

Stabilization of a wrecked and corroded aluminium aircraft

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Abstract

In 1984 the Australian War Memorial (AWM), Royal Australian Air Force and Royal Australian Navy recovered a crashed Japanese Army Air Force Nakajima Ki 43 II "Oscar" fighter aircraft from Papua New Guinea. The aircraft had crashed at the end of an airfield and had been sitting in swampy ground since 1944, and had subsequently corroded and suffered extensive deterioration. In 1996 electrolytic treatment development for corroded composite metal artifacts had reached the stage where it was feasible to electrochemically treat "Oscar" without needing to breakdown the aircraft into small separate components. An above ground swimming pool was erected and filled with a solution of citric acid, sodium hydroxide and water. An electrolytic cell was formed by using expanded stainless steel mesh as anodes and making the aircraft the cathode. An applied potential of approximately 1.15 volts, (with respect to a mercury sulphate electrode) was administered for one month. Electrolysis was followed by a further polarization in fresh water for one week to remove the chemicals. Upon removal from the pool the aircraft was cosmetically treated to remove flash rust and finally coated with wax. During the treatment samples were taken from the pool to monitor pH and concentrations of dissolved chloride, iron, copper and aluminium.

Keywords: Aluminium, citric acid, electrolysis, composite materials ,aircraft.

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1. Introduction

The AWM has in its collection a number of corroded aluminium alloy/metal composite objects that were recovered from aqueous saline environments. Such objects can continue to corrode quite readily after being removed from aqueous environments, even in relative humidities below 35% due to chloride contamination in crevices and the prevalence of bimetallic couples. (Evans, 1960)

A method for stabilizing corroded aluminium/copper alloy objects by using an ammonia-ammonium sulphate buffer in deionized water was developed by MacLeod in 1982. The method works by dissolving copper corrosion products and precipitated elemental copper. This method works well when there is only one alloy involved, but is not satisfactory when other alloys and metals, particularly copper, are part of the object.

In 1991 the AWM (in conjunction with Electricité de France and Research School of Chemistry, Australian National University) began developing an electrochemical method to treat corroded aluminium alloy/metal composite objects. The method was based on doctorate thesis work by Degriigny in 1990. Research has

been supported by donations from The International Group for Historic Aircraft Recovery (TIGHAR) and the Historical Aircraft Restoration Society (HARS).

The method is still being developed and perfected, but has reached the stage where treatment of large composite aluminium/metal objects is feasible and can be confidently carried out with minimal risk to the object. (Adams, 1992 and 1993, Hallam et al 1997)

Over the past five years the size of objects treated has ranged from small pieces of aircraft and ship fittings through to largely complete aircraft engines. This paper describes the treatment of a wrecked and corroded Japanese WWII Nakajima Ki-43 II Hayabusa (Peregrine Falcon) fighter aircraft. This was the latest and largest aluminium alloy/metal composite object to be electrochemically treated with the new method at the AWM.

History of "OSCAR"

The Nakajima Ki-43 II Hayabusa (Peregrine Falcon) was the principle fighter aircraft used by the Japanese Army during World War 2. The Ki-43 was comparable in most respects to the better known Mitsubishi 'Zero' employed by the Japanese Navy (Angelucci and Matricardi, 1988).

During the war the Allies used a system of Christian names to make identification and reporting of Japanese aircraft simpler. Female names were allocated to bombers, flying-boats and land based reconnaissance aircraft. Female names beginning with 'T' were allocated to transport aircraft, and male names were allocated to fighters and seaplane reconnaissance types. Thus the Nakajima Ki-43 Hayabusa was known to the allies as "Oscar". (Okumiya et al, 1958)

Oscar serial No.5465 was probably built in 1943, and was based at the Sek Fighter Airstrip at Alexshafen, near Madang, New Guinea. The aircraft was damaged during a landing accident in 1944, and after being stripped of useable equipment it was abandoned at the end of an airfield in swampy ground. Over the next 40 years Oscar was subjected to aerial attack, grass fires, vandalism, monsoon rains and mud. Subsequently corrosion and decay completed the state of the aircraft as found..

In 1984 the Australian War Memorial, Royal Australian Air Force and Royal Australian Navy recovered Oscar from Papua New Guinea. During recovery it was dismantled into three main components consisting of the wing and cockpit section, rear fuselage and empennage, and engine. Since then the aircraft has been kept in mostly inadequate storage, adding to the slower corrosion process.

2. Condition

To facilitate recovery and transport, Oscar was dismantled into three major pieces, comprising the wings and cockpit (approximately 10 metres x 3 metres x 1.4 metres), rear fuselage and empennage (approximately 4.4 metres x 3.7 metres x 1.6 metres) and the engine and propeller (approximately 2.3 metres diameter x 1.5 metres).

Most of the corrosion of the aluminium had occurred on the lower surfaces of the aircraft, caused by resting in mud. The upper surfaces of the wings and horizontal stabilizers were also corroded, probably from the accumulation of rotting fallen vegetation. The vertical surfaces of the cockpit and fuselage sides are remarkably

corrosion free, however the site from where the aircraft was recovered was in a salt air and salt water environment, so saline corrosion was expected.

All the ferrous alloys, with the exception of the stainless steel fittings, had medium to heavy surface corrosion. The lead-alloy counter-weights located on the leading edges of the elevators had only light corrosion.

Very few rubber and plastic parts remain on the aircraft. Those parts that do remain appear to be stable. Nothing remains of the linen fabric that would have covered the control surfaces.

Some original paint still survives on the aircraft. This paintwork includes Unit markings on the tail and rear fuselage, yellow leading edges on the underside of the wings, stencilled serial numbers and jacking point indicators. Hinomaru (the national Japanese military markings - large red circles with white outline) on the fuselage and wing undersides are still visible. The typical blue-green coating used by the Japanese as a corrosion inhibitor for the internal surfaces was also found in various locations. No evidence was found of camouflage paint.

Pencilled hand written numerals and Japanese characters were found inside the cockpit and rear fuselage. It is believed that these numbers were used as an aid in the manufacturing and assembly process.

Surprisingly, the main undercarriage oil legs are still leaking oil and on examination the pistons were found to be only lightly corroded.

There was a lot of storage dirt, dried mud, vegetation, loose corrosion products and metal fittings, throughout the aircraft. Two large snail shells and two spent 0.5" bullets (a common machine gun calibre used by the USA and allies) were found amongst the debris.

Much of the airframe is buckled and twisted, and there are many holes in the skin. Some of this damage is a result of the landing accident and subsequent Japanese salvage, and Allied air attacks. Other damage is a result of vandalism before the plane was recovered, and damage incurred during the recovery operation. Considerable damage was caused by Australian Customs when the wreck entered Australia. A number of holes were punched through the top skin of the wings by Customs to ensure adequate fumigation. One wonders why this was necessary. If fumigation gases couldn't penetrate a sealed space, then there seems to be little chance of an organism doing so.

3. Treatment method

At the time of writing, only the wing and rear fuselage sections have been treated. Normally the process used involves a series of steps, which are:

1. mechanical cleaning to remove debris and loose corrosion and accretions
2. masking of paint and other features that need to be protected from chemicals
3. polarization in a solution of metasilicate, polyphosphate and bicarbonate to produce a stable magnetite coating on ferrous components
4. washing with fresh water and further mechanical cleaning to remove accretions
loosened in step 3
5. polarization in a solution of citric acid and sodium hydroxide to remove chlorides and aluminium corrosion
6. polarization in fresh water to remove above chemicals, and
7. drying, treating of flash rusting and application of a protective coating to reduce the incident of future corrosion.

For the treatment of Oscar's wing and rear fuselage, it was decided that step 3 would be deleted from the process. There were several reasons for this decision. To include step 3 would have required an additional 110, 000 litres of water plus the associated chemicals to make up the two extra baths, and the additional time. All this would have involved considerable expense. Also, the disposal of large volumes of high pH solution would pose problems. The fact that the amount of ferrous alloys in the two sections is relatively small in relation to the amount of aluminium alloys made it hard to justify the addition expense, time and disposal problems presented by step 3. When the engine and propeller section is treated, step 3 will be included, as the solution volumes will be more manageable, and the ferrous/aluminium alloy ratio is higher.

The difficulty in the treatment of Oscar was not so much the process itself, but the logistics involved. Lifting a fragile object that is 10 metres long, 3 metres wide and weighing almost a tonne requires considerable forethought and planning. The sections needed to be lifted 1.8 metres in order to get them into the pool, and during lifting they had to be kept level and balanced. Much time and testing was involved in identifying suitably strong lifting points and arranging lifting tackle to achieve a safe, level lift.

3.1 Preparing for the treatment

3.2 Treatment container

In order to give Oscar an electrochemical treatment, a suitably large treatment tank was necessary. Factors which influenced the final choice of treatment tank were size, initial cost, capital works needed, resistance to the chemicals to be used, ease of assembly and disassembly, accessibility to the solution during treatment, and ease of disposal by resale at the end of the project. Several options were investigated including purpose built tanks, below ground fibreglass swimming pools, and above ground swimming pool kits.

A purpose built tank proved to be too costly, required capital works to the floor of the treatment area, was too high to allow easy monitoring and sampling, and would not be easy to dispose of at the end of the project

Fibreglass in-ground swimming pools were cheaper than the above ground tanks, but would require considerable earth works. If used above ground, problems with stability and strength of the pool were likely as well as height problems mentioned previously. Resale value of an in-ground pool was better than a purpose built tank.

Above ground swimming pool kits offered the best compromise. They are considerably cheaper than the above two options, do not require any capital works, are relatively simple to transport, position, erect and dismantle, and are popular and cheap enough to make disposal relatively easy. Above ground pools are available with a maximum depth of 1.2 metres. This meant that it would not be possible to completely immerse Oscar during treatment. This was accepted as a compromise, as most of the area that would be exposed was only lightly corroded. A partial solution to this problem will be dealt with in a later paragraph..

Samples of pool lining material were obtained and were tested for compatibility with the chemicals to be used. The samples showed no change in appearance, flexibility or strength after six months soaking in the solutions. Upon completion of the tests a 12 metre x 4.5 metre x 1.2 metre above ground pool kit was purchased.

The pool was positioned in the Treloar Centre Conservation Annex, directly under an overhead gantry. Normally when erecting above ground pools, the framework is buried in ditches. Obviously, this was not possible on the concrete floor of the building, so 2,500 house bricks were donated by Nubrik Pioneer Building Products to build the floor up to the level of the framework. The bricks and frame were covered with sand.

3.3 Anodes

Expanded Stainless Steel mesh was used for the anodes. The mesh was cut to the approximate size and shape of the Oscar pieces and attached to wooden frames to give approximately 30 cm clearance from the Oscar pieces. The anodes/frames used under Oscar were positioned in the pool before it was filled, all electrically connected, and weighted down with bricks.

The anodes for the upper and vertical surfaces, and inside the fuselage and cockpit were tied to the Oscar pieces and electrically connected before each piece was lifted into the pool.

In order to electrically connect all of the anodes, stainless steel tabs were soldered to insulated copper wire. The soldered region was encased with epoxy resin to avoid failure caused by chemical action. The tabs were attached to the mesh using stainless steel screws.

3.4 Preparation of solution

In order to obtain the desired pH and molarity, it was necessary to measure that amount of water put into the pool, so that the appropriate amount of citric acid and sodium hydroxide could be calculated. A water meter of the types that are connected to suburban houses was attached to the hose used to fill the pool. The desired pH was 5.4, and the citric acid concentration was 0.055 moles per litre.

Mixing approximately 800 Kg of chemicals with 55,000 litres of water in a swimming pool poses problems that one doesn't normally encounter in bench-top conservation. It was not possible to add the chemicals directly into the pool, because there was a risk that localised concentrated sodium hydroxide would burn through the pool lining. Another problem is that both the sodium hydroxide and the citric acid tend to form large lumps which dissolve very slowly. To solve this problem, water was circulated from the pool through two large water tanks where the chemicals were gradually added over a period over several days.

3.5 Preparations of “Oscar”

Before immersion the aircraft was thoroughly examined to remove loose pieces of metal and other foreign material. It was during this stage that the two spent 0.5" bullets were found in the floor of the cockpit. The bullets were probably from Allied fighter aircraft that strafed the airfield.

After all loose material was removed the aircraft was washed with a K'Archer pressure spray to remove as much dirt and loose corrosion as possible. The pressure used was limited to approximately 60 psi, so that fragile metal parts and paints were not damaged.

Before immersing the aircraft into the solution, the original paint and pencil markings had to be protected. Previous experience has shown that if the paint is not protected it will swell and loose adhesion with the aluminium substrate. A coating of microcrystalline wax, followed by a sprayed layer of clear acrylic lacquer was applied over the areas to be protected.

Small alligator clips were soldered onto copper wire to electrically connect all parts of Oscar. Series of 10 clips were soldered to two metres lengths of wire to make handling and installation easier. Each end of the wire was fitted with an in-line plug to simplify joining of the wires to each other. The soldered joints were encased with epoxy resin as mentioned previously. Ten large battery clips, each with a separate wire were also made to attach to large ferrous fittings of the aircraft. Approximately 200 metres of insulated copper wire, 700 small alligator clips and 10 large battery clips were used in total.

As mentioned, the swimming pool was not deep enough to completely immerse the Oscar pieces. This presented a potential problem of tide marks resulting from etching and/or corrosion at the solution/air/metal interface. To prevent this, the exposed parts were covered with Engineers Felt and the solution pumped over the felt. The aim was to keep the exposed parts saturated with the solution. A garden hose with small holes every 10 cm or so was placed under the felt on the rear fuselage

section, which was treated first. This solution did prevent etching and corrosion at the interface zone, but resulted in some distinct staining associated with the hose holes. For the cockpit/wing piece, a garden soaker hose was used on top of the felt. This worked much better, with the staining being much less distinct. In both cases, visible etching and corrosion was avoided, although there is a visible stain at the interface zones. This is probably due to lack of electrochemical action above the solution level.

3.6 Treatment

The treatment was instigated by a curatorial request to provide a stable displayable aircraft in relic condition. Oscar was still showing active corrosion and corrosion products and all the species needed to be treated to achieve management requirements.

Once the solution had been mixed and anodes positioned, the rear fuselage section of Oscar was immersed in the pool. All of the anodes were connected to the positive terminal, and Oscar connected to the negative terminal of a Hewlett Packard 6642A System DC Power Supply. An Activon AEP114 Single Junction Hg/Hg₂SO₄ reference electrode connected to a Hewlett Packard 34401A Multimeter was also connected to the negative terminal to measure the potential of the system. A potential of approximately 1.10 - 1.20 volts (with respect to a Hg/Hg₂SO₄ electrode) was applied to the system, as influenced by the treatment to another aircraft part by De Grigny while studying at the AWM. The potential was monitored and adjusted closely for the first two hours until the system had stabilized, and then checked and adjusted on a daily basis. A pump was connected to the hose on the exposed tail to ensure that it was kept wet. Two other pumps were used to keep the solution circulating, thus avoiding localised increases in pH. The temperature of the solution was initially 17°C and rose to 19°C after one month. Figure 1 shows the rear fuselage section during treatment.

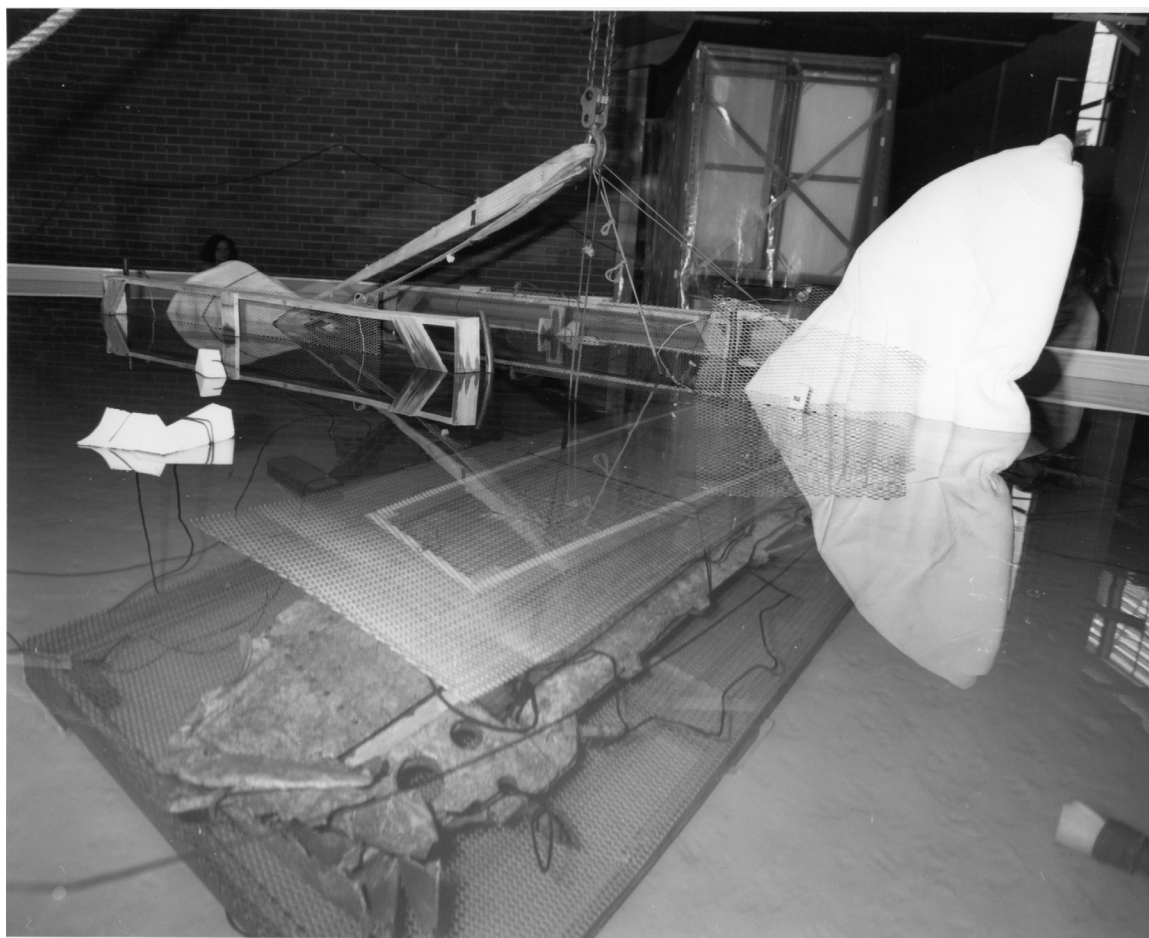


Figure 1. Oscar rear fuselage and empennage during treatment

At weekly intervals the rear fuselage was lifted out of the pool and inspected for progress of the treatment and unexpected corrosion development. After one month all ferrous corrosion and white and blue/green aluminium corrosion products had disappeared, and a thin layer of non-adherent black smut, assumed to be copper oxides, had settled on the rear fuselage. Biological activity had also appeared in the solution. No significant increase in either pH or chloride levels in solution were recorded, so the rear fuselage was removed and the black smut washed off.

The pool was drained, cleaned and refilled with clean water, and the rear fuselage re-immersed for one week to remove remaining traces of the first solution. The same potential as above was applied to the system. Upon removal from the pool again, the rear fuselage was encased in polyethylene and dehumidified for two weeks to completely dry it. During this period, flash rusting occurred on all ferrous parts. These were treated with 5% w/v Tannic acid in ethanol. The rear fuselage was then sprayed with Dinol AV5B inhibited wax to protect it from future corrosion.

The treatment of the wing/cockpit section of Oscar proceeded in same way as the rear fuselage. Biological growth was more prevalent during this treatment, probably because the temperature of the solution had increased to 22°C. The treatment time, pH, and chloride levels were the same as used previously. Figure 2 shows the wing/cockpit section being placed in the empty pool to check the position of the bottom anodes.

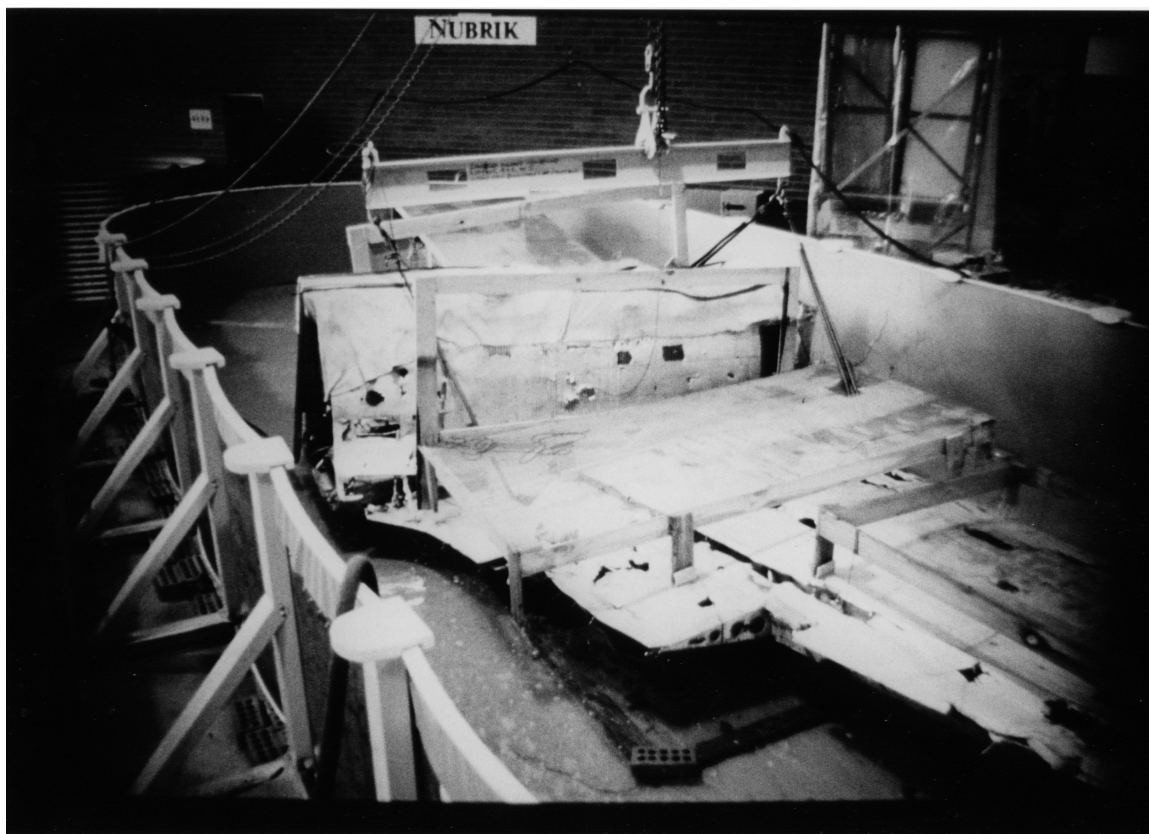


Figure 2. Oscar wing and cockpit section in the pool to check the position of the bottom anodes.

During the rinsing stage, it was noticed that small white spots were starting to appear on the wings. This indicated that pitting corrosion was occurring, suggesting that the potential of the system was not correct. All electrical connections were checked and found to be in order. The reference electrode was then checked and found to be giving inaccurate readings. This is thought to be due to contamination from biological growth blocking the ceramic frit. The correct potential was reapplied, and the section was left for another week. After removal, the wings were scrubbed to remove the remaining white corrosion products, and then dried, tannated and waxed in the same way as the tail section above. Figure 3 shows the wing/cockpit section after treatment.



Figure 3. Oscar cockpit section after treatment.

4. Discussion

4.1 Analyses

Before treatment, samples of the main aluminium alloys were taken and analysed to determine alloy types. The samples were analysed by EDXA in a Scanning Electron Microscope. The results indicated that the majority of the alloy is approximately equivalent to a 2000 Series aluminium alloy, and the main spar composition is approximately equivalent to a 7000 Series alloy.

Samples of the pool solution were taken daily to measure pH and chloride levels. Over the course of the treatments neither the pH nor chloride levels rose significantly. Normally in this type of treatment both levels would be expected to rise. With this particular treatment the lack of change in pH can be attributed to the sheer volume of solution compared to the surface area of the object. Likewise, the volume of solution compared to the amount of chloride present in the objects meant that the change in chloride levels in the solution was difficult to detect.

Further analysis of the solutions samples to measure concentrations of dissolved aluminium, copper and iron has yet to be undertaken. Atomic Absorption Spectroscopy will be used for these analyses. Ideally, these analyses should be conducted as soon as the samples are taken, so that the chemical activity can be monitored and the solution

changed as soon as the solution has become depleted. Again, however, the sheer volume of the solution meant that chemical depletion was not anticipated as a problem.

4.2 Problems Encountered During the Treatment.

A problem that has plagued the treatment throughout its development has been the corrosion and subsequent failure of the alligator clips. Both chrome plated and zinc plated clips are prone to failure. The use of stainless steel clips was considered, but was not adopted due to the high cost and poor availability. Protective solid coatings for the clips was also considered, but problems with conductivity between the clip and the object, and cracking of the coatings on the springs precluded this option.

A coating was needed that would conduct electricity, be flexible enough to cope with flexing of the springs, be cheap and easy to apply, and provide protection from corrosion.

The alligator clips were dipped in molten Vaseline Petroleum Jelly. This made the clips a little difficult to apply. The performance of the clips coated with vaseline was not perfect, but the number of clips that failed was substantially reduced.

Because the pH of the solution is fairly neutral, and citric acid is biodegradable, algal and fungal growth occurred in the solution. The temperature of the solution, which was about 22°C also exacerbated the problem. Biological growth in the solution is undesirable because it consumes the citric acid, produces by-products whose effects are unknown, lowers the clarity of the solution, and produces offensive odours. In this treatment it also contaminated the reference electrode. Biological growth could have been avoided by adding a biocide to the solution, but this would then pose problems with the disposal of the used solution. Without the biocide, the used solution could be disposed of in the sewerage system, where it would go through the water treatment plant to be processed.

Visibility of the object through the solution dropped quite dramatically due to a combination of biological growth and the dissolution of mud that was still trapped in the wings.

During the treatment of the wings/cockpit section, some electrical problems were encountered. Disruptions to the electrical supply due to building works meant that for several periods up to two hours the object was not protected electrically.

Contamination of the reference probe by biological material in the pool also caused an incorrect potential to be applied to the wing/cockpit section during the final rinsing stage. This resulted in some minor pitting of the aluminium.

5. Conclusions

Despite the problems encountered above, the overall treatment of Oscar was considered a success. The total treatment time for Oscar, less the motor which is still to be treated, was seven months, including the erection and dismantling of the pool. The development of the treatment method has still to be perfected, with further work being needed to reduce the failure rate of the alligator clips, to eliminate flash rusting of ferrous parts, and finding environmentally friendly ways to control biological growth in the solution. The stabilization of Oscar shows that large metal composite objects can be relatively quickly and successfully electrochemically treated using biodegradable solutions, provided that of the pH, molarity and potential of the system is carefully controlled.

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