Instructor A thesis

By Rodney Norton

IB 326

A study into the effects of corrosion on metal parachute hardware due to exposure to marine environments.

Index:

	Page
Title	1
Index	2
Preface	3
Introduction	4
Corrosion of parachute assembly components	5
Types of corrosion on metal components	6
Common Metal components in parachute assemblies	7
Anti-corrosive protective finishes	9
Summary of coated surfaces	9-10
Examples of corroded metal parachute components	11-12
Stainless steel as an alternative metal	12-20
Recommended inspections of metal components:	21-22
Summary	23
Bibliography/references	24

Preface:

The past twenty years has seen a transition within the commercial sector of the Australian parachuting industry to increased numbers of skydiving operations located within close proximity to the marine environment.

The resultant increased exposure of metal parachuting hardware to the effects of corrosion and the resulting deterioration of the metal hardware on parachute assemblies may lead to a serious failure of the equipment resulting in serious injury and/or death.

As an active skydiver working in the commercial operations for the past 14 years I have directly witnessed the effects of corrosion on metal parachute assembly components via the exposure to the marine environment.

This area of concern I believe needs to be addressed in the interests of safety and the longevity of parachute assembly components.

Introduction:

There are certain types of hardware that are more susceptible to corrosion, however if the correct hardware were utilized it may greatly reduce the risk to the parachutist.

There is a necessity for corrosion resistant materials in the manufacture and development of metal parachuting hardware. The use of stainless steel as opposed to the drawbacks of electroplated steels or anodized aluminum appears to be the most obvious transition required by the manufacturer.

For the purpose of this thesis I have examined a number of tandem and sports rigs that have been used extensively within the industry and more importantly in close proximity to the marine environment

Corrosion of metal components:

The study of corrosion and corrosion products is an extremely critical subject and the average layman may not know too much about it. There are however certain aspects that should be sufficiently well known that will greatly reduce corrosion therefore lengthening the lifespan of metal components and in turn reducing friction wear on parachute webbing and associated parts directly in contact with corroded (ing) metals.

Certain aspects of dealing with corrosion should be known by parachute riggers and indeed any parachutists performing the routine inspection of their gear. With care much of the corrosion can be treated thereby, lengthening the useful life of the item, however, this will often involve removing the part from the rigging, treating the corrosion by electroplating (e.g. cadmium plating) or a chemical conversion of the surface, (e.g. black oxide) and then sewing it back into the rigging. This would prove to be a long and costly process.

Metals used in the aviation industry are usually high grade alloys specifically formulated over many years to achieve the required standard, and in many cases a certified standard demanded. If the same or consistent standard was applied to parachuting related hardware the quality of metal hardware would be greatly improved leading to a higher standard within the industry itself.

4140.

A very widely internationally used alloy is 4140. Let us take a look at the constituent parts. 4140 is a 1% chromium - molybdenum medium harden ability general-purpose high tensile steel - generally supplied hardened and tempered in the tensile range of 860 - 1130 Mpa. Brinell hardness range 265 - 330 (Rc 28 - 36). Characterized by high strength and good impact properties with good machinability, but low weld ability. Pre hardened and tempered 4140 can be further surface hardened by flame or induction hardening and by nitriding. 4140 is used extensively in most industry sectors for a wide range of applications, utilizing its considerable savings on weight and machining time over solid bar. Typical applications are: Bearings, Bushes, Cylinders (Various), Gears, Conveyor Rolls, Hydraulic Shafts, Hollow Shafts, Hollow Parts (Various), Nuts and Rings. Notwithstanding the qualities of the steel, it is still susceptible to rust and corrosion hence the necessity for the use of stainless steel.

Corrosion:

When items made of steel are subjected to moist atmosphere conditions they will commence oxidation or begin to rust. The constant exposure to the elements particularly operations which have repetitive landings on the beach, (or close proximity to the marine environment), increases the rate of corrosion of the metal plating. Rust is the common name for a very common compound, iron oxide. Iron oxide, the chemical Fe_2O_3, is common because iron combines very readily with oxygen -- so readily, in fact, that pure iron is only rarely found in nature. Iron (or steel) rusting is an example of **corrosion** -- an electrochemical process involving an anode (a piece of metal that readily gives up electrons), an electrolyte (a liquid that helps electrons move) and a cathode (a piece of metal that readily accepts electrons). When a piece of metal corrodes, the electrolyte helps provide oxygen to the anode. As oxygen combines with the metal, electrons are liberated. When they flow through the electrolyte to the cathode, the metal of the anode disappears, swept away by the electrical flow or converted into metal 'cations' in a form such as rust. For iron to become iron oxide, three things are required: iron, water and oxygen. Here's what happens when the three get together:

When a drop of water hits an iron object, two things begin to happen almost immediately. First, the water, a good electrolyte, combines with carbon dioxide in the air to form a weak carbonic acid, an even better electrolyte. As the acid is formed and the iron dissolved, some of the water will begin to break down into its component pieces -- hydrogen and oxygen. The free oxygen and dissolved iron bond into iron oxide, in the process freeing electrons. The electrons liberated from the anode portion of the iron flow to the cathode, which may be a piece of a metal less electrically reactive than iron, or another point on the piece of iron itself.

The chemical compounds found in liquids like acid rain, seawater and the salt-loaded spray from snow-belt roads make them better electrolytes than pure water, allowing their presence to speed the process of rusting on iron and other forms of corrosion on other metals.

Examples of types of corrosion.

1 Corrosion Bloom:

This type of corrosion is evident on battery terminal ports or on zinc plated items. It presents a whitish powdery "bloom". It is the result of 'sulphates' forming at the oxygen/basis metal interface that can result in fabric corrosion and sliding parts jamming.

2 Rust:

Iron or ferrous oxide, this presents as brownish colored flakes or powder. It can have the effect of severe pitting of the surface and in time can completely destroy the entire item. In the flaking stages the flakes can jam moving parts such as rings as seen on tandem drogue assemblies leading to severe friction wear of webbing and failure of deployment release systems

3 Dimensional Changes:

Corrosion can critically affect parts by reducing diameters {and indeed increasing internal diameters} by the corrosion product eating away at the surface.

Common Metal components in parachute assemblies:

The following table illustrates some of the metal parts used in parachute rigging.

These examples were taken from the leading manufacturer of metal parachute parts in America as well as leading suppliers of parachuting equipment around the world.

Part	Base Metal	Surface finish
O Ring	Aluminum	Anodized
D Ring	Steel	Cadmium plated
D Ring	Steel	Black oxide finish
D Ring	Stainless Steel	Stainless steel
Quick fit ring	Steel	Zinc Plated
Quick fit ring	Steel	Nickel plated

The above table represents only a very small selection of available hardware and provides only a broad indication of the various types of surface protection methods available.

The catalogue also states that no certification is available and while in no way do I question the personal and professional integrity of the company or personnel involved I feel that if all the component parts were of stainless steel the failure possibility would appear to be greatly reduced.

Anti-corrosive protective finishes:

1. **Anodized Aluminum:**

This is achieved by producing an oxide film on the surface of the aluminum item by immersing it in a solution of chromic acid{Chromatic anodizing} or a solution of sulphuric acid{Sulphuric acid anodizing.}The item is made anodic by connecting it to the positive terminal of a direct current generator during the process. A series of interlocking cells form over the basis metal. The item is then placed in a tank of boiling distilled water or sodium dichromate. This has the effect of closing or sealing the oxide cells shutting off the basis metal from the atmosphere.

2. **Cadmium Plating:**

Cadmium metal was chosen as a protective coating when it was found to be "self-sacrificial". This means that the coating has special properties that enable it to corrode more from the outside than closer to the basis metal thus giving it greater protection. It is not subject to sulphate bloom. The coating is produced by suspending the item in a solution that contains among others -cadmium cyanide and cadmium oxide. The plating bath contains cages of pure cadmium metal as anodes. During the process the cadmium anodes are dissolved and the cadmium ions are deposited on the item being plated, in turn forming a molecular bond with the basis metal of the item being plated. The thickness of the coating is generally about 0.0003mm.

3. **Zinc Plating:**

This is not in use on aircraft structural parts due mainly to the susceptibility of sulphate bloom and its attendant problems. This problem is further compounded by the adverse effect on surrounding parts in particular those in direct contact. Zinc plating is similar to cadmium plating however is inferior in a marine environment.

4. <u>Nickel Plating:</u>

Whilst this is in use in general aviation, its use as an anti corrosive protective is not widespread due to the cost of the ingredients and the requirement of close chemical controls of the solutions during the plating process.

5. <u>Black Oxide Finish:</u>

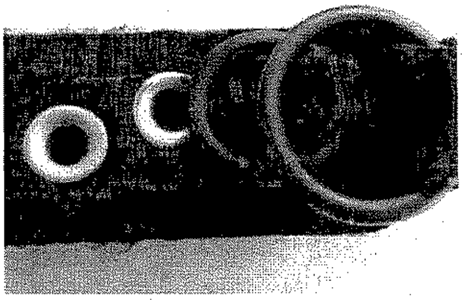
This is a soft oxide finish that is mainly used on tooling. It does however abrade easily and degrades rapidly with both use and exposure to marine environment.

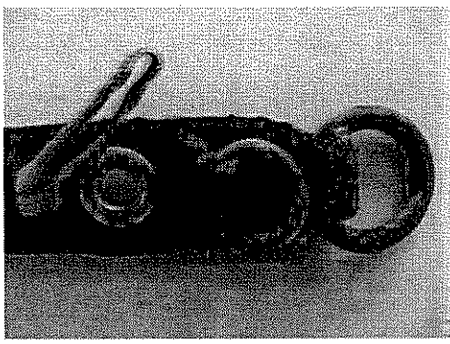
Summary of coated surfaces:

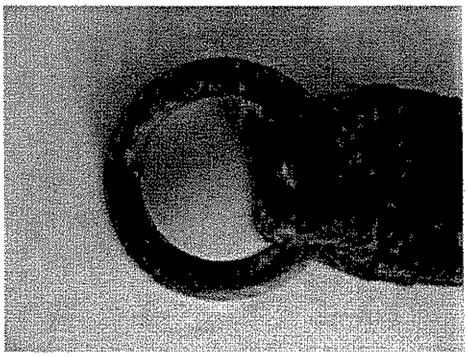
The main drawback of these coated surfaces is that like a painted surface they all have minute pinholes in their structures that go down to the base metal. In the correct atmospheric conditions moisture will enter these pinholes and work its way down to the base metal and setup the corrosion process. This will not happen to items made of marine grade stainless steel. An agreement on a common method of construction of parachute rigging parts, or standard to be adhered to, will then overcome many of the problems of corrosion in the rigging.

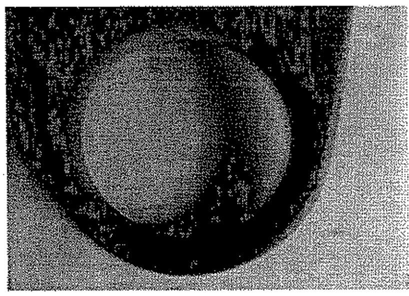
Examples of metals which are not of marine grade stainless steel can be seen below, these have been taken from a range of different manufacturers and examples of corrosion and wear resulting in corrosion can be clearly identified in the photographs.

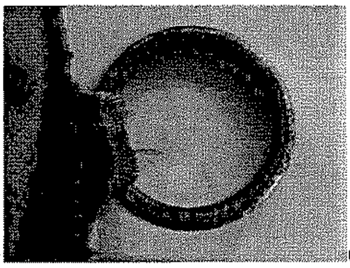
Examples of corroded metal parachute components:

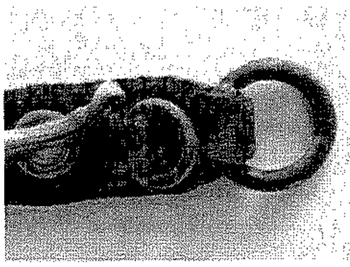

1

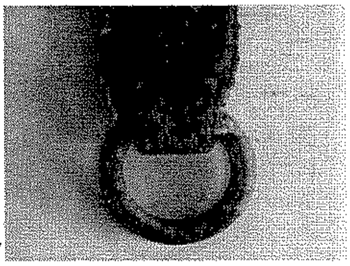

2

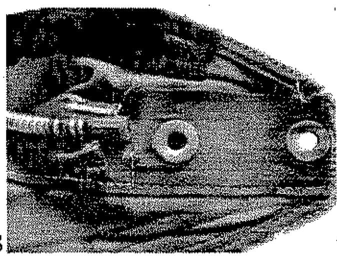

3

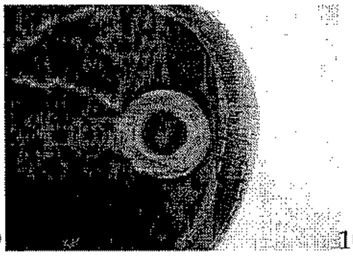

4

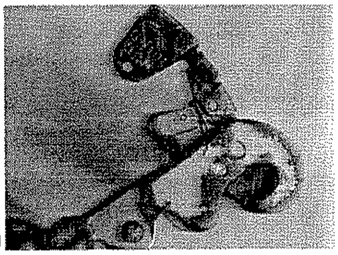

5

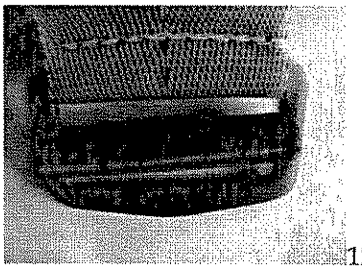

6

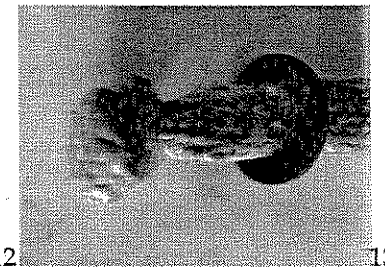

7

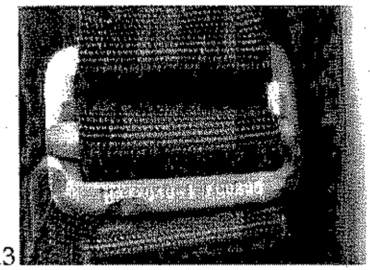

8


9


10


11


12


13

*Picture index page 24.

Alternatives to plating for metal parachute components:

1: Stainless Steel

Grade 316 is the standard molybdenum-bearing grade, second in importance to 304 austenitic stainless steels. The molybdenum gives 316 better overall corrosion resistant properties than Grade 304, particularly higher resistance to pitting and crevice corrosion in chloride environments. It has excellent forming and welding characteristics. It is readily brake or roll formed into a variety of parts for applications in the industrial, architectural, and transportation fields. Grade 316 also has outstanding welding characteristics. Post weld annealing is not required when welding thin sections.

Grade 316L, the low carbon version of 316 and is immune from sensitization (grain boundary carbide precipitation). Thus it is used in heavy gauge welded components(over about 6mm).Grade 316H with its higher carbon content has application at elevated temperatures, as does stabilized grade 316Ti.

The austenitic structure also gives these grades excellent toughness, even down to cryogenic temperatures.

Key Properties

These properties are specified for flat rolled product (plate, sheet and coil) in ASTM A240/A240M. Similar but not necessarily identical properties are specified for other products such as pipe and bar in their respective specifications.

Composition.

Table 1. Composition ranges for 316 grade of stainless steel

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
316	Min	-	-	-	0	-	16.0	2.00	10.0	-
	Max	0.08	2.0	0.75	0.045	0.03	18.0	3.00	14.0	0.10
316L	Min	-	-	-	-	-	16.0	2.00	10.0	-
	Max	0.03	2.0	0.75	0.045	0.03	18.0	3.00	14.0	0.10
316H	Min	0.04	0.04	0	-	-	16.0	2.00	10.0	-
	Max	0.10	0.10	0.75	0.045	0.03	18.0	3.00	14.0	-

Mechanical Properties.

Table 2. Mechanical properties of 316 grade stainless steels

Grade	Tensile Str (MPa) min	Yield Str 0.2% Proof (MPa) Min	Elong (%in 50mm) Min	Hardness Rockwell B (HR B) max	Brinell(HB) max
316	515	205	40	95	217
316L	485	170	40	95	217
316H	515	205	40	95	217

Note 316H also has a requirement for a grain size of ASTM No.7 or coarse

Physical Properties

Table 3. Typical physical properties for 316 grade stainless steels

Grade	Density (kg/m3)	Elastic Modulus (GPa)	Mean Co-Eff of thermal expansion (um/m/oC	Thermal Conductivity (W/m.K)	Specific Heat0-100oC (J/kg.K)	Elec Resistivity
316/L/H	8000	193	15.9 16.2 17.5	16.3 21.5	500	740

Grade Specification Comparison

Table 4. Grade specifications for 316 grade stainless steel

Grade	UNS No	Old British BS	Old British En	Euronorm No	Euronorm Name	Swedish SS	Japanese Jis
316	S31600	316S31	58H, 58J	1.440	X5CrNiMo17-12-2	2347	SU5316
316L	S31603	316S11	-	1.440	X5CrNiMo17-12-2	2348	SU5316 L
316H	331609	316S51	-	-			

Note: These comparisons are approximate only, the list is intended as a comparison of functionally similar material not as a schedule of contractual equivalents. If exact equivalents are needed original specifications must be consulted.

Possible Alternative Grades

Table 5. Possible alternative grades to 316 stainless steel.

Grade	Why it might be chosen instead of 316?
316 Ti	Better resistance to temperatures around 600-900oC is needed
316N	higher strength than standard 316
317 L	Higher resistances to chlorides than 316L, but with similar resistance to stress Corrosion cracking
904L	Much higher resistance to chlorides at elevated temperatures with good form Ability
2205	Much higher resistance to chlorides at elevated temperatures, and higher Strength than 316

Corrosion Resistance:

The metals most commonly used today in the construction of yachts, marine structures and fittings are stainless steel and aluminum. While aluminum is light, it has limited corrosion resistance in seawater and requires significant maintenance. Stainless steel, on the other hand, is recognized as the premium material for marine applications where it is used for its excellent corrosion resistance, luster, strength and stiffness.

For many boating applications grade 304 (UNS S30400/S30403) stainless steel fittings have proven adequate. The current industry standard, however, is grade 316 (UNS S31600/S31603 - commonly termed "marine grade" stainless) which offers a solution to around 90% of marine applications. Grades 304 and 316 are austenitic (300 series) stainless steels due to their metallurgical structure (austenite) which gives them excellent ductility, good strength, non-magnetic properties, good weld ability and very good corrosion resistance.

Stainless steels corrosion resistance depends on the formation of a "passive" chromium oxide film on the metal surface which is highly resistant to corrosion. In grades 304 and 316, about 18% of chromium is added to generate this film and, in 316, 2% molybdenum is added to further improve the corrosion resistance. Grade 304 is usually only suitable for fittings which are frequently washed with fresh water. Grade 316 is suitable for the construction of deck fittings and critical rigging components where salt can concentrate due to evaporation and lie in crevices - conditions which can cause pitting of 304.

Occasional failures of stainless steel due to pitting and crevice corrosion, stress corrosion cracking and fatigue have been recorded, but availability of improved materials such as duplex stainless steels, and better information on grade selection for specific operating conditions, offer solutions where there are problems.

Duplex stainless steels consist of a microstructure of approximately 50% austenite and 50% ferrite grains. The three most common types in marine applications are UNS S32304 (commonly known as 2304), UNS S31803 (2205) and UNS S32750 (2507)* and of these the most common is S31803. Some properties of S31803 include:

- yield strength twice that of 304 or 316;
- much higher resistance to pitting and crevice corrosion in seawater than 316; and
- Twice the fatigue and corrosion fatigue strength of 316.

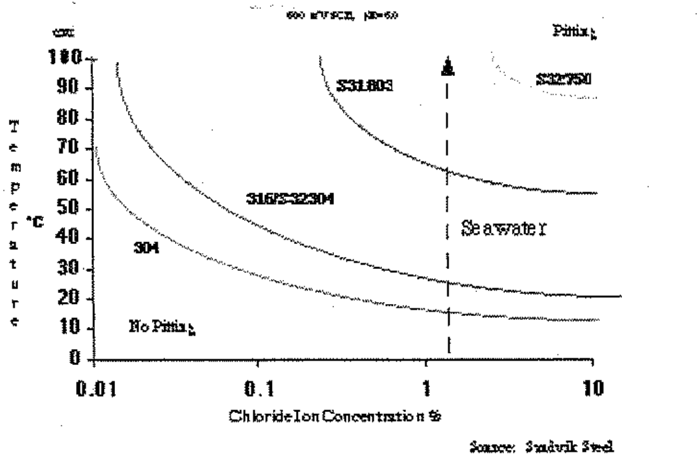
The key to obtaining optimum results from stainless steel in marine applications is the use of the appropriate stainless steel for the specific application.

* S32750 is a member of the super duplex family, which contains a number of similar proprietary alloys with different names and UNS designations.

Pitting Corrosion

The diagram below indicates the temperature and salt (chloride) concentration at which pitting occurs for various austenitic and duplex stainless steels. It is clear that in seawater 316 will perform well up to around 30çC while the more highly alloyed S32750 will not suffer corrosion at all in seawater up to boiling point.

Pitting Corrosion in Marine Applications



Crevice Corrosion

In situations where crevices exist, such as at propeller shaft glands and bearings where bolts and chain plates pass through the hull or deck, or where barnacles can grow, severe crevice corrosion can occur. As a general rule, crevice corrosion will occur at around 15-20çC below the temperature at which pitting occurs.

In many cases, grade 316 proves satisfactory. The diagram above shows that crevice corrosion can be expected in grade 316 at temperatures above 10-15çC in seawater, thus making it unsuitable for immersed applications where crevices exist. For this reason, propeller shafts made from 316 are usually galvanic ally protected. This may be with a separate zinc anode, but a bronze propeller on the 316 shaft could provide the same effect - the bronze slowly corrodes, protecting the shaft and allowing it to perform satisfactorily.

Stress Corrosion Cracking

This form of corrosion is quite common in grades 304 and 316 in wet diesel exhausts above 60çC. There have also been cases reported in cold-worked

304 and 316 rigging, chain links, deck fittings and chain plates under operating conditions. This is most usually overcome by using duplex grades or, in some special applications, high nickel alloys.

Stagnant, aerated sea water is a very corrosive medium and equipment should be designed to self drain when not in use. It may be necessary to flush and blow dry components such as cooling systems if the less resistant grades are used.

The following list of applications is a practical guide to the suitability of various stainless steel grades for specific purposes. The availability of suitable products and cost limitations has been taken into account.

The following general rules apply:

- 304 may be used for fully exposed components, frequently washed with fresh water;
- 316 may be used for all hull and deck fitting applications above the water line;
- S31803 offers higher strength and, therefore, lighter weight components for the same applications as 316 and can additionally be used up to 60çC in wet exhaust systems and in fully submersed applications; and
- S32750 offers even higher strength and weight savings, and can handle all marine applications with no risk of corrosion even in tropical waters and hot, wet exhaust applications.

While stainless steel grades 304, 316 and duplex steels can all be used in marine applications, they do provide varying degrees of corrosion resistance and durability. The key to their successful application is, therefore, being aware of the strengths and limitations of each grade and how they can be used to their optimum potential.

The corrosion resistance of all stainless steels also improves if they are kept clean. The buildup of salt encrustations, grease or dirt allows corrosion to occur in these regions. After use in marine situations, it is good practice to wash down with clean water and to remove any deposits on the surface.

Excellent in a range of atmospheric environments and corrosive media-generally more resistant than type 304. Subject to pitting and crevice corrosion in chloride environments, and to stress corrosion cracking above about 60degrees C. Considered resistant to potable water with up to about 1000mg/L chlorides at ambient temperatures, reducing to about 500mg/L at 60 C.

316 is usually regarded as the "marine grade stainless steel" but it is not resistant to warm sea water, in many marine environments 316 does exhibit surface corrosion, usually visible as brown staining, this is particularly associated with crevice and rough surface finish.

Heat resistance:

Good oxidation resistance in intermittent service to 870oC and continuous service to 925oC. Continuous use of 316 in the 425-860oC range in not recommended if subsequent aqueous corrosion is important. Grade 316L is more resistant to carbide precipitation and can be used in the above temperature range. Grade 316H has higher strength at elevated temperatures and is sometimes used for structural and pressure-containing applications at temperatures above about 500 C.

Heat treatment:

Surface treatment (annealing) -Heat to 1020-1120 C and cool rapidly. These grades cannot be hardened by thermal treatment.

Welding:

Excellent welding properties by all standard fusion methods, both with and without filler metals. AS1554.6 pre-qualifies welding of 316 with grade

316 and 316L with grade 316l rods or electrodes (or their high silicone equivalents). Heavy welded sections in 316 require post weld annealing for maximum corrosion resistance. This is not required for 316L. Grade 316Ti may also be used as an alternative to 316 for heavy section welding.

Machining:

A"Ugima" improved machinable version of grade 316 is available in round or hollow bar products. These machines significantly better than standard 316 or 316L, giving higher machine rates and lower tool wear in many operations.

Dual Certification:

It is common for 316 and 316L to be stocked in "dual certified" form, mainly in plate and pipe. These items have chemical and mechanical properties complying with both 316 and 316L specifications. Such dual certified product does not meet 316H specification and may be unacceptable for high temperature applications.

Stainless Steel Applications:

Typical applications include:

- Food preparation equipment particularly in chloride environments.
- Laboratory benches& equipment.
- Coastal architectural paneling, railing and trim.
- Boat fittings.
- Harness Fittings.
- Chemical containers, including for transport.
- Heat exchangers.
- Woven or welded screens for mining, quarrying& water filtration.
- Threaded fasteners.
- Springs.

Recommended Inspections of metal components:

As part of the regular visual inspection of parachute assemblies, hardware should also be inspected. Generally once you notice the plating 'peeling' off the inspection should include determining the extent of corrosion to any metal surfaces and the level of abrasiveness of this corrosion.

It is almost impossible to inspect some parts of hardware due to them being covered by webbing and only when a parachute/container system has been retired and cut up can you fully see the results of corrosion.

Generally before a parachute assembly/container has been retired, the process to remove some metal parts from the assembly will raise the question of economics, the cost of repair versus retirement.

Cleaning:

Once the hardware has been inspected there exist a number of methods to maintain the hardware.

Emery paper: Used to smooth over any rough surfaces such as rust and scratches which leave the base metal exposed thus exposed to the elements. Once you have started using emery paper you will need to keep inspecting the part more frequently than the normal inspection process, due to the emery paper further removing surface plating and exposing more metal surfaces to the environment.

Buffing wheel/Dermal tool:

Used to polish hardware giving it a smoother finish, a dermal tool with interchangeable bits is a very handy tool as it can access areas too small to use with a buffing wheel and the bits that you can buy have a varied range of uses giving there rigger a greater number of options for the maintenance of the hardware. The interchangeable bits can be used first to clean the surface of any corrosion or rough surfaces and then changed to polish the hardware.

Silicone/Graphite:

Components such as side ejectors on passenger harnesses that have internal springs and drogue riser rings can be sprayed with a fine grade graphite or silicone. An awareness of the buildup of sand in the hard to reach spaces can be alleviated by use of a high pressure air tool to blow out any buildup of sand. Using an air tool keeps the surfaces dry and enhances the application of the silicone/graphite directly on the metal surfaces.

On parts such as drogue risers or any metal part that is covered by webbing, the inspection process must ensure that there is no corrosion on the metal component that may affect or alter the structural integrity of the webbing surrounding it.

To date no evidence has presented itself to prove this to be the case and all containers run the duration of their life. The replacement of the 'L' bar on strong container systems when corrosion is detected prevents the damage of the drogue riser assembly.

Testing:

Once a container has been retired, cut out/extract the parts that were not visible by normal inspection, you will then have a clearer picture of what is occurring internally to the webbing and the metal hardware alike.

Once you have removed metal components it can be established what the useful life of assembly is for your environment.

The documenting of the components, and further testing of load-bearing capabilities of the webbing will enable further determinations as to the useful life of assemblies at your location.

This process will provide an on-hand guide in conjunction with any manufacturer's recommendations for those carrying out inspections as to useful lifespan of rigs within your organization.

Some parts will wear out faster or slower due to repetitive use and the above are a guideline , Riggers and manufacturers should be consulted in the decision making process in the life of your parachute.

Summary:

This thesis has examined many of the effects of corrosion on non stainless steel hardware components commonly used in parachute assemblies.

It has revealed that there is a need for Stainless Steel to be more widely used in parachute rigging. All major metal fittings and/or hardware used in marine craft, (subjected to higher levels of exposure to marine environments), are made or ideally from stainless steel. This is for one reason; stainless steel's resistant properties to corrosion are far greater than any other metals currently used in parachute assemblies. The reduced wear and tear to the parachute assembly by using stainless steel is without doubt far safer to the parachutist as a whole.

The study of the effects of corrosion from exposure to the marine environment on metal, (non stainless) components in use in parachute assemblies also shows the need for these items to be included in the routine inspection process of parachute equipment as carried out by organizations.

Bibliography:

- Technical details from Canning's Handbook of Electroplating.
- Journal of the American Society of Electroplaters.
- Hawker De Havilland journals
- The Parachute Manual-Dan Poynter

Photographic Index:

1:	Drogue riser:	*(Note the wear on the forged rings however the stainless steel grommets show no signs of corrosion)*
2:	Riser corrosion	
3:	Riser Corrosion	
4:	Style ring	
5:	Solid ring:	*(Commonly used for passenger attachments).*
6:	Riser corrosion	
7:	Riser corrosion	
8:	Closing flap grommets:	*(Copper grommet corrosion as with the cap on the bendix housing)*
9:	Closing flap grommets:	*(Note the green corrosion on the copper grommet)*
10:	Quick ejector:	*(Nickel plating peeling due to effects of corrosion and poor electroplating procedures)*
11:	Quick fit adapter	
12:	Closing loop washer	
13:	Leg strap quick fit adapter	

Reference Index:

- Mr. Marcel Van Neuren; Gravitator Air ware APF R122
- Mr. Max Wallace APF R22
- Bourdon Forge Company Inc
- The Australian Skydive Company