the pit (Figure 9.19). There is one other pitted hole in the sample. The side that displays more advanced corrosion (A) appears to have corrosion nodules in areas only where the paint has disappeared. I expect that, on this aircraft, corrosion will colonize in areas where paint loss has already occurred, and the areas which have large nodules will also have deep circular-shaped pits underneath. The prevalence of corrosion on the exposed sample may suggest that water chemistry has less effect on susceptibility to pitting as opposed to bacterial and marine life growth. More study, focused on the interior spaces of the aircraft, is needed to test this theory.



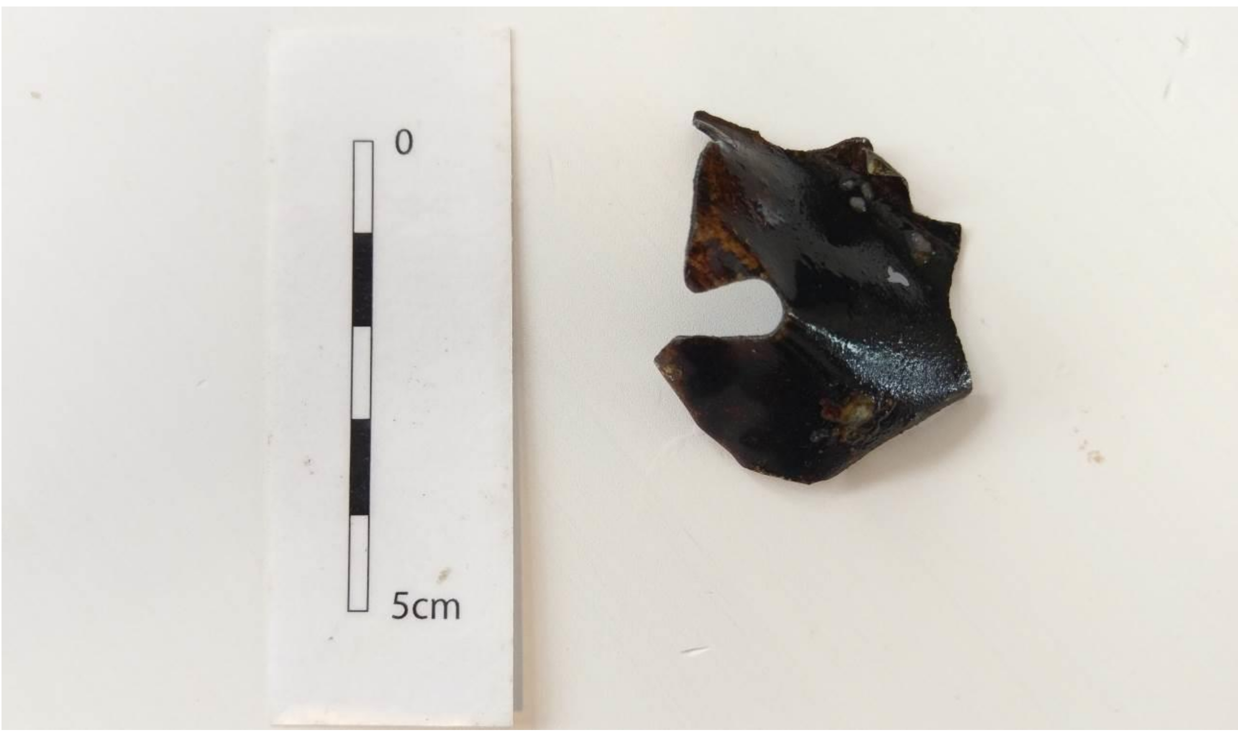


Figure 9.18- (Top) Side A of the PBM-5 sample with nodules of corrosion. Side B (bottom) shows as nearly free from corrosion. Photos by the author.

Figure 9.19- (Top) Side B of the PBM-5 sample after scraping a nodule of corrosion, which shows to be pitting through the wall of the piece from side A (bottom). The arrow on side A shows scraping of the tan color to reveal bare metal, showing loss of paint. Photos by the author.

I sent the sample to NHHC UAB Archaeology and Conservation Lab director Kate Morrand for XRF analysis on the piece for baseline information. She and Dr. Pearson at the US Naval Academy ran the XRF using a Bruker M4 Tornado micro-XRF machine. The Navy scientists tested several areas, including corrosion nodules and open pits, dark brown areas, light brown areas, and an area of bare metal. The peaks of the elements presented fairly evenly across all sample locations; the alloy is a standard 2xxx series alloy with copper, magnesium, and small iron peaks. Chromium and zinc peaks were present on painted areas, and the dark brown area presented with a slightly higher magnesium peak. Trace amounts of silicon and potassium also registered on the machine, most likely signatures of corrosion. The Navy UAB plans to run further testing on the corrosion products and nodules of the sample, as well as water chemistry analysis, to discover any key mechanisms that differ from aircraft in saltwater sites.

9.4 3D Modeling

Initial experimentation proved the superiority in photos between the Sony A7RIII and the GoPro Hero 3+. Even with the supplemental lighting, video on the Sony far surpassed the quality of the GoPro video. A contributing factor was the barrel distortion of the GoPro lens. We processed the models with Agisoft Photoscan. One unforeseen problem in the modeling process, however, was the color of the wreck, which currently presents as dark brown, against the color of the water, which is also a dark brown. We experienced difficulty with Photoscan being able to register the dark colored points against a dark colored background and rendering the object with a loss of information in those areas. Photoscan aligned the images without issue and with texture mapping produced a high quality model that showed even light scratches clearly and accurately (Figures 9.20-9.23).

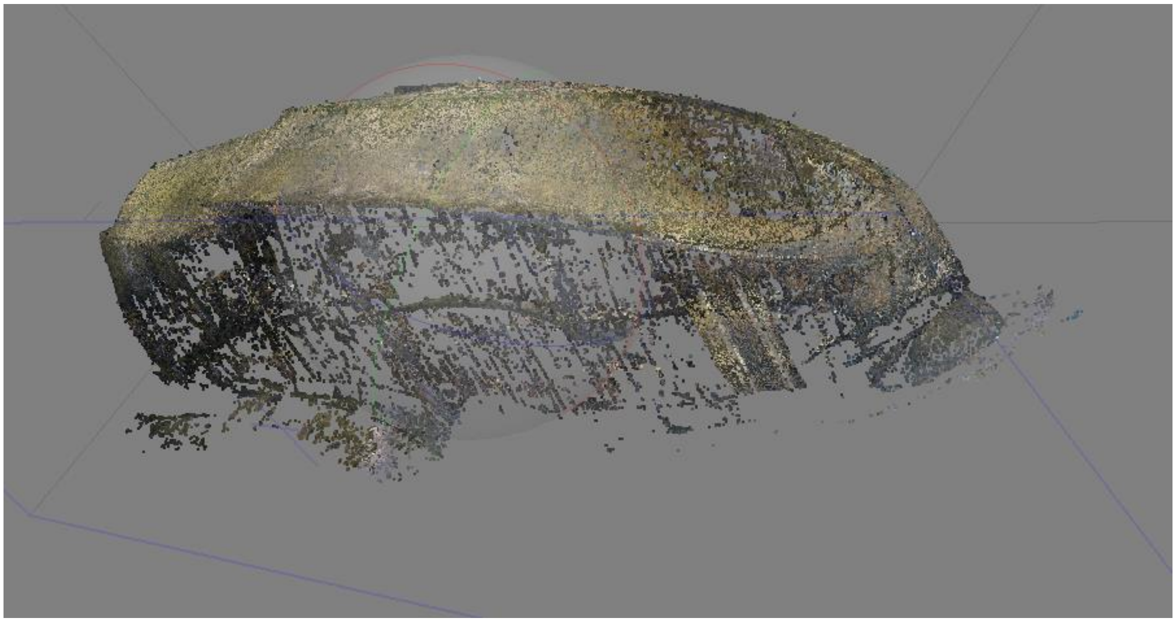


Figure 9.20- The sparse point could of the PBM-5 aircraft in Lake Washington (using Agisoft Photoscan). Gaps in the cloud will somewhat fill in the dense point cloud stage, but the program has difficulty rendering dark objects. Photo and model by Kees Beemster Leverentz.

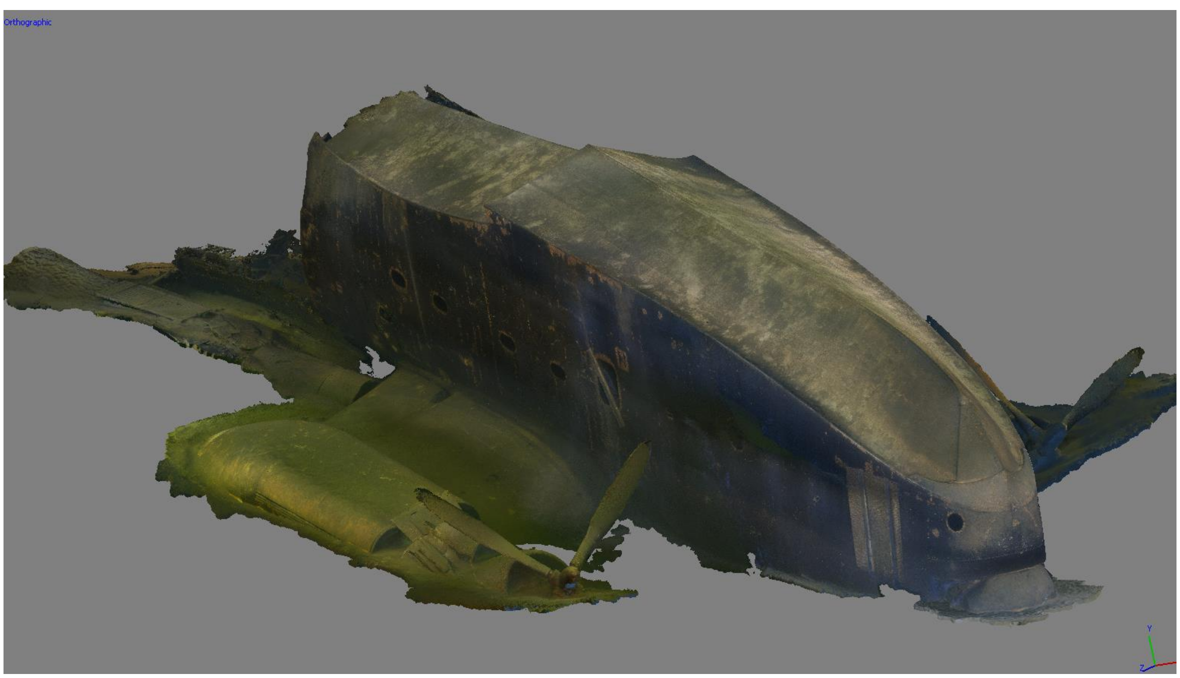


Figure 9.21- Forward view of the PBM-5 3D model. Model by Kees Beemster Leverentz and the author.

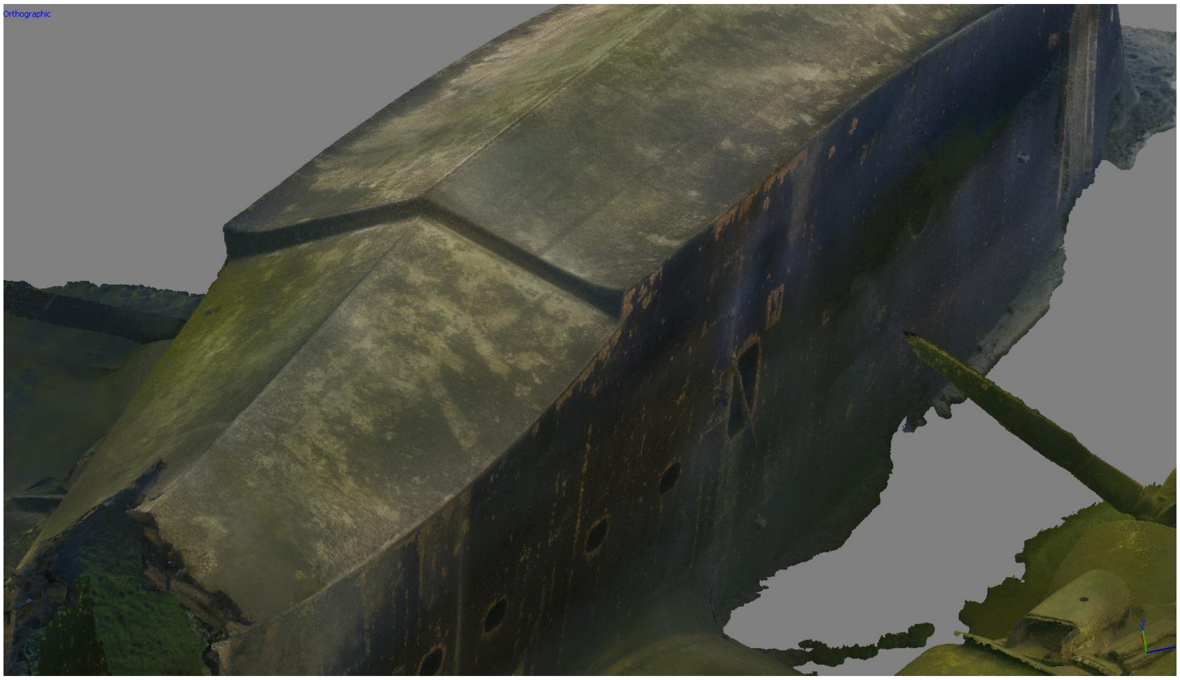


Figure 9.22- The curve of the hull and the step, beautifully rendered by Photoscan. Model by Kees Beemster Leverentz and the author.

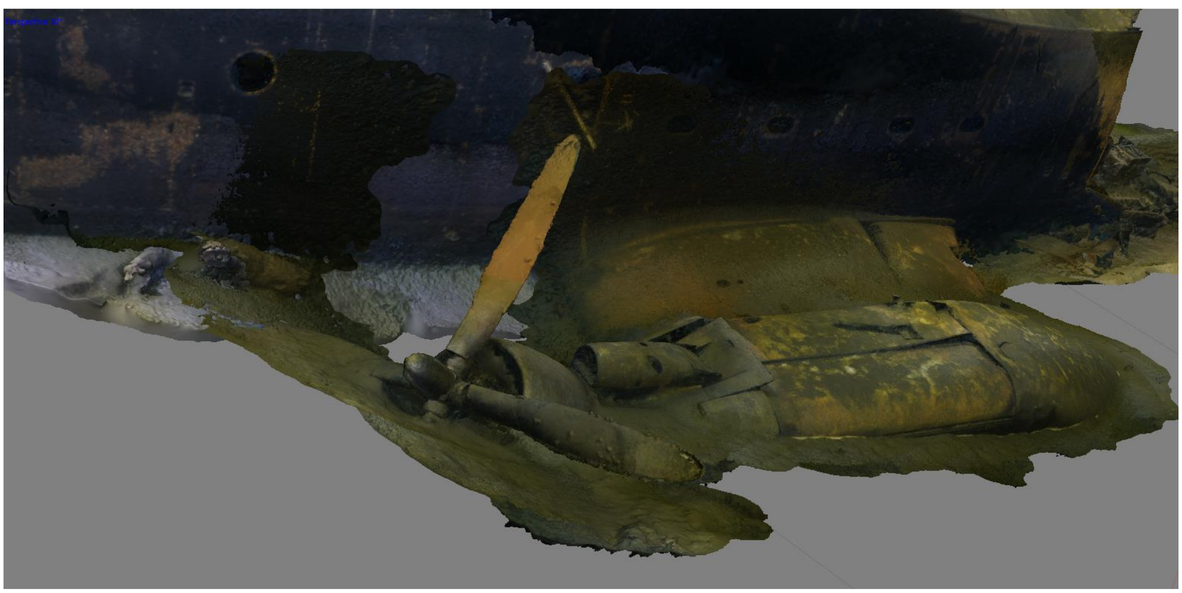


Figure 9.23- The PBM-5 rests on an incline that begins sloping down from the bow. This view shows the extent of the sediment removal and how it disrupted the incline's slope. There is a deeper hole in the sediment behind the tree limb in the left of the image. Model by Kees Beemster Leverentz and the author.

Our methodology was for divers swim a series of half-circular arcs around each third of the fuselage. Divers flew a camera over the wings and the remaining ceiling of the tail section in a mow-the-lawn pattern. Two support divers swam behind the primary diver and held supplemental 30k lumen cameras on either side, pointed to the wreck (Figure 9.24). We also experimented with one supplemental diver and the primary diver carrying a smaller lamp. The color change in the photographs was noticeable; there was a glare present in the photos with both sets of lights although this may have been due to their proximity to the diver and the diver's proximity to the wreck.

Figure 9.24- GUE divers hold lights strategically over the port engine for photogrammetry image acquisition. Photo by Kathryn Arant.

Both GUE volunteers and I processed this 3D model to check alignment and coverage issues. Our best case scenario was to process the fuselage as one ‘chunk’ and the wings and engines as separate ‘chunks’ for merging at the dense point cloud stage. Our swim pattern methodology provided for accurate and quick alignment of the model on all areas except the port wing, which was better after a second dive to capture more images. An unforeseen circumstance of using the Sony camera was the large size of the files; neither my or the GUE purpose-built computers could process the mesh required for this model. One solution was to down-sample the images so the mesh was easier to process; to do this effectively I had to remove all exchangeable image file format (EXIF) metadata when reducing the file size in order for correct alignment (Figure 9.25). The solution I used was to process the mesh on an alternative computer server with 256GB RAM and a robust, multiple-core processor. Once the mesh was complete I was able to process the texture on my home computer. In order to upload the model within Sketchfab’s (a 3D model viewing platform) limits, I then decimated the model to 15 million vertices.

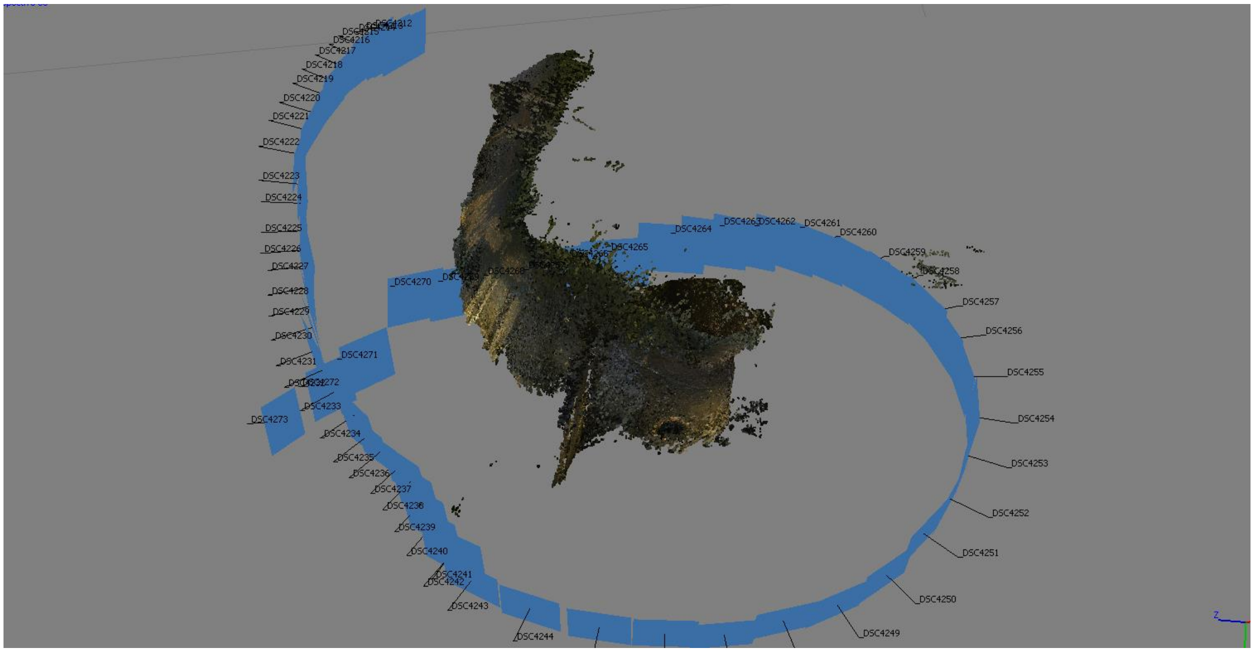


Figure 9.25- Alignment issues caused by keeping the original focal length in reduced-size images. Reducing the file size without keeping the correct parameters, such as height/width agreement, can also result in 'banana models' (incorrect curvature). Model by the author.

9.5 Existing Artifact Assembly and Conservation

PBM-5 59172 has been subject to diver looting since its relocation in the early 1970s. A pair of young divers, Matt McCauly and Jeff Hummel, removed the two browning machine guns from the bow nose turret in 1983, and were among the first to receive notice from the US Navy for the artifacts' return. A number of items removed from the site prior to 1990 but not returned to the Navy included a metal framed Plexiglas port light, a sextant, a flare pistol, and a metal hatch cover. The items were given to salvor Robert Mester, who registered the PBM-5 with the Washington Office of Archaeology and Historic Preservation (OAHP) in 1989. Mester loaned the artifacts to the Pearson Air Park Museum in Vancouver, Washington for display and they remained there for a number of years. The original donor and Mester discovered that the items were all missing from the Pearson Air Park Museum's collection prior to 2006. Museum staff explained the disappearance as due to theft, although no original records exist of the loan.

9.5.1 Artifacts at NNAM

In the early 1980s a group named the Underwater Historical Research and Recovery Foundation (UHRRF) began to dive on the aircraft and remove artifacts. The group contracted with recovery agents to salvage the aircraft and award it to the Commemorative Air Force (at the time the Confederate Air Force, CAF).[290] Soon afterwards the US Navy claimed ownership of the aircraft, which, after a well-publicized battle between the two sides, resulted in the Navy's favor. UHRRF turned over just under 100 artifacts, recovered in 1980-1981, to the NNAM in Pensacola for collection accession.[291] These artifacts, collected by members of an organized group, are the majority of items recovered from the PBM site prior to 1996. After the 1996 salvage attempt the site was secured and little else could be easily taken from the aircraft. The material from the 1996 savage attempt was accessioned by NNAM as a group and sent there. All of the Lake Washington PBM-5 59-172 items remained in the NNAM stored collection in Pensacola until the museum loaned them to Pima Air and Space Museum in 2002.

9.5.2 Artifacts at Pima

The loaned items from NNAM arrived as a group in 2002, where they were kept in storage. Some of the items were used in the restoration of the loaned PBM-5A at Pima, which was undergoing concentrated restoration from 2000-2007. Pima also had several items on permanent loan from the Smithsonian's NASM. As part of the loan, NHC included a

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[290] Wills 1997b.
[291] A list of these artifacts from the NNAM is available in Appendix N.

conservation plan dated 9/27/2001, which outlined issues to expect with aircraft recovered from underwater and cleaning procedures in regards to the loaned artifacts. Pima stored larger items in the NNAM collection outside, including the salvaged tail section, due to space restrictions. The museum began exhibiting the tail section debris in 2006, and the PBM-5A joined the exhibit space in 2007. The rest of the NNAM loan items remain in storage, either indoor or outdoor. As Pima expands aircraft parts move to indoor storage as space allows, but there is no information as to when this may occur for the PBM-5 58172 items.

Large objects from the 1996 salvage are on display or in outdoor storage at the museum, including the aft fuselage and tail section.[292] These large sections of airframe present with various levels of corrosion severity, mostly from pitting on the aluminum parts and rusting on steel parts. Surprisingly, the PBM airframe artifacts stored outside do not present with different issues or more advanced corrosion than the artifacts on display, although the time difference is, at this time, 10-12 years. The displayed tail section incorporates areas of extreme pitting corrosion near areas of pristine metal (Figure 9.26). The paint on the tail has largely disappeared, although some primer and light blue areas of paint remain. Sections of the aft fuselage and vertical stabilizers, which are stored outside, display nearly the same corrosion levels and paint retention (Figure 9.27). Fabric also remains attached to some areas of the vertical stabilizers.

[292] Images of the artifacts and corrosion at Pima Air & Space Museum is available in Appendix N.

Figure 9.26- Areas of the PBM-5 59172 tail, currently on indoor display at Pima Air & Space Museum. Notice the extensive corrosion on the left photo, compared with the photo on the right, where an area shows primer and faded paint, as well as patches of bare metal. Photos by the author.

Figure 9.27- Areas of corrosion next to areas of intact and primer-covered metal on a piece of PBM-5 59172 aft fuselage (L), currently in outdoor storage at Pima Air & Space Museum. The vertical stabilizer's metal (R) is bleached but otherwise in good condition. Photo by the author (L) and Andrew Boehly (R).

One of the items recovered in 1980-1981 by UHRRF, given to NNAM and later loaned to Pima, is an outer door hatch. It is in good condition and has been stored in the interior archive space at Pima, protecting it from further decay (Figure 9.28). The rubber seal around the door appears intact, and the paint still shows in the original colors, although somewhat faded. Active corrosion in the form of pitting and exfoliation, probably a galvanic reaction, surrounds the key hole in the center. There is also some paint loss in small circular patches, most obviously in the red paint of the insignia. Some light pitting corrosion appears to be bubbling under the light blue paint of the door but no extreme pits mar the surface except near the keyhole. On the back of the hatch door there are a few spots of rust and more exfoliation corrosion, but only in localized areas.

Figure 9.28- An outdoor hatch recovered from the Lake Washington PBM-5 in 1980-1981. Photo by the author.

9.6 Interpretive Display

Pima Air & Space Museum have the only complete and full-size example of a Mariner (BuNo 122071) on display anywhere in the world, along with the recovered tail section of BuNo 59172 (Figure 9.29). The surrounding space in the museum discusses seaplanes as a thematic group, and, in terms of exhibit cases with small artifacts, follows a loosely chronological order from left to right. These cases also include examples and stories of several different smaller seaplanes. The overall exhibit space was one of the first themed exhibits in the Pima Air & Space Museums and dates from the 1990s. Over the years, curators have added sections and artifacts, creating a slight inconsistency in the order and now forms a collection of smaller areas.

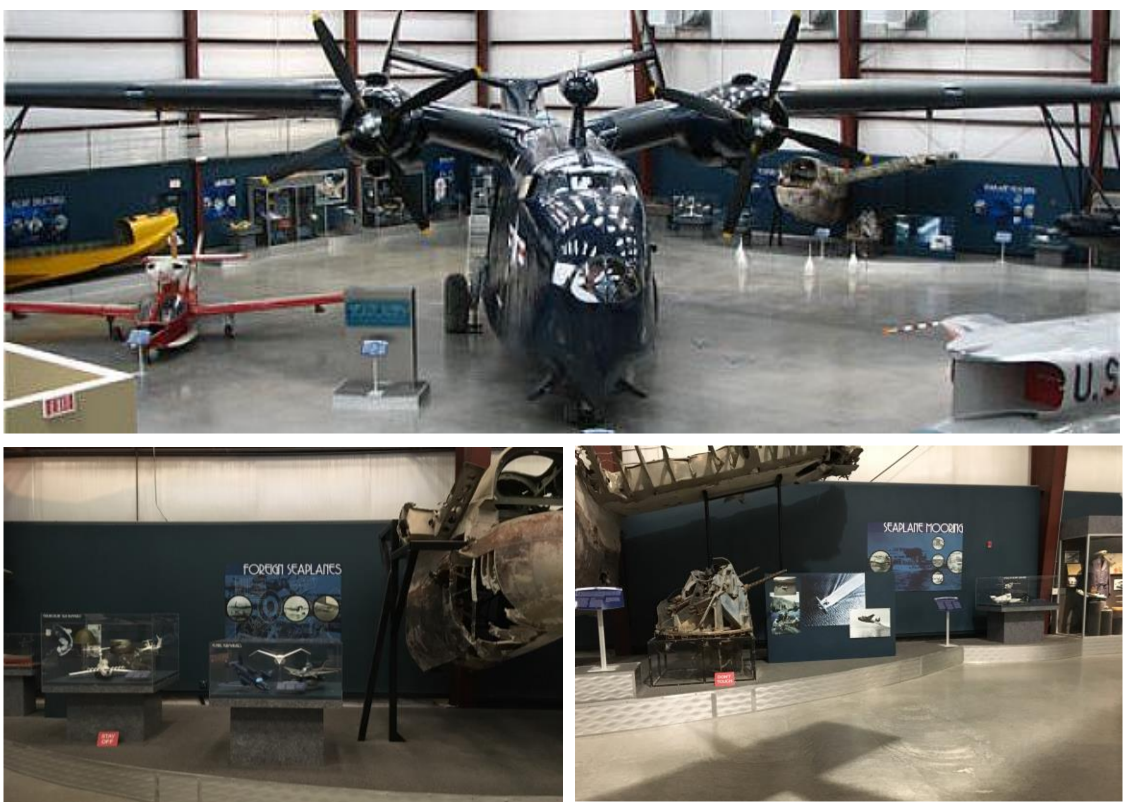

Figure 9.29- (Top) The display space for 'Seaplanes' at Pima Air & Space Museum, which includes a full-size PBM Mariner. The PBM-5 tail section is in the rear right. (Bottom) Closer photos of the spaces to the left and right of the tail section. Photos courtesy of Pima Air & Space Museum.

Pima chose to display and interpret PBM-5 59172's tail section and turret without restoration. They appear in their wrecked state after cleaning, although there is some active corrosion, most noticeably on the detached turret. Prior to our updated display this section had a single small placard which provided information about aircraft recovery and the unsuccessful attempts to salvage this airframe. A short wall, about 1.5 m^2, stood to the right of the turret and held some historic images of PBM Mariners in action.

9.6.1 Research Goals and Funding

My ideas for this display project derived largely out of a conversation with GUE members as we were experimenting with ROV work and diving on these low-light aircraft sites. 3D modeling is a tool that archaeologists can use to not only measure and document underwater sites, but to interpret them as well. The majority of 3D models the public sees and interacts with, however, are online; usually interpretation is minimal and the model fails to convey its potential. The display at Pima, a wreck recovered from under water, also has potential to invite more visitor engagement by offering access points to aviation history vie archaeology and data visualization. I began planning this project with a goal to marry the interpretation of the recovered artifact to the existing submerged wreck site, and place it all in context of post-WWII aircraft use and stakeholder priorities. A 3D model can perfectly illustrate this artifact which, in this case, otherwise cannot be seen as a complete object. The research question is this: can providing a 3D reconstruction in a museum setting, through an access point like aviation archaeology, make the display inherently more fascinating and, thus, increase the impact of the historical preservation message to the public?[293] I believe the answer is yes: museum visitors

[293] Marburg and Lickliter-Mundon OER grant proposal 2018.

arrive pre-disposed to learning, and the placement of interpretive text, images, and the rest of the wreck as recovered on display facilitates engagement and learning. I tested this assumption by creating a touch screen exhibit with supporting interpretation materials to accompany the PBM 59172 tail section at Pima Air & Space Museum.

I planned this exhibit to work within the practical constraints of museum exhibit budgeting. Adding technology can be expensive, but does not require a major financial commitment and upgrades can often be completed in-house. The Edward E. and Marie L. Matthews Foundation provided funding for this project in 2017 as a $4000 grant to the Pima Air & Space Museum. Funding included the collaboration in designing, building, and installing an exhibit showcasing the 3D model of the submerged PBM-5 59172 forward section next to the displayed tail section in Pima's museum hangar. GUE donated services such as boat time, fuel, ROV, and diver equipment costs, as well as an additional dedicated processing computer.

Table 9.1 Budget breakdown for Matthews Foundation grant for PBM display.

NVIDIA GTX Graphics Card x 2	Enhanced Processing of Models	*$600*
Samsung Galaxy View Tablet 18.4 in	Touch Screen Display Unit	*$400*
Tablet Kiosk Software	Software related to securing display tablets	*$100*
Exhibit Carpentry, Graphic Labels	A 4x6ft wall unit with interpretive context text and graphics, and a built in stand for the tablet.	*$2000*
Travel Costs	Flight Seattle to Tucson for installation and testing, hotel	*$400 flight or miles, $500 hotel*
Total		*$4000*

9.6.2 Exhibit Design and Installation

For the exhibit I proposed a new, larger wall to stand at the right side of the salvaged turret and an accompanying kiosk for a touch-screen tablet. This large tablet holds the 3D model of the submerged PBM-5 59172 site. Working together with Pima curators, I conceptualized the exhibit to be a stand-alone section in the larger ‘Seaplanes’ area, but also to tie the wreck to the restored Mariner on display. The interpretation provides more context for the tail section and its communication objectives, which are about wreckage recovery and restoration choices. The new wall is approximately 2.4 m^2 facing the visitor and then curving around 40° to follow the floor plinth and extending another 1.6 m at the same height. Pima volunteers planned and built the wall and kiosk at the curators’ and my’s combined direction. The new exhibit wall comprises text panels and images with a graphic format that matches the surrounding exhibit (Figures 9.30-9.32). The tablet kiosk is at floor level with the visitor but rises up to attach to the wall just before the 40° angle, so the visitor can view the tail section while they are interacting with the 3D model. The kiosk also has accompanying text instruction for the touch tablet. The exhibit was installed in April-May 2018. Pima curators and I also decided to incorporate the hatch artifact discussed in section 9.5.2, and an interior bulkhead door into the new display.

Figure 9.30- The new display wall and wreck sections of the PBM-5 Mariner at Pima Air & Space Museum. Photo by the author.

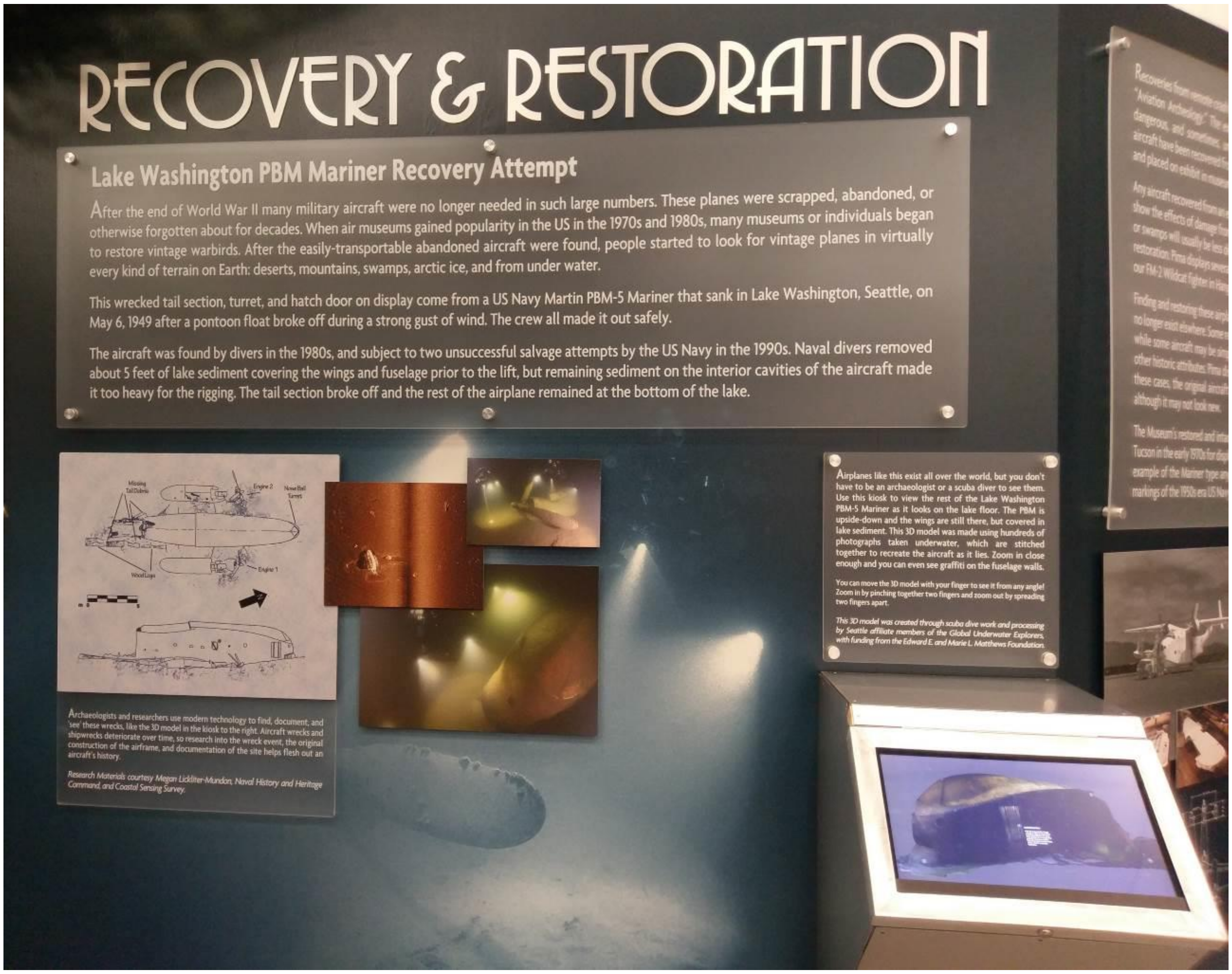

Figure 9.31- Text, images, and 3D model kiosk on the left side of the new exhibit wall. The exhibit text now introduces the wreck in the context of where most aircraft on display come from. It also marries the wreckage to the right of this wall with the 3D model in the kiosk. Text by the author and Pima curators, graphic design by Great Projections, Inc. Photo by the author.

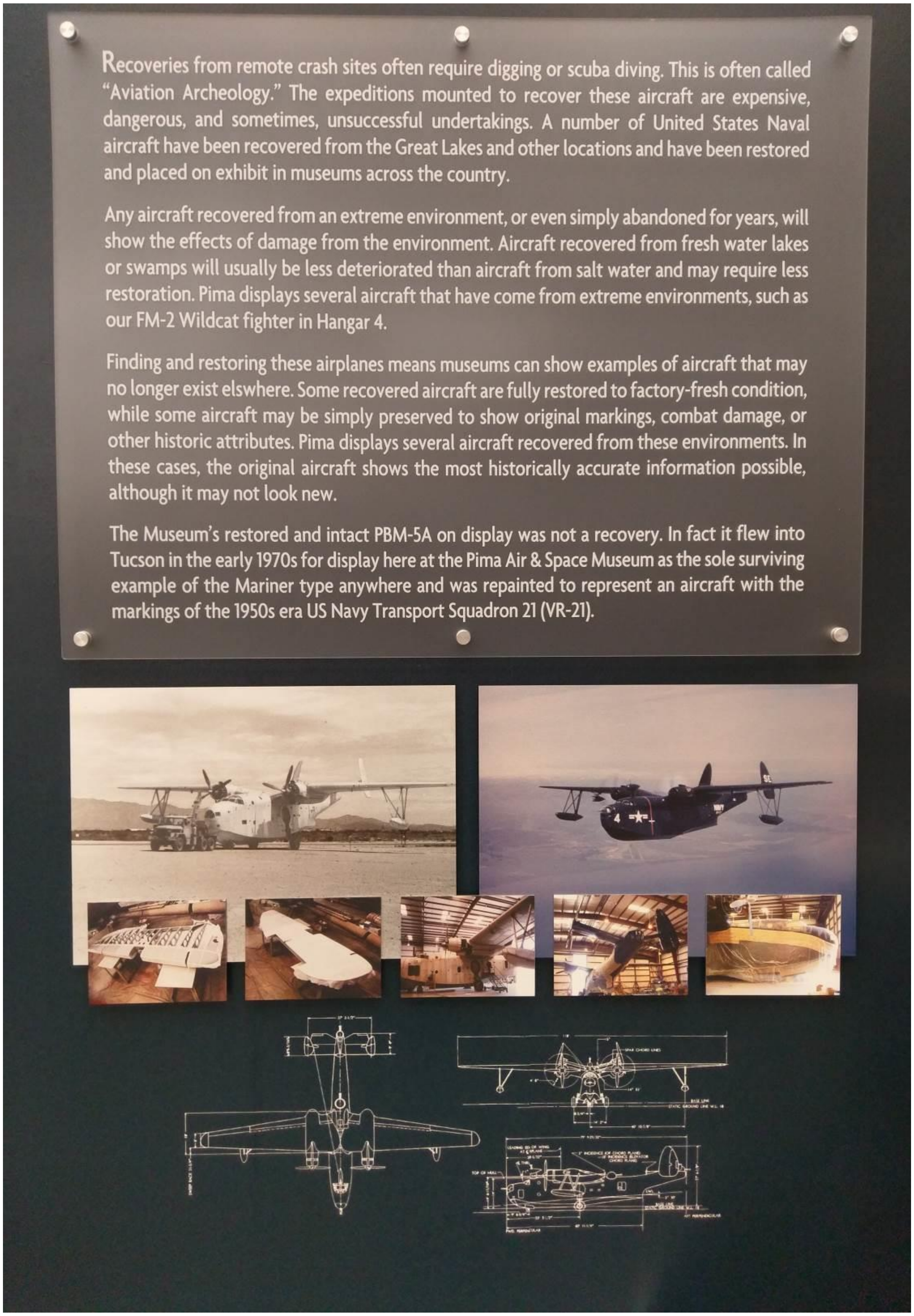

Figure 9.32- Text and images from the right side of the new exhibit wall. Text by the author and Pima curators, graphic design by Great Projections, Inc. Photo by the author.

The tablet, a Samsung Galaxy View, with a larger than average display, holds the 3D model (Figure 9.33). Visitors are prevented from accessing anything but the model on the screen by using kiosk-lock software and the tablet is enclosed in a locked case. The use of this tablet allowed for visitor interaction and the inclusion of technology in an otherwise static display area. I planned the model viewer to be through Sketchfab, a popular web-based platform that supports VR, AR, web, and mobile use and display of 3D models. After installation and set-up, the tablet proved slightly underpowered for large model display because of its performance ability. We had to decimate the model again to 750k vertices and utilize Sketchfab's least memory-consuming settings. I added 10 annotations to the model, after which I set up the model to move on an autopilot roll through these annotations and each of their respective camera angles. When the model switches to the next annotation, the viewer watches the model move.

Figure 9.33- The underwater PBM-5 3D model, viewed here via Sketchfab. Photo by the author.

The new communication objectives of this wall explain the point of the display of the wreck pieces, as well as the tie between aircraft in the environment either as wreckage or an unrestored state, and restored aircraft on display. The 3D model gives the visitor the ability to understand that this aircraft now exists in different locations, and probably pieces of it exist on another aircraft. Not only is the understanding of one aircraft's different display techniques important, but the ability to see a full aircraft that otherwise is completely hidden is also an excellent visual aid. Determining the success of the exhibit requires time and exposure to Pima Air & Space Museum's visitors. Museum exhibit success can be measured with a variety of tools including visitor survey, attendance statistics, responses to direct marketing, and/or targeted visitor surveillance.[294]

9.7 Summary of Deterioration

The hatch artifact from Section 9.5.2, which I believe is representative of many multi-phase aircraft recovery projects, presents researchers with a fascinating study of aircraft deterioration. The PBM sank in good condition in 1949. This artifact was recovered by 1981, at most 32 years later, and given only a cursory desalination treatment. In 1996, at least 15 years after the hatch recovery and 47 years after deposition, Wills described the recovered tail section as appearing dark blue and light blue, with an overall lighter color underneath, and visible markings on the vertical stabilizer. He also reported corrosion nodules on the metal surfaces of the PBM, and noted a newly recovered, similar hatch as having extensive corrosion growth.[295] The items recovered in 1996 and kept in museum storage are noticeably more deteriorated than the hatch, and retain less paint. It is possible that this is also due to storage conditions prior to their display. Today, 22 years after the most recent recoveries, 37 years after the first recoveries, and 69 years after the PBM sank, its paint now appears dark brown, with no indication of naval insignia or other markings.

Another artifact studied at Pima shows a different set of insights into the corrosion process. The 1996 salvage report shows a number of images of the rear afterbody area of the recovered fuselage section, and comments from Wills suggest that it contained more corrosion nodules than nearby areas (Figure 9.34).[296] This piece of PBM-5 material was rinsed several

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[294] A recent study of visitor surveillance is at http://www.ucl.ac.uk/archaeology/research/directory/digital-museum.
[295] Wills 1997b, 87.
[296] Wills 1997b.

times before being transferred to Pima, but has been in outdoor storage since the recovery. Consequently the paint has largely disappeared from the exterior skin, but so have the nodules of corrosion product. The bare metal today appears only slightly marred by light pitting corrosion in the same area, suggesting that, at least in 1996, the nodules were not advanced enough to eat all the way through the metal (Figure 9.35).

Figure 9.34- Corrosion nodules on the rear afterbody of the PBM-5 hull the day of recovery in 1996. Photos courtesy of NHHC UAB.

Figure 9.35- Corrosion pitting damage to the rear afterbody as seen in 2018. Note the bare metal has a slight hint of green primer and the pits do not appear to go all the way through the reinforced aluminum in this area. Photo by the author.

As discussed in previous sections, there is extensive formation of corrosion nodules on the aircraft currently and I suspect localized pitting under each. How deep the pitting is currently may vary, although they are probably increasing in size and depth as time passes. A more rapid pace of deterioration seems to have occurred in the last 30 years than in the first after deposition. The hatch is not visibly decaying and requires little in terms of stabilization, whereas any artifact recovered from the same site today would need extensive treatment. The aircraft or artifact would also likely lose the appearance of being whole after any conservation process, which would remove corrosion products.

9.8 Management Strategies

The PBM-5 59172 case study also exemplifies universal challenges for public awareness and interaction with archaeological sites, and local and federal management strategies for underwater cultural resources. Looting of this aircraft site is no longer a significant issue, somewhat due to the looting that took place in the 1980s-1990s. The site is deteriorating from environmental factors, however, and divers will continue to visit the Mariner and further affect it as well. The PBM-5 is one of eight other WWII aircraft sites in Lake Washington, and many others rest in other lakes and in salt water in the state of Washington.

Washington state law identifies

> …all historic archaeological resources abandoned for thirty years or more in, on, or under the surface of any public lands or waters owned by or under the possession, custody, or control of the state of Washington, including, but not limited to all ships, or aircraft, and any part or the contents thereof, and all treasure trove is hereby declared to be the property of the state of Washington.[297]

This, of course, cannot apply to Navy-owned aircraft, which are otherwise protected under the Sunken Military Craft Act (SMCA). For all other aircraft, however, treatment in terms of permitted research, disturbance, or salvage, is similar to historic ships. Under Washington state law, permitted salvage can be allowed, including "fair compensation to the salvor".[298] Herein lies

[297] Chapter 27.53 RCW, Archaeological Sites and Resources, Section 27.53.045
[298] Chapter 27.53 RCW, Archaeological Sites and Resources, Section 27.53.110

a management and perception issue, borne from prior salvage claims on aircraft and general salvage law in the state; aircraft, seen as high-value objects and especially viable for salvage if in fresh water, were subject to increased attention from divers and salvors in the 1990s which abruptly dropped off after the PBM recovery attempt and the introduction of the SMCA. Only Navy aircraft are submerged in Lake Washington, and are all off-limits in terms of salvage. Management strategies do not currently exist for aircraft distinguishing them from other historical objects on submerged bottomlands. Neither the Washington State Office of Archaeology and Historic Preservation (OAHP) or the Department of Natural Resources (DNR) have a robust underwater archaeology program, and since applications for aircraft disturbance are not brought forward often, no maintenance surveys or active submerged cultural resources programming exist. After the activities of Grant and Wills in the 1990s, only passive collection of site data on aircraft has taken place, although some researchers have put forward site management proposals.[299]

In Washington, and in the Seattle area especially, government ability to monitor underwater cultural resources is hampered by logistical concerns of underwater research. One possible solution is collaboration between amateur, academic, and federal organizations. In this case, Global Underwater Explorers (GUE) represent a movement that I believe is becoming more common in the US; an organized, non-profit group of highly-trained individual local divers who visit historical sites annually if not more often, as is the case with Lake Washington wrecks. GUE divers have more experience and equipment than state government programs, and also are dedicated to using the most advanced documentation equipment and techniques, such as

[299] Grant et al. 1996; Grant, David 1996; Wills 1997b; Meyer 2014.

cameras, lighting, and 3D modeling. A collaboration between GUE and WDNR could result in the availability of annual 3D models for submerged historical sites, including aircraft, as well as reports of visual deterioration and conditions. University of Washington archaeology program could provide course or research-based credit for graduate students to complete the necessary site forms to accompany the reports and their entry into the state databases. All of this information could be sent directly to NHHC's UAB, who also provide internship opportunities for archaeology students in naval and aircraft archaeology.

9.9 Case Discussion

The PBM-5 59172 case study represents a conventional set of circumstances for submerged aircraft sites and their associated artifacts. In this case, portions of the aircraft exist underwater, recovered and in storage, and recovered for museum display. This scenario is representative of many aircraft sites around the world. A combination of archeological stewardship and local enthusiast collaboration presents an opportunity for several best-case scenarios. The concept of museums acting as stewards for local wreck sites is becoming more common, and this case study illustrates how this idea can apply to aviation museums as well. The PBM-5 59172 display constitutes a model for the integration of submerged collections into museum display. This is a small-scale solution, but the display concept proves effective in providing an access point for visitor engagement.

In this case study, both traditional archaeological site survey and site visualization are hindered by a variety of circumstances. Federal ownership of the wreck mandates stewardship, but the lack of both federal and local-level resources make maintenance surveys a low priority. Research on underwater aircraft sites has focused primarily on saltwater examples, and the timeline and formation processes of aircraft materials decay in fresh water is not as well known.

Interest in this site by enthusiast divers, and the collaboration between that group, local academic archaeologists, and federal archaeologists, created an opportunity for this research to take place. The aircraft is deteriorating, and while previous intentions were for its recovery, that goal is no longer suitable. The aircraft will, however, continue to be a dive site and should remain in the realm of public knowledge and accessibility. One of the best ways to accomplish this is via museum display. In this project the archaeology survey goals were secondary to promoting public interaction with this aircraft. The archaeological significance at this time is relatively low, and the project was planned according to the museum's needs, while still documenting archaeological information.

Several aviation museums face challenges on how to display recovered material, and thousands of aircraft remain underwater. Museums who source aircraft from either fresh or salt water can display them as restored or not, given current conservation treatment methods. Future museum designs could include 3D models of underwater aircraft sites in large screen format, opening the door for virtual displays and digital-only artifacts in collections. While aircraft left in situ can be display pieces, their heritage management needs must also be taken into account. Successful management of this, and other aircraft sites in Lake Washington depends on the future working relationship between stakeholder communities.

10. CONCLUSIONS

In this dissertation I have argued for the recognition of a variety of influences on the subfield of aviation archaeology that each affect its practice. Knowledge of these will determine the success of a project in terms of research viability, stakeholder acceptance, and reporting methodology. While academic influence over aviation archaeology as a subfield is rising, it remains decades behind enthusiast interest in aircraft artifacts. Stakeholder groups remain separated by ideology on the treatment of artifacts and their value. Despite this, it is evident that as the academic influences strengthen in their ethos, all stakeholder groups will come to recognize that different survey, treatment, or display methodologies depend on the best interests and use of the artifact. As a result, each site or artifact must be surveyed, treated, and/or displayed in the best way possible taking into account its particular case merits, and the associated logistical, financial, and practical concerns.

10.1 Discussions of Best Practices

Ideally, best practices reflect current archaeological standards and ethos. Not all stakeholders will be aware of, and not all reports will conform to, these standards. In order to use site report information from any source, researchers must be able to understand aviation terminology, materials, systems, and resulting site formation influences. Site formation, especially for submerged aircraft, is the most important information to interpret and convey in site reports. This information should be standardized to include environment and water chemistry, local knowledge of disturbance, wreck event information, and materials decay. Interpretations should be based on specialist knowledge of aircraft materials deterioration timelines in the fresh or salt water and should include reference to correlations in the wreck report or survivor accounts. I would recommend any archaeologist consult an aviation history or aircraft specialist in preparation for, and interpretation of, research on underwater aircraft sites.

The type of information required determines the methodology used for aviation archaeology survey. Techniques and technology used differs on baseline, monitoring, and excavation projects and also depends on access conditions such as depth and visibility. These methodologies should be research goal-based. For example, monitoring or public-awareness surveys might prioritize visual data interpretation over measurements, and plan accordingly for team and technology composition. A baseline data survey, however, should include accurate site maps, site formation interpretation, recommendations on maintenance surveys, excavation, and conservation or in situ preservation treatments. New technologies will help not only archaeologists, but all underwater aircraft site researchers conducting useful site documentation that also appeals to a wider audience.

Display methodology of previously-submerged aviation artifacts also depends on each case, and should be in the artifact's best interests. Submerged aircraft can be effectively displayed without full recovery. In cases where the artifact may not survive recovery efforts, it is possible to display the archaeological site, which will provide an access point to the history, personal stories, or other communication objectives. If the recommendation includes recovery, or if it has already taken place, conservation treatments to stabilize the material are necessary. At a minimum, determining corrosion patterns and improving environmental conditions can extend the life of any recovered aircraft artifact.

Some submerged aircraft sites, which have experienced historical looting or archaeological excavation, will have associated artifact assemblages that may be dispersed in museums or in private collections. Arguably, it is the archaeologists' responsibility to trace and describe these artifacts in relation to research on the submerged site. Given this particular subfield's history and treatment of aircraft remains, these items are especially important and supply an opportunity to study the long-term effects of recovery and conservation methodologies. Reports concerning submerged sites should always include disassociated artifact whereabouts, condition, ownership, storage conditions, and relate these to the site's future management.

The three case studies I presented represent projects in various stages of archaeological research. The survey, treatment, and display methodologies chosen for each differ based on the research goals and desired outcomes. The data products are similar across all three sites, however, because they each include partial excavation and museum display. All three sites began with amateur enthusiast interest that then attracted archaeological study, and all have artifacts that are in varying states of storage conditions and care. *The Tulsamerican* site represents a good example of a site with strong community ties to two very different local communities; the collective historical community of Tulsa and the diving community of Croatia. The survey methodology was to provide baseline information that could be easily pared and repeated in future monitoring surveys. The results can inform site deterioration and wreck event formation research given the inclusion of extensive in situ corrosion studies on local B-24 sites. The USS *Macon* project is an example of a site-monitoring survey focused on providing site deterioration information to the federal government and determining the best site mapping and object conservation methodologies. The PBM-5 Mariner survey focuses on demonstrating management issues, data visualization methodologies, and a working museum display module for aviation archaeology results. Each survey is a best-case example for the time, financial, and practical limitations of this dissertation.

10.2 Future Directions

Aviation archaeology will develop rapidly over the next 20-30 years following the passage of time from the original object and participant's usage, and the acceptance of the subfield as standard archaeological practice. Stakeholder concerns will continue to shape the development of the subfield, and archaeologists should consider these when proposing future research.

First, we should realize the inherent strengths, weaknesses, and agendas of all the different groups and acknowledge the fact that the groups sometimes collaborate well, but also sometimes still work actively against each other. The question remains as to whether the development of the subfield of aviation archaeology depends on representative field projects or on position papers dealing with theory and methodology. Even given the multitude of papers on the subject in the 1990s and 2000s, the looting and recovery of aircraft sites without documentation continues. This may be the result of a lack of recognition by museums, enthusiasts, and other salvagers of the value of academically published papers such as study justifications and wreck site reports. Archaeologists must identify components of documentation that are crucial across the board, and use them to agree on a methodology and documentation level that is acceptable, as well as accessible, to professionals, academics, and amateur archaeologists.

We should do this by articulating how and why archaeological methodology yields results on aviation sites. There are many publications outlining the reasons why aviation archaeology is beneficial, but few publications have been able to exemplify additions to our knowledge base through excavated material. Even given the current lack of universal dissemination of theory papers, both position papers and projects are valuable for the development of the field in the future. A non-disturbance survey can provide information about site formation from a visual conservation study, or if possible, simple and non-damaging metered samples can provide an accurate picture of how quickly metal decay takes place. Site mapping is not as complicated, tedious, or expensive as in days past, and, therefore, accurate documentation using new technologies can be easily taught to members of the interested public (amateurs and museum) who would otherwise undertake such projects even without this knowledge. The consistent articulation of methodology will inspire increased feelings of stewardship across the groups of stakeholders. In this manner archaeologists can lead the field by example. In all cases, while it is possible that an aviation site might not have archaeological value that currently clarifies human behavior, it will make the field of archaeology remain both relevant and interesting to the general public, as well as help future research by both amateur enthusiasts and academics alike.

Second, aviation archaeologists must begin to anticipate future research questions on cultural and maritime or aviation landscapes/airscapes, or researching more advanced site deterioration issues. Individual site surveys, either focused on identification of the aircraft and/or formation studies can provide accessible information in the reports. Research questions should be obvious and well justified in order to lead the field. The three case studies, as well as the smaller project examples that highlight other chapters, suggests that reports on individual and multiple aircraft sites should include research and viewpoints from several stakeholder groups, as well as information about aircraft deterioration and site formation matched to known loss data.

Third, a submerged aircraft site, or a recovered aviation heritage object, have archaeological and display potentials that may change over time. Management of the resources, by either governments or museums, should take into account the range of issues and information associated with these objects, and the information that archeological study can provide. Collaboration often proves invaluable for both archaeological survey, interpretation, and management of aviation heritage.

The study of aviation archaeology and the treatment of aerospace heritage objects has the potential to develop according to a range of different influences. Original WWI aircraft, wrecks, and heritage objects are either approaching or have passed their centennial anniversaries. Before interwar and WWII aircraft reach theirs and are considered more in the realm of historical archaeology, the treatment, value of, and protected status of aviation objects must standardize. Museums will continue to seek exciting and innovative display techniques to appeal to native technology users. By providing archaeological information on aviation heritage, drawn from proper documentation techniques, we can help inspire future generations by preserving and communicating their stories.

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APPENDIX A IMAGES AND DESCRIPTIONS OF EXPERIMENTAL METAL SAMPLES

Figure A.1 - There are multiple aircraft wrecks around Vis island, off the coast of Croatia. Along with fieldwork on *The Tulsamerican* site, I visited dump sites for aircraft debris in local harbors. I took sediment, water chemistry, and corrosion potential readings from two of the dumped B-24 wings in 2015. I discovered small metal fragments in one of the sediment samples, VISB-2401 and VISB-2402, and decided to analyze these fragments with XRF. VISB-2401 (R) and VISB-2402 (L) are possible aluminum samples. Both present with a large amount of biofilm, some calcareous encrustation, and other marine growth. Upon scraping, VISB-2401 clearly is shiny bright metal, while VISB-2402 remains a dark color and resembles lead. Photo by the author.

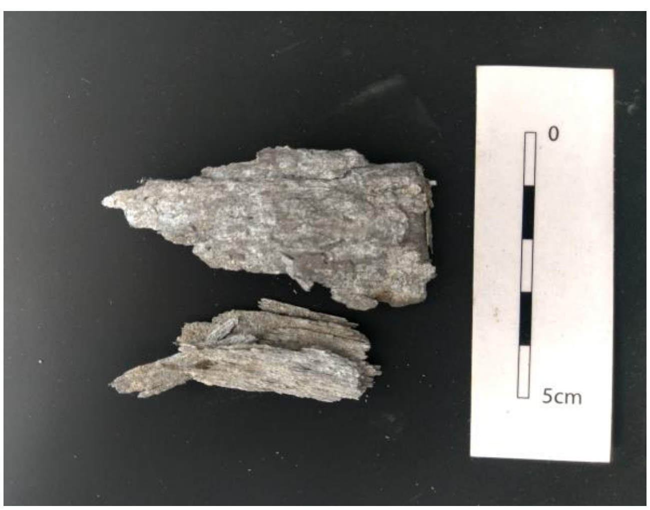


Figure A.2- RAFMDeH01 is a sample of propeller blade material from Handley Page Hampden that crashed in a terrestrial site in Russia in 1942 and was exposed to the elements until 1991. The sample was from the root of a propeller blade and had delaminated into thin slivers from exfoliation or intergranular corrosion. Photo by the author.

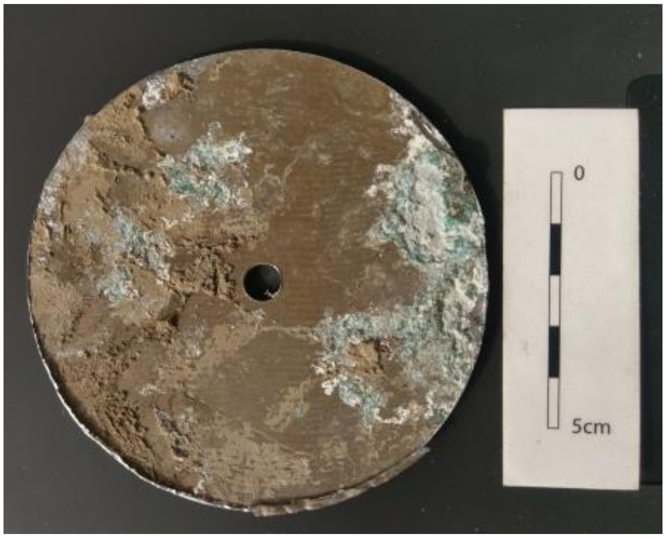


Figure A.3- In January 2009, US Airways Flight 1549 struck geese on takeoff and ditched in New York's Hudson River. The aircraft was underwater and filled with brackish water and silt for two days, and a missing engine was retrieved after eight days submerged. The aircraft and contents were allowed to dry while undergoing NTSB accident investigation. In 2010 the aircraft was donated to the Carolinas Aviation Museum, and the fuselage was sent to Charlotte, NC for conservation treatment and display. The engines remained with American Airlines for restoration but did not undergo conservation treatment. The engines currently present with pitting corrosion and an unknown pimpling corrosion. In 2017 I acquired a sample (CAMAB01) of the cowling ring from Engine #2 in order to examine it for conservation treatment, which included XRF analysis. CAMAB01 is a metal disk with heavy sediment and corrosion on one side. It is likely circa 2000 construction and noticeably thicker than other samples of WWII sheet aluminum. Photo by the author.

Figure A.4- A sample from the Norsk Luftfartsmuseum from a Focke Wulf 190 aircraft, WWII-era. This sample NLMFW-19001 was recovered from the ocean surrounding Norway and left exposed to the environment. Photo by the author.

Figure A.5- Sample NLMFW-19002, photo by the author.

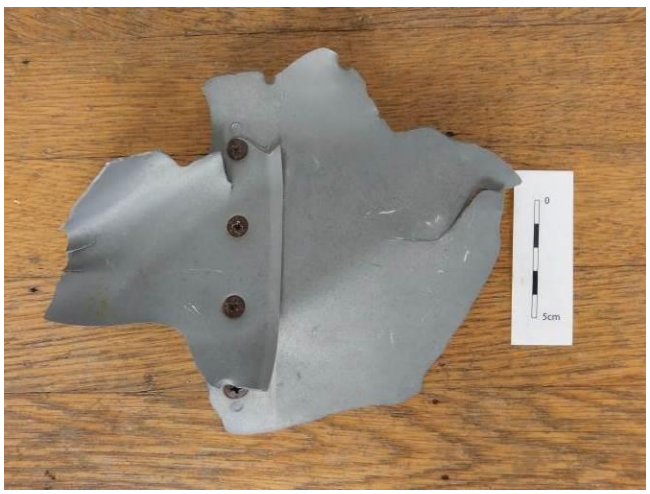


Figure A.6- A recovered piece of T-33 aircraft skin from a terrestrial crash site in Greenland. T-33 is post-WWII era, one of the first jet aircraft. Photo by the author.

Figure A.7- Two samples from a WWII P-38 aircraft, submerged on a beach in Wales, UK. MoHP-3801 (L) is structural aluminum with a zinc-chromate primer, and MoHP-3802 (R) is, I believe, aluminum covered with corroded and concreted ferrous alloy metal from the engine. Photo by the author.

Figure A.8- FVMDC-301 was taken from the Swedish DC-3 in the ‘Catalina Affair’, after its recovery from the Baltic and the application of an oil-based corrosion inhibitor. Photo by the author.

Figure A.9- CAMP-4701 is a piece of skin from a WWII P-47 aircraft found on a beach in North Carolina, recovered, then stored outside. Photo by the author.

Figure A.10- CAMP-4702 is a piece of cast aluminum and rivets suffering from exfoliation corrosion. Photo by the author.

APPENDIX B XRF ANALYSIS OF AIRCRAFT ALUMINUM SAMPLES

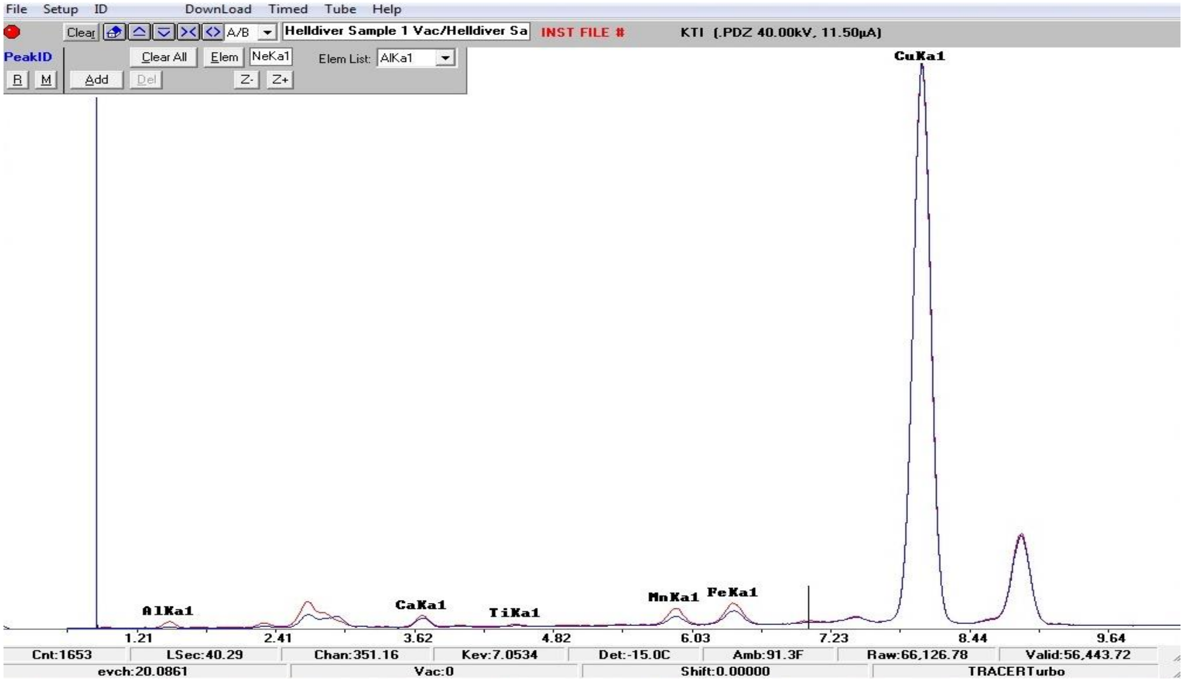


Figure B.1- Refer to Figure 5.11, page 139 for locations of Helldiver sample UABSB2C01. XRF by the author.

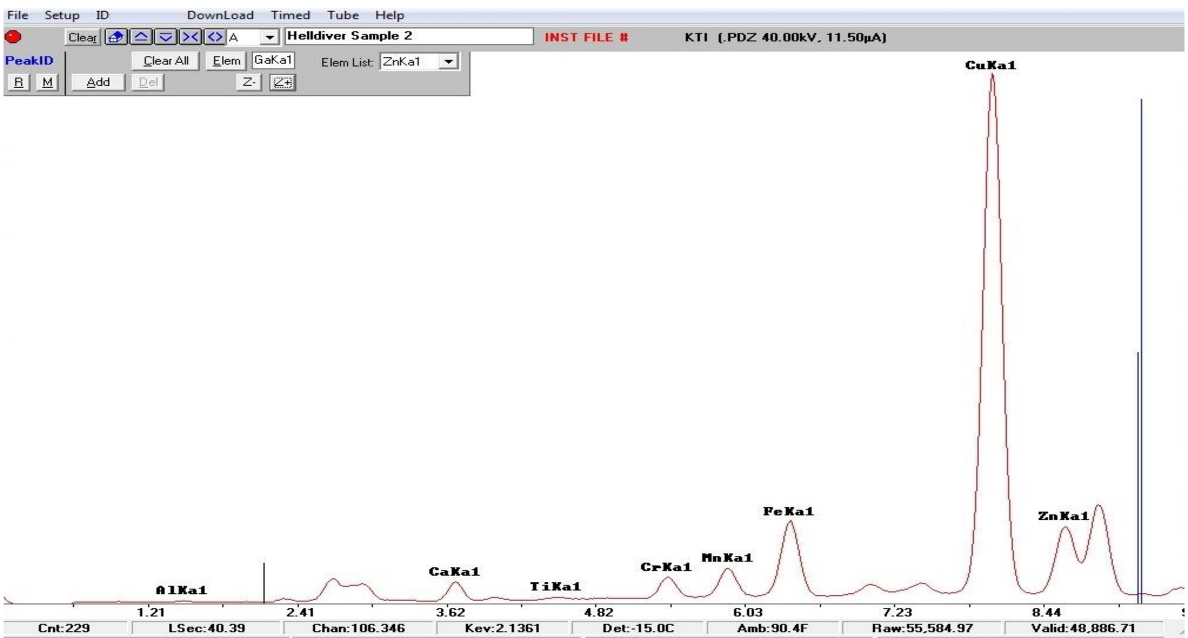


Figure B.2- Refer to Figure 5.11, page 139 for locations of Helldiver sample UABSB2C01. XRF by the author.

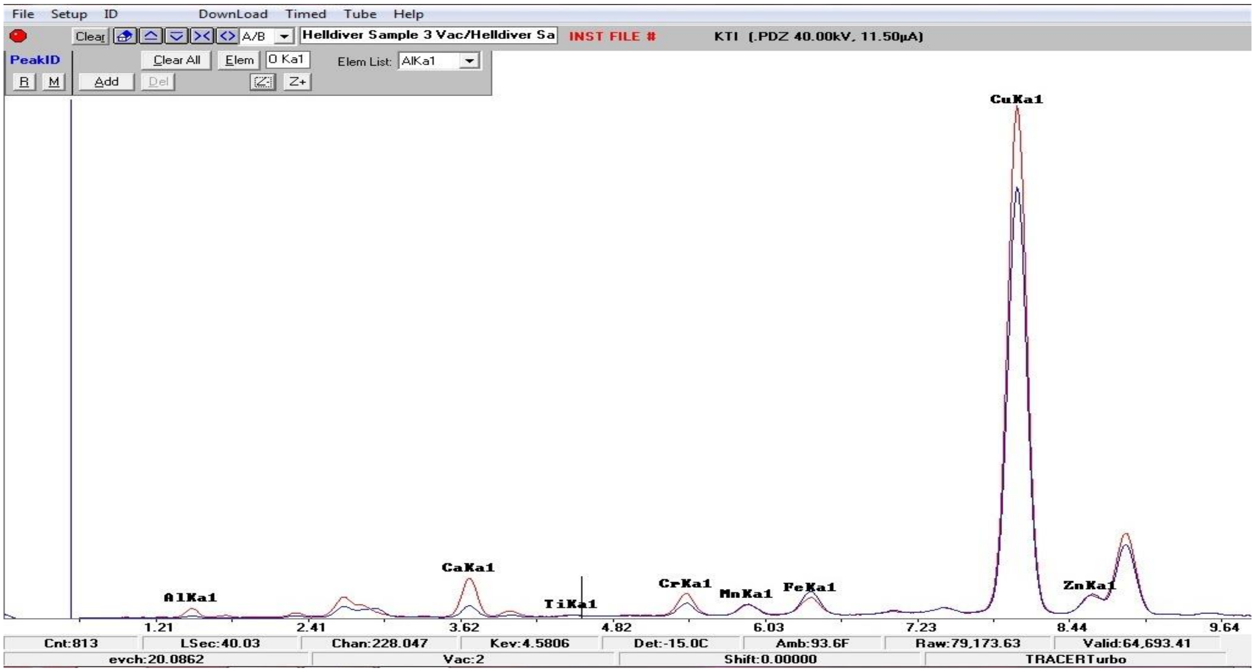


Figure B.3- Refer to Figure 5.11, page 139 for locations of Helldiver sample UABSB2C01. XRF by the author.

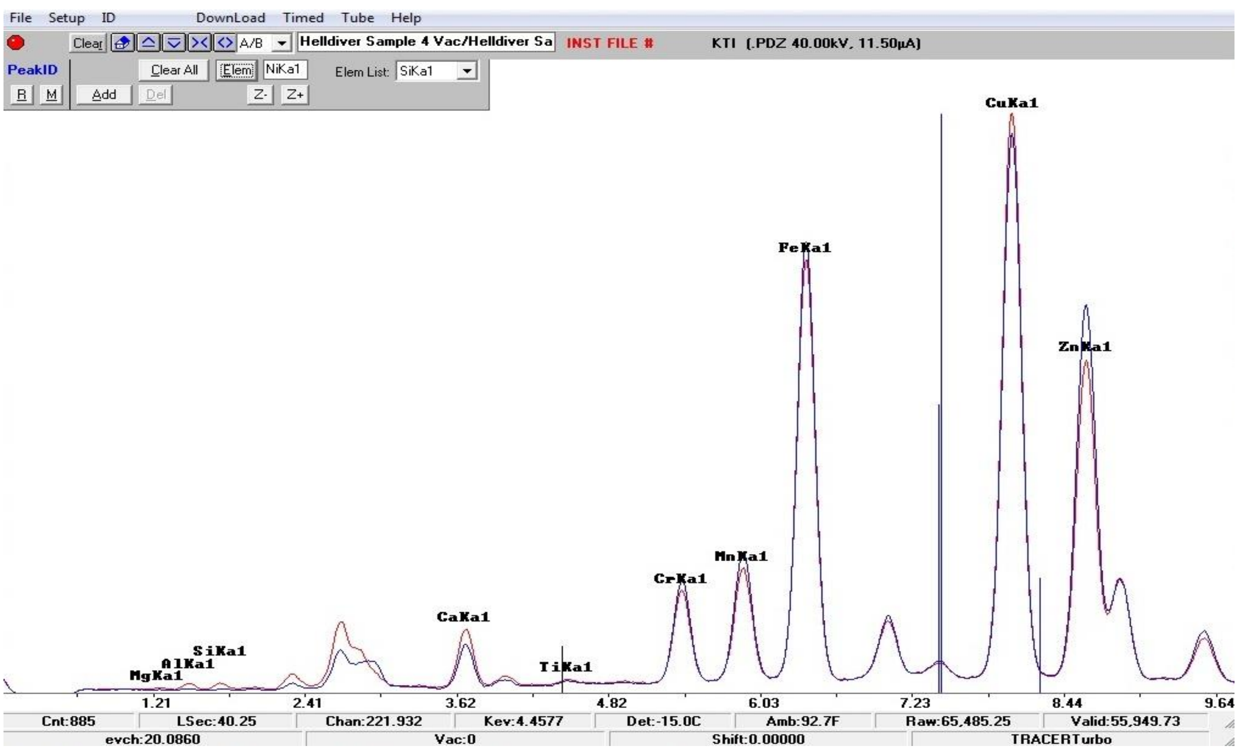


Figure B.4- Refer to Figure 5.11, page 139 for locations of Helldiver sample UABSB2C01. XRF by the author.

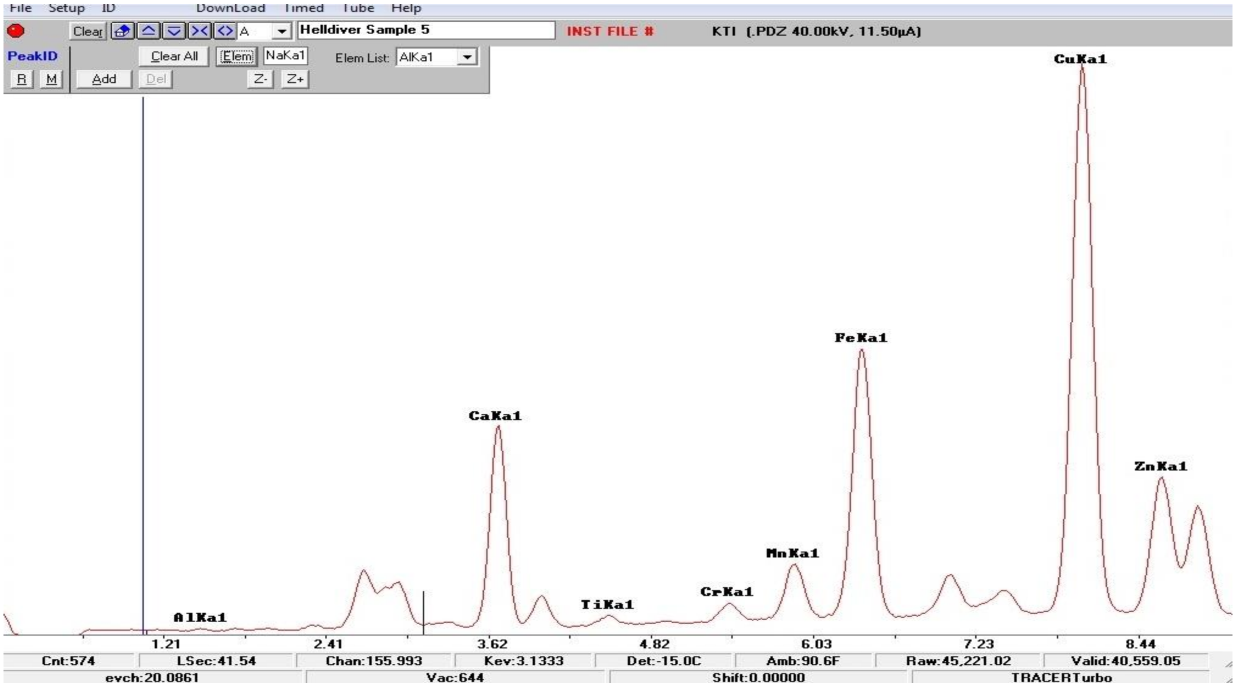


Figure B.5- Refer to Figure 5.11, page 139 for locations of Helldiver sample UABSB2C01. XRF by the author.

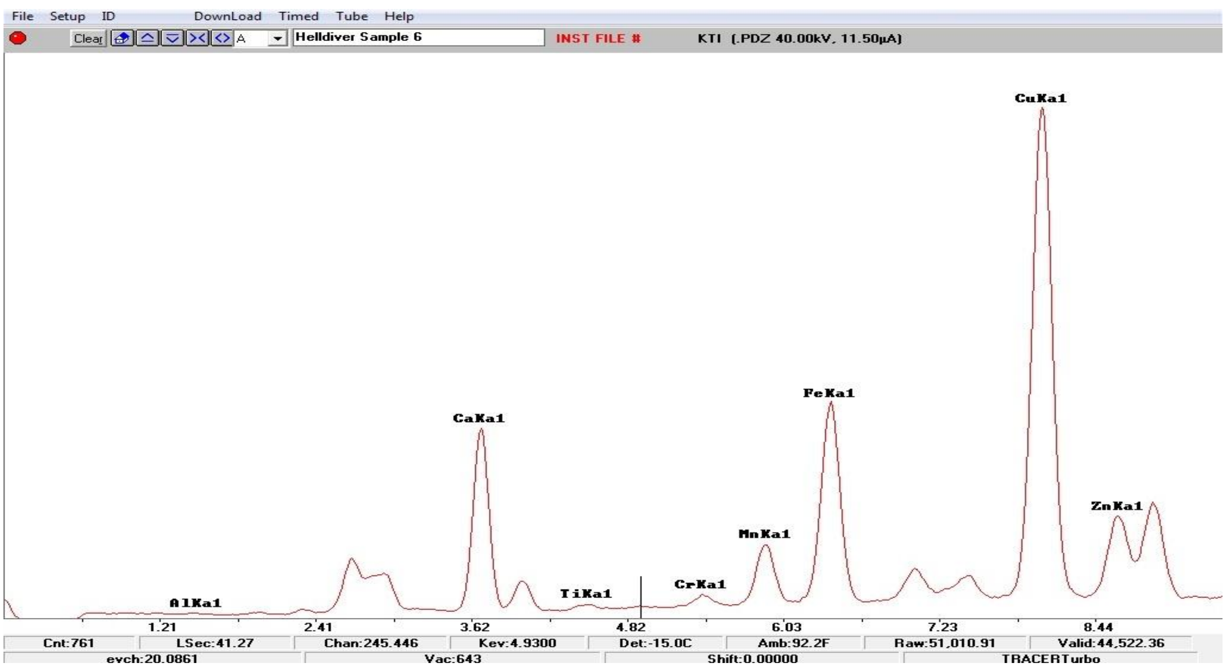


Figure B.6- Refer to Figure 5.11, page 139 for locations of Helldiver sample UABSB2C01. XRF by the author.

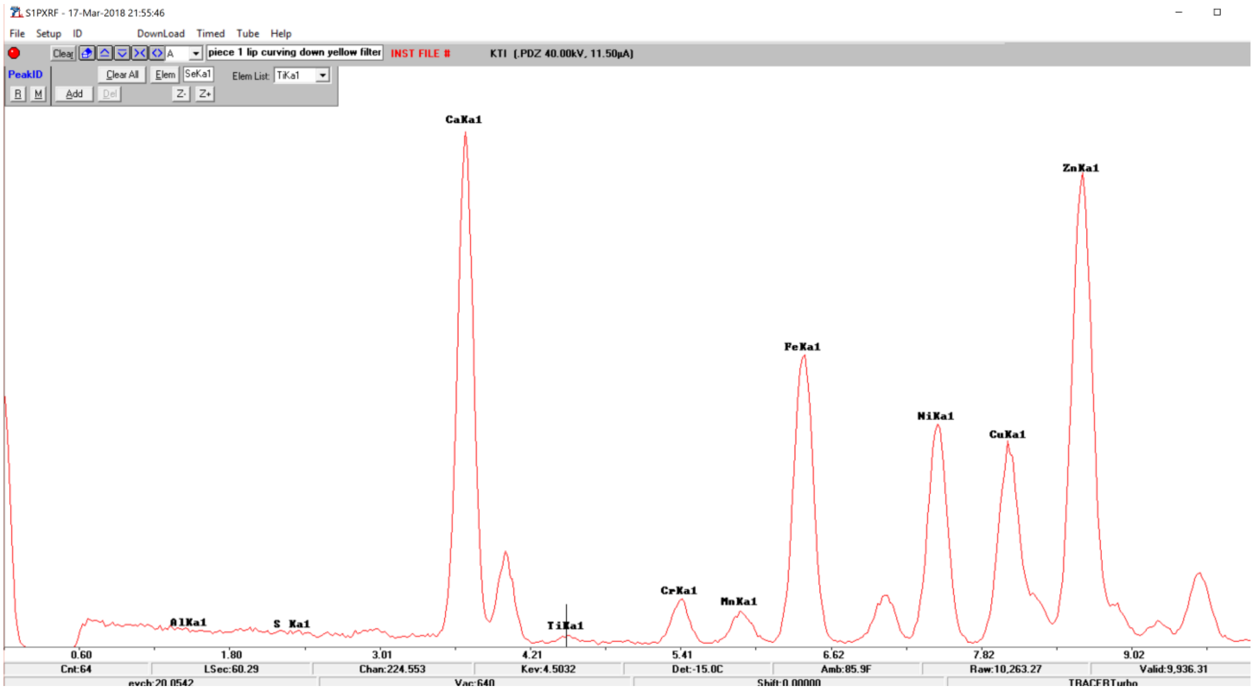


Figure B.7- VISB-2401 lip curving up with yellow filter. XRF by Chris Dostal.

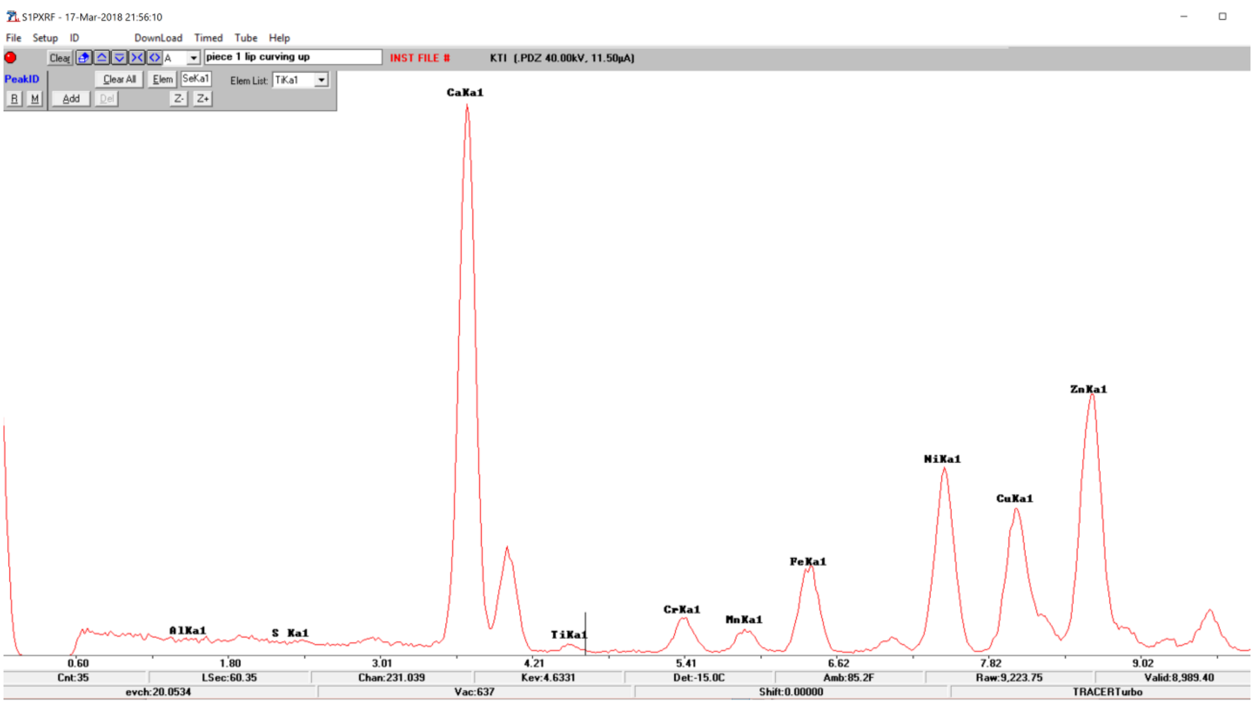


Figure B.8- VISB-2401 lip curving down with yellow filter. XRF by Chris Dostal.

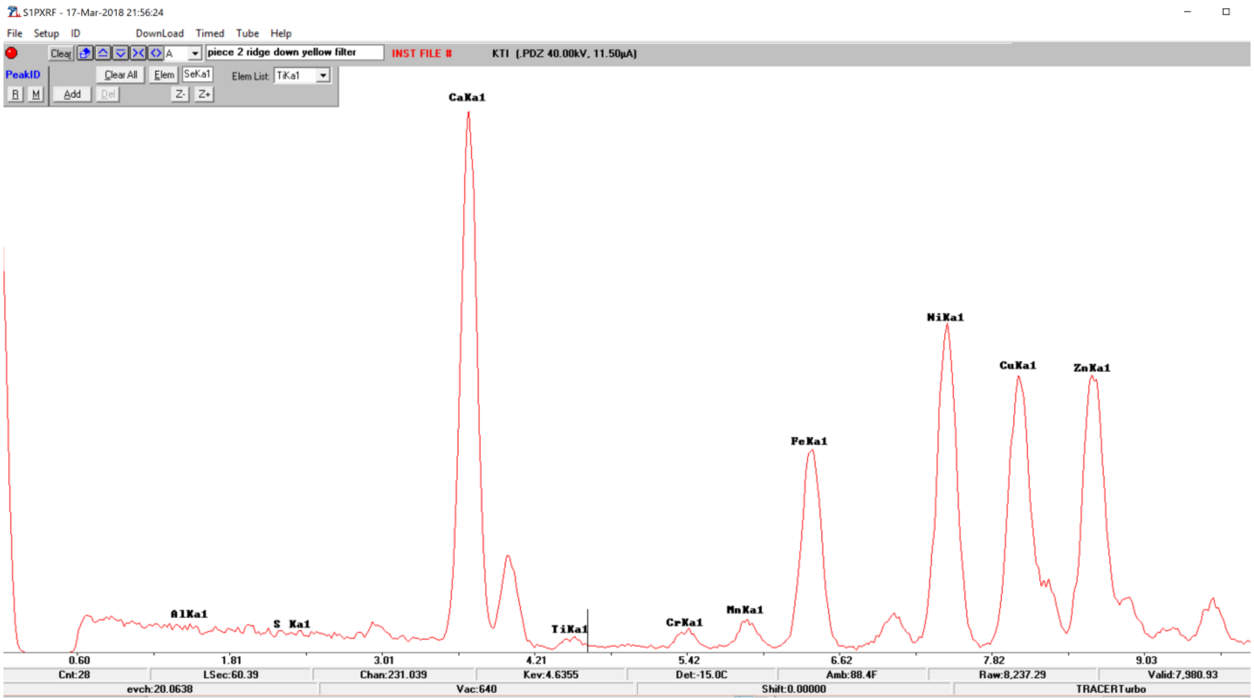


Figure B.9- VISB-2402 lip ridge down with yellow filter. XRF by Chris Dostal.

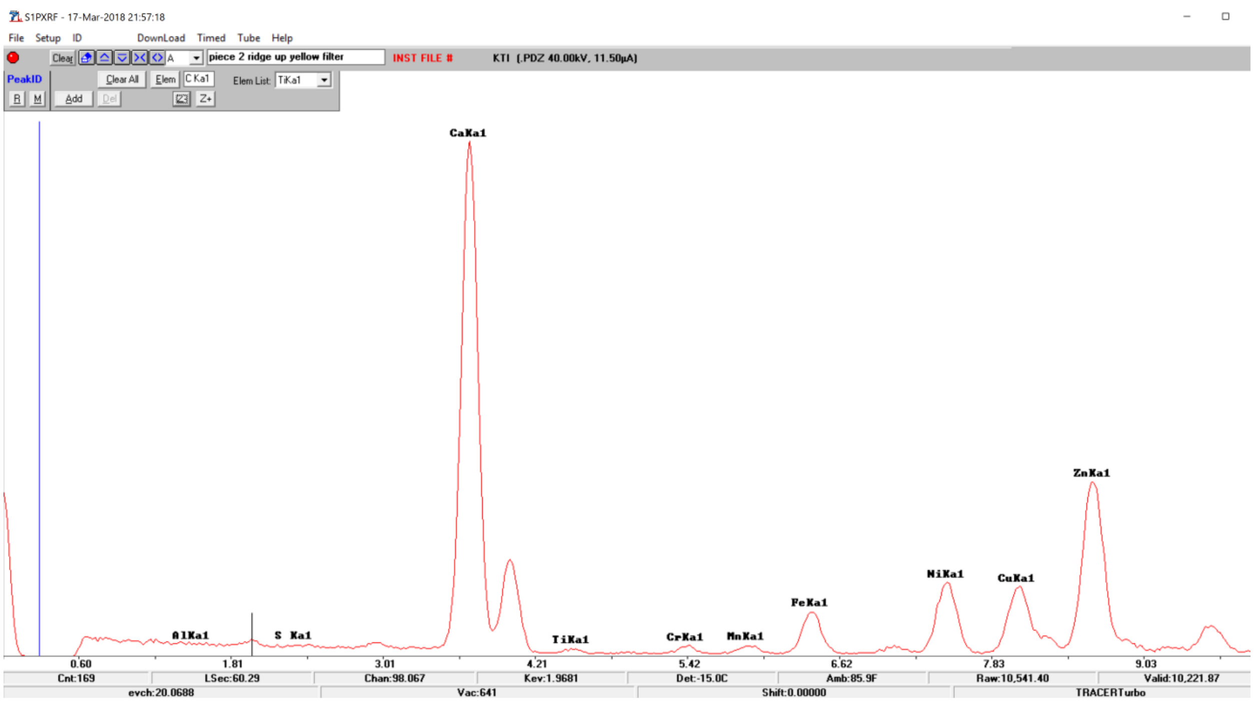


Figure B.10- VISB-2402 ridge up with yellow filter. XRF by Chris Dostal.

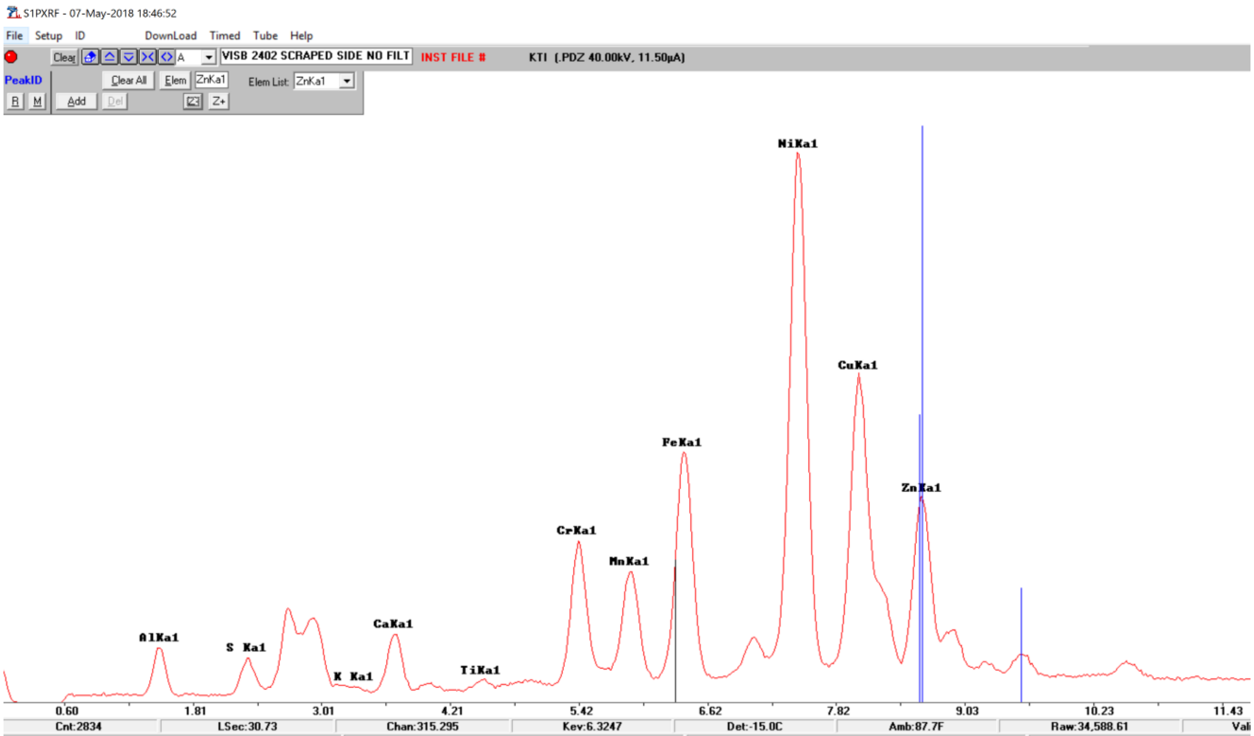


Figure B.11- VISB-2401 lip curving up, after scraping and no filter. XRF by Chris Dostal.

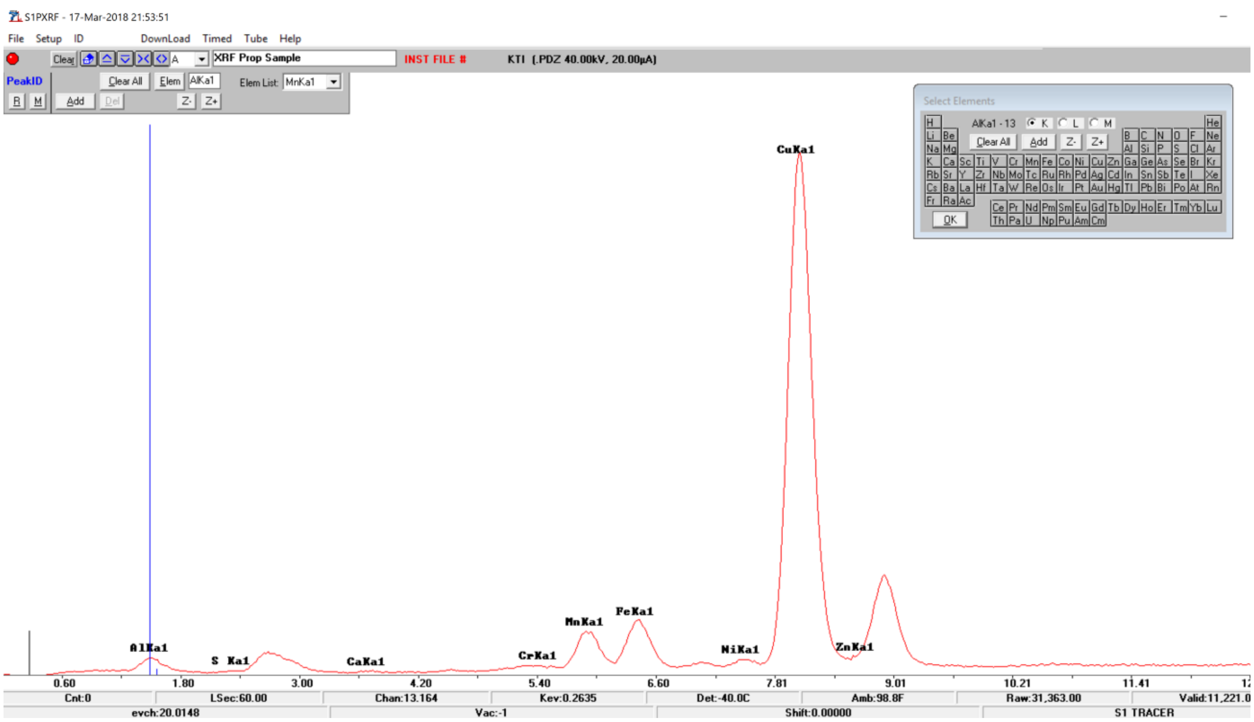


Figure B.12- RAFMDeH01 propeller sample with no filter. XRF by the author.

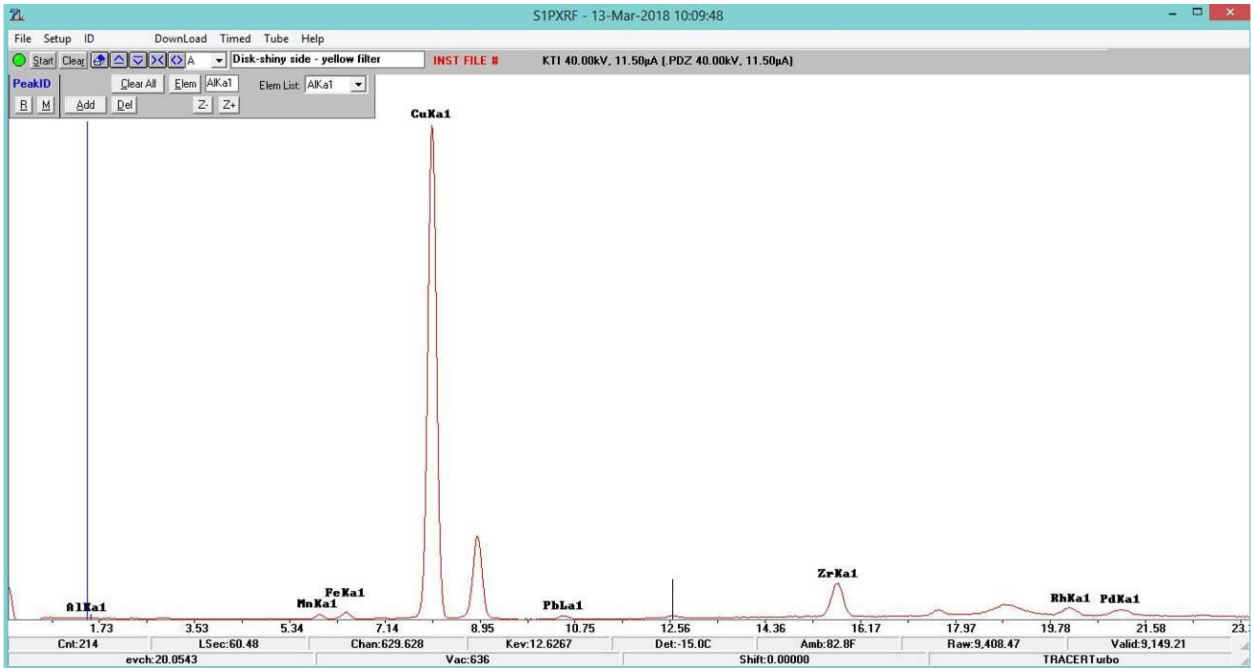


Figure B.13- CAMAB01 on the shiny side with a yellow filter. XRF by Chris Dostal.

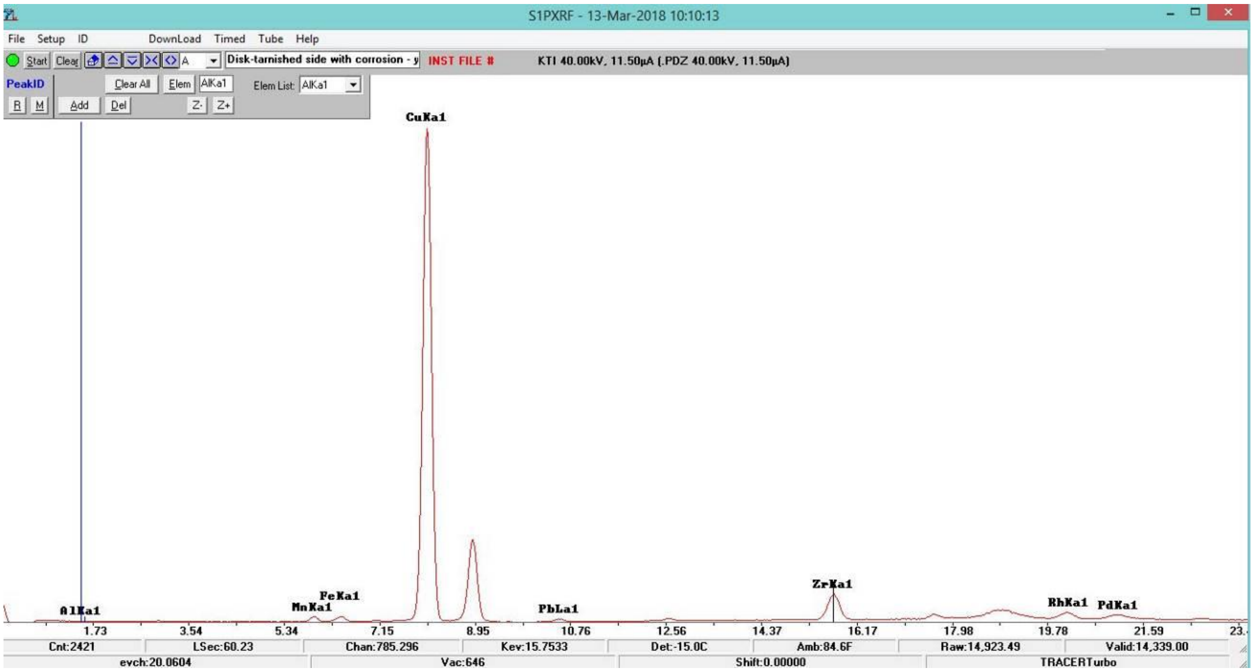


Figure B.14- CAMAB01 on the sediment covered side, centered on corrosion products, with a yellow filter. XRF by Chris Dostal.

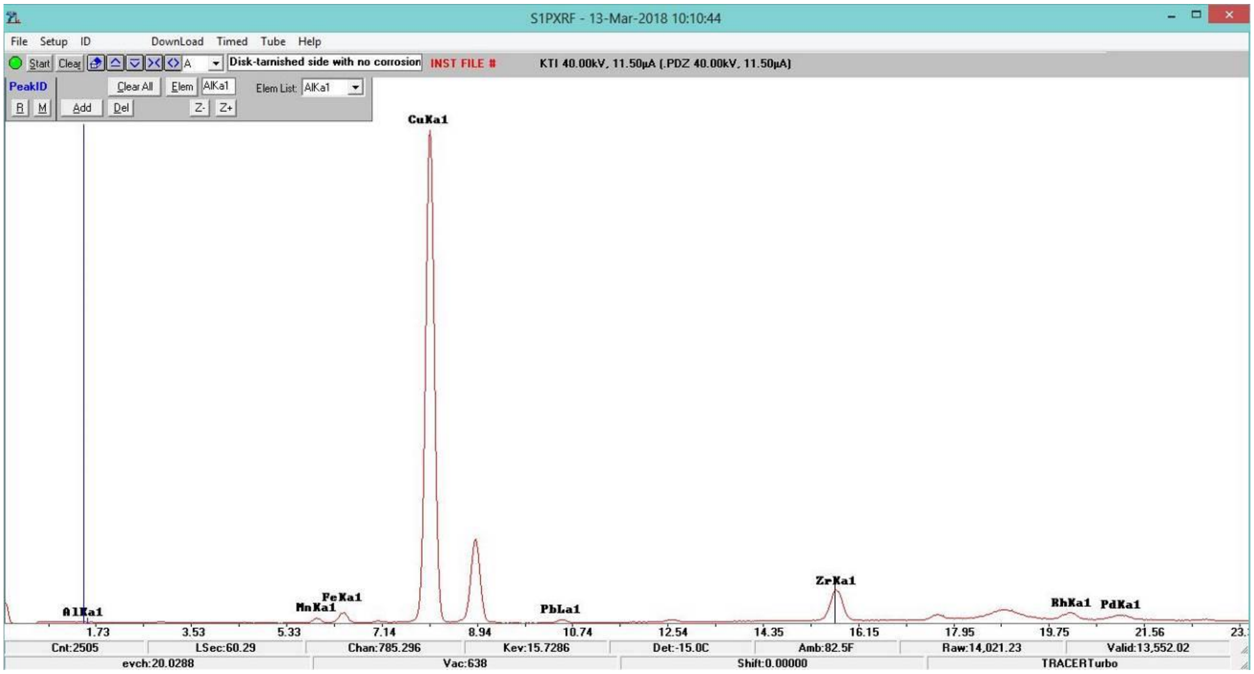


Figure B.15- CAMAB01 on the sediment covered side, not centered on corrosion products with a yellow filter. XRF by Chris Dostal.

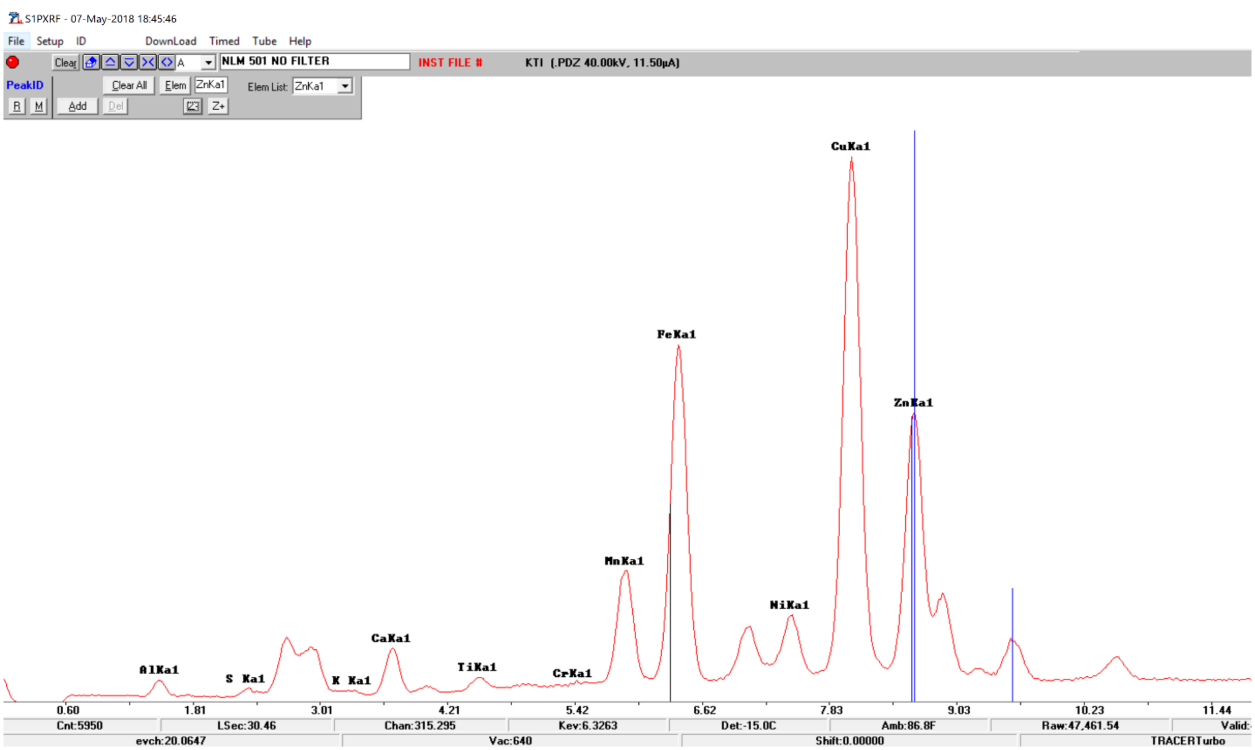


Figure B.16- NLMFW-19001 with no filter. XRF by Chris Dostal.

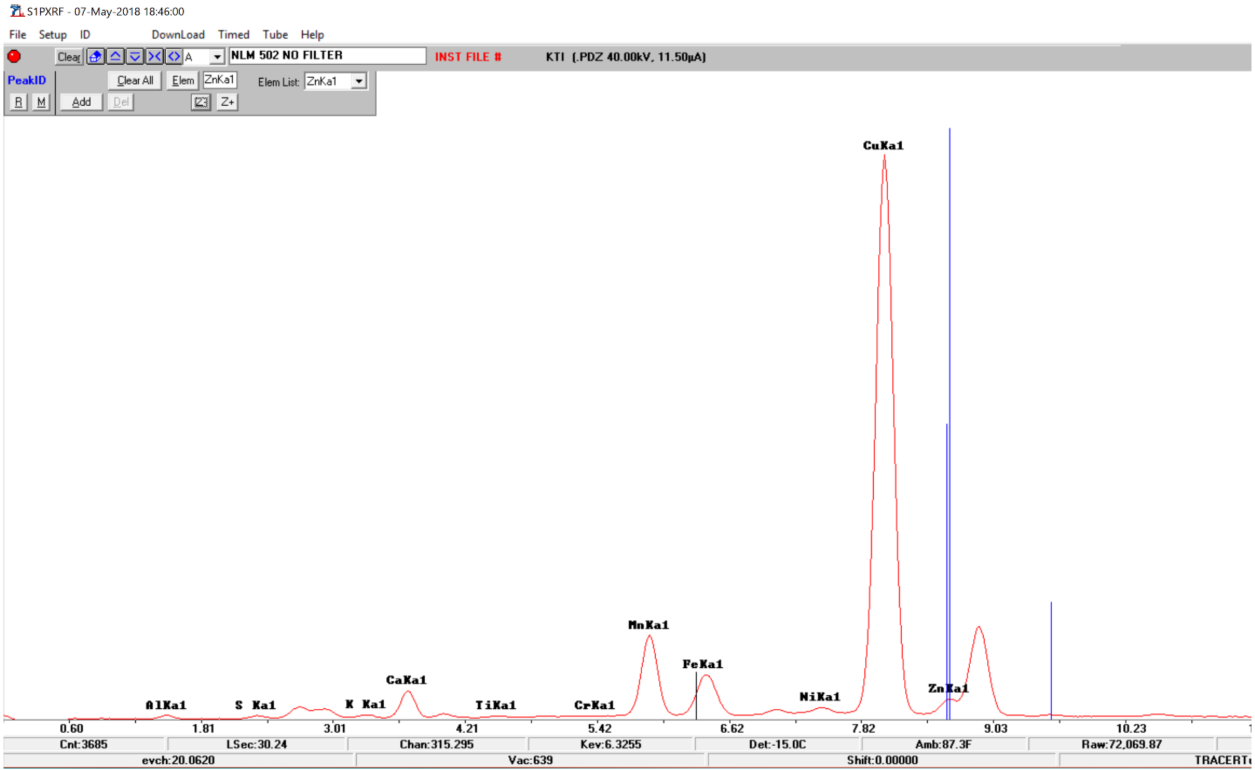


Figure B.17- NLMFW-19002 with no filter. XRF by Chris Dostal.

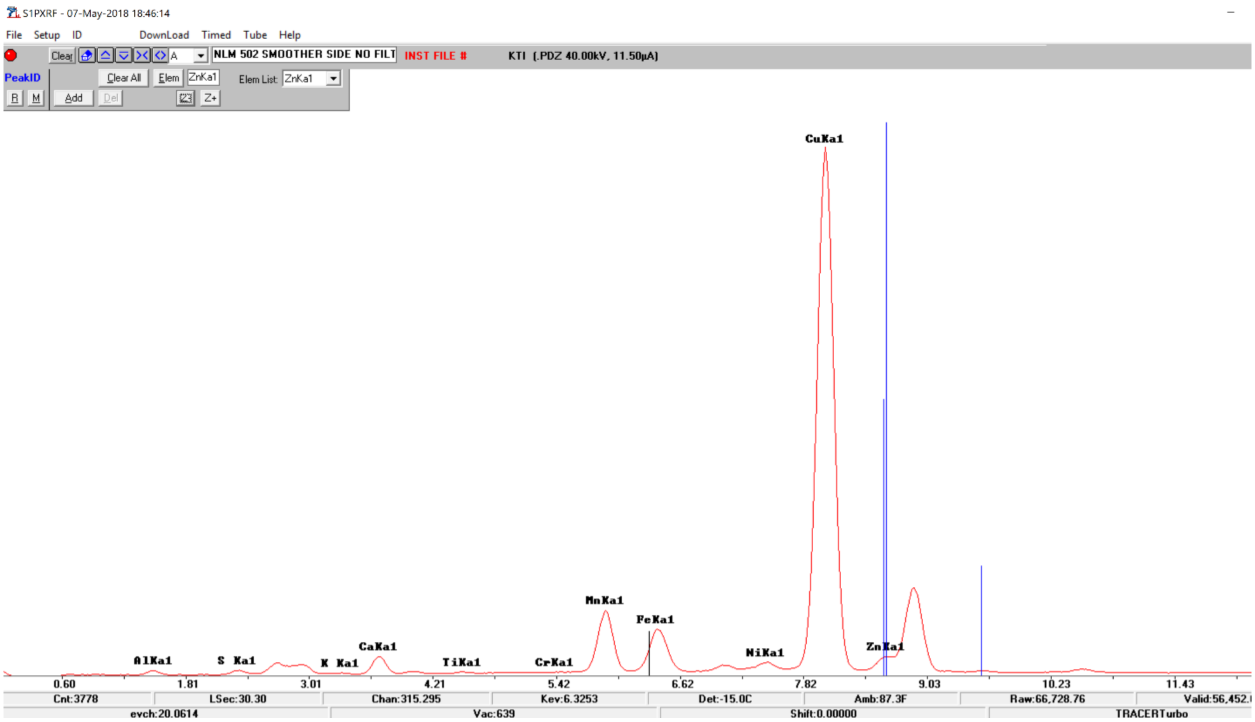


Figure B.18- NLMFW-19001 on the smoother side with no filter. XRF by Chris Dostal.

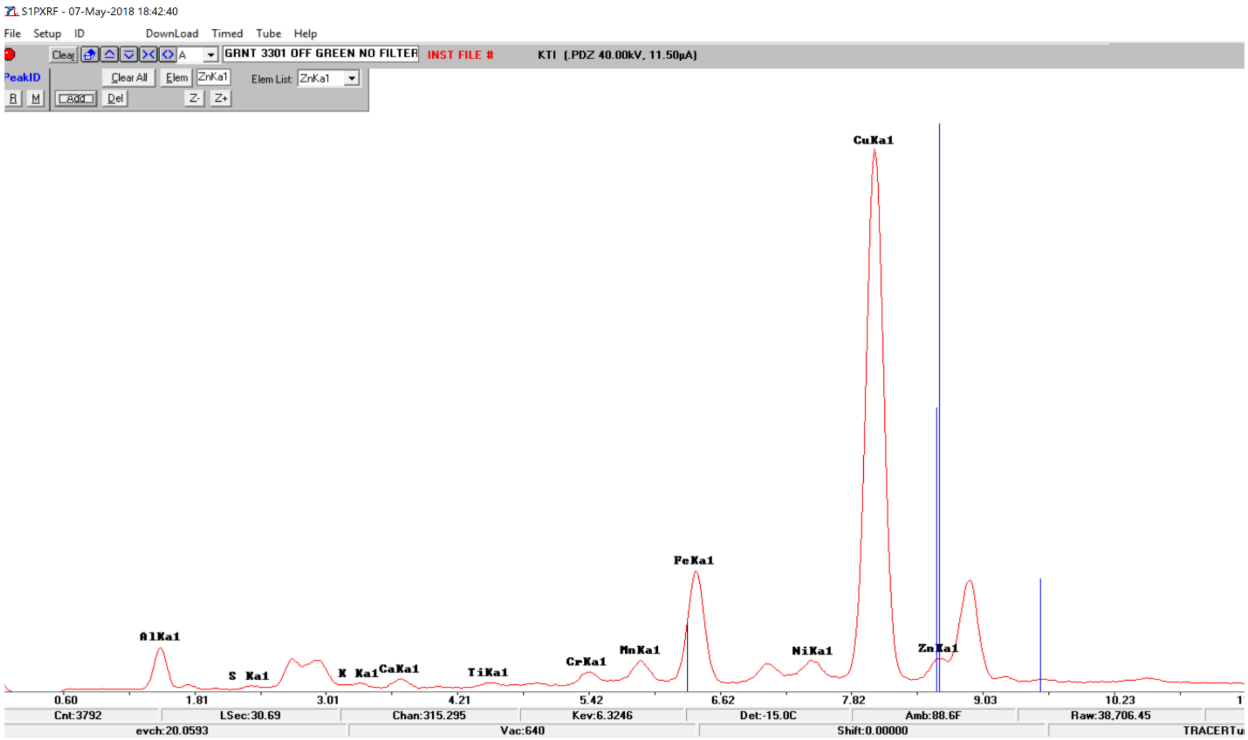


Figure B.19- GRNT-3301 sample bare metal side, no filter. XRF by Chris Dostal.

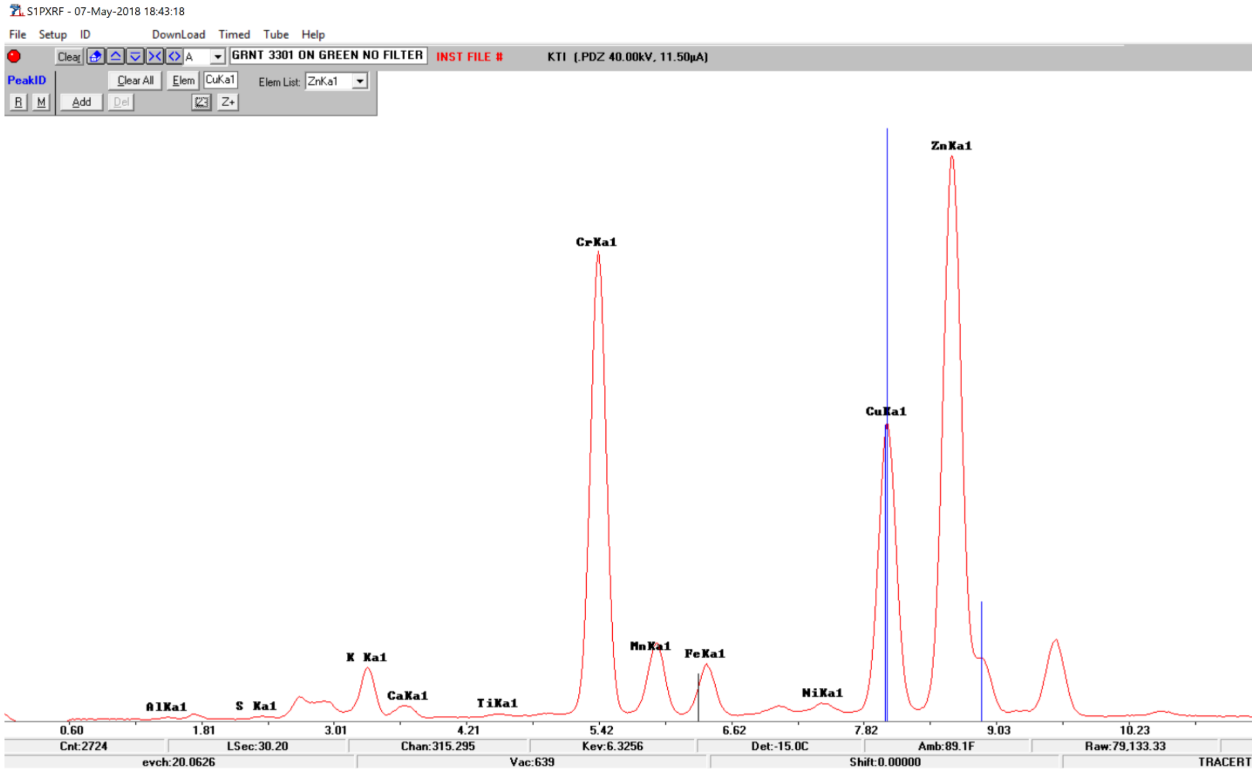


Figure B.20- GRNT-3301 sample on primer-covered metal side, no filter. XRF by Chris Dostal.

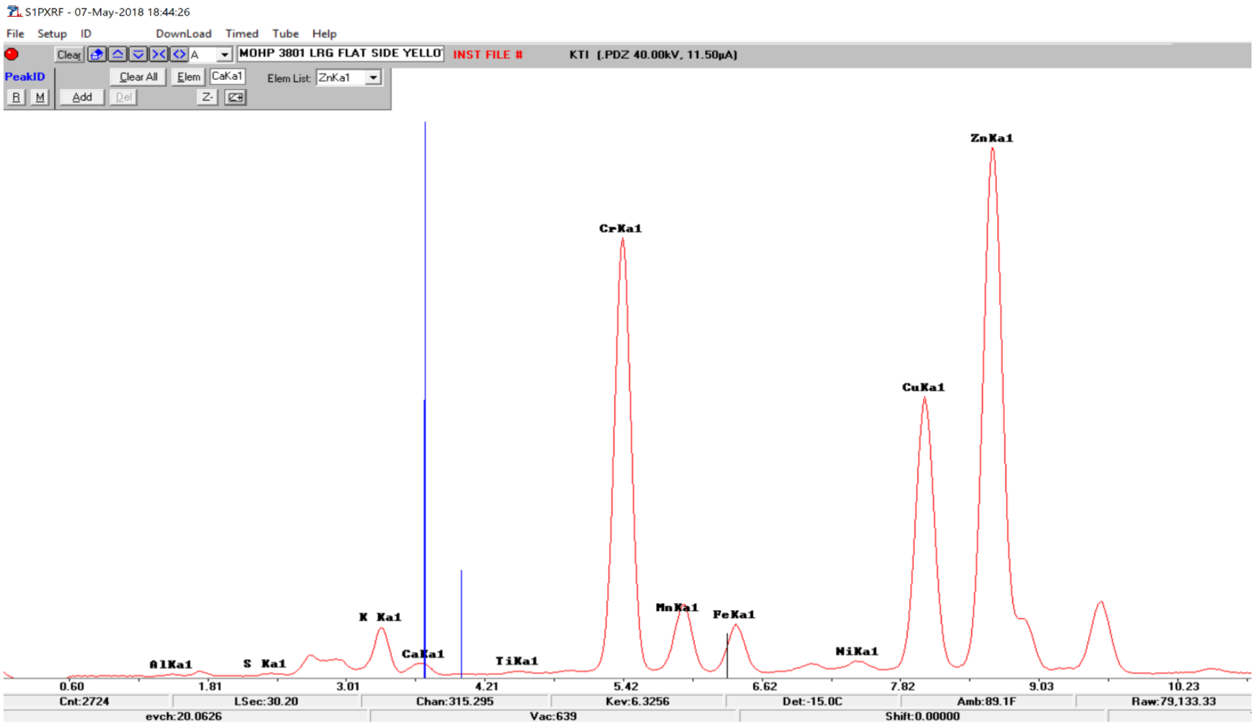


Figure B.21- MoHP-3801, long flat side, with a yellow filter. XRF by Chris Dostal.

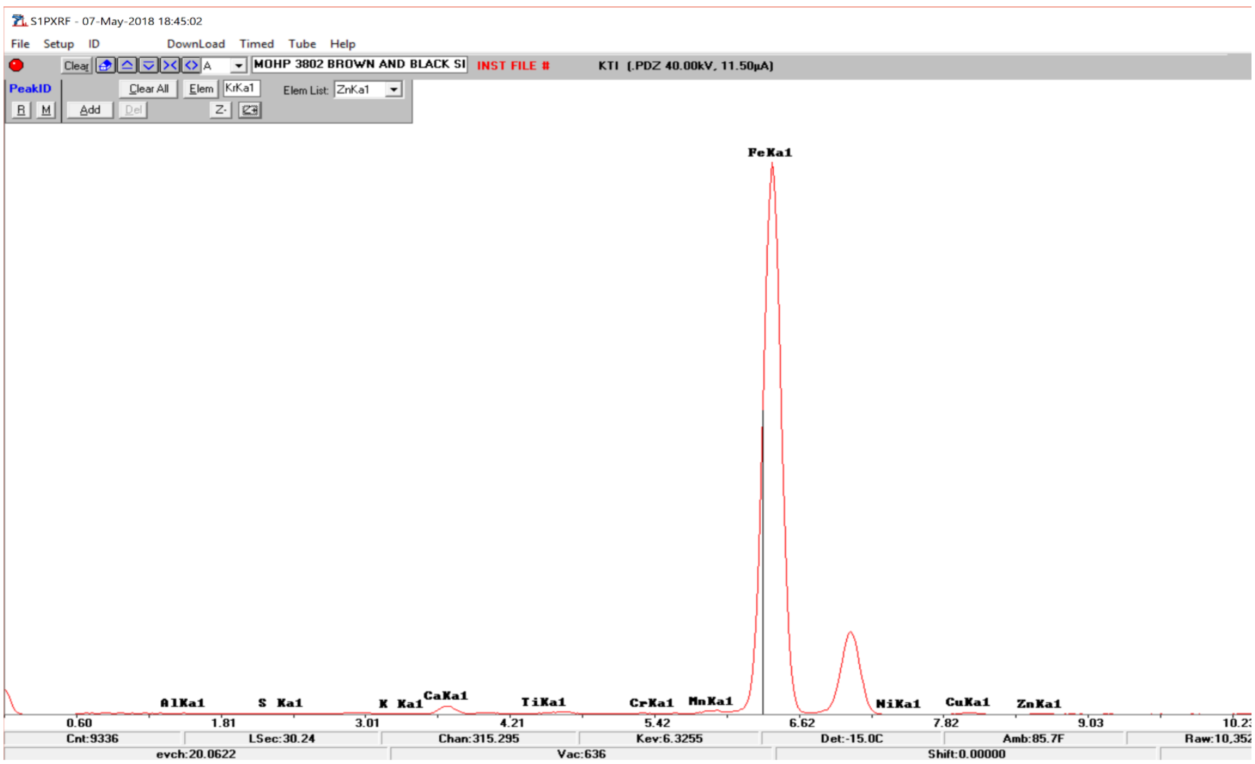


Figure B.22- MoHP-3802, brown and black spot, with a yellow filter. XRF by Chris Dostal.

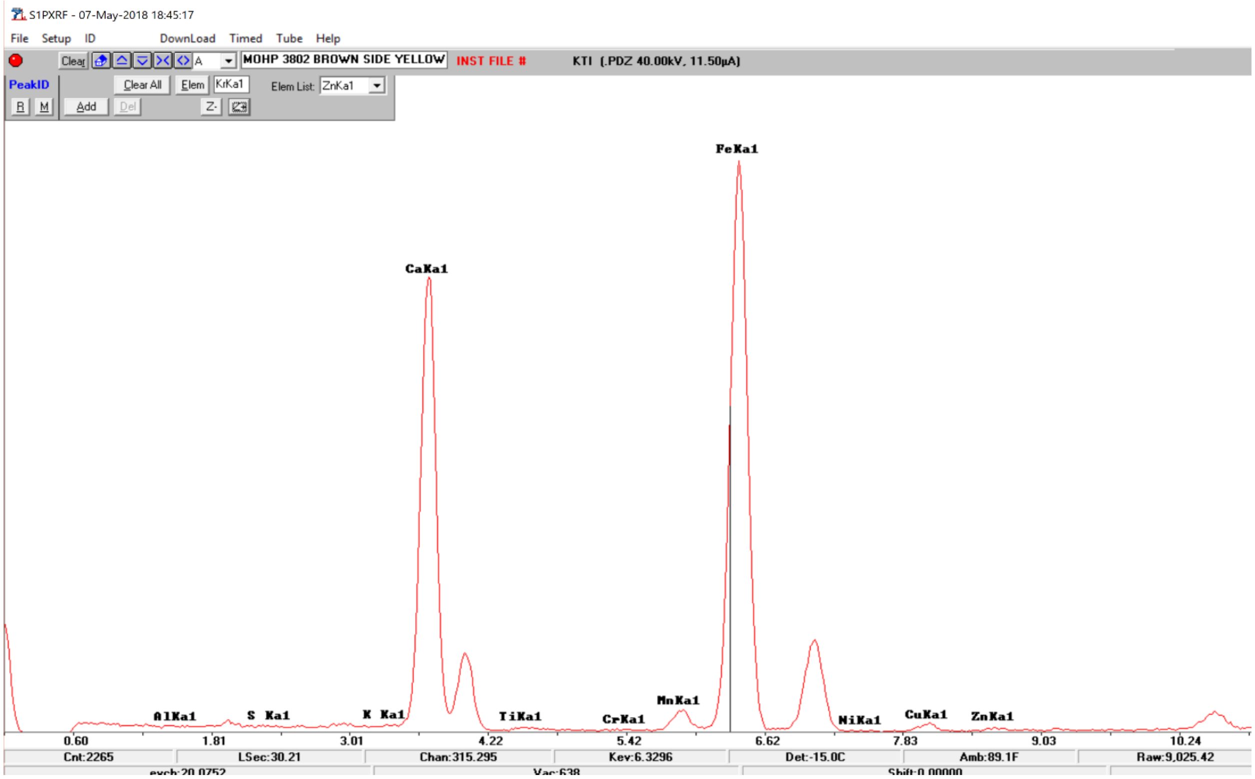
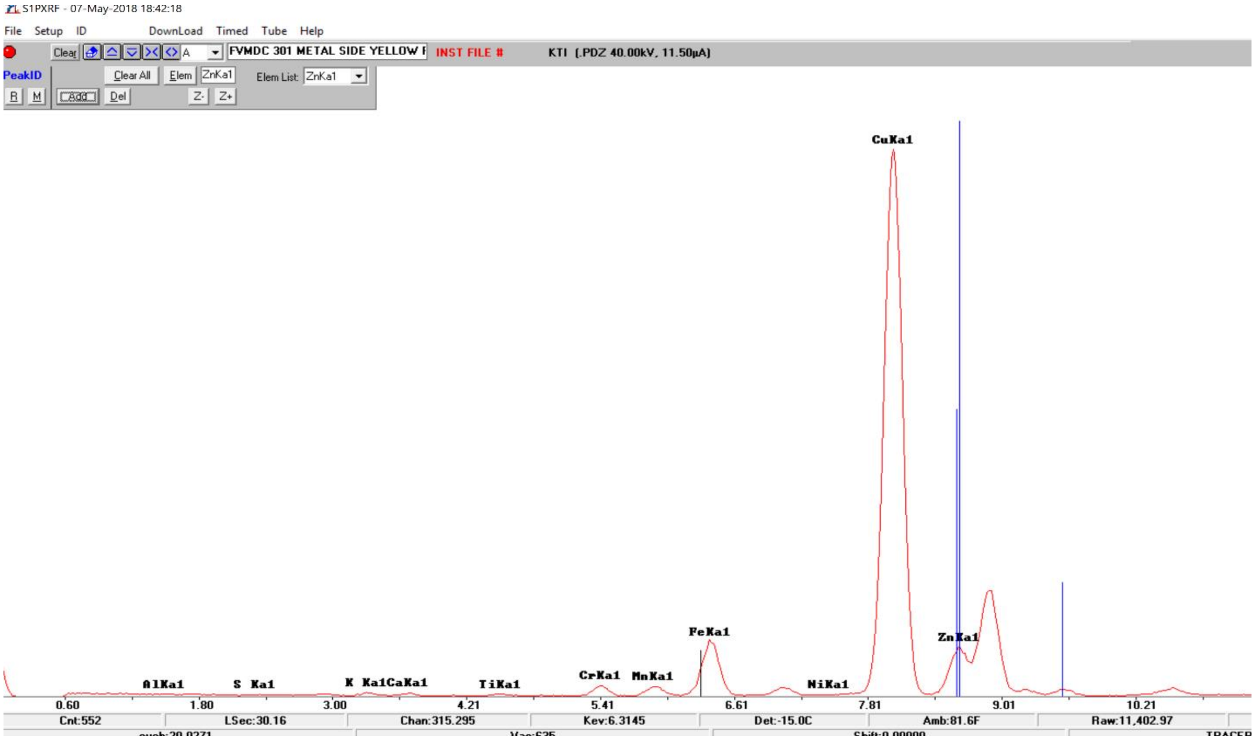


Figure B.23- MoHP-3802, brown spot, with a yellow filter. XRF by Chris Dostal.



B.24- FVMDC-301 shiny metal side with yellow filter. XRF by Chris Dostal.

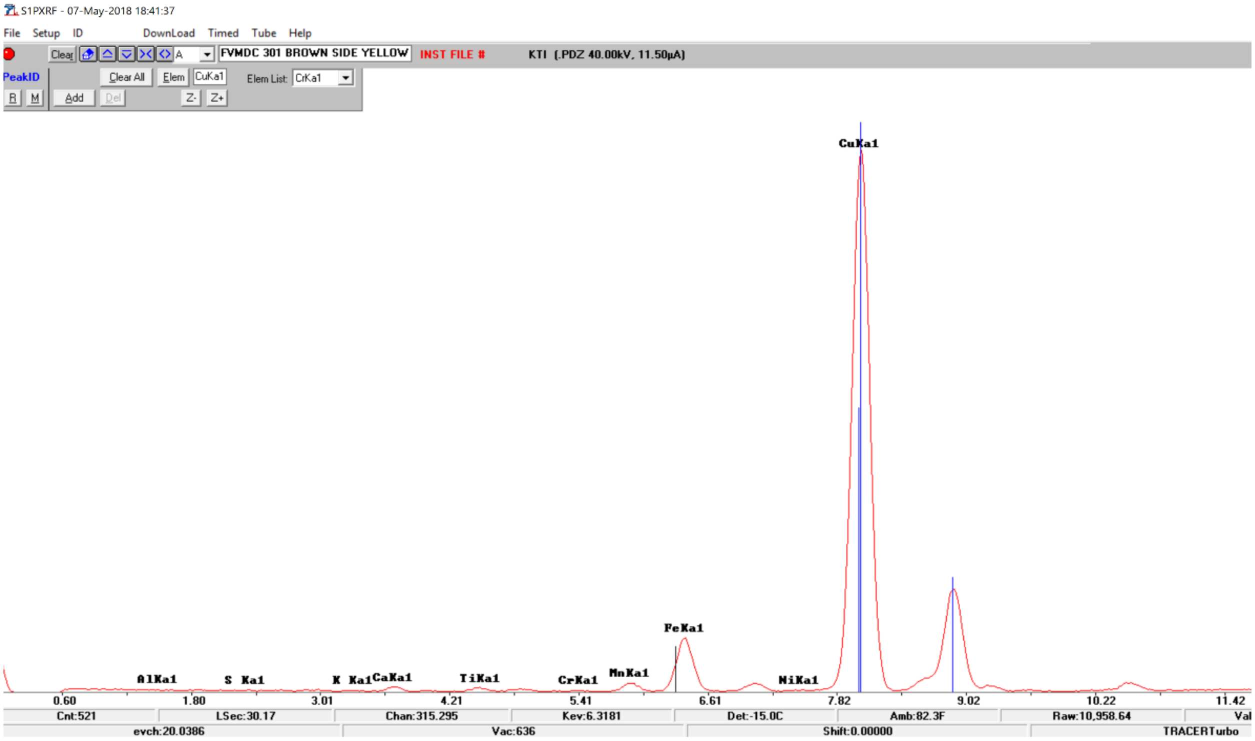


Figure B.25- FVMDC-301 shiny metal side with yellow filter. XRF by Chris Dostal.

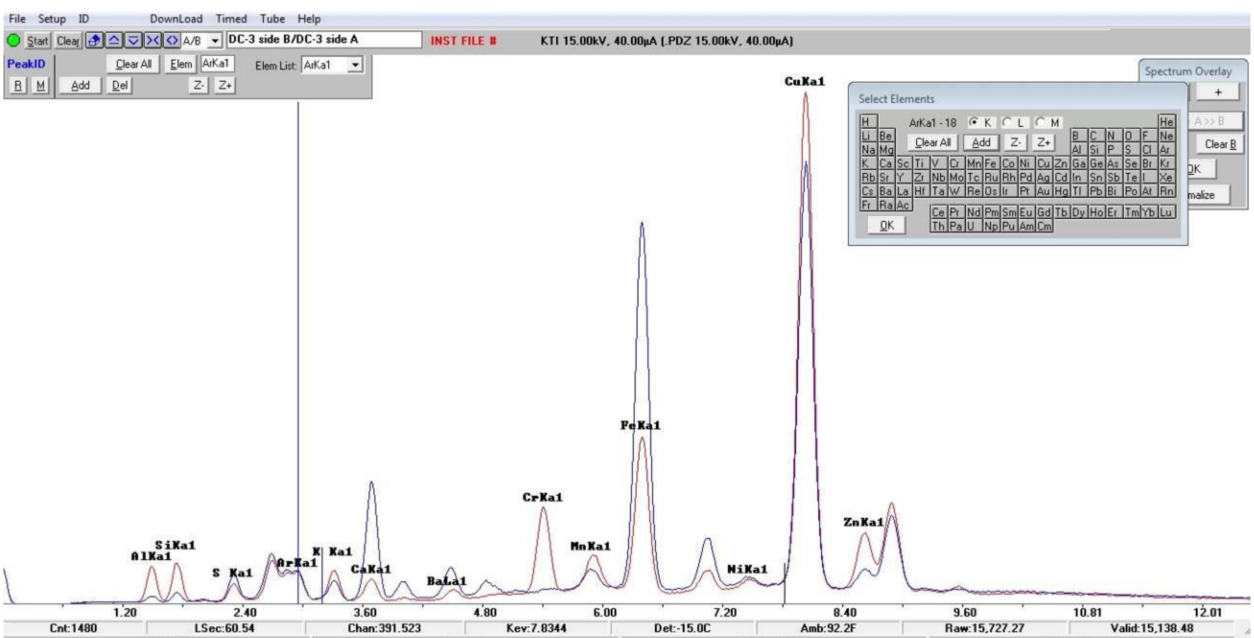


Figure B.26- FVMDC-301 both sides, no filter and with a vacuum. XRF by the author.

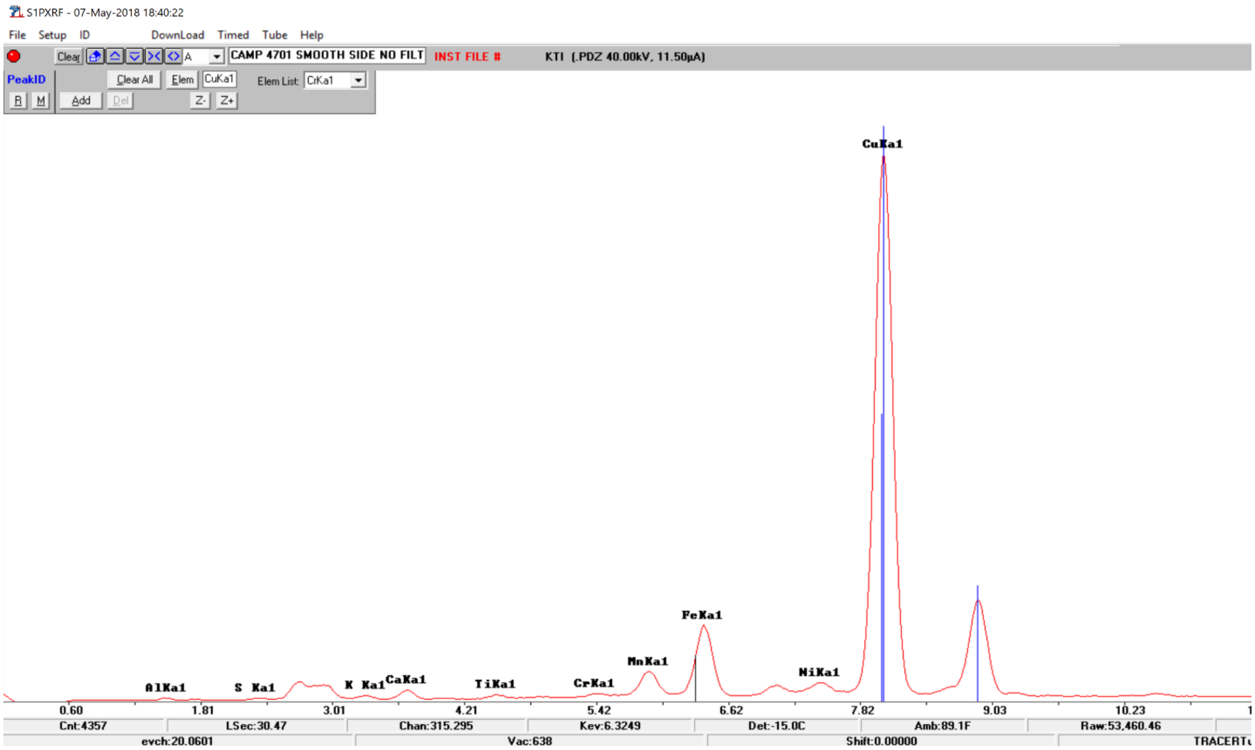


Figure B.27- CAMP-4701 on the smooth side, no filter. XRF by Chris Dostal.

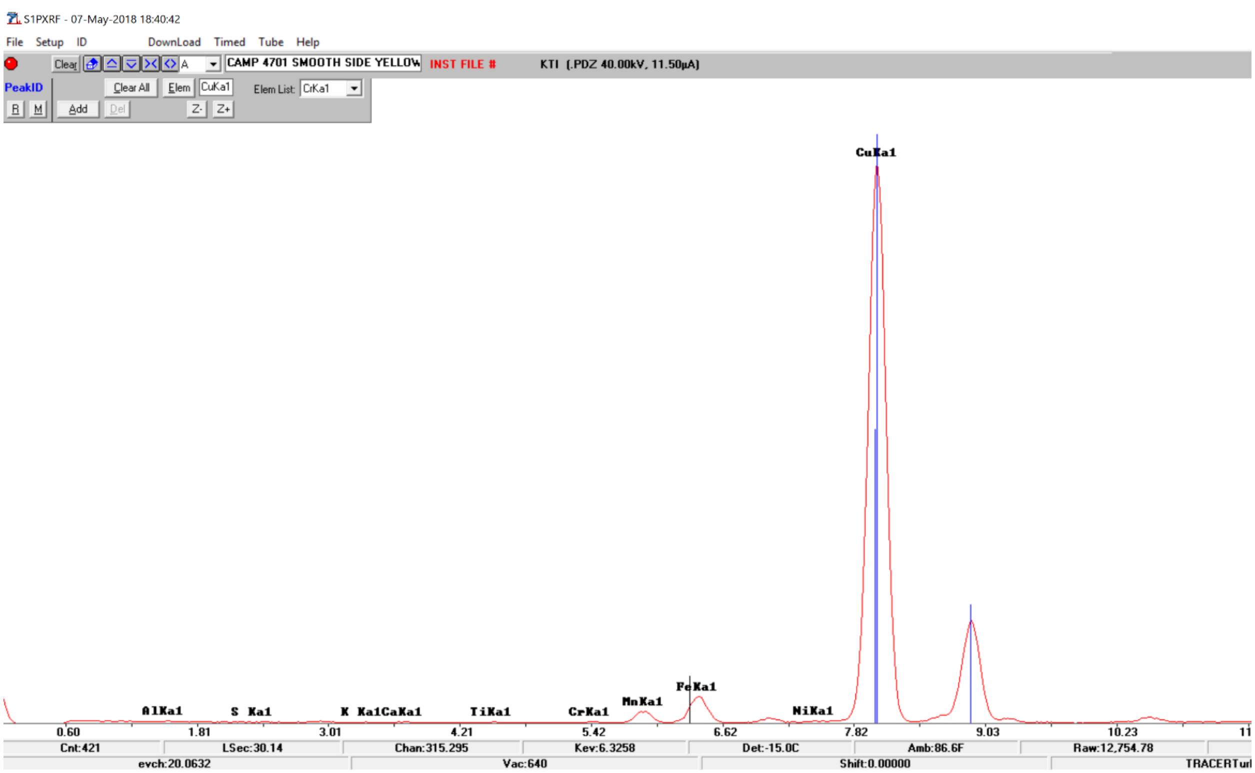


Figure. B.28- CAMP-4701 on the smooth side, with a yellow filter. XRF by Chris Dostal.

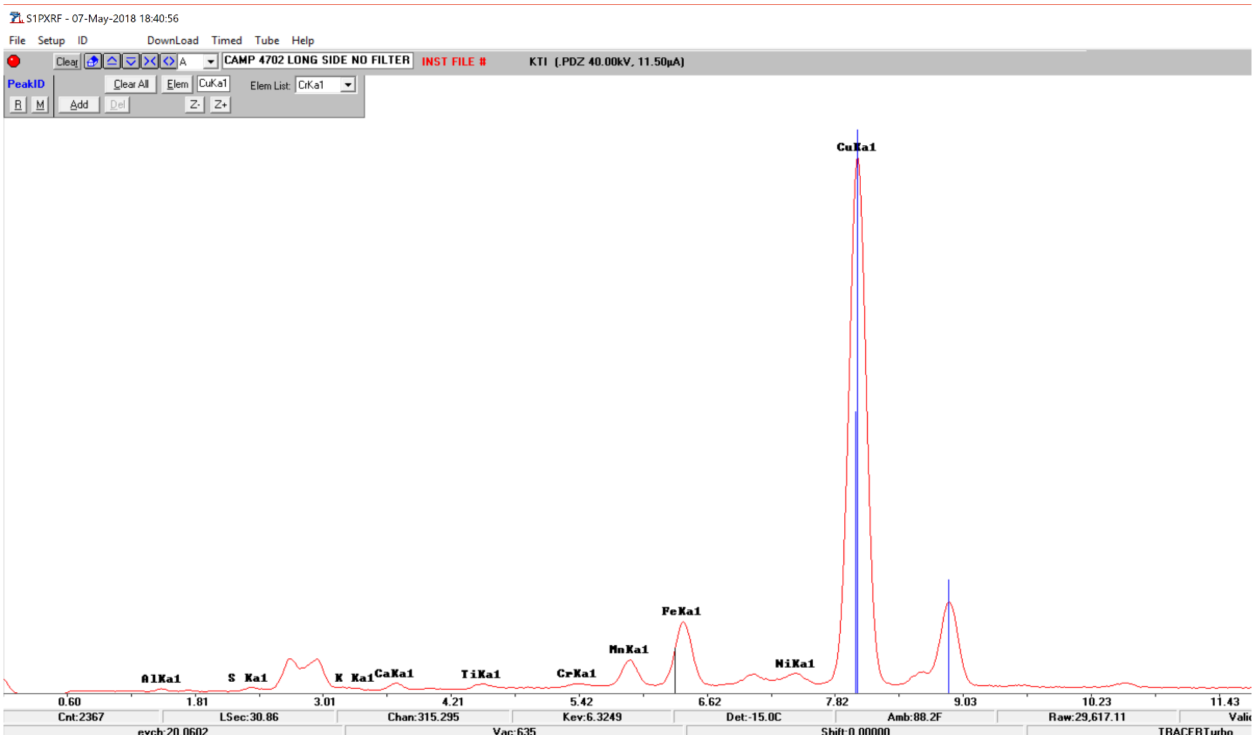


Figure B.29- CAMP-4702 on the long side, no filter. XRF by Chris Dostal.

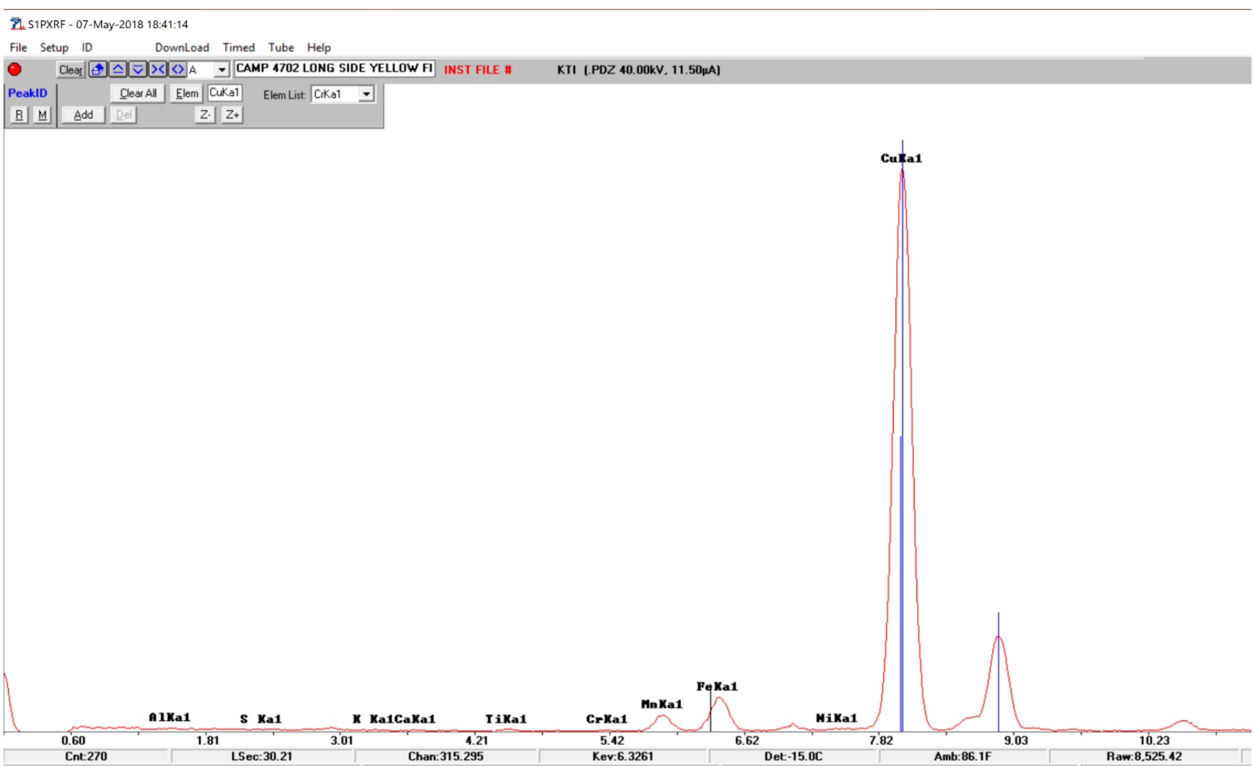


Figure B.30- CAMP-4702 on the long side, with a yellow filter. XRF by Chris Dostal.

APPENDIX C PREPARATION AND TREATMENT OF EXPERIMENTAL ALUMINUM SAMPLES

RAF Museum Samples

The two long pieces of Dornier Do 17 material (RAFMDo01-02) was cut into four parts (RAFMDo01a, b, c, d, etc) and fully documented. The third piece, RAFMDo03, was cut into two pieces. The one piece of Navy Helldiver material (UABSB2C01) was compared to XRF analysis of an existing helldiver in the Smithsonian's Nation Air & Space Museum.

Sample RAFMDo01 is a fragile piece if stringer material that is pitting and exfoliating extensively. It presents with clearly visible blue copper corrosion products, some maroon discoloration, and relatively shiny aluminum. RAFMDo02 is also long and thin, but is in a much better state of preservation that RAFMDo01. There are remains from a suspected leather covering, which was glued to the piece. The leftover glue covers the piece. There are rust spots from iron rivets, and a small amount of blue copper corrosion product. RAFMDo03 is a cast aluminum curved object with four aluminum rivets and one ferrous rivet. The ferrous rivet is surrounded with rust. The object was painted with a light blue paint and remnants of it remain on the surface along with dirt.

NHHC UAB Sample

Initial visual documentation of all samples was completed with a microscope and with general observation. Under a microscope the surface of the Helldiver wing sample (UABSB2C01) in sample areas 2-3 shows a delamination of green material over a metal surface with colors of black, silver, and the salmon pinkish color of copper. I can see that the grain of the metal is still intact but the ridges are raised. Sample area 4 appears to be the most intact area, in terms of laminate intact-ness and being free from marine growth, on the wing sample, and is likewise registering the highest peaks in all elements. Sample area 1 appears to be the most deteriorated area on the wing sample that I can see, although other areas beneath the marine growth might be more so.

During preparation I removed a conical metal piece from the inward side of the wing sample, which was filled with a gel-like white substance. This gel is indicative of aluminum corrosion and has hardened slightly in the time I have had the sample.[300] Under the microscope this area looks like it could have more features underneath the marine growth. It resembles a hinge or what would have been a thin flap. There might be a rivet in this area but I unable to make a positive identification yet.

In some areas on the outward facing side but most noticeably on the inward side, there appear to be hardened, pustule-like white growths attached to some otherwise clean metal surfaces. Interestingly, five growths had re-appeared on sample area 1 in the time between May preparation and November XRF analysis. I believe these to be corrosion products forming (and re-forming) over pitting common in aluminum alloys with Mg and Mn-Si. The quick re-formation of the pitting corrosion is worrying, as it perhaps shows how un-stable this wing sample is, even in dark, refrigerated conditions.

It appears that the outwards angled side of the metal sample is plated with a thin layer of metal that is different than the structural metal; i.e. a laminate. Aluminum 2024 is a well-known alclad aircraft aluminum that has a laminate made of a thin, high-purity aluminum layer over an aluminum alloy. The double layer resists corrosion, especially in marine environments. I suspect that the metal is the 2024 alclad and the alloy's main component is copper, although no amount

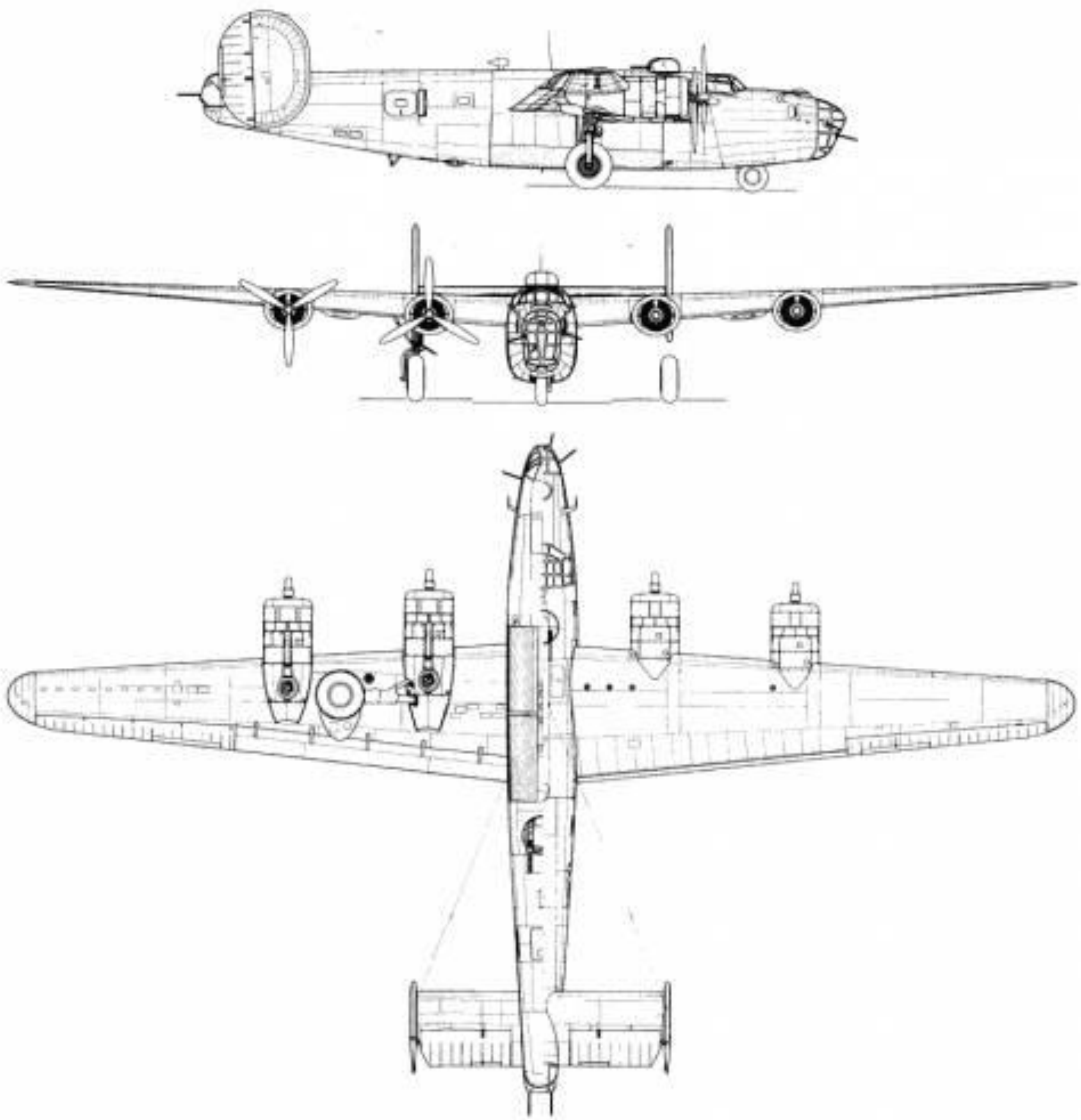
[300] Totten and MacKenzie 2003; Degrigny 2004

of analysis will be able to tell us the original properties of the alloy due to deterioration over time. The laminate appears to be flaking away in sample areas 2-3 and sample area 2 in particular seems to have developed a thin layer of cupreous corrosion products in between either the laminate layers or the metal and the primer. The inward side appears to have the most visible traces of copper, suggesting aluminum degradation has been the most active on the inward side. USNH01 is extremely fragile and any conservation method is likely to result in an unpredictable level of surface loss on the outward side.

Treatment Methodology for Both Samples

Given the fragility of RAFMDO1 and the relative integrity of the other two Dornier samples I chose to alternate the treatments on both pieces, so two of the four sections of the first piece would be washed and the other two conserved in ER. I was certain enough actual metal remains in both samples for a successful polarization. The Helldiver piece was not subject to electrolysis and followed the washing process. The washing and ER solution was a .055 M solution of citric acid with sodium hydroxide and the pH was maintained at 5.4. Due to the high risk of re-pitting during processing the solutions and pH was meticulously stirred, maintained, and refreshed. The ER vat was plastic with a stainless steel mesh to counteract the citric acid, and the voltage was set low at only 1.15-1.2 volts. The alligator clips were taped in order not to introduce any copper into the tank. After both treatments, the ER samples were rinsed and thoroughly dried. I also experimented with coatings of a spray Dinitrol wax, a matte krylon, and a microcrystalline renaissance wax.

APPENDIX D   SPECIFICATIONS AND PLANS FOR B-24 LIBERATOR



General characteristics

Crew: 11 (pilot, co-pilot, navigator, bombardier, radio operator, nose turret, top turret, 2 waist gunners, ball turret, tail gunner)

Length: 67 ft 8 in (20.6 m)

Wingspan: 110 ft 0 in (33.5 m)

Height: 18 ft 0 in (5.5 m)

Wing area: 1,048 ft^2 (97.4 m^2)

Airfoil: Davis 22% / Davis 9.3%

Empty weight: 36,500 lb (16,590 kg)

Loaded weight: 55,000 lb (25,000 kg)

Max. takeoff weight: 65,000 lb (29,500 kg)

Zero-lift drag coefficient: 0.0406

Drag area: 42.54 sq ft (3.952 m2)

Aspect ratio: 11.55

Powerplant: 4 × Pratt & Whitney R-1830-35 or -41 turbosupercharged radial engines, 1,200 hp (900 kW) each

Performance

Maximum speed: 290 mph (250 kn, 488 km/h)

Cruise speed: 215 mph (187 kn, 346 km/h)

Stall speed: 95 mph (83 kn, 153 km/h)

Range: 2,100 mi (1,800 nautical miles (3,300 kilometres))

Ferry range: 3,700 mi (3,200 nmi (5,900 km))

Service ceiling: 28,000 ft (8,500 m)

Rate of climb: 1,025 ft/min (5.2 m/s)

Wing loading: 52.5 lb/ft² (256 kg/m²)

Power/mass: 0.0873 hp/lb (144 W/kg)

Lift-to-drag ratio: 12.9

Armament

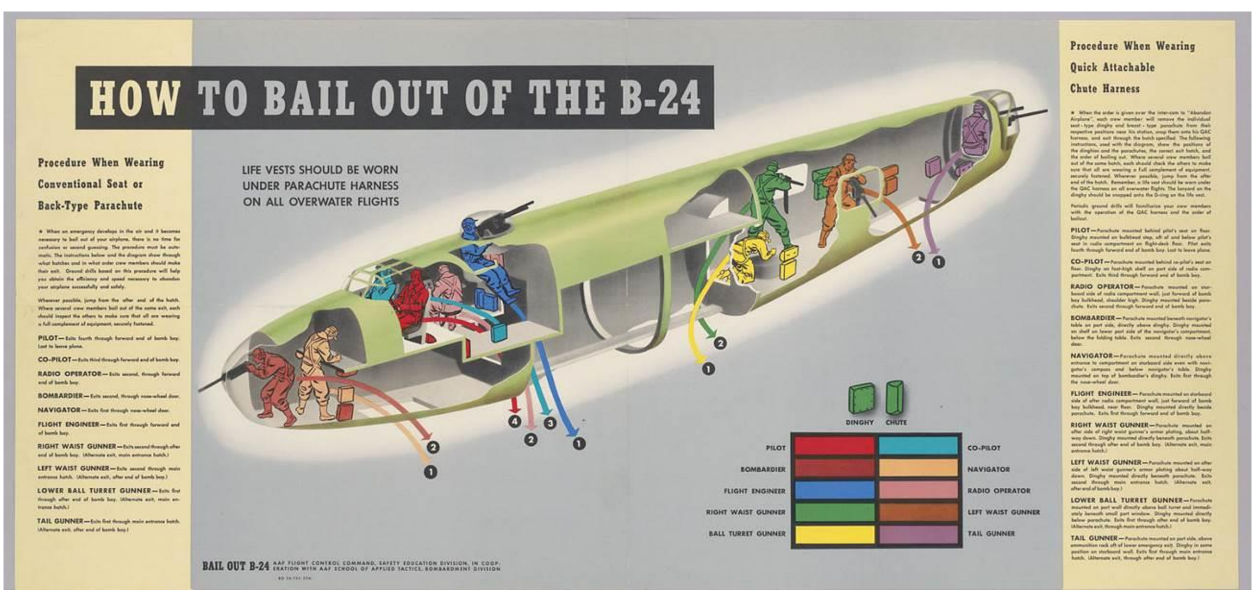
Guns: 10 × .50 caliber (12.7 mm) M2 Browning machine guns in 4 turrets and two waist positions

Bombs:

Short range (˜400 mi [640 km]): 8,000 pounds (3,600 kg)

Long range (˜800 mi [1,300 km]): 5,000 pounds (2,300 kg)

Very long range (˜1,200 mi [1,900 km]): 2,700 pounds (1,200 kg)




How to ditch the B-24
AIRPLANE MODELS AND EQUIPMENT STOWAGE VARY...ADAPT THIS PROCEDURE TO FIT THE SPECIFIC MODEL YOU ARE FLYING
1 Jettison bombs, ammunition, guns and all loose equipment and secure that equipment which might cause injury. Close bomb bay doors and lower hatches. If insufficient time to release bombs, depth charges place them on SAFE. Retain enough fuel to make a power landing.
2 Navigator calculates position, course, speed and passes it to R/O. Latter tunes liaison transmitter to MFDF and sends SOS, position, and call sign continuously. R/O also turns IFF to distress and remains on intercomm; clamps down key on order to "take ditching post."
3 These tips will help you determine wind direction and speed: (a) waves in open sea move downwind; (b) direction of spray indicates wind direction; (c) wind lanes—a series of lines or alternate strips of light and shade—also show direction; (d) approach on waves should be made into wind at right angles to them; (e) approach on swells should be made along top, parallel to swell and may be executed in winds not over 10 m.p.h.
HOW TO DETERMINE WIND SPEED
A few white crests.....10 to 20 m.p.h.
Many white crests.....20 to 30 m.p.h.
Foam streaks on water.30 to 40 m.p.h.
Spray from crests......40 to 50 m.p.h.
THESE POSITIONS should best enable crew members to withstand the impact of crash landings on either land or water. On water two impacts will be felt, the first a mild jolt when the tail strikes, the second a severe shock when the nose strikes the water. Positions should be maintained until the aircraft comes to rest.
The Flight Engineer should take the position shown if a ditching belt is available. Otherwise he lies on his back, feet braced against the step into the pilot's compartment. In this position, his knees should be slightly bent, his hands clasped behind his head.
Emergency equipment for use in the dinghy should be carried to crash positions. Any equipment carried free must be held securely during ditching.
Parachute pads, seat cushions, etc., should be used to protect the face, head, and back.
KNOW YOUR DITCHING DUTIES! PRACTICE THEM! DRILL IS IMPORTANT!
Each crewman's duty is briefly and clearly indicated at the right. These duties should be studied, altered if necessary to agree with any modifications, memorized, and practiced until each member of the crew performs them mechanically. Drill is the responsibility of the pilot.
The pilot's warning to "prepare for ditching" should be acknowledged by the crew in the order given here—co-pilot, navigator, bombardier, flight engineer, radio operator, right waist gunner, left waist gunner, tunnel gunner, tail gunner, i.e., "co-pilot ditching," "navigator ditching," "bombardier ditching," etc.
Upon acknowledgment, crew members remove parachutes, loosen shirt collars and remove tie and oxygen masks unless above 12,000 feet, in which case main oxygen supply or emergency oxygen bottle is used until notification by the pilot. All crew members wearing winter flying boots should remove them. No other clothing should be removed.
Releases on dinghies should not be pulled until the plane comes to rest.
Beware of puncturing rafts on wing and horizontal surfaces after launching. The dinghies should be tied together as soon as possible.
Injured personnel should get first consideration and assistance when abandoning the aircraft.
Life vests should not be inflated inside the plane unless the crewman is certain that the escape hatch through which he will exit is large enough to accommodate both him and the vest.
When personnel are in dinghy, stock of rations and equipment should be taken by the captain (pilot or co-pilot). Strict rationing must be maintained. Flares should be used sparingly and only if there is a reasonable chance that they will be seen by ships or aircraft. Don't forget the Very pistol.
If a source of rescue is within reasonable distance, it is recommended that crew personnel when possible utilize a parachute with a one-man life raft and abandon the airplane in air.
PILOT
(1) Warns "prepare for ditching" over intercomm, giving altitude; rings signal bell (5 or 6 short rings); (2) fastens safety harness, assists co-pilot with his harness; (3) orders R/O to ditching post, gives order to crew to "brace for ditching" 5 seconds before impact, long ring on signal bell; (4) approaches, prepares to alight, tail well down—into wind if strong, along swell top if wind light; (5) releases safety harness, parachute straps when plane comes to rest; (6) exits sixth from F.D. hatch; inflates vest, boards left dinghy last, takes command.
CO-PILOT
(1) Assists pilot to fasten safety harness, fastens own; (2) releases safety harness, parachute straps when plane comes to rest; (3) exits fifth from F.D. hatch, inflates vest, boards right dinghy last, takes command.
NAVIGATOR
(1) Calculates course, position, speed, giving info. to R/O; destroys secret papers, gathers maps, compass, celestial equipment, goes to flight deck; (2) takes ditching post; (3) exits first from F.D. hatch, inflates vest, receives emergency radio from bombardier (if stored in radio compartment), goes to left dinghy.
BOMBARDIER
(1) Jettisons bombs, closes bomb doors, destroys bomb sight, goes to flight deck, fixes emergency radio set rope to arm (if stored in radio compartment); (2) takes ditching post; (3) hands radio to navigator, exits second from F.D. hatch, inflates vest, goes left dinghy.
FLIGHT ENGINEER
(1) Turns guns aft, throws loose equipment into bomb bay after bombs jettisoned; (2) opens, fastens down top F.D. hatch, closes lower hatch and rear door to F. D. after bombardier, navigator arrive, affixes rope on emergency ration box to arm; (3) takes ditching post; (4) operates dinghy releases after plane comes to rest; (5) exits third from F.D. hatch, inflates vest, receives ration box from R/O, to right dinghy.
RADIO OPERATOR
(1) Turns IFF to distress, switches on liaison transmitter tuned to MFDF, sends SOS position, calls signal continuously; (2) continues SOS, obtains MFDF fix, remains on intercomm; (3) on pilot's order, clamps down key, hinges up radio table, takes ditching post, repeats pilot's warning to "brace for ditching"; (4) hands emergency ration box to the Flight Engineer and exits fourth from the flight deck hatch, inflating life vest, and going to right dinghy.
R. WAIST GUNNER
(1) Jettisons gun, ammunition, r. waist gun window, secures emergency radio to arm (if stored in rear compartment), attaches ditching belt, remains on intercomm, inflates vest; (2) as plane halts throws radio out, keeping rope to arm; (3) exits first from r. waist window to right dinghy, holds radio rope firmly.
L. WAIST GUNNER
(1) Jettisons gun, ammunition, window, remains on intercomm; (2) attaches emergency ration box rope to arm, inflates vest; (3) remains on intercomm, repeating "brace for ditching" warning; (4) when plane halts, throws ration box out left window, holding rope; (5) exits first from left window to left dinghy, holding to ration box rope.
TUNNEL GUNNER
(1) Jettisons gun, ammunition, tests tunnel gun hatch to see if tightly closed; (2) takes ditching post, vest inflated; (3) exits second from right waist window to right dinghy.
TAIL GUNNER
(1) Turns tail gun aft, helps side gunners jettison equipment; (2) takes ditching post; (3) exits second from left waist window to left dinghy.
HEADQUARTERS AAF, OFFICE OF FLYING SAFETY, SAFETY EDUCATION DIVISION, IN COOPERATION WITH AAF SCHOOL OF APPLIED TACTICS, BOMBARDMENT DIVISION
AP 1-6001 Training Aids Division, Army Air Forces, 1 Park Ave., New York City 16, N. Y. will provide additional copies upon request.

APPENDIX E B-24 *THE TULSAMERICAN* AIRCRAFT RECORD CARD AND MACR

~~16508~~

16501

AAF Form 14 (10 Apr. 43) — MACR No. 16507

MISSING AIR CREW REPORT

WAR DEPARTMENT
HEADQUARTERS ARMY AIR FORCES
WASHINGTON

IMPORTANT: This report will be compiled in triplicate by each Army Air Forces organization within 48 hours of the time an aircraft is officially reported missing.

1. ORGANIZATION: LOCATION ____ COMMAND OR AIR FORCE ____
   GROUP ____; SQUADRON 765 Bomb Sq.; DETACHMENT ____
2. SPECIFY: POINT OF DEPARTURE ____; COURSE ____
   INTENDED DESTINATION Odertal, Germany; TYPE OF MISSION ____
3. WEATHER CONDITIONS AND VISIBILITY AT TIME OF CRASH OR WHEN LAST REPORTED: ____
4. GIVE: (A) DATE 17 Dec 44, TIME ____; AND LOCATION OF LAST KNOWN WHEREABOUTS OF MISSING AIRCRAFT ____
   (B) SPECIFY WHETHER ( ) LAST SIGHTED; ( ) LAST CONTACTED BY RADIO; ( ) FORCED DOWN; ( ) SEEN TO CRASH; OR ( ) INFORMATION NOT AVAILABLE.
5. AIRCRAFT WAS LOST, OR IS BELIEVED TO HAVE BEEN LOST, AS A RESULT OF (CHECK ONLY ONE): (X) ENEMY AIRCRAFT; ( ) ENEMY ANTI-AIRCRAFT; ( ) OTHER CIRCUMSTANCES AS FOLLOWS: Crashed landed in Adriatic Sea near Isle of Vis before reaching target.
6. AIRCRAFT: TYPE, MODEL AND SERIES B-24-J; AAF SERIAL NO. ____
7. ENGINES: TYPE, MODEL AND SERIES ____; AAF SERIAL NO. (A) ____ (B) ____ (C) ____ (D) ____
8. INSTALLED WEAPONS (FURNISH BELOW MAKE, TYPE AND SERIAL NUMBER)
   (A) ____ (B) ____ (C) ____ (D) ____
   (E) ____ (F) ____ (G) ____ (H) ____
9. THE PERSONS LISTED BELOW WERE REPORTED AS: (A) BATTLE CASUALTY ____
   OR (B) NON-BATTLE CASUALTY ____
10. NUMBER OF PERSONS ABOARD AIRCRAFT: CREW ____; PASSENGERS ____; TOTAL ____
    (Starting with pilot, furnish the following particulars: If more than 11 persons were aboard aircraft, list similar particulars on separate sheet and attach original to this form)

CREW POSITION	NAME IN FULL (LAST NAME FIRST)	RANK	SERIAL NUMBER	STATUS
(1) PILOT	Ford, Eugene P.	1/Lt.	0-805804	KIA 17 Dec 44
(2) CO-PILOT	Landry, Russell C.	1/Lt.	0-719208	KIA 17 Dec 44
(3)	McLemore, Wallace H.	S/Sgt.	34827720	EUS 28 Jan 45
(4)	Priest, Charles E.	T/Sgt.	38189197	KIA 17 Dec 44
(5)	Ecklund, Vincent O.	1/Lt.	0-768489	RTD 31 Dec 44
(6)	Hazel, James R.	S/Sgt.	36535391	RTD 9 Mar 45
(7)	Miller, Val R.	1/Lt.	0-708932	EUS 22 Jan 45
(8)	Steelandt, Edward F.	S/Sgt.	36482462	RTD 23 Dec 44
(9)	Toney, John F.	S/Sgt.	38588581	EUS 28 Jan 45
(10)	Walenga, Casimir P.	S/Sgt.	36462456	EUS 25 Feb 45
(11)				

11. IDENTIFY BELOW THOSE PERSONS WHO ARE BELIEVED TO HAVE LAST KNOWLEDGE OF AIRCRAFT, AND CHECK APPROPRIATE COLUMN TO INDICATE BASIS FOR SAME:

NAME IN FULL (LAST NAME FIRST)	RANK	SERIAL NUMBER	CONTACTED BY RADIO	LAST SIGHTED	SAW CRASH	SAW FORCED LANDING
(1)						
(2)						
(3)						

12. IF PERSONNEL ARE BELIEVED TO HAVE SURVIVED, ANSWER YES TO ONE OF THE FOLLOWING STATEMENTS: (A) PARACHUTES WERE USED ____; (B) PERSONS WERE SEEN WALKING AWAY FROM SCENE OF CRASH ____; OR (C) ANY OTHER REASON (SPECIFY) ____
13. ATTACH EYEWITNESS DESCRIPTION OF CRASH, FORCED LANDING, OR OTHER CIRCUMSTANCES PERTAINING TO MISSING AIRCRAFT.
14. ATTACH AERIAL PHOTOGRAPH, MAP, CHART, OR SKETCH, SHOWING APPROXIMATE LOCATION WHERE AIRCRAFT WAS LAST SEEN.
15. ATTACH A DESCRIPTION OF THE EXTENT OF SEARCH, IF ANY, AND GIVE NAME, RANK AND SERIAL NUMBER OF OFFICER IN CHARGE ____

(Date of Report) (Signature of Preparing Officer)

REMARKS: (Use additional sheet if necessary)
Prepared by OQMG
Washington, D. C., 27 Sept 48

765th BOMBARDMENT SQUADRON

16507

Tragedy struck home for the members in the squadron this month. It was a mission which proved to be disastorous. The target was the oil refineries at ODERTAL, GERMANY, the date was December 17. Seven aircrafts took to the air from this squadron, one aborted and returned early, four others though were unaccounted for, and the other two returning safely, but severly damaged. From information gathered, our planes were struck by enemy aircrafts, which were encountered shortly before reaching the I. P., however, with determination one of our ships got through to the target. Latest information has it that our group had lost approximately ten ships for this day's operation. To our credit, the gunners claimed to have shot down three enemy aircrafts and one probable. The plane piloted by Lt. Ford is MIA.

Ford, Eugene P.	1st. Lt.	805804	KIA	17 Dec. 44
Landry, Russell C.	1st. Lt.	0-719208	KIA	17 Dec. 44
3 McLemore, Wallace H.	S/Sgt.	34827720	EUS	28 Jan. 45
Priest, Charles E.	T/Sgt.	38189197	KIA	17 Dec. 44
1 Ecklund, Vincent O.	1/Lt.	0-768489	RTD	31 Dec. 44
2 Hazel, James R.	S/Sgt.	36535391	RTD	9 Mar. 45
4 Miller, Val R.	1st. Lt.	0-708932	EUS	22 Jan. 45
5 Steelandt, Edw. F.	S/Sgt.	36482462	RTD	23 Dec. 44
6 Toney, John F.	S/Sgt.	38588581	EUS	28 Jan. 45
9 Walenga, Casimir P.	S/Sgt.	36462456	EUS	25 Feb. 45

AGPO-CG 201 Priest, Charles E.
(28 Oct 46) 38 189 197

19 February 1947

Staff Sergeant Dale F. Priest
RA-17 182 236
717th Air Material Squadron
475th Air Service Group
APO 171 c/o Postmaster
New York, New York

Dear Sergeant Priest;

A copy of your letter of 28 October 1946, addressed to the Quartermaster General, has been referred to this office for further direct reply regarding your brother, the late Technical Sergeant Charles E. Priest.

I fully appreciate your desire to learn all availabe details regarding the death of your brother. Reports received in the War Department reveal that Sergeant Priest was serving as right waist gunner aboard a B-24 J type aircraft which was engaged in a combat mission over Germany on 17 December 1944. The target was the Odertal Oil Refinery. Just before reaching the target, the aircraft ecnountered heavy enemy fighter opposition. The plane on which your brother was serving was badly damaged but was able to reach the Isle of Vis on returning. On the first attempt to land on the island, the wheels of the plane would not lock into position, making it necessary to circle the island for the second time. On the down wind leg the third operating engine cut out and the pilot was forced to crash land in the sea. Sergeant Priest and two other crew members were killed in the crash of the plane, while seven members of the crew survived.

The records pertaining to Sergeant Priest reveal that he had completed 28 combat missions prior to his death.

Your inquiry concerning decorations and citations in the case of your brother will be the subject of a later communication.

A copy of your communication is being referred to the Administrator of Veterans Affairs, Veterans Administration, Washington 25, D. C., inasmuch as that official has jurisdiction over all matters pertaining to National Service Life Insurance.

AGPO-CG 201 Priest, Charles E.
(28 Oct 46) 38 189 197

The Armed Forces Leave Act of 1946 provides no benefits for the survivors of persons who died while in the service since beneficiaries of those persons were entitled to the six months' gratuity pay.

My deepest sympathy is extended to you in the loss of your brother.

Sincerely yours,

EDWARD F. WITSELL
Major General
The Adjutant General of the Army

Copy for:
Casualty file......

FIFTEENTH AIR FORCE

Office of the Commanding General

APO 520

22 January 1945

Mrs. Hazel Priest
Route #1
Hazelton, Kansas

My dear Mrs. Priest:

I wish to extend heartfetl sympathy in the loss of your son, Technical Sergeant Charles E. Priest, 38189197, who passed away on December 17, 1944, when his bomber was forced to make a water landing in the Adriatic Sea off the coast of Yugoslavia. I am very sorry to report that your son and two other crewmen were unable to get out of the ship before it sank.

Charles' personal possessions have been assembled for shipment to the Effects Quartermaster, Army Effects Bureau, Kansas City, Missouri, who will in turn forward them to the dsignated beneficiary.

Your son's courage and ability served as a constant source of inspiration to all his fellow airmen. In recognition of meritorious achievement in operations he was awarded the Air Medal and two Oak Leaf Clusters in addition to the Distinguished Flying Cross; for wounds received in action he was decorated with the Purple Heart. May the knowledge of Charles' accomplishments help to ease your suffering during the trying days that lie ahead.

Very sincerely yours,

CHARLES F. BORN
Brigadier General, USA
Acting Commander

22 January 1945

Mrs. Marian Ford
Rural Delivery #3, Box #139
Blairsville, Pennsylvania

Dear Mrs. Ford:

It is my sad duty to confirm the report of the War Department that your husband, First Lieutenant Eugene P. Ford, 0-805804, passed away on December 17, 1944, while returning from a combat mission to Odertal, Germany. Due to flak damage which the bomber received over the target it was forced to make a water landing in the Adriatic Sea. I am sorry to say that three of the crewmen including your husband, were unable to get out of the plane before it sank.

His personal possessions have been assembled for shipment to the Effects Quartermaster, Army Effects Bureau, Kansas City, Missouri, who will in turn forward them to the designated beneficiary.

I am proud to have had your husband in my command. In recognition of his splendid work as the pilot of his ship he has been awarded the Air Medal and three Oak Leaf Clusters in addition to the Distinguished Flying Cross. In the name of a grateful nation and in behalf of the comrades who continue the fight, to which Eugene so nobly gave himself, I extend heartfelt sympathy.

Very sincerely yours,

CHARLES F. BORN
Brigadier General, USA
Acting Commander

APPENDIX F *THE TULSAMERICAN* SITE'S ASSOCIATED RECOVERED ARTIFACTS

Figure F.1- A flak jacket, partially folded. The iron inserts are corroded and exfoliating but the canvas remains in good shape. There are also some snaps and a rubber hose attached to the canvas. Photo by the author.

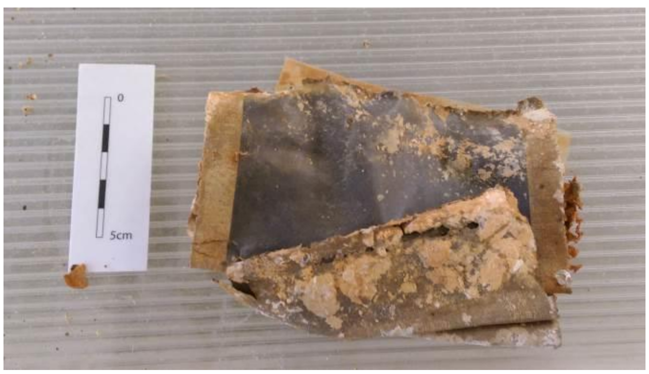


Figure F.2- A wallet, empty with no distinguishing marks remaining. Unknown site provenience. Photo by the author.

Figure F.3- A plug and socket, possibly from a headpiece. Photo by the author.

Figure F.4- Aluminum radio box. Photo by the author.

Figure F.5- A signal torch, used in the tail section of the aircraft. This one says GRIMES MI 6.00, Model K-3, Urbana Ohio, on the handle. It is an early plastic material. The lens is intact. This is the only artifact kept in wet storage in Split. Photo by the author.

Figure F.6- Another aluminum radio box. Photo by the author.

Figure F.7- A lens cover for the signal torch. Photo by the author.

Figure F.8- .50 caliber bullets for the machine guns. Photo by the author.

Figure F.9- The nose turret gun, a M2 browning machine gun. There were 10 aboard the B-24 in the turrets and waist guns. Photo by the author.

Figure F.10- An unknown piece of aircraft equipment. Photo by the author.

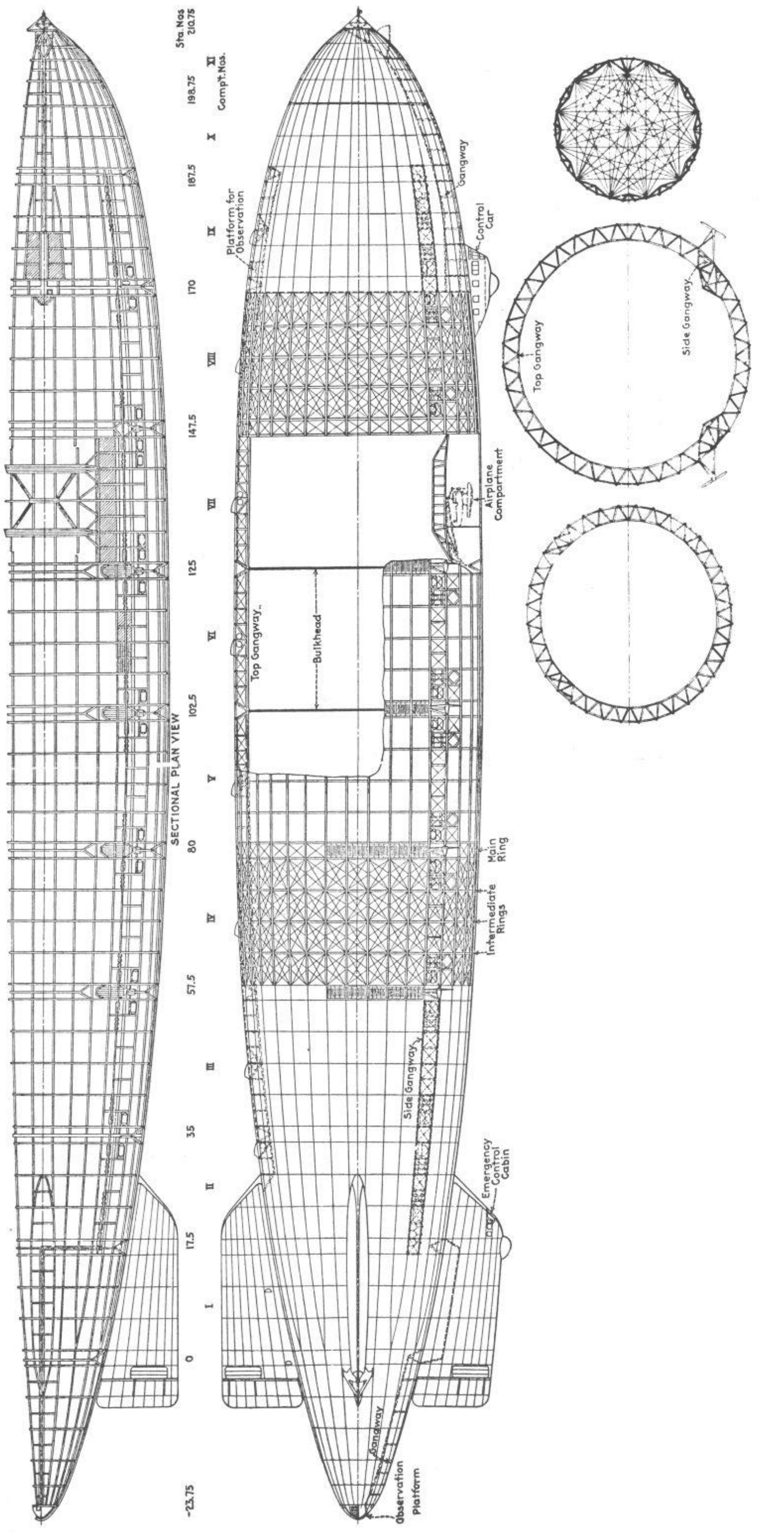
Figure F.11- B-24 42-51430 data plate, conserved and sealed by the Croatian Conservation Institute in 2010. Photo by the author. Photo by the author.

Figure F.12- Earphones for a headset, excavated by DPAA in 2017. This artifact is kept in wet storage in Vis Museum. Photo by the Niall Brannigan, DPAA.

Figure F.13- A cockpit panel instrument and some wiring for a headset. This artifact is kept in wet storage in Vis Museum. Photo by the Niall Brannigan, DPAA.

Figure F.14- A small piece of cockpit plexiglass. This artifact is kept in wet storage in Vis Museum. Photo by the Niall Brannigan, DPAA.

APPENDIX G   SPECIFICATIONS AND PLANS FOR USS *MACON* AIRSHIP



General characteristics (as built)

Class and type: Akron-class airship

Displacement: 7,401,260 cu ft (209,580.3 m3)

Length: 785 ft (239.3 m)

Beam: 133 ft (40.5 m) (hull diameter)

Draft: 146 ft 5 in (44.6 m) (height)

Installed power: 560hp per engine

Propulsion: Eight Maybach VL-2 12-cyl water-cooled fuel injected 33.251 liter (2,029.1 cubic inches) 60° V-12 engines producing 560 horsepower at 1,600 r.p.m., each.

Three-bladed variable-pitch, rotable metal propellers

Speed: 55 knots (102 km/h; 63 mph) (cruising)

75 knots (139 km/h; 86 mph) (maximum)

Range: 5,940 nmi (11,000 km; 6,840 mi) at 10 knots (19 km/h; 12 mph)

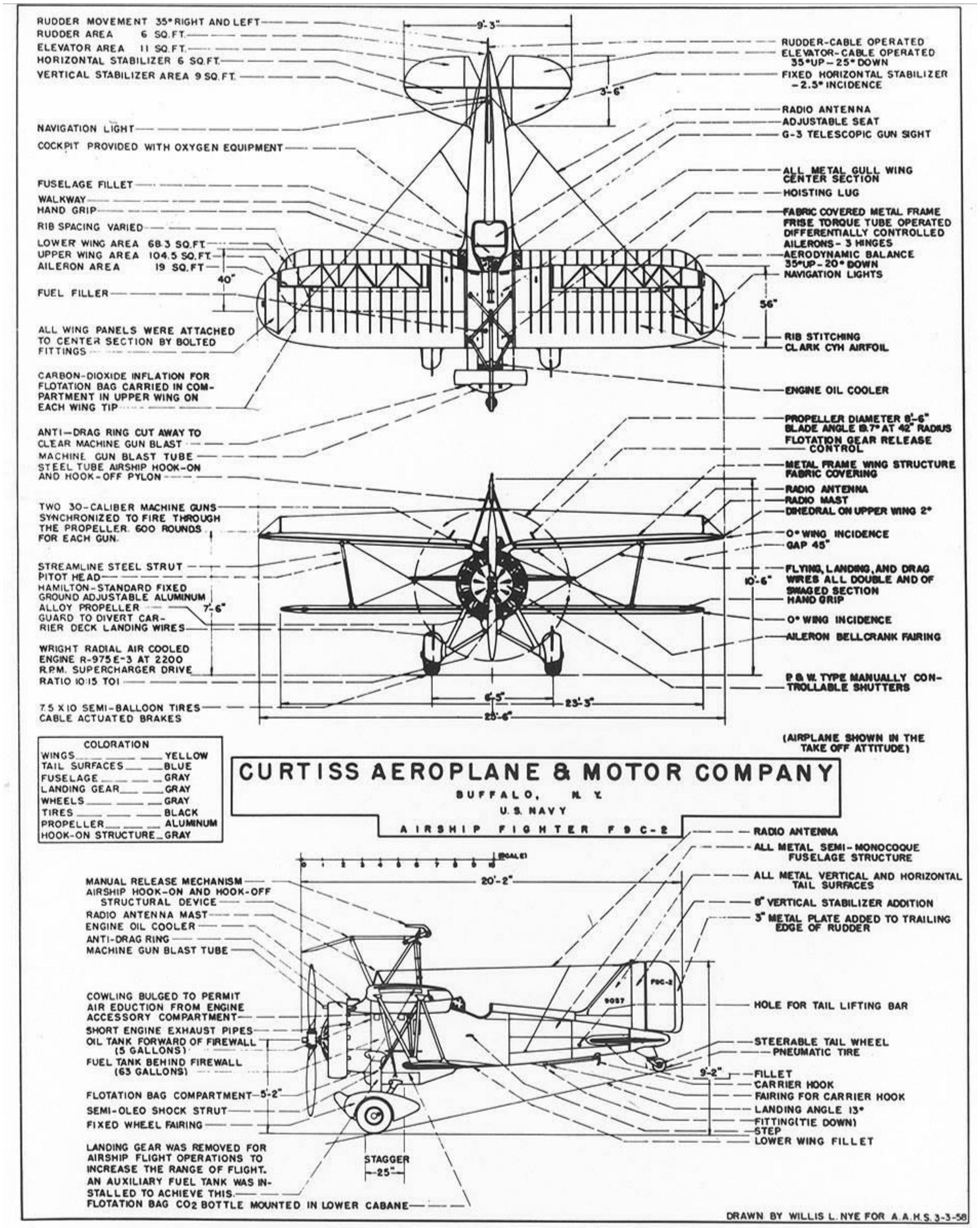
Complement: 60

Armament: 8× .30-cal machine guns

Aircraft carried: 4 Curtiss F9C Sparrowhawk

Aviation facilities: 1 aircraft launch trapeze

APPENDIX H SPECIFICATIONS AND PLANS FOR F9C-2 SPARROWHAWK AIRCRAFT



General characteristics

Crew: 1

Length: 20 ft 2.0 in (6.147 m)

Wingspan: 25 ft 6.0 in (7.772 m)

Height: 10 ft 6 in (3.2 m)

Wing area: 172.79 sq ft (16.053 m2)

Empty weight: 2,089 lb (948 kg)

Gross weight: 2,776 lb (1,259 kg)

Powerplant: 1 × Wright R-975-E3 9-cyl. air-cooled radial piston engine, 438 hp (327 kW)

Performance

Maximum speed: 176.5 mph (284 km/h; 153 kn)

Range: 297 mi (258 nmi; 478 km)

Service ceiling: 19,200 ft (5,900 m)

Rate of climb: 1,700 ft/min (8.6 m/s)

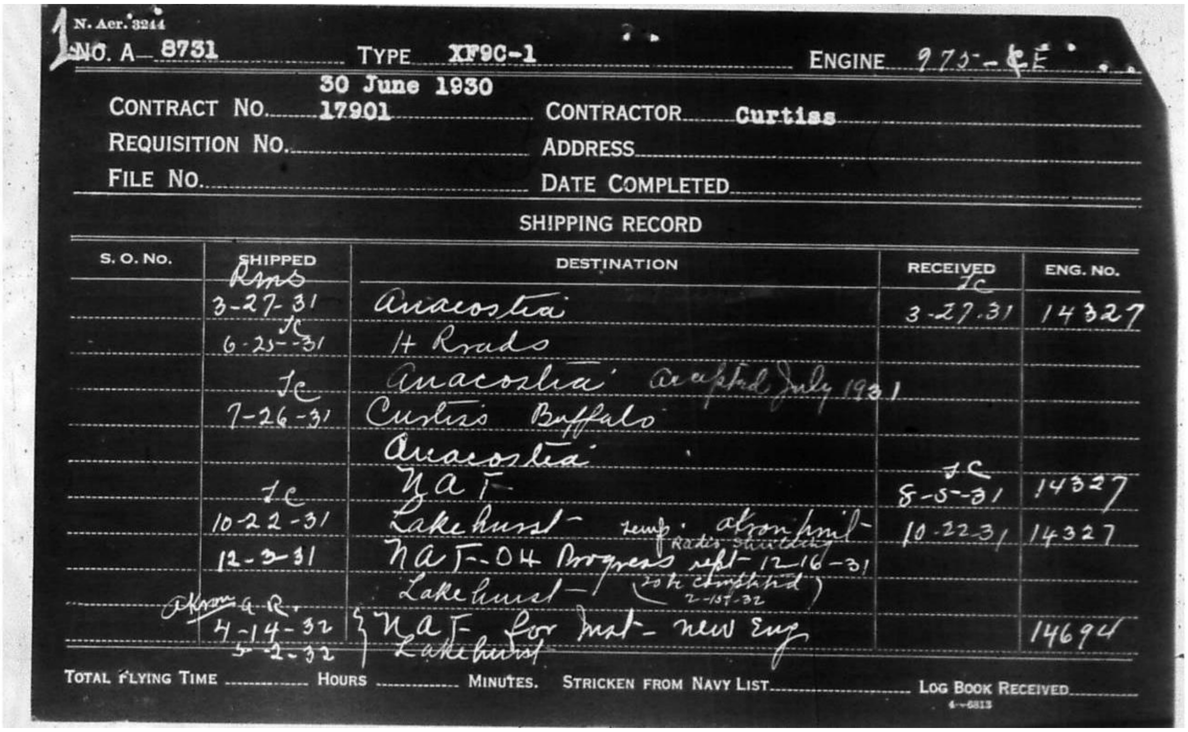
Wing loading: 16 lb/sq ft (78 kg/m2)

Power/mass: 0.086 hp/lb (0.259 kW/kg)

Armament

Guns: 2 × .30 in (7.62 mm) Browning machine guns

APPENDIX I USS *MACON* AND F9C-2 AIRCRAFT RECORD AND ACCIDENT REPORT CARDS



1

N. Aer. 3244

NO. A– 8731 TYPE XF9C-1 ENGINE 975-CE

CONTRACT NO. 30 June 1930 17901 CONTRACTOR Curtiss

REQUISITION NO. ADDRESS

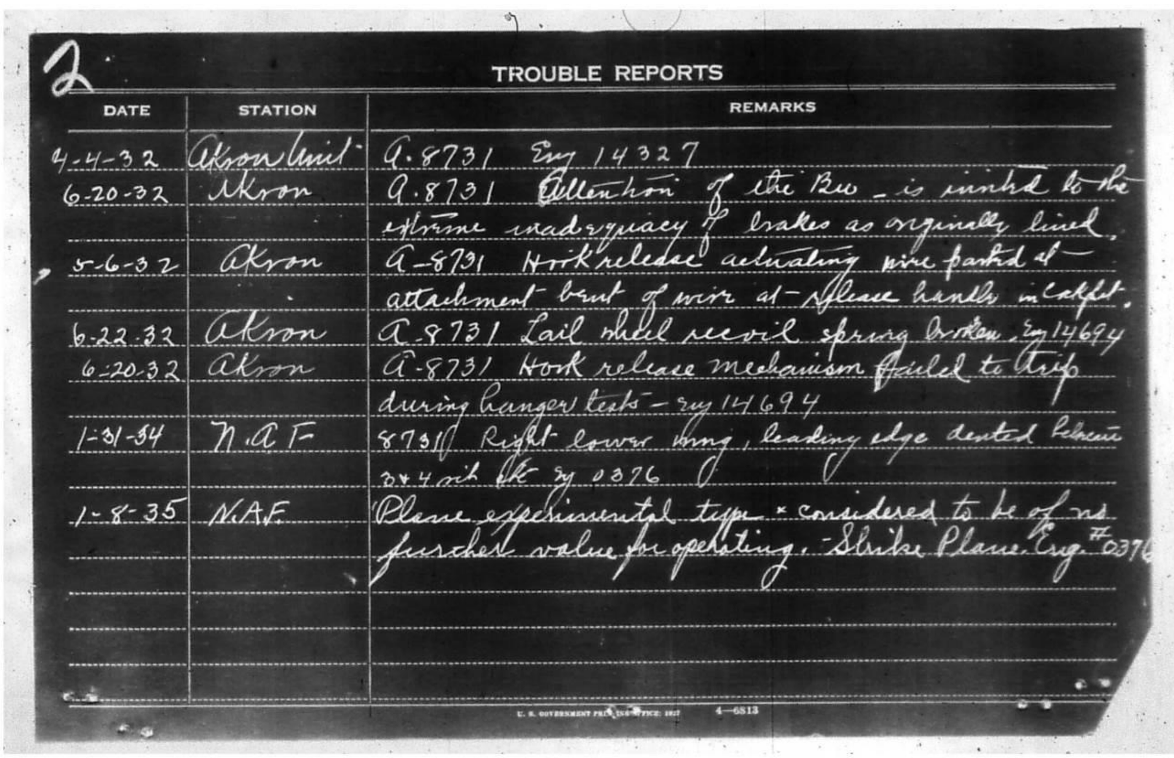
FILE NO. DATE COMPLETED

SHIPPING RECORD

S. O. No.	SHIPPED	DESTINATION	RECEIVED	ENG. NO.
	RMS 3-27-31	Anacostia	JC 3-27-31	14327
	JC 6-25-31	H Roads		
	JC	Anacostia accepted July 1931		
	7-26-31	Curtiss Buffalo		
		Anacostia		
	JC	NAF	JC 8-5-31	14327
	10-22-31	Lakehurst – temp. Akron Unit – Radio Shielding	10-22-31	14327
	12-3-31	NAF – 04 Progress rept – 12-16-31		
		Lakehurst – (Work completed 2-15-32)		
	Akron A.R. 4-14-32 5-2-32	NAF for inst – new Eng Lakehurst		14694

TOTAL FLYING TIME ________ HOURS ________ MINUTES. STRICKEN FROM NAVY LIST ________ LOG BOOK RECEIVED ________

4—6813



2

TROUBLE REPORTS

DATE	STATION	REMARKS
4-4-32	Akron Unit	A-8731 Eng 14327
6-20-32	Akron	A-8731 Attention of the Bu – is invited to the extreme inadequacy of brakes as originally lined.
5-6-32	Akron	A-8731 Hook release actuating wire parted at attachment bent of wire at release handle in cockpit.
6-22-32	Akron	A-8731 Tail wheel recoil spring broken, Eng 14694
6-20-32	Akron	A-8731 Hook release mechanism failed to trip during hanger tests – eng 14694
1-31-34	N.A.F.	8731 Right lower wing, leading edge dented between 3+4 rib [illegible] eng 0376
1-8-35	N.A.F.	Plane experimental type + considered to be of no further value for operating. – Strike Plane. Eng # 0376

U. S. GOVERNMENT PRINTING OFFICE 4—6813

3 N. Aer. 3244

NO. A– 8731 TYPE XF9C-1 ENGINE R975-E

CONTRACT NO. 17901 CONTRACTOR Curtiss

REQUISITION NO. ADDRESS

FILE NO. DATE COMPLETED

SHIPPING RECORD

S. O. No.	SHIPPED	DESTINATION	RECEIVED	ENG. No.
	6-27-32	NAF for study of hook tripping mechanism	7c 6-25-32	14694
	sel	Akron Unit - AR. 8-1-32		
9278	9-26-32	Curtiss Buffalo for inst. of strength safe [illegible]	9-26-32	
9816	sel 11-4-32	Akron Unit - record purposes	11-4-32	
	11-11-32	NAF for inst. of newly designed carrier hook		
		Akron Unit	1-17-33	
	3-27-33	INA - Curtiss For a few days.		
	Fly [illegible] 5-5-33	Lakehurst - Macon Unit -	a 5-5-33	14694
1429	6-1-33	NAF - storage for future [illegible]	6-5-33	14694
	7-14-33	Lakehurst temp. - back to NAF		14694

TOTAL FLYING TIME .... HOURS .... MINUTES. STRICKEN FROM NAVY LIST .... LOG BOOK RECEIVED ....

4—6813

4 N. Aer. 3244

NO. A– 8731 TYPE XF9C-1 ENGINE R975-E

CONTRACT NO. 17901 CONTRACTOR

REQUISITION NO. ADDRESS

FILE NO. DATE COMPLETED

SHIPPING RECORD

S. O. No.	SHIPPED	DESTINATION	RECEIVED	ENG. No.
		NAF		
		Macon Unit	a 7-14-33	14694
	a 9-18-33	NAF eng change Remove hook on 21-34 since 9-29-33	9-18-33	14694
	Stricken - Sec Navy Ltr. Aer-Ma-12-BEM A4-1 1-31-35			

TOTAL FLYING TIME 213.3 HOURS .... MINUTES. STRICKEN FROM NAVY LIST 1/31/35 LOG BOOK RECEIVED 8/15/35

4—6813

N. Aer. 3244

4

AIRCRAFT NO. 9056 MODEL XF9C-2 ENGINE MODEL R-975-E3 22

CONTRACT NO. 24021 CONTRACTOR Curtiss Co.

DATE ACCEPTED 8/9/32 DATE STRICKEN 31 October 1939

S.O. No.	SHIPPED	DESTINATION	RECEIVED	ENG. No.
2219	a 9-19-33	Sunnyvale for Battle Force Pool	yel. 10-26-33	0775
	a 11-13-34	San Diego Bat.For. For O.H. Eviction 10/1/36	a 11-14-34 TC	0775
6175		NAS San Diego	4-1-35	0775
1602	PR 3 10-9-36 TC	Norfolk, Bat.For.	Y PR AR 10-19-36 TC	0772
	AR 11-6-36 TC	Norfolk, NAS MAJOR O H 5-14-37	PR AR 11-6-36 TC	0772
	AR 5-18-37 TC	Norfolk Oper.	AR 5-18-37 TC	0772
4339		Navy yard, Wash. for Smithsonian Institution		

TOTAL FLYING TIME 676.3 (2 logs) LOG BOOK RECEIVED 8-17-40

4-6813

N. Aer. 3244

1

AIRCRAFT NO. 9056 MODEL F9C-2 ENGINE MODEL R-975-E3

CONTRACT NO. 24021 CONTRACTOR Curtiss Co.

DATE ACCEPTED

DATE STRICKEN

S.O. No.	SHIPPED	DESTINATION	RECEIVED	ENG. No.
	RMS 5-3-32	Anacostia	T.C. 5-3-32	0374
	T.C. 6-15-32	H. Roads		0374
		Anacostia	T.C. 6-20-32	
	T.C. 6-28-32	NAS, Lakehurst		
		Anacostia		
	T.C. 7-11-32	Curtiss Co.		
		Anacostia	T.C. 8-6-34	0374
	T.C. 8-12-32	Curtiss Motor Co.		0374
8957	RMS 9-12-32	Lakehurst for Akron	yel. T.C. 9-12-32	0374
		NAF O/H	T.C. 3-30-33	0374
	T.C. 6-1-33	Lakehurst		0374
	a. 9-19-33	NAF - Eng. change		0374

TOTAL FLYING TIME

LOG BOOK RECEIVED

4-6813

2

TROUBLE REPORTS

DATE	STATION	REMARKS
10-18-32	USS AKRON	9056 Main spring in oleo unit of tail assembly failed in two places Eng. 0374
11-29-32	USS AKRON	9056 E-4 Gun Synchronizer Cam follower cut burned and inoperative Eng. 0374.
12-12-32	USS AKRON	9056 Booster magneto astuating cable carried away Eng. 0374
12-12-32	USS AKRON	9056 A two inch circumferential crack developed about five inches from the leading edge of the anti-drag right - Eng. 0374.
12-23-32	USS AKRON	9056 Binding in right aileron - Eng. 0374
2-8-33	USS AKRON	9056 Fuel pump hachet cracked Eng. 0374
3-2-33	" "	9056 No damage to plane - Eng. 0374
4-12-33	" "	9056 Both blades of propeller bent and windshield broken Eng.0374
6-27-33	MACON	9056 Broken by pass line on oil coler - Eng. 0374
6-25-33	"	9056 Spring in oleo broken etc. - Eng. 0374.
11-16-36	Norfolk	Trouble report recommends overhaul. Eng. 0772.
3-16-39	Norfolk	Lower right wing bent and damaged beyond economical repair. right upper landing gear fuselage fitting cracked, etc. Eng.

U.S. GOVERNMENT PRINTING OFFICE: 1934 4—6513

3 9056

TROUBLE REPORTS

DATE	STATION	REMARKS
10-20-39	Norfolk	Obsolete. Stricken due to cost of overhaul. Eng. 0772. Strike both.

U.S. GOVERNMENT PRINTING OFFICE: 1934 4—6513

N. Aer. 3244

AIRCRAFT NO. 9057 MODEL XF9C-2 ENGINE MODEL R-975-22

CONTRACT NO. 24021 CONTRACTOR Curtiss Co.

DATE ACCEPTED 8-9-32 DATE STRICKEN 11-30-36

S.O. NO.	SHIPPED	DESTINATION	RECEIVED	ENG. NO.
	HMS 7-12-32	Anacostia	TC 7-12-32	0375
	TC 8-15-32	Curtiss Co.		0375
8957	HMS 9-12-32	Lakehurst for Akron	yel. TC 9-12-32	0375
		NAF O/H	3-29-33 TC	0375
	TC 6-1-33	Lakehurst		0375
	a 8-3-33	NAF for engine change		0375
2219	Gal. 10-3-33	Sunnyvale for Bat. Force Pool	yel. 10-15-33	0772
	a. 11-13-34	San Diego Bat. For. for O.H.	a 11-14-34 TC	0772
6175		NAS San Diego	4-1-35	
1602	PR S TC 10-9-36	Norfolk	~~10-19-36~~	0775
		San Diego	PR 10-21-36 TC	0775

Stricken - Sec.Navy's ltr. Aer-Ma-12-EM A4-1 dated 30 Nov. 1936

TOTAL FLYING TIME 325.6 LOG BOOK RECEIVED 3/22/37

4-6813

2

TROUBLE REPORTS

DATE	STATION	REMARKS
12-12-32	USS AKRON	9057 Rudder jammed while plane was tarying from line to take off aera - Eng. 0375.
3-3-33	USS AKRON	9057 No damage to plane - Eng. 0375
4-8-33	USS AKRON	9057 Guard tube of hook-on gear bent - Engs. 0375
8-2-34	USS MACON	9057 No damage to engine - Both spars of right lower wing bent. Both blades of propeller bent Eng. #0772.
9-17-34	USS MACON	Both spars of right lower wing badly bent, right landing gear drag strut badly bent - Eng. #0772.
12-10-34	USS MACON	Both spars right lower wing badly bent, tail wheel strut broken. Etc. Eng. 0772.
10-14-36	Bat.For.Pool	Fuselage buckled and broken just aft of cockpit. Wings warped. Vertical stabilizer & ruddder crushed at top. Engine apparently in good condition. Eng.#0775. Strike plane.

U.S. GOVERNMENT PRINTING OFFICE: 1934 4-6813

1

N. Aer. 3244

AIRCRAFT NO. 9058 MODEL F9C-2 ENGINE MODEL R-975-22

CONTRACT NO. 24021 CONTRACTOR Curtiss

DATE ACCEPTED DATE STRICKEN 2-28-35

S.O. No.	SHIPPED	DESTINATION	RECEIVED	ENG. No.
		Lakehurst for AKRON	TC. 9-12-32	0373
		NAF	TC. 2-21-33	0373
		AKRON Unit	a 3-28-33	
	a 8-24-33	NAF for Inspection Eng.		
2219	Sal. 10-3-33	Sunnyvale for Bat. Force Pool	Yd. 10-15-33	0773
	TC. 8-15-34	San Diego MAJOR O H -10-19-34	TC. 8-16-34	0773
	a TC. 11-13-34	(Sunnyvale) USS MACON Lost at sea aboard Macon 2-12-35	a. 11-15-34	0381
	Stricken	- Sec. Navy Letr. Aer-Ma-12-REM A4-1		

TOTAL FLYING TIME 408.5 Hrs. LOG BOOK RECEIVED 3-28-35

4—6813

2

TROUBLE REPORTS

DATE	STATION	REMARKS
7-5-33	MACON	9058 Exhaust valve tappet and socket of #2 cylinder - Eng. 0373
1-31-34	MACON	9058 Upper end of piston rod (Tail wheel oleo unit) grooved by wear etc. Eng. 0773.
7-5-34	MACON	Nose and tail of auxiliary fuel tank badly crumpled. - Eng. 0773.
2-20-35	MACON	Lost at sea with MACON. Eng. #0381 - Strike both.

U.S. GOVERNMENT PRINTING OFFICE: 1934 4—6813

1

N. Aer. 3244

AIRCRAFT NO. 9059 MODEL F9C-2 ENGINE MODEL R-975-E3

CONTRACT NO. 24021 CONTRACTOR Curtiss

DATE ACCEPTED ______ DATE STRICKEN 2-28-35

S.O. No.	Shipped	Destination	Received	Eng. No.
	NMS 9-21-32	N.A.F.	T.C. 9-22-32	0378
9301	T.C. 9-28-32	Lakehurst	yel. 9-28-32	0378
		AKRON Unit	a 3-28-33	
	a 9-19-33	N.A.F. Eng. change		
2219	sal. 10-26-33	Sunnyvale for Battle Force Pool	yel. 10-26-33	0774
	T.C. 8-15-34	San Diego MAJOR O H 10-12-34	T.C. 8-15-34	0774
	T.C. 11-13-34	(S unnyvale) USS MACON Lost at sea aboard macon 2-12-35	a. 11-15-34	0378
	Stricken	- Sec. Navy Letr. Aer-Ma-12-REM A4-1		

TOTAL FLYING TIME 193.6 Hrs. LOG BOOK RECEIVED 3-28-35

4-6813

2

TROUBLE REPORTS

Date	Station	Remarks
4-24-31	AKRON	9059 Eng. 0378
5-3-33	AKRON	9059 Eng. 0381
11-6-33	MACON	9059 Gas tank split in after bulkhead - Eng. 0774
5-12-34	MACON	Head on #9 cylinder loose - Eng. 0774.
2-20-35	MACON	Lost at sea with MACON. Eng. #0378 Strike both.

U. S. GOVERNMENT PRINTING OFFICE: 1934 4-6813

1

N. Aer. 3244

AIRCRAFT NO. 9060 MODEL F9C-2 ENGINE MODEL 975-E3-22

CONTRACT NO. 24021 CONTRACTOR Curtiss Co.

DATE ACCEPTED DATE STRICKEN 2-28-35

S.O. No.	SHIPPED	DESTINATION	RECEIVED	ENG. No.
	~~RMS~~ 9-21-32	N.A.F.	T.C. 9-22-32	0376
9301	T.C. 9-28-32	Lakehurst	yel. T.C. 9-28-32	0376
		N.A.F.	T.C. 2-21-33	0376
		Akron Unit A.R. 3-31-33	a 3-28-33	
		MACON Unit May 1933		
2109	sal. a 9-19-33	N.A.F. MAJOR O 1-5-34	yel. T.C. 9-19-33	0376
[illegible]	sal. 1-13-34	San Diego for Bat. F.Pool	yel. T.C. 1-24-34	0373
	T.C. 8-16-34	(Sunnyvale) Macon Lost at sea with Macon 2-12-35	T.C. 8-15-34	0694
	Stricken - Sec. Navy Letr. Aer-Ma-12-REM A4-1			

TOTAL FLYING TIME 220,5 Hrs. LOG BOOK RECEIVED 3-28-35

4—6813

2

TROUBLE REPORTS

DATE	STATION	REMARKS
6-21-34	San Diego	No. 6 & 6 Piston pin and knuckle pin bent, Power and nose sect and bearing support broken Eng. #0373.
8-17-34	USS MACON	Gun generator assembly synchronizer type E-4 Cam shaft bearing scored. Etc. Eng. #0694.
2-20-35	USS MACON	Lost at sea with MACON. Eng. #0374 Strike both.

U.S. GOVERNMENT PRINTING OFFICE: 1934 4—6813

1 N. Aer. 3244

AIRCRAFT NO. 9061 MODEL F9C-2 ENGINE MODEL R-975-E3-22

CONTRACT NO. 24021 CONTRACTOR Curtiss Co.

DATE ACCEPTED DATE STRICKEN 2-28-35

S.O. No.	SHIPPED	DESTINATION	RECEIVED	ENG. No.
	HMS 9-21-32	N.A.F.	T.C. 9-22-32	0377
9301	T.C. 9-28-32	Lakehurst	yel. T.C. 9-28-32	0377
275	sal. 2-16-33	Curtiss	yel. 2-17-33	
793	sal. HMS 5-5-33	Lakehurst MACON UNIT	yel. 5-5-33	0377
2109	sal. a 9-19-33	N.A.F. MAJOR O.H. 1-5-34	yel. T.C. 9-19-33	0377
2110	Sal. 1-13-34	San Diego for Bat. F. Pool	yel. T.C. 1-24-34	0375
	T.C. 8-16-34	(Sunnyvale) Macon Lost at sea aboard Macon 2-12-35	T.C. 8-15-34	0375
	Stricken	- Sec. Navy Letr. Aer. Ma-12-REM A4-1		

TOTAL FLYING TIME 193.6 Hrs. LOG BOOK RECEIVED 3-28-35

4—6813

2

TROUBLE REPORTS

DATE	STATION	REMARKS
10-7-32	USS AKRON	A 9061 Leather washer in piston of left flotation bag release cylinder blew out - Eng. 0377.
12-12-32	USS AKRON	9061 Booster magneto out of commission Eng. 0377.
10-16-34	USS MACON	Right magneto shaft sheared at inner end of tapered shoulder and flush with mounting flange. #0375
11-13-34	USS MACON	Airship hook-on device damaged. Guard tube broken thru at junction with hook assy. Eng. #0375.
2-20-35	USS MACON	Lost at sea on board MACON Eng. #0375. Strike both.

U.S. GOVERNMENT PRINTING OFFICE: 1934 4—6813

N. Aer. 3244

AIRCRAFT NO. 9264 MODEL XF9C-2 ENGINE MODEL SR-975-E-322

CONTRACT NO. 29095 CONTRACTOR Curtiss

DATE ACCEPTED

DATE STRICKEN 11-30-36

S.O. No.	SHIPPED	DESTINATION	RECEIVED	ENG. No.
	RMS 1-9-33	Lakehurst for Akron		
		NAF	1-10-33 TC.	0694
			3-29-33 TC.	0373
	6-1-33 TC.	Lakehurst		
2109	sal. 9-19-33 a	NAF	yel. 9-19-33 TC.	0379
2110	sal. 1-13-34 TC.	Battle Force Pool - San Diego	yel. 1-25-34 TC.	0380
7471	8-26-35 TC	ANACOSTIA To be placed on line for general [illegible]	8-29-35	0380 0773
2367	AR 11-3-36 TC	Norfolk [illegible]	11-4-36	0773
Stricken -	Sec.Navy's ltr. Aer-Ma-12-EM A4-1 dated 30 Nov., 1936	11/2/36		

TOTAL FLYING TIME 254.0 LOG BOOK RECEIVED 8/12/37

4—6512

2

TROUBLE REPORTS

DATE	STATION	REMARKS
1-9-33	Lakehurst	9264 Electric starting motor lost all four brushes - Eng. 0694.
2-28-33	Akron	9264 Eng. 0694.
2-14-33	Akron	9264 Modernized to F9C-2 Eng. 0694.
11-8-35	Anacostia	No damage to plane. Eng. #0380.
11-16-36	Norfolk	Strike plane. Eng.#0773.

U.S. GOVERNMENT PRINTING OFFICE: 1934 4—6513

L.T.A. ACCIDENT

Date of accident: 12 Feb. 1935

Model: ZN-4 **Number:** (USS MACON)

Aircraft attached to: NAS, Sunnyvale, Calif.

Purpose of flight: Scouting - J

Place of accident: Atsea, off Point Sur, Calif.

Pilot: Lt.Comdr. H.V. Wiley,USN

Co-Pilot:

Passengers: 82 passengers, including
E.E. Daley,RMlc,USN (killed)
F. Edquida, Mess Attlc,USN (killed)

Responsible pilot: Lt.Comdr. H.V. Wiley,USN

Responsible pilot's flight experience:

Total	This type	Last 3 months
5,595.55	---	295.5

CLASSIFICATION OF ACCIDENT
NATURE. B

RESULTS:
PERSONNEL: CLASS (A-2;B-1;
MATERIEL: CLASS A (C-80

IMMEDIATE CAUSES OF ACCIDENT — MATERIEL 100%; STRUCTURAL FAILURE — STABILIZING SURFACES X 100%

UNDERLYING CAUSES OF ACCIDENT — MATERIEL FAILURES — DESIGN X

Entered on Pilot's Card

Summarized account of accident: The USS MACON, was unable to gain altitude and landed in the water off Point Sur. Personnel took to boats, and all but two were picked up by naval vessels which had come to their rescue.

Damage: Strike.

Injury to personnel: Two killed - E.E. Daley, RMlc,USN and F. Edquida, MessAttlc,USN
One serious injury - J.C. Gilmore, EMlc,USN
80 minor injuries.

Note: This report prepared in the Statistics section, Bureau of Aeronautics, for record purposes only.

m
Approved: M.A. Mitscher,
Commander, U.S.N.
Flight Officer

APPENDIX J USS *MACON* SITE ASSOCIATED RECOVERED ARTIFACTS

Figure J.1- A Tabasco bottle from Field A of the wreckage, in the galley area, recovered in 1992. The red cap is plastic and the bottle glass. The contents are foggy with sediment. This artifact is at the National Naval Aviation Museum. Photo by the author.

Figure J.2- A piece of girder frame recovered in 1992. This artifact is in private collection. Photo by the author.

Figure J.3- A piece of conserved girder frame, recovered in 1992. This artifact is at the National Naval Aviation Museum. Photo by the author.

Figure J.4- Two beetleware plastic bowls, recovered in 1992 from the galley area in Field A. This artifact is at the National Naval Aviation Museum. Photo by the author.

Figure J.5- Two beetleware plastic bowlplates, recovered in 1992 from the galley area in Field A. This artifact is at the National Naval Aviation Museum. Photo courtesy of NNAM.

Figure J.6- A ‘skyhook’ recovered from Biplane 3 in Field A. It was conserved at ECU soon after recovery. This artifact is at the National Naval Aviation Museum. Photo by the author.

Figure J.7- A pully wheel, possibly associated with the hangar area. It was conserved at ECU soon after recovery. This artifact is at the National Naval Aviation Museum. Photo by the author.

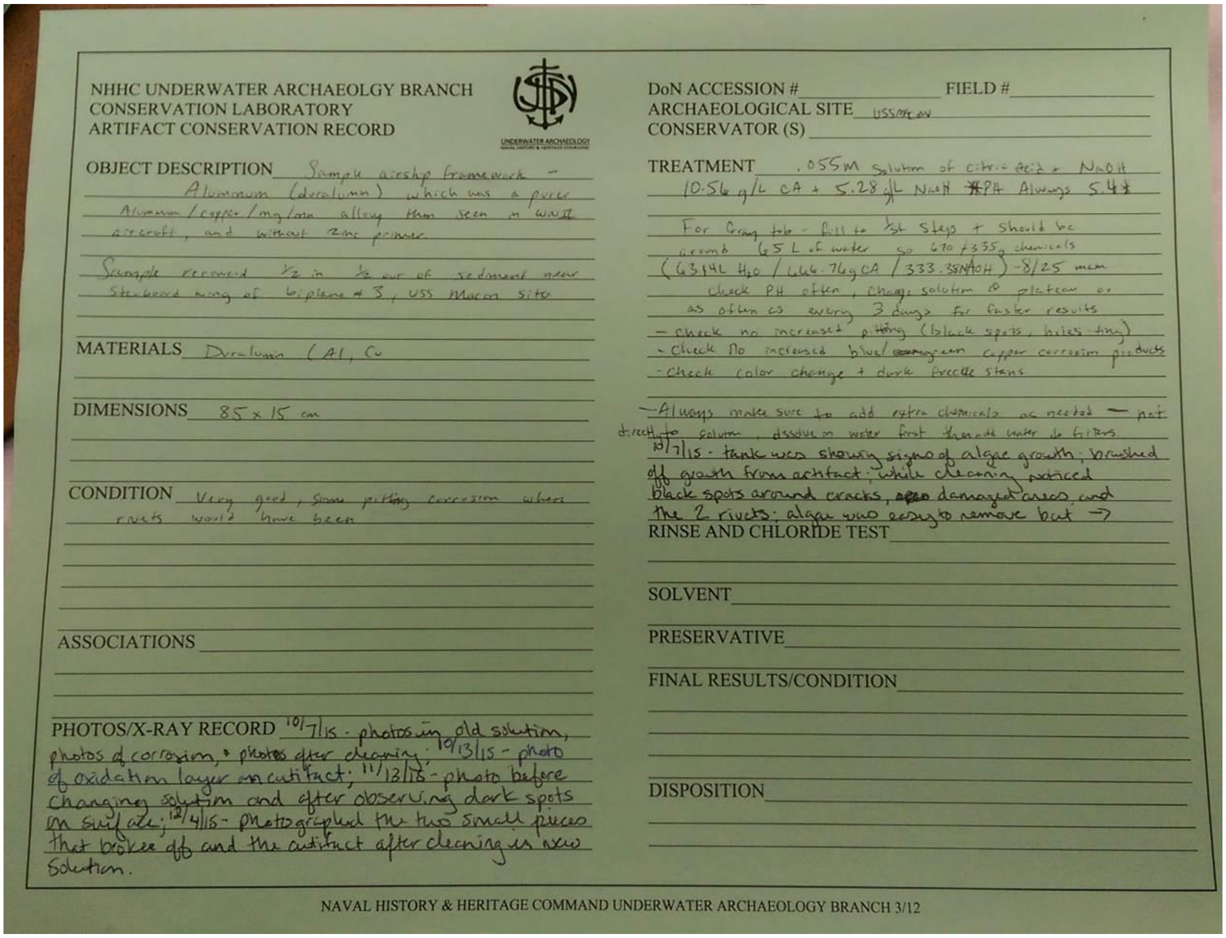
Figure J.8- A piece of girder frame recovered in 1992. This artifact is in private collection. Photo courtesy of Chris Grech.

Figure J.9- Structural frame from the cockpit of Biplane 3, recovered in 1992. This artifact did not undergo conservation and is on loan for display at Moffett Field Historical Museum. Photo courtesy of Moffett Field Historical Society.

Figure J.10- Two bowlplates and pieces of aluminum, recovered in 1992. These artifacts did not undergo conservation and are on loan for display at the Point Sur Lighthouse. Photo courtesy of Doug Williams.

Figure J.11- A piece of girder frame, recovered in 2015. This piece has undergone conservation and is currently at the NHHC UAB lab. Photo by the author.

APPENDIX K CONSERVATION OF RECOVERED ITEMS FROM THE USS *MACON* SITE



NHHC UNDERWATER ARCHAEOLGY BRANCH
CONSERVATION LABORATORY
ARTIFACT CONSERVATION RECORD

OBJECT DESCRIPTION Sample airship framework – Aluminum (duralumin) which was a purer Aluminum/copper/mg/mn alloy than seen in WWII aircraft, and without zinc primer.

Sample recovered ½ in ½ out of sediment near Starboard wing of biplane # 3, USS Macon site

MATERIALS Duralumin (Al, Cu

DIMENSIONS 85 x 15 cm

CONDITION Very good, some pitting corrosion where rivets would have been

ASSOCIATIONS

PHOTOS/X-RAY RECORD 10/7/15 - photos in old solution, photos of corrosion, + photos after cleaning; 10/13/15 - photo of oxidation layer on artifact; 11/13/15 - photo before changing solution and after observing dark spots on surface; 12/4/15 - Photographed the two small pieces that broke off and the artifact after cleaning in new solution.

DoN ACCESSION # FIELD #
ARCHAEOLOGICAL SITE USS MACON
CONSERVATOR (S)

TREATMENT .055M solution of citric acid + NaOH
10.56 g/L CA + 5.28 g/L NaOH *PH Always 5.4*

For Gray tub - fill to 1st step + should be around 65 L of water so 670 + 335 g chemicals
(63.14L H₂O / 666.76g CA / 333.38 NaOH) - 8/25 mcm
check PH often, change solution @ plateau or as often as every 3 days for faster results
– check no increased pitting (black spots, holes - tiny)
- check no increased blue/green copper corrosion products
- check color change + dark freckle stains

– Always make sure to add extra chemicals as needed – not directly to solution, dissolve in water first then add water to filters.
10/7/15 - tank was showing signs of algae growth; brushed off growth from artifact; while cleaning noticed black spots around cracks, damaged areas, and the 2 rivets; algae was easy to remove but →

RINSE AND CHLORIDE TEST

SOLVENT

PRESERVATIVE

FINAL RESULTS/CONDITION

DISPOSITION

NAVAL HISTORY & HERITAGE COMMAND UNDERWATER ARCHAEOLOGY BRANCH 3/12

NHHC UNDERWATER ARCHAEOLGY BRANCH
CONSERVATION LABORATORY
ARTIFACT CONSERVATION RECORD

OBJECT DESCRIPTION Part of airship framework

MATERIALS

DIMENSIONS

CONDITION

ASSOCIATIONS

PHOTOS/X-RAY RECORD

DoN ACCESSION # FIELD #
ARCHAEOLOGICAL SITE USS Macon
CONSERVATOR (S) K. Morrand, S. Daniel

TREATMENT 10/7/15 (cont.): black spots took a little more efforts so brushing around the rivet areas and one of the rivets broke from the artifact; also a small piece broke off during cleaning around on of the damaged areas; Removed artifact from old solution and placed in fresh solution with a pH reading around 5.44 (total liquid = 64,200 mL added 677 grams of citric acid and 338 grams of NaOH); Also XRF areas where corrosion (dark spots) were observed (see reverse side)

10/13/15 - noticed grey oxidation layer on artifact after placing in new solution - it was easily brushed off

10/20/15 - brushed off grey oxidation and clear algae that formed on surface; obtained sample of dark corrosion around rivet; placed artifact in new solution (65,000 mL: 666.76 g CA / 333.3 NaOH)

RINSE AND CHLORIDE TEST 11/9/15 - Cl⁻ test: 57.603 (MT); 38 ppm (QT) pH = 5.68

11/13/15 - brushed surface with a soft bristle brush and

SOLVENT tap water; placed artifact in new solution (65,000 mL; 666.76 CA g / 333.3 NaOH g);

PRESERVATIVE 15-20 minutes later observed black spots on surface - photographed and then

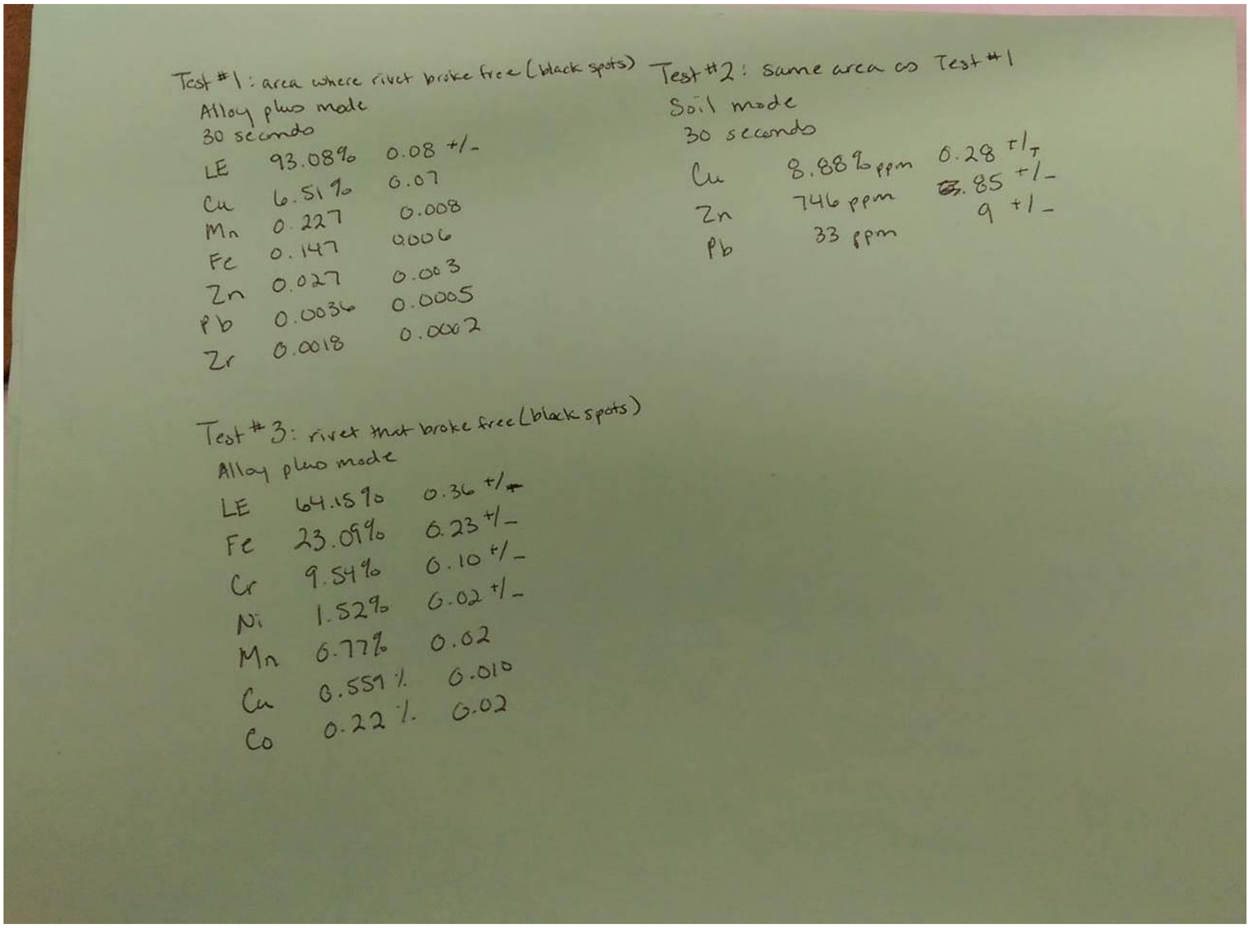
FINAL RESULTS/CONDITION brush away spot with soft bristle brush while in solution - looks better

11/18/15 - Cl⁻ test: 53.172 ppm (MT); pH = 5.67

12/1/15 - Cl⁻ test: 53.172 ppm (MT) 31 ppm (QT); pH = 5.53

DISPOSITION 12/4/15 - solution was changed out but kept artifact in old container w/ solution and placed the new solution into a different container;

next page



Test #1: area where rivet broke free (black spots)
Alloy plus mode
30 seconds

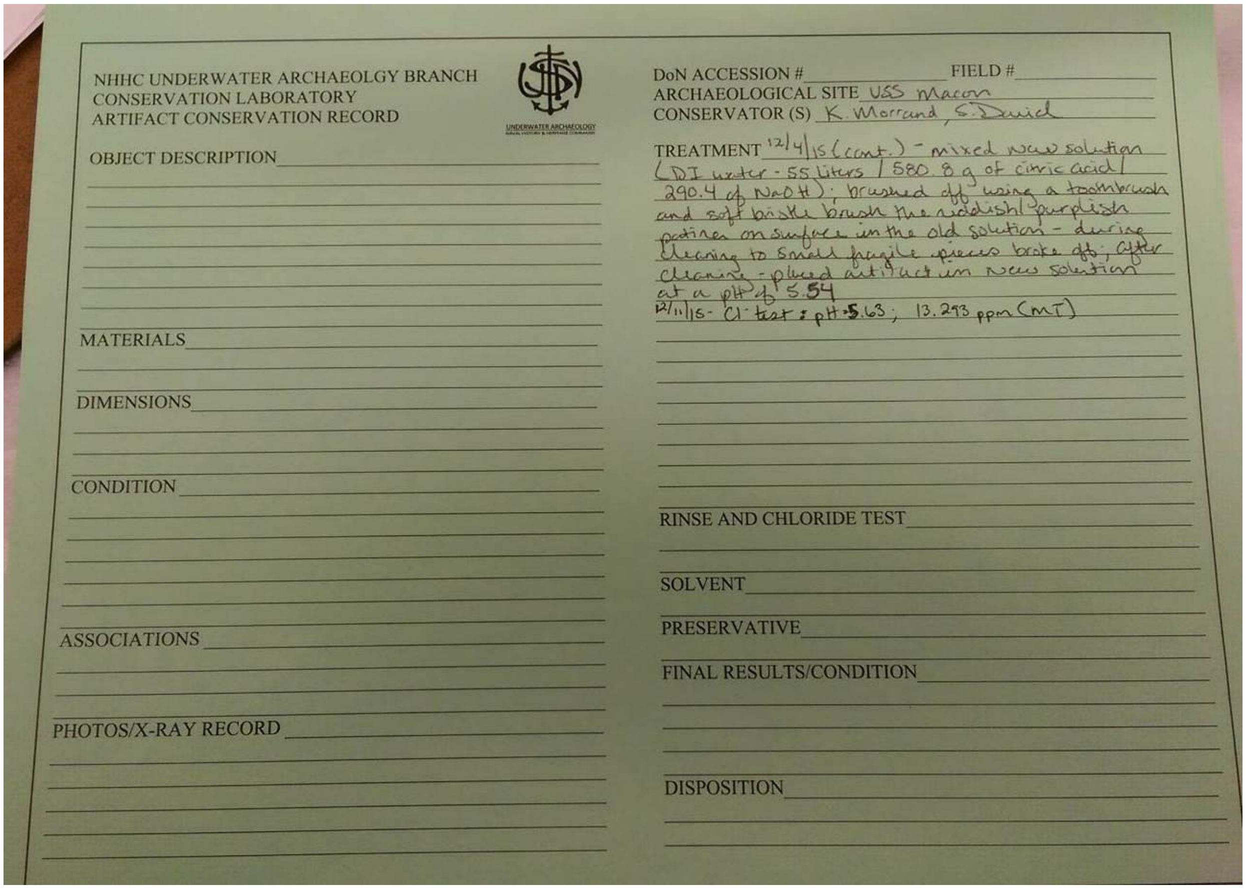
LE	93.08%	0.08 +/-
Cu	6.51%	0.07
Mn	0.227	0.008
Fe	0.147	0.006
Zn	0.027	0.003
Pb	0.0036	0.0005
Zr	0.0018	0.0002

Test #2: same area as Test #1
Soil mode
30 seconds

Cu	8.88% ppm	0.28 +/-
Zn	746 ppm	.85 +/-
Pb	33 ppm	9 +/-

Test #3: rivet that broke free (black spots)
Alloy plus mode

LE	64.15%	0.36 +/-
Fe	23.09%	0.23 +/-
Cr	9.54%	0.10 +/-
Ni	1.52%	0.02 +/-
Mn	0.77%	0.02
Cu	0.557%	0.010
Co	0.22%	0.02



NHHC UNDERWATER ARCHAEOLGY BRANCH
CONSERVATION LABORATORY
ARTIFACT CONSERVATION RECORD

OBJECT DESCRIPTION

MATERIALS

DIMENSIONS

CONDITION

ASSOCIATIONS

PHOTOS/X-RAY RECORD

DoN ACCESSION # FIELD #
ARCHAEOLOGICAL SITE USS Macon
CONSERVATOR (S) K. Morrand, S. David

TREATMENT 12/4/15 (cont.) - mixed new solution (DI water - 55 liters / 580.8 g of citric acid / 290.4 of NaOH); brushed off using a toothbrush and soft bristle brush the reddish/purplish patina on surface in the old solution - during cleaning to small fragile pieces broke off; after cleaning - placed artifact in new solution at a pH of 5.54
12/11/15 - Cl⁻ test: pH 5.63; 13.293 ppm (MT)

RINSE AND CHLORIDE TEST

SOLVENT

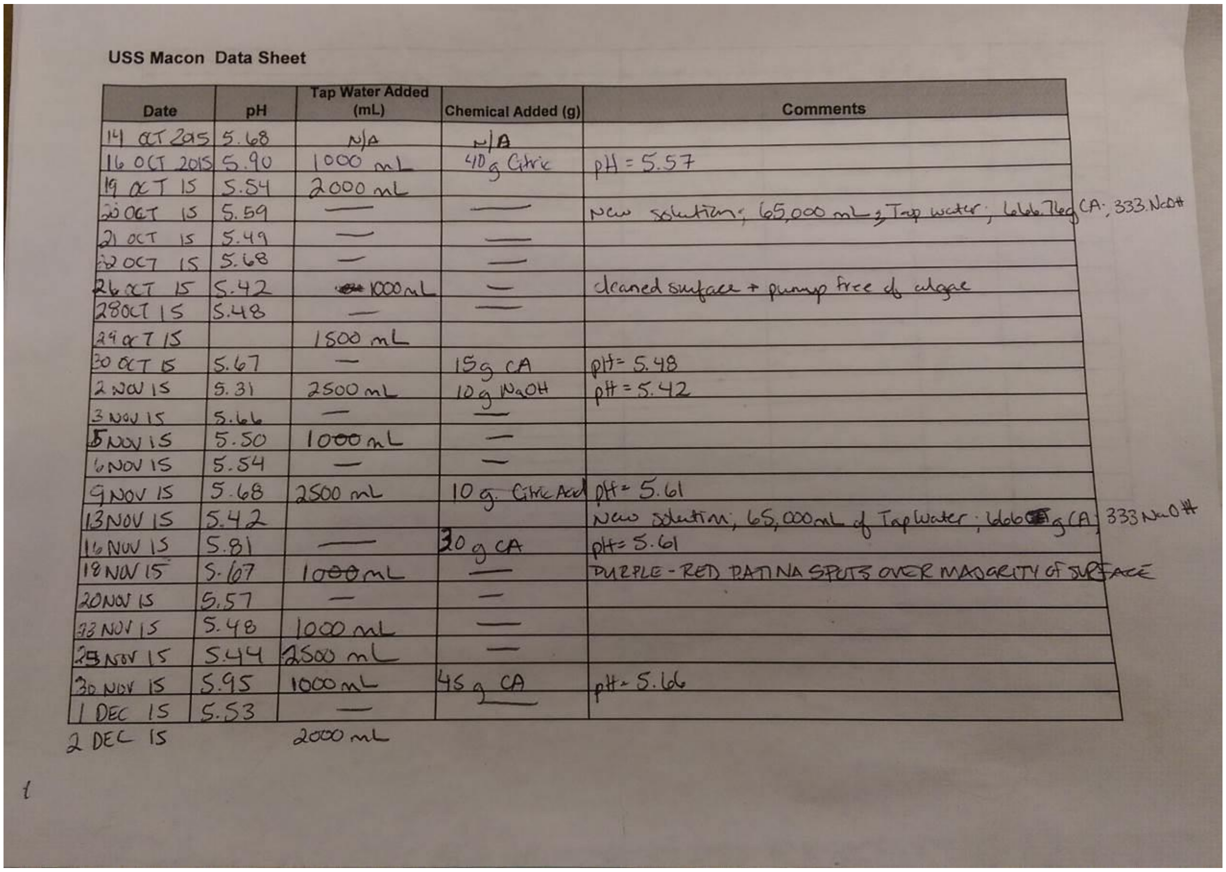
PRESERVATIVE

FINAL RESULTS/CONDITION

DISPOSITION

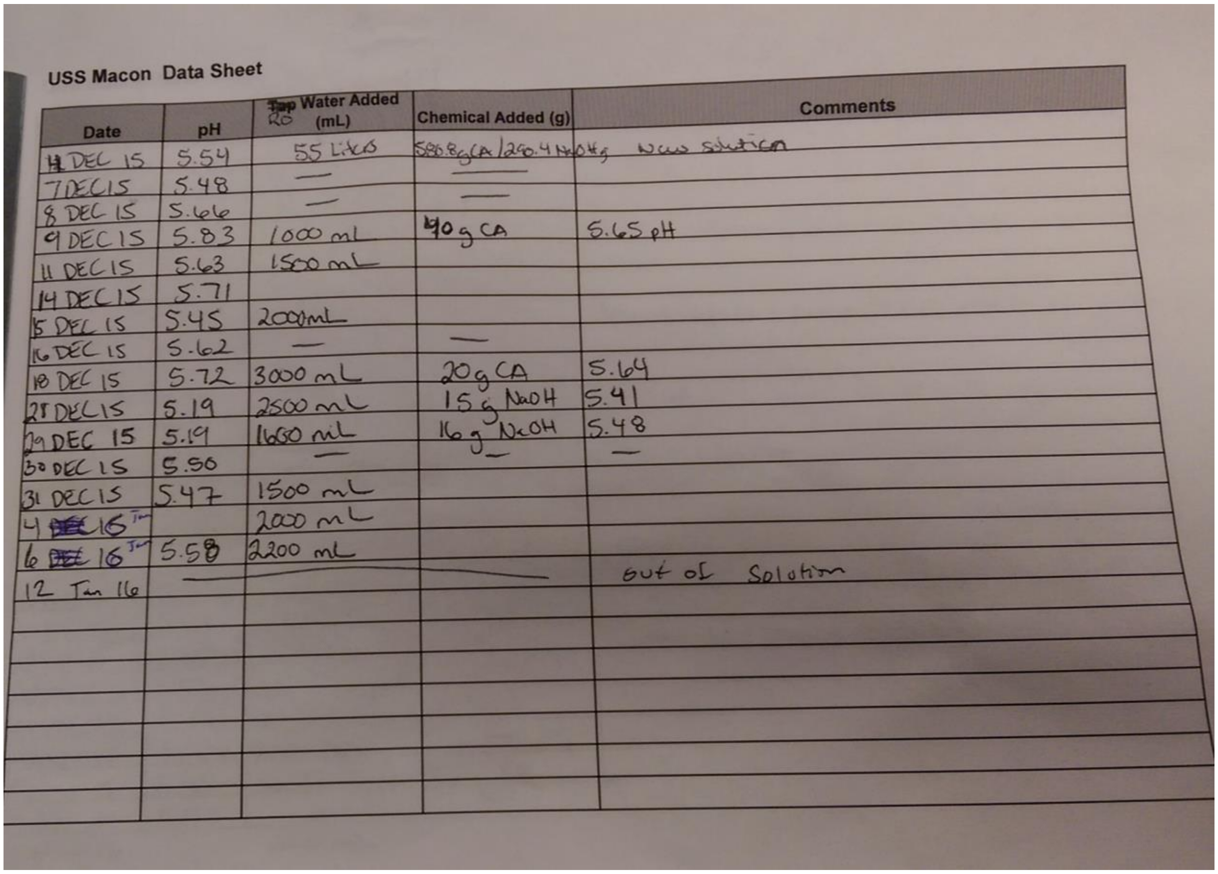
USS Macon Data Sheet

Date	pH	Tap Water Added (mL)	Chemical Added	Comments
3 SEPT 2015	5.47	1000 mL	20 grams NaOH	test pH again after NaOH pH = 5.54
4 Sept 2015	5.68	800 mL	5 grams Citric Acid	test " " " Citric acid pH = 5.56
8 " "	5.74	1400 mL	25 grams Citric Acid	test " " " Citric acid pH = 5.56
9 Sept 2015	5.59		10 grams Citric Acid	test pH " " Citric Acid pH = 5.55-56
10 Sept 2015	—	700 mL		
11 Sept 2015	—	1400 mL		
14 Sept	5.47	1500 mL	15 grams NaOH	test pH " " NaOH, pH - 5.56-5.57
15 SEPT	5.65	N/A	N/A	
16 SEPT	—	700 mL	N/A	
17 SEPT	—	1000 mL	N/A	
18 Sept	5.66	700 mL	25 grams Citric Acid	test pH " " Citric Acid pH = 5.51-5.52
21 Sept	5.58	2000 mL	—	
23 Sept	—	1600 mL	N/A	
24 Sept	5.65	—	30 grams	test pH " " Citric Acid pH - 5.47-5.46
25 Sept	—	1000 mL	N/A	
28 Sept	5.42	2000 mL	N/A	
30 Sept	5.56	1000 mL	N/A	
2 OCT	5.44	2000 mL	N/A	
5 OCT	5.71	1000 mL	30 grams	test pH " " Citric Acid pH = 5.54
6 OCT	—	800 mL	—	
7 OCT	5.44			changed out solution; 64,200 mL Tap; 677g CA; 338g NaOH
8 OCT	5.40	—	—	
9 OCT	5.39-5.40	1000 mL	—	
13 OCT	5.35	N/A	20 grams	test pH again after NaOH; pH = 5.54



USS Macon Data Sheet

Date	pH	Tap Water Added (mL)	Chemical Added (g)	Comments
14 OCT 2015	5.68	N/A	N/A	
16 OCT 2015	5.90	1000 mL	40 g Citric	pH = 5.57
19 OCT 15	5.54	2000 mL		
20 OCT 15	5.59	—	—	New solution; 65,000 mL of Tap water; 666.7 g CA; 333 NaOH
21 OCT 15	5.49	—	—	
22 OCT 15	5.68	—	—	
26 OCT 15	5.42	1000 mL	—	cleaned surface + pump free of algae
28 OCT 15	5.48	—	—	
29 OCT 15		1500 mL		
30 OCT 15	5.67	—	15 g CA	pH = 5.48
2 NOV 15	5.31	2500 mL	10 g NaOH	pH = 5.42
3 NOV 15	5.66	—	—	
5 NOV 15	5.50	1000 mL	—	
6 NOV 15	5.54	—	—	
9 NOV 15	5.68	2500 mL	10 g. Citric Acid	pH = 5.61
13 NOV 15	5.42			New solution; 65,000 mL of Tap Water; 666 g CA; 333 NaOH
16 NOV 15	5.81	—	30 g CA	pH = 5.61
18 NOV 15	5.67	1000 mL	—	PURPLE - RED PATINA SPOTS OVER MAJORITY OF SURFACE
20 NOV 15	5.57	—	—	
23 NOV 15	5.48	1000 mL	—	
25 NOV 15	5.44	2500 mL	—	
30 NOV 15	5.95	1000 mL	45 g CA	pH = 5.66
1 DEC 15	5.53	—		
2 DEC 15		2000 mL		



USS Macon Data Sheet

Date	pH	~~Tap~~ RO Water Added (mL)	Chemical Added (g)	Comments
4 DEC 15	5.54	55 Liters	580.8g CA / 290.4 NaOH g	New solution
7 DEC 15	5.48	—	—	
8 DEC 15	5.66	—	—	
9 DEC 15	5.83	1000 mL	40 g CA	5.65 pH
11 DEC 15	5.63	1500 mL		
14 DEC 15	5.71			
15 DEC 15	5.45	2000 mL		
16 DEC 15	5.62	—	—	
18 DEC 15	5.72	3000 mL	20 g CA	5.64
28 DEC 15	5.19	2500 mL	15 g NaOH	5.41
29 DEC 15	5.19	1650 mL	16 g NaOH	5.48
30 DEC 15	5.50	—	—	—
31 DEC 15	5.47	1500 mL		
4 ~~DEC~~ Jan 16		2000 mL		
6 ~~DEC~~ Jan 16	5.58	2200 mL		
12 Jan 16	—	—	—	out of Solution

APPENDIX L SPECIFICATIONS AND PLANS FOR MARTIN PBM-5 MARINER

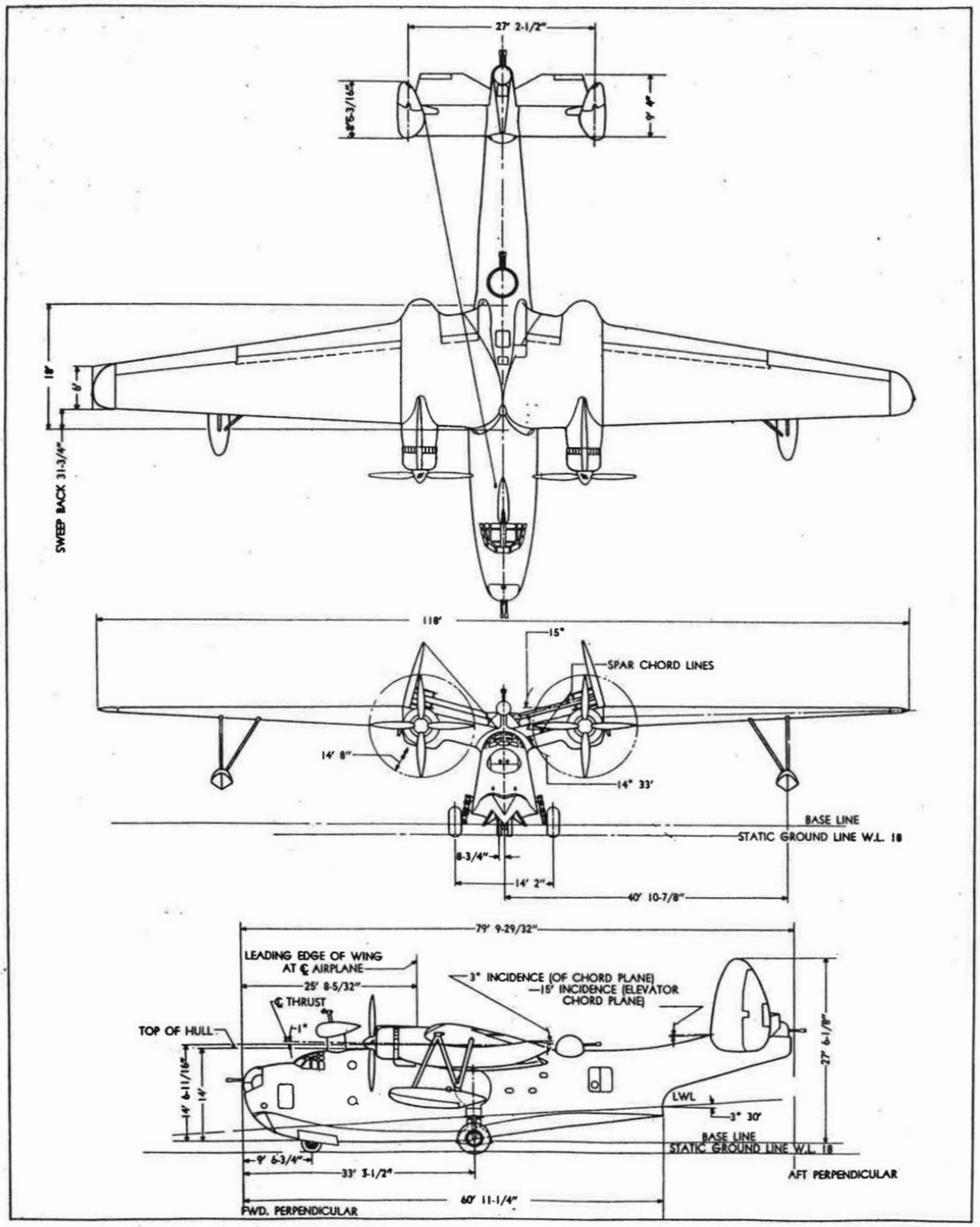


Figure 1-1. Three-View Dimensions

General characteristics

Crew: Seven

Length: 79 ft 10 in (23.50 m)

Wingspan: 118 ft 0 in (36 m)

Height: 27 ft 6 in (5.33 m)

Wing area: 1,408 ft² (131 m²)

Empty weight: 33,175 lb (15,048 kg)

Loaded weight: 56,000 lb (25,425 kg)

Powerplant: 2 × Wright R-2600-6 14-cylinder radial engines, 1,600 hp (1,194 kW) each

Performance

Maximum speed: 178 kn (205 mph, 330 km/h)

Range: 2,600 nmi (3,000 mi, 4,800 km)

Service ceiling: 19,800 ft (6,040 m)

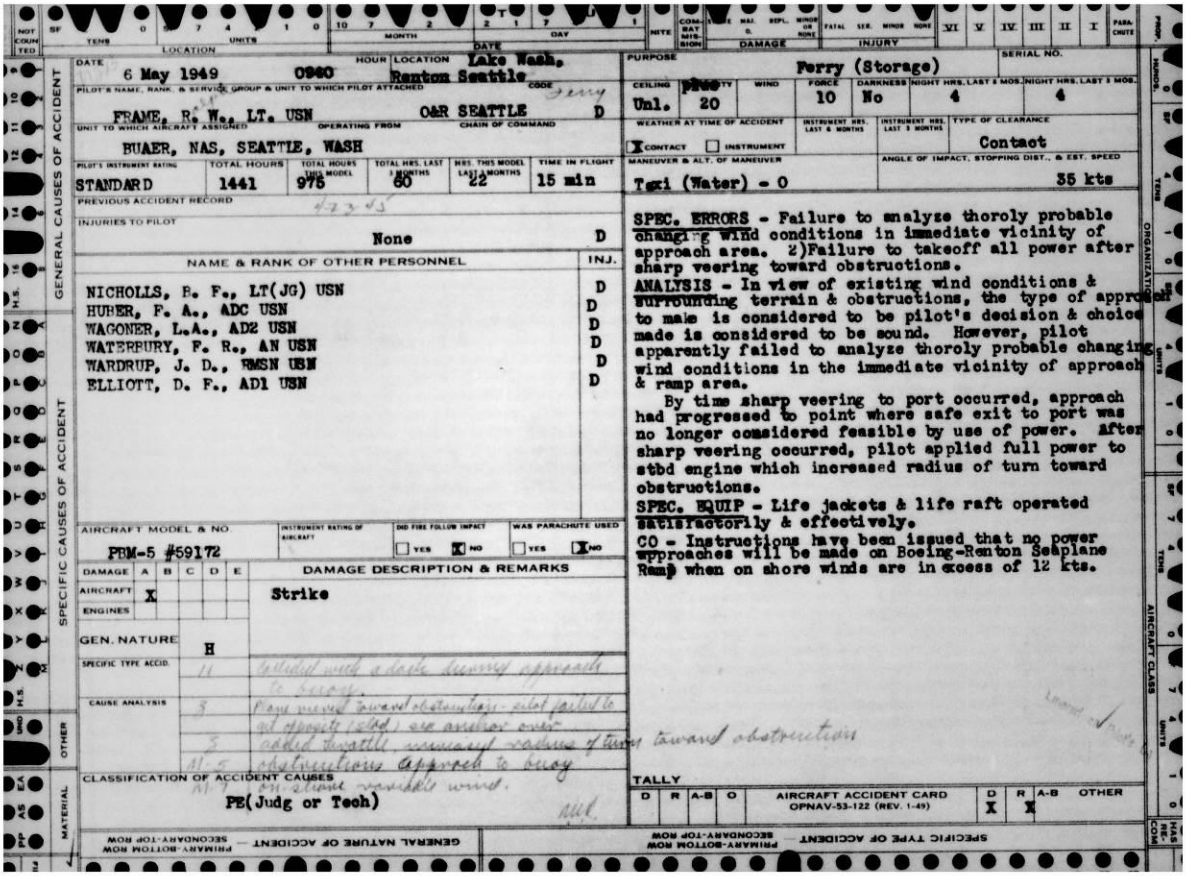
Rate of climb: 800 ft/min (4.1 m/s)

Armament

Guns: 8 × .50 in (12.7 mm) M2 Browning machine guns (two each in nose, dorsal and tail turrets, one each in blisters amidships)

Bombs: 4,000 lb (1,800 kg) of bombs or depth charges or 2 × Mark 13 torpedoes

APPENDIX M PBM-5 BUNO 59172 AIRCRAFT RECORD AND ACCIDENT REPORT CARDS



DATE: 6 May 1949 HOUR: 0960 LOCATION: Lake Wash., Renton Seattle

PILOT'S NAME, RANK, & SERVICE GROUP & UNIT TO WHICH PILOT ATTACHED: FRAME, R. W., LT. USN — O&R SEATTLE — CODE: D

UNIT TO WHICH AIRCRAFT ASSIGNED: BUAER, NAS, SEATTLE, WASH

PILOT'S INSTRUMENT RATING	TOTAL HOURS	TOTAL HOURS THIS MODEL	TOTAL HRS. LAST 3 MONTHS	HRS. THIS MODEL LAST 3 MONTHS	TIME IN FLIGHT
STANDARD	1441	975	60	22	15 min

PREVIOUS ACCIDENT RECORD: 4-23-45

INJURIES TO PILOT: None — D

NAME & RANK OF OTHER PERSONNEL	INJ.
NICHOLLS, B. F., LT(JG) USN	D
HUBER, F. A., ADC USN	D
WAGONER, L.A., AD2 USN	D
WATERBURY, F. R., AN USN	D
WARDRUP, J. D., RMSN USN	D
ELLIOTT, D. F., AD1 USN	D

AIRCRAFT MODEL & NO.: PBM-5 #59172 — DID FIRE FOLLOW IMPACT: NO — WAS PARACHUTE USED: NO

DAMAGE	A	B	C	D	E
AIRCRAFT	X				
ENGINES					

DAMAGE DESCRIPTION & REMARKS: Strike

GEN. NATURE: H

CLASSIFICATION OF ACCIDENT CAUSES: PE(Judg or Tech)

PURPOSE: Ferry (Storage)

CEILING	VISIBILITY	WIND	FORCE	DARKNESS	NIGHT HRS. LAST 6 MOS.	NIGHT HRS. LAST 3 MOS.
Unl.	20		10	No	4	4

WEATHER AT TIME OF ACCIDENT: [X] CONTACT [ ] INSTRUMENT — TYPE OF CLEARANCE: Contact

MANEUVER & ALT. OF MANEUVER: Taxi (Water) - 0 — ANGLE OF IMPACT, STOPPING DIST., & EST. SPEED: 35 kts

SPEC. ERRORS - Failure to analyze thoroly probable changing wind conditions in immediate vicinity of approach area. 2)Failure to takeoff all power after sharp veering toward obstructions.

ANALYSIS - In view of existing wind conditions & surrounding terrain & obstructions, the type of approach to make is considered to be pilot's decision & choice made is considered to be sound. However, pilot apparently failed to analyze thoroly probable changing wind conditions in the immediate vicinity of approach & ramp area.

By time sharp veering to port occurred, approach had progressed to point where safe exit to port was no longer considered feasible by use of power. After sharp veering occurred, pilot applied full power to stbd engine which increased radius of turn toward obstructions.

SPEC. EQUIP - Life jackets & life raft operated satisfactorily & effectively.

CO - Instructions have been issued that no power approaches will be made on Boeing-Renton Seaplane Ramp when on shore winds are in excess of 12 kts.

TALLY

AIRCRAFT ACCIDENT CARD OPNAV-53-122 (REV. 1-49) — D: X R: X

Serial No. 59172 Model PBM-5 Contract No. NOa(s) 909

Acceptance Date 12-26-44

Delivery Date 1-17-45 Date Reconditioning Completed

TRANSFER RECORD

Date in	Unit	Date out	Time in status	For use of CNO
	HDN 2 FAW 5			
	OTU VPB2 4			
	VPB 99			
1946	Hedron FAW 8			
	Pool Adm FAW 8			
	Pool FAW 14			
	Under Recond A&R Coco Solo			
1947	Pool A&R Coco Solo		O/H 4-25-47	
	Pool ADAU CS			
	ATU VP MS 10			
	Avia Trn Dept Jax			
1948	Avia Trng Dept. Jax			

AIRCRAFT HISTORY CARD NAVAER-1925 (9-44) (For use of CNO and Fleet Air & Area Com)

Serial No. 59172 Model PBM-5 Contract No.

STRICKEN 4-5-F Cat I 5/31/49

Acceptance Date

Delivery Date Date Reconditioning Completed

TRANSFER RECORD

Date in	Unit	Date out	Time in status	For use of CNO
'48	ATU VP 10	Corpus		

AIRCRAFT HISTORY CARD NAVAER-1925 (9-44) (For use of CNO and Fleet Air & Area Com)

APPENDIX N PBM-5 BUNO 59172'S ASSOCIATED RECOVERED ARTIFACTS

Pages below are from NNAM's records on the PBM-5 59172 loan.

Inventory of Recovered Parts PBM-5 Bureau Number 59172

	Item	Photo #	Comment
1.	Radio	1	
2.	Port Hole Window	2	
3.	Pickle Bomb Key	3	
4.	Kitchen Bench Seat	4	
5.	Bombing Sequencer	5	
6.	Spent Shell Feed Tray	6	
7.	Rolled up Plastic Balloon Energy Kit	7	
8.	**50 Caliber Shell**	»	**Not found in 6/19/01 inventory**
9.	Radio Base Plate(s)	9	Two plates are joined together
10.	Brief Case Top	10	
11.	Motor Shroud	11	Two Each
12.	Motor Shroud	12	
13.	Toilet Floor	13	
14.	Toilet Lid and Seat	14	
15.	Toilet Can	15	
16.	Shroud, Large	16	
17.	**Shroud, Medium**	»	**Not found in 6/19/01 inventory**
18.	Shroud Medium	18	
19.	Shroud, Small	19	
20.	Bulkhead Door	20	
21.	Bulkhead Door	21	
22.	Bulkhead Door	22	
23.	Outer Door	23	
24.	Bombardier's Door	24	Bombing Window Door
25.	Dome Turret Floor	25	
26.	Entry Ladder, Large	26	
27.	Ladder, 4-foot	27	
28.	Ammunition Box (empty)	28	
29.	Ammunition Box (empty)	29	
30.	Floor Panel	30	
31.	Floor Panel	31	
32.	Floor Panel	32	
33.	Floor Panel	33	
34.	Floor Panel	34	
35.	Floor Panel	35	
36.	Floor Panel	36	
37.	Panel, Shroud	37	
38.	Floor Panel, Round	38	
39.	Floor Panel	39	
40.	Floor Panel	40	
41.	Ammunition Feed Trays	41	
42.	Ammunition Feed Trays	42	
43.	Ammunition Feed Trays	43	
44.	Ammunition Feed Trays	44	
45.	Panel Plate (flt. Eng.)	45	
46.	Box	46	
47.	Ammunition Box (empty)	47	
48.	Ammunition Box (empty)	48	
49.	Flexible Ammunition Trays	49	
50.	Flexible Ammunition Trays	50	
51.	Sea Hoop Anchor	51	
52.	Radio	52	

Inventory of Recovered Parts PBM-5 Bureau Number 59172

	Item	Photo #	Comment
53.	Radio	53	
54.	Radio	54	
55.	Radio	55	
56.	Radio	56	
57.	Radio	57	
58.	Radio	58	
59.	Radio Base Plate	59	
60.	Radio Mount	60	
61.	Motor	61	
62.	Motor	62	
63.	Motor	63	
64.	Band	64	
65.	Winch	65	
66.	Box	66	
67.	Filter	67	
68.	Hoe	68	
69.	Handle	69	
70.	Light Assembly	70	
71.	Radio Lid	71	
72.	Plate	72	
73.	Post	73	
74.	**Parachute**	»	**Not found in 6/19/01 inventory**
75.	Microphone	75	
76.	3 Head Set Earpads	76	
77.	Microphone	77	
78.	Microphone	78	
79.	Information Panel	79	
80.	Leather Seat	80	Small Piece
81.	Plastic Bag	81	
82.	Plastic Bag	82	
83.	Mircrophone	83	
84.	Wire	84	
85.	Emergency Pack	85	
86.	Spent Shell	86	
87.	De-Icing Pot	87	
88.	Toolbox Lock	88	
89.	Parachute Pieces	89	
90.	Fire Ax	90	
91.	**Machine Gun**	»	**Stored inside locker Bldg. 604??**
92.	**Machine Gun**	»	**Stored inside locker Bldg. 604??**
93.	Gun Box	93	
94.	De-Salt Capsules	94	
95.	Door Rod	95	
96.	Plastic Emergency Cover	96	
97.	Ammunition Box	97	
98.	Monkey Wrench	98	
99.	Altitude Gauge	99	
100.	Wiring Diagram Panel	100	
101.	Round Cover	101	
102.	Data Plate Cover	102	
103.	Olympia Beer Can	103	
104.	Aircraft Part	104	
105.	Round Cover	105	

Inventory of Recovered Parts PBM-5 Bureau Number 59172

	Item	Photo #	Comment
106.	Mount Plate for Cover	106	
107.	Blue Vinyl Material	107	
108.	Aircraft Metal	108	
109.	Aircraft Part	109	
110.	Dual Hose w/ Metal Attached	110	
111.	Copper Gasket	111	
112.	Tubing	112	
113.	Salt Water Conversion Kit	113	Rubber Bag
114.	Small Motor	114	
115.	Gun Part (?)	115	
116.	Round Aluminum Back Plate	116	
117.	Electric Plug	117	
118.	Mount Plate	118	
119.	Mount Plate	119	
120.	Remains of Flare Gun Cartridge	120	
121.	Hand Tool (?)	121	
122.	Aircraft Light Bulb	122	
123.	Steering Control Linkage	123	
124.	Parts of Aircraft Rib (?)	124	
125.	Remains of Gauge	125	
126.	Aircraft Skin	126	
127.	Aircraft Skin	127	
128.	Floor Panel	128	
129.	Panel	129	
130.	Panel	130	
131.	Panel	131	
132.	Panel	132	
133.	Airframe Part	133	
134.	Airframe Part	134	
135.	Airframe Part	135	
136.	Airframe Part	136	
137.	Airframe Part	137	
138.	Airframe Part- Rib	138	
139.	Airframe Part	139	
140.	Plastic Item, Small	140	
141.	Plastic Item, Medium	141	
142.	Aluminum Tubing	142	
143.	Aluminum Tubing	143	
144.	Tubing w/ Clamps, Small	144	
145.	Tie Down Ring (Cleat)	145	
146.	Shroud, Small	146	
147.	Tubing, Long	147	
148.	Hatch Cover	01	

Figure N.1 – PBM-5 recovered tail section showing areas of damage and corrosion. Likely the loss of the panel was due in part to the corrosion of the stringers underneath. Photo by the author.

Figure N.2- The inside of the tail section, showing areas that are free of any corrosion. Photo by the author.

Figure N.3- An exterior view of the tail section showing some faded paint lines. Bare metal interior structure pieces show little corrosion. Photo by the author.

Figure N.4- Some chipping paint is still visible on the elevator structure. Photo by the author.

Figure N.5- The interior central control panel of the Martin 250CH-2B tail turret, recovered in 1996. Active corrosion presents in the middle of the panel. Photo by the author.

Figure N.6- One of the two M2 Browning machine guns inside the tail turret. Both display the same level of rusting and light pitting. Photo by the author.

Figure N.7- Light blue paint is peeling, but obvious on a section of the tail turret. Little corrosion appears on these cast aluminum and steel parts, although the steel parts have faint rust marks in some areas. Photo by the author.

Figure N.8- A close-up of the pitting and exfoliation corrosion on the hatch door artifact recovered in 1980-1981. Blue paint still appears mostly intact. Photo by the author.

Figure N.9- Pieces of the tail and vertical stabilizer, fabric hanging at the bottom, in outdoor storage at Pima Air & Space Museum. Photo by the author.

Figure N.10- Another view of pieces of the tail and vertical stabilizer in outdoor storage at Pima Air & Space Museum. Photo by the author.

Figure N.11- The rear afterbody of PBM-5 59172, resting on its side in outdoor storage at Pima Air & Space Museum. Photo by the author.

Figure N.12- The front of an interior bulkhead door, in outdoor storage at Pima Air & Space Museum. Photo by the author.

Figure N.13- An exterior tail section hatch door with mounts for jet-assisted take off (JATO) propulsion bottles, currently in outdoor storage at Pima Air & Space Museum. Photo by the author.

Figure N.14- Light corrosion patches on the rear afterbody of PBM-5 59172, resting on its side in outdoor storage at Pima Air & Space Museum. Photo by the author.

Figure N.15- The bleached bare metal side of the rear fuselage of the PBM-5, presenting with patches of light corrosion and increased corrosion around the circular hole central top of the photo. Photo by the author.