Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

COMPANY CONFIDENTIAL
NLR-CR-2014-129

Inventory of corrosion occurrences on two NH90 helicopters after operation in tropical and saline environment

L. 't Hoen-Velterop

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Anthony Fokkerweg 2
P.O. Box 90502
1006 BM Amsterdam
The Netherlands
Telephone +31 (0)88 511 31 13
Fax +31 (0)88 511 32 10
www.nlr.nl

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Executive summary

Inventory of corrosion occurrences on two NH90 helicopters after operation in tropical and saline environment

NH90 helicopter landing on a ship

Report no.
NLR-CR-2014-129

Author(s)
L. 't Hoen-Velterop

Report classification
COMPANY CONFIDENTIAL

Date
May 2014

Knowledge area(s)
Vliegtuigmaterialen
Levensduurbewaking en onderhoud van vliegtuigen

Descriptor(s)
corrosion
NH90
saline operation
inventory

Problem area The Royal Netherlands Air Force has acquired NH90 helicopters for marine missions, amongst which are ship-bound missions in tropical regions. Widespread corrosion is found during routine maintenance inspections of two helicopters with each about 250 flight hours in saline environment. The degree of corrosion in the short time period has led to the initiation of an inventory of the corrosion damage.

Description of work
The corrosion inventory on two NH90 helicopters is performed in cooperation with the Royal Netherlands Air Force. The type of corrosion and potential preventive measures are identified for each of the corrosion findings. Additionally the findings are classified according to their probable cause. In this classification a distinction is made between insufficient application of corrosion protective measures, the use of materials that are ill-suited for application in saline environment, errors in design and wrong manufacturing where the assembly does not comply with the instructions.

Results and conclusions
Similar corrosion is found on both helicopters. The corrosion preventive measures that were taken on one of the helicopters have worked rather well. The consequence of some of the measures was that the corrosion shifted to the one-but-least noble metal because the least noble metal was protected. Much of the corrosion occurred because prevention of galvanic coupling was not taken into account in the design. Galvanic coupling of metals to carbon fiber reinforced composites leads in almost all cases to accelerated and widespread corrosion of the metal when it comes in contact with a corrosive environment. Electrical insulation of the metal from the carbon fibers by using

for instance jointing compound or sealant prevents the galvanic coupling and hence the accelerated corrosion. Other causes for widespread corrosion are the absence of sealant, although the assembly instructions clearly state that sealant should have been applied, and ill-applied sealant that allows water to enter the joint.

The remaining causes of corrosion are the use of materials that are not resistant to corrosion in salt water environment or component designs where the operational use of the helicopter, like folding of the tail on ships, was not taken into account in the design of the structure and thereby some design details act as water entrapments in some circumstances.

Applicability

The results of the corrosion inventory can be used to reduce the corrosion sensitivity of the NH90 helicopter. This will lead to an improved operational availability of the helicopter. The results can also be used as guidance for acceptance inspections of helicopters that are not yet delivered.
It should be noted that the corrosion analyses in the report are preliminary and based on visual inspections only and that the preventive measures are an advice meant to assist in improving the corrosion resistance of the helicopter. They are not meant as maintenance instructions.

Nationaal Lucht- en Ruimtevaartlaboratorium, National Aerospace Laboratory NLR

Anthony Fokkerweg 2, 1059 CM Amsterdam,
P.O. Box 90502, 1006 BM Amsterdam, The Netherlands
Telephone +31 88 511 31 13, Fax +31 88 511 32 10, Web site:
www.nlr.nl

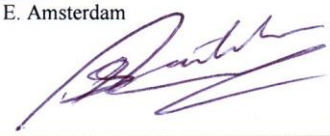
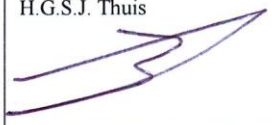
Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

COMPANY CONFIDENTIAL
NLR-CR-2014-129

Inventory of corrosion occurrences on two NH90 helicopters after operation in tropical and saline environment

L. 't Hoen-Velterop

Customer	Defence Materiel Organisation
Contract number	712.0.07104.01
Owner	Defence Materiel Organisation
Division NLR	Aerospace Vehicles
Distribution	Limited
Classification of title	Unclassified
	May 2014
Approved by:	

Author			Managing department
L. ‘t Hoen-Velterop	Reviewer E. Amsterdam  Date: 08-05 '14	Managing department H.G.S.J. Thuis  Date: 8-5-2014	H.G.S.J. Thuis
Date:	Date:		Date:

COMPANY CONFIDENTIAL

Summary

Two NH90 helicopters are subjected to a corrosion inspection after almost 250 flight hours in saline environment. The inspections are performed by maintenance personnel of the Royal Netherlands Air Force. The corrosion occurrences are confirmed by inspections by NLR personnel.
NLR performed a preliminary analysis based on the visual appearance and the materials involved. The analysis incorporated the type of corrosion, the probable cause of corrosion and potential corrective measure to prevent corrosion in the future. Finally the corrosion occurrences are classified according to their probable cause: the absence of sufficient corrosion preventative measures and errors in materials selection, design or assembly.

In total 92 corrosion occurrences are reported. They are classified as follows:

- 52 caused by insufficient corrosion protection
- 20 caused by wrong materials selection
- 20 caused by wrong design
- 14 caused by wrong manufacturing.

Note that some of the occurrences reported are actually clusters of corrosion occurrences that are clustered for convenience and that fourteen occurrences obtained double classifications.

Contents

Abbreviations

AFB	Air Force Base
ATLA	Automatic Tail Locking Actuator
CFRP	Carbon Fibre Reinforced Polymer
CPC	Corrosion Preventive Compound
ECS	Environmental Control System
EECU	Electronic Engine Control Unit
FOC	Fully Operational Capable
FWD	Forward
IETP	Interactive Electronic Technical Publication
ML	Maintenance Level

MOC	Meaningful Operational Capable
MRA	Main Rotor Actuator
MRBFA	Main Rotor Blade Folding Actuator
MRSLA	Main Rotor Safety Lock Assembly
NFH	NATO Frigate Helicopter
NLG	Nose Landing Gear
NLR	National Aerospace Laboratory
RH	Right Hand
RNLAF	Royal Netherlands Air Force
RTH	Reaction Torque Housing
SB	Service Bulletin
SCD	Sliding Cabin Door
SDE	Supportability Data Exchange
SR	Service Request
TGB	Tail Gear Box

1 Introduction

NLR is asked to make an inventory of the corrosion occurrences on two NH90 helicopters operated by the Royal Netherlands Air Force. The details of the helicopters are listed in Table 1. The inventory is based on a number of visits to the helicopters and discussions with RNLAF (maintenance) personnel. The photographs in the report are delivered by the RNLAF. The work is performed in the framework of the NH90 NLR support contract number 712.0.07104.01 (Ondersteuning PB NH90 2010-2014).

Table 1 NH90 helicopter usage and inspection details

Tail number	N227	N233
Maintenance program	600 hours inspection & 3 years saline inspection	300 hours inspection & 1 / 2 years saline inspection
Start of the inspection	28 August 2013	Week 4, 2014
Total number of flight hours	511.3	299.3[1)]
Total number of saline[2)] flight hours	243.9	246.9
Total number of folding cycles	148	94

[1)] The helicopter has had about 50 flight hours in Italy before being handed over to the RNLAF.

[2)] Saline conditions prevail not only on ships but also on Naval Air Base De Kooy.

Areas of operation	Somalia (20/01/2013 – 08/06/2013)	Caribbean (11/08/2013 – 13/12/2013)
Visit date(s)	29 Jan 2014, 13 Feb 2014, 19 Feb 2014, 19 Mar 2014	6 Feb 2014
Location	Gilze-Rijen AFB	Naval Air Base De Kooy

The inventory of corrosion issues on the N227 and the N233 is frozen on 20 March 2014 for reporting in the present report. The corrosion inspections on the N227 have been continued since then and many more corrosion occurrences are found. These new occurrences will be reported in Issue 2 of the report. Additionally all corrosion findings will be incorporated in the supportability data exchange (SDE) database.

1.1 General remarks:

Both helicopters are NATO frigate helicopters (NFH), which are designed for use on ships. N227 is a MOC (Meaningful Operational Capable) helicopter, while N233 is a FOC (Fully Operational Capable) helicopter. The corrosion protection measures are the same on both helicopters. Differences between the MOC and FOC version are, amongst others, the intermediate gearbox housing (aluminium in the MOC and magnesium in the FOC), the nose landing gear and several of the avionics systems.
The FOC version is supposed to be better suited for operations in saline environment but comparison of the corrosion found on the N227 (MOC) and the N233 (FOC) shows that both versions are equally sensitive to corrosion. The corrosion on the N233 is slightly less severe than on the N227 because corrosion preventive measures (grease) are applied to the N233 based on the results of the 300 flight hours inspection of the N227 and because the N233 has less flight hours than the N227. Another difference that may have contributed to the difference in corrosion is the height (above sea level) of the helicopter deck of the ship they were stationed on. This height was significantly larger for the N233 than for the N227.

The corrosion seems to be more severe on the right hand side of the N227 than on the left hand side. This may have to do with asymmetrical air flow when flying with the cabin door open. Another possible explanation lies in the landing procedure on deck: the helicopter approaches the ship from the left and lands sideways on the ship. A third option is the orientation of the helicopter on the ship. If the right hand side faces the ocean it can be expected that this side of the helicopter experiences more salt water spray than the left hand side that is facing the ship.

Rinsing of the helicopter has to be done after each flight, to remove salt and reduce the risk of corrosion. Since at higher sea states the rotor blades and tail of the helicopter must be folded and secured within 20 minutes after landing on deck, this leaves no time for rinsing. Hence

rinsing is done in folded state. The more extensive and less frequent washing of the helicopter is done in operational state, with the rotor blades and tail unfolded.
Salt deposits are generally found in location where humid air enters the helicopter during operation. However, some of the salt deposits are found in locations where the salt must have been deposited during rinsing operations, by drying of run-off waters or by air circulation that was unforeseen.

Some components on the N233 helicopter had been protected against corrosion before its mission to the Caribbean. This indeed prevented corrosion on the protected components, but resulted in corrosion on some of the components next to the protected ones. An example is the fan casing on the upper deck, where the unprotected mounting bolts and nuts are corroding on the N227. These bolts and nuts are protected with grease on the N223 and hence they do not corrode, but the fan casing itself started corroding. For some components it may be more economical to let the cheap components corrode and replace them periodically. This way they protect the more expensive components against corrosion. Another option that will protect the whole assembly is to add sacrificial components of less noble material than the components that need protection, like the sacrificial anodes used on the submerged parts of the hull of ships.

Electric currents can accelerate corrosion. The effect of electric currents on corrosion is well known for buried structures like pipelines, where stray current corrosion is found at locations where the currents leave the structures. Helicopters are known to generate a lot of static electricity. If this electricity can leave the metallic components at unforeseen locations, for instance through the presence of a salt water film on the surface, this may cause stray current corrosion.

1.2 Corrosion analysis

A preliminary corrosion analysis has been performed on all corrosion findings. These analyses are based on the visual appearance and the available information regarding materials and corrosion preventive measures. Based on the analyses a number of corrosion preventive measures are identified to reduce the risk of corrosion once the corrosion is corrected or the component is replaced.
The information about materials and protective measures are delivered by RNLAF maintenance personnel.

The tables in chapters 2 to 6 list the details of the corrosion findings:

- the part location (ATA-code),
- part identification and manufacturer code (NCage code),
- some images of the corroding component,

- the preliminary analysis containing ○ the corrosion cause, ○ corrective and/or preventive measures,
    - the reference numbers if a service request (SR) has been filed or a service bulletin (SB) has been issued and
    - the classification of the corrosion (see also section 1.3 for further explanation of the classification).

1.3 Corrosion classification

All corrosion occurrences are classified according to their probable cause. The classifications used are:

- Wrong design.
  Insufficient measures are taken to prevent corrosion. This classification focusses on the geometry of design and incorporates a design where water could collect or drainage holes that are positioned in the wrong location for draining all water in all situations. Materials selection, protective coatings and sealants are not incorporated in this classification.
- Wrong manufacturing.
  Manufacturing is not according to the specifications. Manufacturing according to superseded drawings and specifications is also included in this classification.
- Wrong materials selection.
  The materials selected are corrosion sensitive in a salt water environment or enhance galvanic corrosion while components with corrosion protective coatings or corrosion resistant materials could and should have been selected.
- Insufficient corrosion protection.
  Insufficient measures are taken to prevent corrosion. This classification focuses on the application of corrosion preventive materials. It incorporates lack of insulation between different materials thereby enabling galvanic corrosion, the absence of sealant, grease or corrosion preventive compounds to prevent contact with water or water entry in recesses, crevices and components.

The corrosion findings are grouped, each group covering an area or functional group of the helicopter. The groups are:

- Fuselage: zone 100 ○ Forward fuselage: zones 110, 120, 130 ○ Center fuselage: zones 140, 150, 160, 180, 190 ○ Upper fuselage (upper deck)
- Cockpit: zone 200 ○ Aft section: zone 300 ○ Intermediate structure: zones 310, 330 ○ Tail: zones 340, 350
- Power plant, transmission and rotors: zone 400
- Landing gear and sponsons: zone 700

2 Fuselage: zone 100

2.1 Forward fuselage: zones 110, 120, 130

Tail number		N227, N233
ATA nr		53-10
NCage code		Not applicable. Nose section NCage code C0418
Picture(s)		 
Corroding component		Steel fastening ring in titanium rivets
Component coupled to		Carbon fibre reinforced polymer (CFRP) fuselage (FWD part)
	Corrosion cause	The CFRP fuselage has a glass outer ply to reduce galvanic coupling, but the rivets are installed dry. This leads to galvanic coupling of the rivets with the fuselage. The component with lowest potential corrodes when (salt) water can enter the rivets from the outside or from the inside. In the present case the corroding component is the steel ring that holds the stem of the rivet.

Preliminary analysis	Corrective and/or preventive measures	Wet installation of the rivets when they are replaced. Sealing of the rivets on the inside with a soft film corrosion preventive compound (CPC).

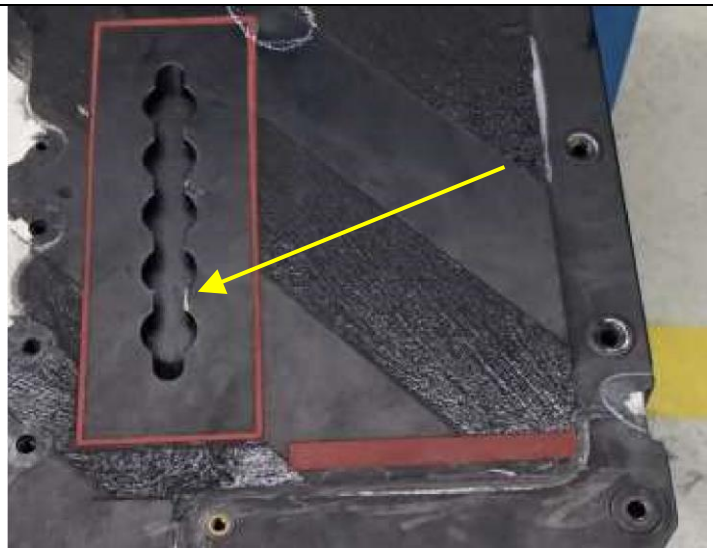
	SR / SB ?	SR 1-10302047 document ED_NH_227_009 describes the corrective measures to be taken to replace the rivets (drilling out of the corroded ones and replace them, use with oversized rivets if necessary). Note that replacement of the rivets is not a straightforward procedure. Some of the rivets are very hard to reach from the back side, hence supporting the CFRP skin during drilling out of the rivet is not possible. Unsupported drilling out may lead to delamination of the CFRP skin near the hole. Rivets in forward fuselage: ASNA 0341T05xx Rivets in window frame, below rubber seal: CR 7770S-04-03W
	Classification	Insufficient corrosion protection

Tail number		N233
ATA nr		24-44
NCage code		S244A4001051:F0210
Picture(s)		Not available
Corroding component		Recess for external power connection shows water staining and some corrosion of the attachment bracket (RH fuselage)
Component coupled to		CFRP fuselage
Preliminary analysis	Failure cause	Water ingress is possible while draining of the area is not foreseen. This leads to stagnant water and possible corrosion of the aluminium bracket.
	Corrective and/or preventive measures	Improve sealing of the hatch, for instance with grease or a soft film CPC between the hatch and the fuselage. Allow draining of the recess to prevent stagnant water.
	SR / SB ?	
	Classification	Wrong design

Tail number		N227, N233
ATA nr		53-10
NCage code		Not applicable, too many different components
Picture(s)		Not available
Corroding component		Several bolts and nuts behind the fairing of the forward fuselage of the helicopter; aluminium mounting trays of electronic equipment.
Component coupled to		CFRP structure of the helicopter and metallic components (several metals)
Preliminary analysis	Failure cause	The cover is closed with a quick release system and rubber seals. This allows water to enter the area. Water stains show that stagnant water has been present. Galvanic coupling of the bolts to the CFRP fuselage accelerated the corrosion of the fasteners. The mounting trays are bolted onto the CFRP structure without proper insulation to prevent galvanic corrosion.
	Corrective and/or preventive measures	Apply a corrosion preventive compound to the fasteners and mounting trays (e.g. grease, hard film CPC or sealant) and take measures to prevent stagnant water (e.g. drainage holes). Mount all fasteners wet to prevent galvanic coupling to the CFRP structure of the helicopter. Improve the sealing of the rubber seals by using grease on the seals.
	SR / SB ?	M5 notification: 10199296
	Classification	Insufficient corrosion protection

Tail number		N233
ATA nr		24-33
NCage code		170CH-1:F6177 and/or S243A30A1001:F0210
Picture(s)		Not available
Corroding component		Aluminium bracket at the battery connection
Component coupled to		CFRP fuselage
Preliminary analysis	Failure cause	Stagnant water has caused corrosion of the aluminium bracket.
	Corrective and/or preventive measures	Prevent stagnant water by sealing the entry and by adding a drainage hole. Seal the bracket to prevent contact with water.
	SR / SB ?	
	Classification	Wrong design

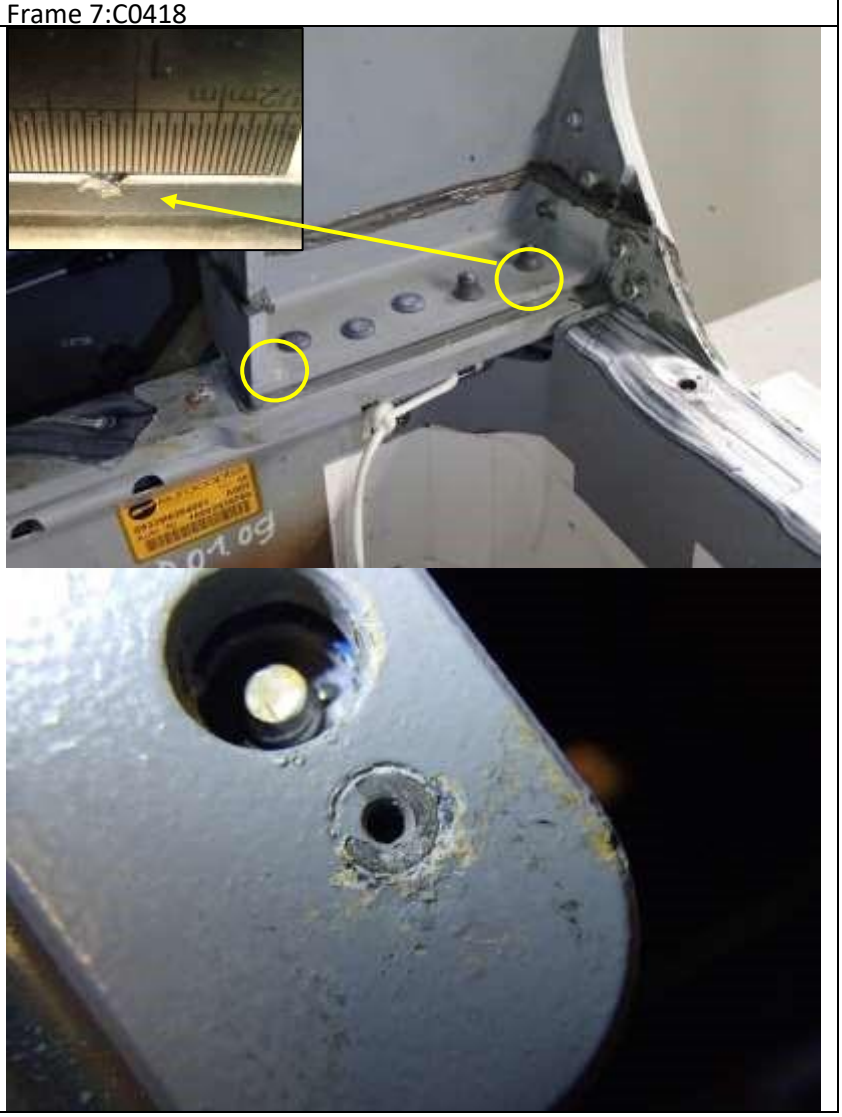
2.2 Center fuselage: zones 140, 150, 160, 180, 190

Tail number		N227, N233
ATA nr		53-35
NCage code		S533M5080051:C0418, S533M5079051:C0418, S533M5089051:C0418
Picture(s)		
Corroding component		Aluminium tracks in the cabin floor
Component coupled to		Titanium fasteners, CFRP structure of the helicopter
Preliminary analysis	Failure cause	Paint on the tracks may get damaged because components are attached to the floor (mechanical damage). At those locations corrosion can start if these locations get into contact with salt water. Galvanic coupling of the aluminium tracks to the CFRP structure and titanium fasteners leads to accelerated corrosion of the aluminium. According to the IETP sealant should be applied, but this was not done.
	Corrective and/or preventive measures	Electrically insulate the aluminium from titanium and CFRP (wet installation of fasteners, use jointing compound between fasteners and aluminium and between aluminium and CFRP). Repair the paint when damaged. Apply temporary corrosion protection (hard film CPC).
	SR / SB ?	SR: 1-111-32076
	Classification	Insufficient corrosion protection Wrong manufacturing

Tail number	N227, N233
ATA nr	53-35
NCage code	S533M5080051:C0418, S533M5079051:C0418, S533M5089051:C0418 Assembly of floorpanels: A0126

Picture(s)	
	
Corroding component	Aluminium floor panels
Component coupled to	Titanium fasteners

Preliminary analysis	Failure cause	Galvanic coupling of the aluminium floor panels to titanium fasteners leads to corrosion of the aluminium if the paint is damaged and water can reach the metal. Paint damage occurs readily when mounting the floor panels. The lack of sealant between the floor panels enables water leakage into the floor, thereby enabling corrosion at the bottom of the floor panels.
	Corrective and/or preventive measures	Electrical insulation of the floor panels from the fasteners by wet installation of the fasteners and application of jointing compound. Application of jointing compound or CPC between the fasteners and floor panels or sealing of the fasteners after installation would prevent galvanic corrosion. Sealing of the floor panels prevents water leakage into the area underneath. According to the manuals, TP42 grease should have been used on the bolts, but this was absent.
	SR / SB ?	SR: 1-111-32076
	Classification	Insufficient corrosion protection Wrong manufacturing

Tail number	N233, N227
ATA nr	53-30
NCage code	Frame 7:C0418
Picture(s)	

		
Corroding component		Corrosion on fasteners and frames at the inside of the doorpost
Component coupled to		CFRP fuselage
Preliminary analysis	Failure cause	The aluminium lower part of frame 7 is painted, but damage to the paint results in fast pitting corrosion. No paint/primer is applied to the inside of the doorpost, leaving the fasteners unprotected. If water enters the area, then corrosion can start. Galvanic coupling of the fasteners with the CFRP fuselage is an issue that can speed up corrosion.
	Corrective and/or preventive measures	Apply primer to the inside of the doorpost. Apply sealant or a hard film CPC to the fasteners at the inside of the doorpost.
	SR / SB ?	SR: 1-11542683
	Classification	Insufficient corrosion protection

Tail number		N227
ATA nr		28-24
NCage code		Pressure refuelling valve: S282M4003000:C0418 Grounding: S282M4022051:C0418, LN29736E:D8442
Picture(s)		Not available
Corroding component		Bolts of the pressure refuelling system and grounding point (inside the doorpost)
Component coupled to		CFRP fuselage
Preliminary analysis	Failure cause	Water condensation occurs during pressure refuelling when cold fuel is taken in. The water is trapped behind the cabin panels and causes corrosion of the least noble metals in contact with the CFRP skin. Additionally part of the doorpost is open to allow inspection of the valve before refuelling. Through this hole salt water can enter the interior of the doorpost.

	Corrective and/or preventive measures	Apply primer or sealant to the bolts in the area of the pressure refuelling system. Close the inspection hole with a transparent plastic window to prevent salt water entering the interior of the doorpost and seal the window.
	SR / SB ?	Not yet
	Classification	Insufficient corrosion protection

Tail number		N233
ATA nr		56-21
NCage code		S562M1000000:C0418
Picture(s)		Not available
Corroding component		Area under the windows in the cabin
Component coupled to		Not applicable
Preliminary analysis	Failure cause	Water leaks from the sides of the windows into the area between cabin panels and fuselage. The window sealant fails due to rattling of the window during operation of the helicopter. This rattling is enabled by the large difference in stiffness between very stiff CFRP fuselage and floppy window that is bolted with only 6 bolts on either side of the window (12 in total).
	Corrective and/or preventive measures	Change the window material to a stiffer material. Use more bolts to fasten the window, instead of relying on the sealant. Use a more flexible sealant that can withstand the rattling of the window.
	SR / SB ?	
	Classification	Wrong design Wrong material selection

Tail number	N227
ATA nr	52-13
NCage code	S521F3000200:H1822
Picture(s)	 
Corroding component	Corrosion of the sliding door hinge and jettison system
Component coupled to	Several steel grades, CFRP door structure

Preliminary analysis	Failure cause	Galvanic coupling of steel components to CFRP structure of the door accelerated corrosion of the plain steel (or cadmium plated) components. Corrosion of some of the components is severe and led to blocking of the movement so that the jettison system was not functioning anymore. According to the IETP the system should be installed with grease and anti-seize compound to prevent corrosion and seizing of the materials. This has not been applied during manufacturing and installation of the door. According to the manufacturer this is not included in their manufacturing and assembly documentation.
	Corrective and/or preventive measures	Apply grease to the system to delay corrosion. This is done for the N233 after the 300 hours inspection of the N227 and has worked well. Follow the IETP and assemble the sliding door assembly with grease and anti-seize compound. Select other materials for the operating mechanism: materials that are more corrosion resistant and more compliant with each other (from a corrosion point of view).
	SR / SB ?	SR: 1-10180263 SB will be issued: replace hinge if corroded and use a fluid film product (AV25) to prevent corrosion and salt built-up. This is in contradiction with the IETP. An SB is issued that pre-scribes a monthly test of the jettison system.
	Classification	Wrong material selection Wrong manufacturing (documentation)

Tail number		N227, N233
ATA nr		28-12
NCage code		S281M2000000:C0418
Picture(s)		Not available
Corroding component		Aluminium plates at bottom of bladder fuel tanks
Component coupled to		CFRP fuselage
Preliminary analysis	Failure cause	The aluminium plates are directly connected to the fuselage without any electrical insulation. This leads to accelerated galvanic corrosion of the cadmium plated steel bolts and the aluminium plates. This corrosion is possible because water can enter the fuel tank area through the gaps between the floor panels. The floor should have been sealed to prevent water entry along the gaps between the floor panels. Water (spray) entry into the cabin cannot be prevented when flying with the door open. Additionally the cadmium-plated bolts that are exposed on the outside of the fuel tank, next to the fuel drainage holes, show corrosion of the plating. This corrosion of the plating on the bolts protects the aluminium plate. Galvanic coupling to the CFRP fuselage accelerated the corrosion of the cadmium plating.
	Corrective and/or preventive measures	Temporary measure issued by the industry: GFRP insulation plate between aluminium and CFRP to prevent galvanic coupling. Additionally the bolts should be installed wet to prevent contact between the bolt and the CFRP skin. Sealing of the floor panels will prevent water entry into the fuel tank area.
	SR / SB ?	SB will be issued: temporary solution is a glass shim between the CFRP skin and aluminium plate. The permanent solution will be to apply a glass liner in the fuel tank area on which the aluminium plate will be mounted. Note that the bolts to be used must be wet installed to prevent galvanic coupling of the aluminium plate to the CFRP fuselage.
	Classification	Insufficient corrosion protection (aluminium plate) Wrong manufacturing (absence of sealant in floor panels)

Tail number	N227
ATA nr	93-51
NCage code	S935M10A1003:C0418

Picture(s)		
Corroding component		Corrosion of antennas (IFF=identification friend or foe)
Component coupled to		CFRP fuselage and CFRP tail
Preliminary analysis	Failure cause	Water can enter the lower fuselage through the open door and openings in the floor between the panels. Cracking of the paint or sealant then allows the water to enter the connection of the antenna and cause corrosion. Galvanic coupling of the metal parts to the CFRP fuselage accelerates the corrosion.
	Corrective and/or preventive measures	Replace antenna. Use self-levelling green to prevent water ingress along fasteners and along the lap joint of the antenna connection. Seal the floor panels.
	SR / SB ?	SR 1-10883695
	Classification	Insufficient corrosion protection

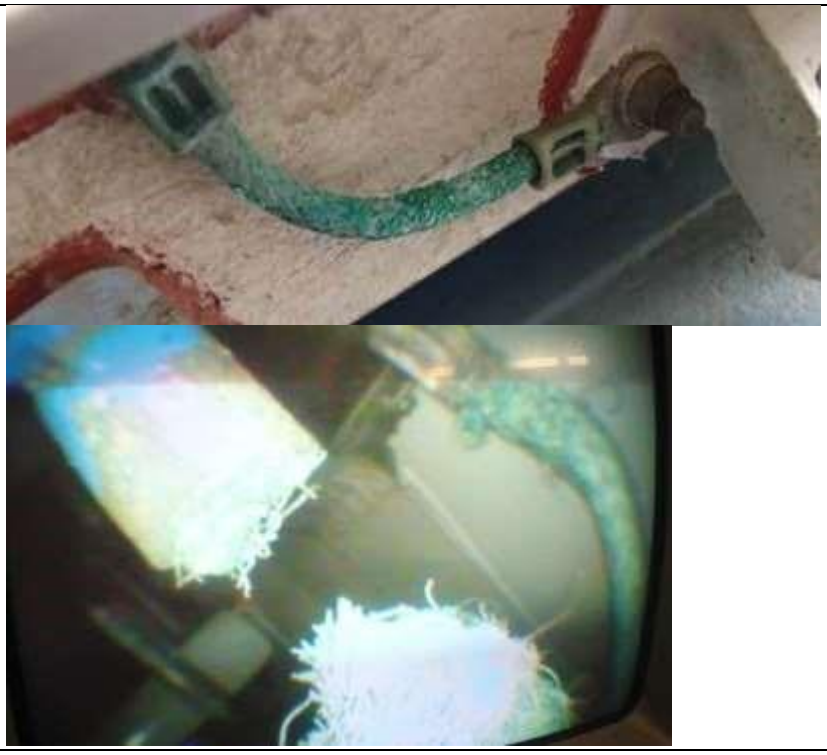
Tail number	N227
ATA nr	34-52
NCage code	S345M20A1003:C0418

Picture(s)		
Corroding component		Corrosion antenna connections (DF = direction finder)
Component coupled to		CFRP cover and fuselage and stainless steel bushings and fasteners
Preliminary analysis	Failure cause	Absence of sealant that should have been present allowed widespread corrosion of the aluminium connections of the antenna box. The aluminium is bolted to the CFRP cover of the antenna, resulting in galvanic corrosion of the aluminium. The corrosion was further accelerated by the presence of stagnant water due to drainage holes that were not at the lowest location. Additionally water could enter the lap joint connecting the antenna
		cover to the fuselage and cause corrosion of the copper bonding strips.

	Corrective and/or preventive measures	Apply sealant over the aluminium connections as prescribed. Apply sealant over the lap joint of the antenna cover with the fuselage. Ensure proper draining of the cover (drainage hole at the lowest point, if necessary use sealant to fill up the lower areas).
	SR / SB ?	SR: 1-10945893
	Classification	Wrong manufacturing

Tail number		N227, N233
ATA nr		53-36
NCage code		S533M0068101:C0418
Picture(s)		Not available
Corroding component		Attachment lug for boarding steps
Component coupled to		Titanium bolts
Preliminary	Failure cause	Crevice corrosion of the aluminium lugs is potentially accelerated by galvanic coupling of the lug to titanium bolts.
	Corrective and/or preventive measures	Application of jointing compound in the hole of the lug, to prevent electrical contact between the titanium bolt and the aluminium lug and to prevent water ingress in the area between bolt and lug.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number		N227
ATA nr		53-30
NCage code		DIN65307-0512B:D8286
Picture(s)		Not available
Corroding component		Sponson attachment lug
Component coupled to		CFRP fuselage
Preliminary analysis	Failure cause	The attachment lug consists of a cadmium plated bushing in an aluminium housing. The aluminium housing of the attachment lug is corroding. The cadmium plating may be damaged during installation of the bushing in the aluminium housing. The assembly is poorly sealed, which allowed water to get into contact with the bare metal. This lead to galvanic corrosion of the cadmium plating followed by corrosion of the aluminium lug.
	Corrective and/or preventive measures	Seal the bushings after installation. Seal the assembly to prevent contact with water.
	SR / SB ?	
	Classification	Insufficient corrosion protection

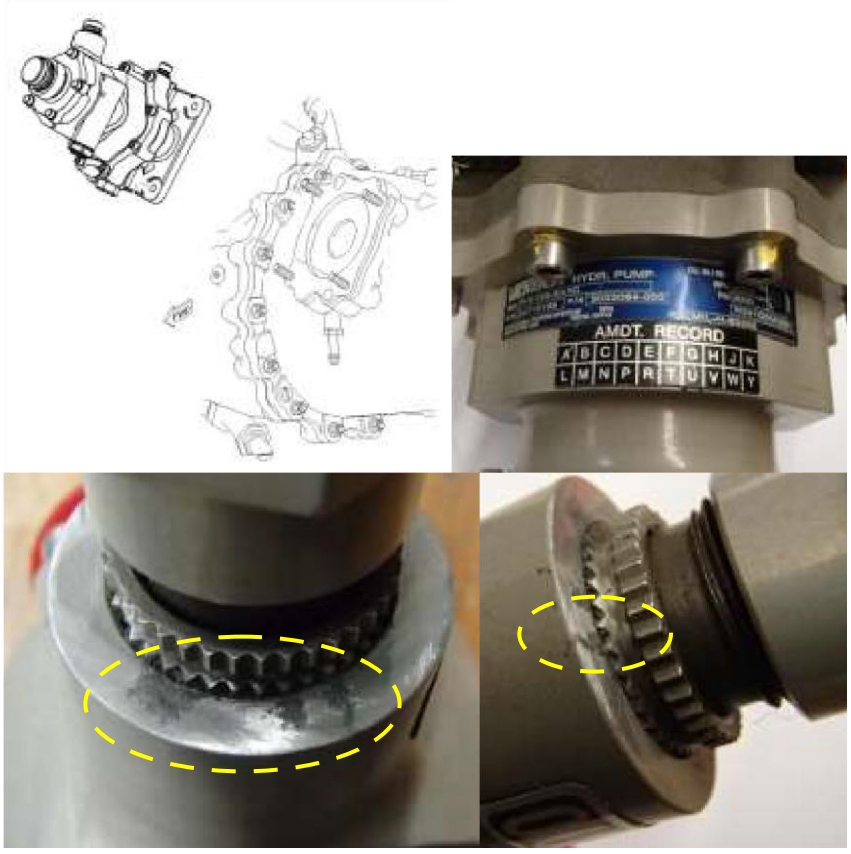
Tail number		N227, N233
ATA nr		All over the helicopter
NCage code		Too many to list
Picture(s)		
Corroding component		Several bonding leads (copper braid)
Component coupled to		Steel bolts, CFRP fuselage
Preliminary analysis	Failure cause	Salt water environment and galvanic coupling to more noble CFRP results in corrosion. Corrosion weakens the strength of the bonding leads and makes them more brittle, which leads to fracture of the bonding lead upon movement. Note that not all bonding leads are corroding. The degree of corrosion is severe if they are coupled directly to CFRP. Bonding leads connecting metal components show only light to moderate corrosion.
	Corrective and/or preventive measures	Inspect the bonding leads and replace them if they are corroded severely. Use nickel plated copper for bonding leads to slow down corrosion. Seal the bonding leads from the environment with rubber or polymeric sealing sleeves, sealant or paint to protect the copper. If sealing is chosen as protection, then water ingress into the seal must be prevented.
	SR / SB ?	
	Classification	Insufficient corrosion protection

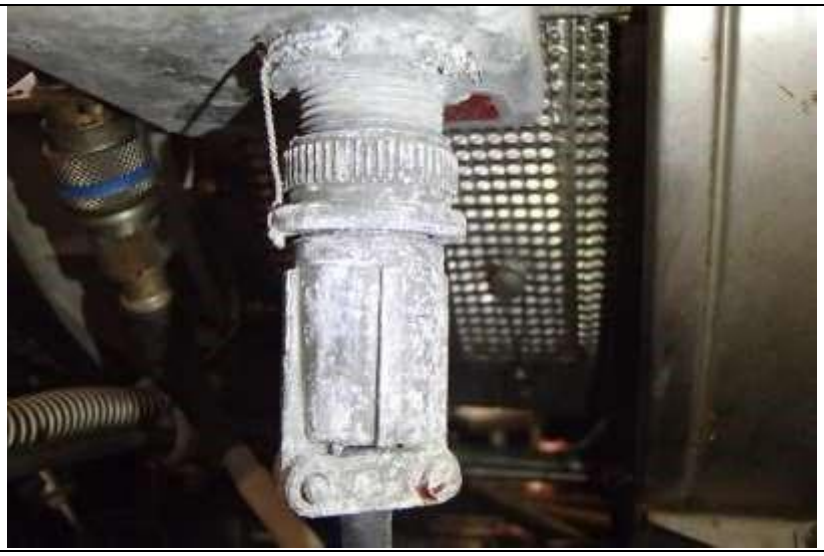
2.3 Upper fuselage (upper deck)

Tail number	N227, N233

ATA nr	73-22
NCage code	S732A10T1000:F0210
Picture(s)	   
Corroding component	Steel standing seam on stainless steel EECU anti-vibration mounts (on upper deck)
Component coupled to	Silver plated bolts, stainless steel shock mount and CFRP

Preliminary analysis	Failure cause	Galvanic coupling of steel standing seams to more noble stainless steel anti-vibration mount, silver-plated bolts and CFRP leads to accelerated corrosion of steel seams.
	Corrective and/or preventive measures	Use of stainless steel standing seams. Use of grease or a soft film CPC to protect the seam from the environment. The silver-plated bolts must be protected as well, because tooling may damage the plating and in the absence of grease or a CPC salt water may come into contact with the steel bolt, which will lead to corrosion of the bolt under the silver plating.
	SR / SB ?	
	Classification	Wrong materials selection

Tail number		N227
ATA nr		29-00
NCage code		N291G00A2001:A0126
Picture(s)		
Corroding component		Pressure outlet of the hydraulic system
Component coupled to		Steel and aluminium are coupled
Preliminary analysis	Failure cause	Intercrystalline corrosion is found in the aluminium housing of the pressure outlet of the hydraulic system. This may be stress corrosion cracking, but the true nature can only be determined with destructive analysis (fractographic investigation using electron microscopy). The anodic layer of the pressure outlet is most probably damaged during insertion of the (steel) Rosan coupling. This resulted in electrical coupling of the steel coupling to the aluminium and subsequent corrosion of the aluminium when the part came into contact with salt water during operation of the helicopter.
	Corrective and/or preventive measures	Replace the pressure outlet. Seal the coupling area to prevent contact with water.
	SR / SB ?	SR 1-11147272 and SR 1-11147612
	Classification	Insufficient corrosion protection
Tail number		N233

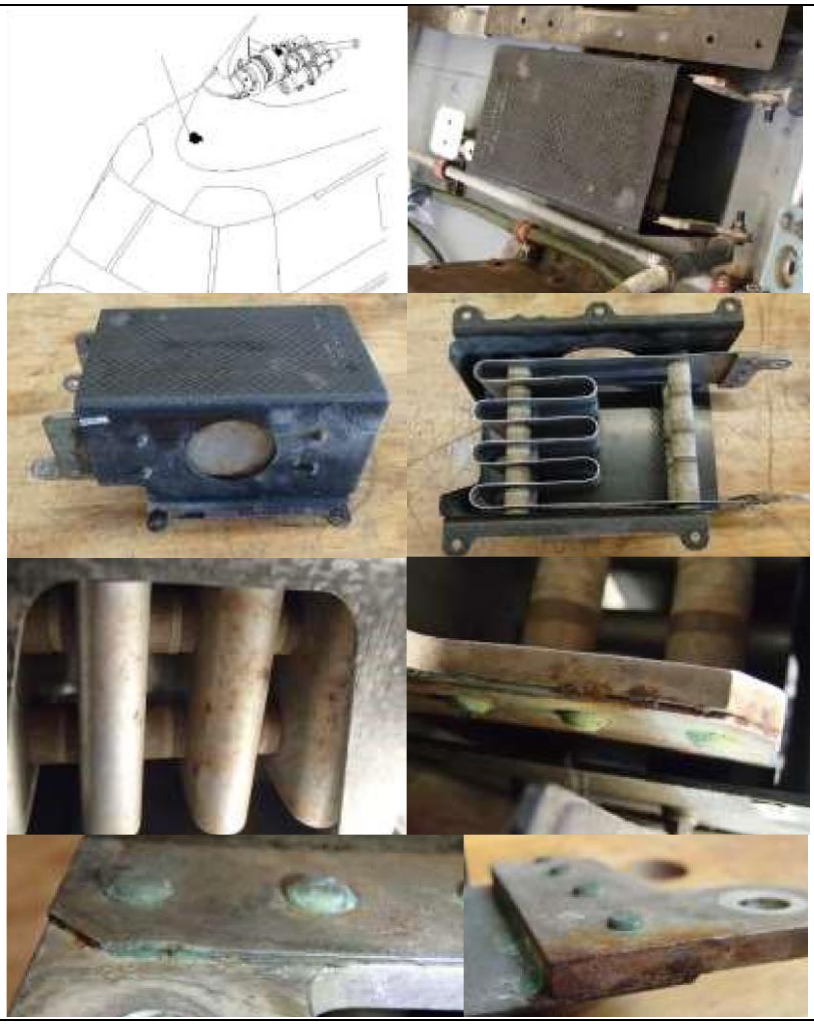
ATA nr		49-40
NCage code		S494A1000000:F0210
Picture(s)		
Corroding component		APU high energy unit connector
Component coupled to		CFRP fuselage
Preliminary analysis	Failure cause	Large amounts of moist and saline air are flowing past the connector, causing corrosion of the metal.
	Corrective and/or preventive measures	Protect the connector with a CPC or prevent the passing of moist and saline air. Insulate the connector by using sealant or jointing compound between connector and CFRP.
	SR / SB ?	
	Classification	Insufficient corrosion protection

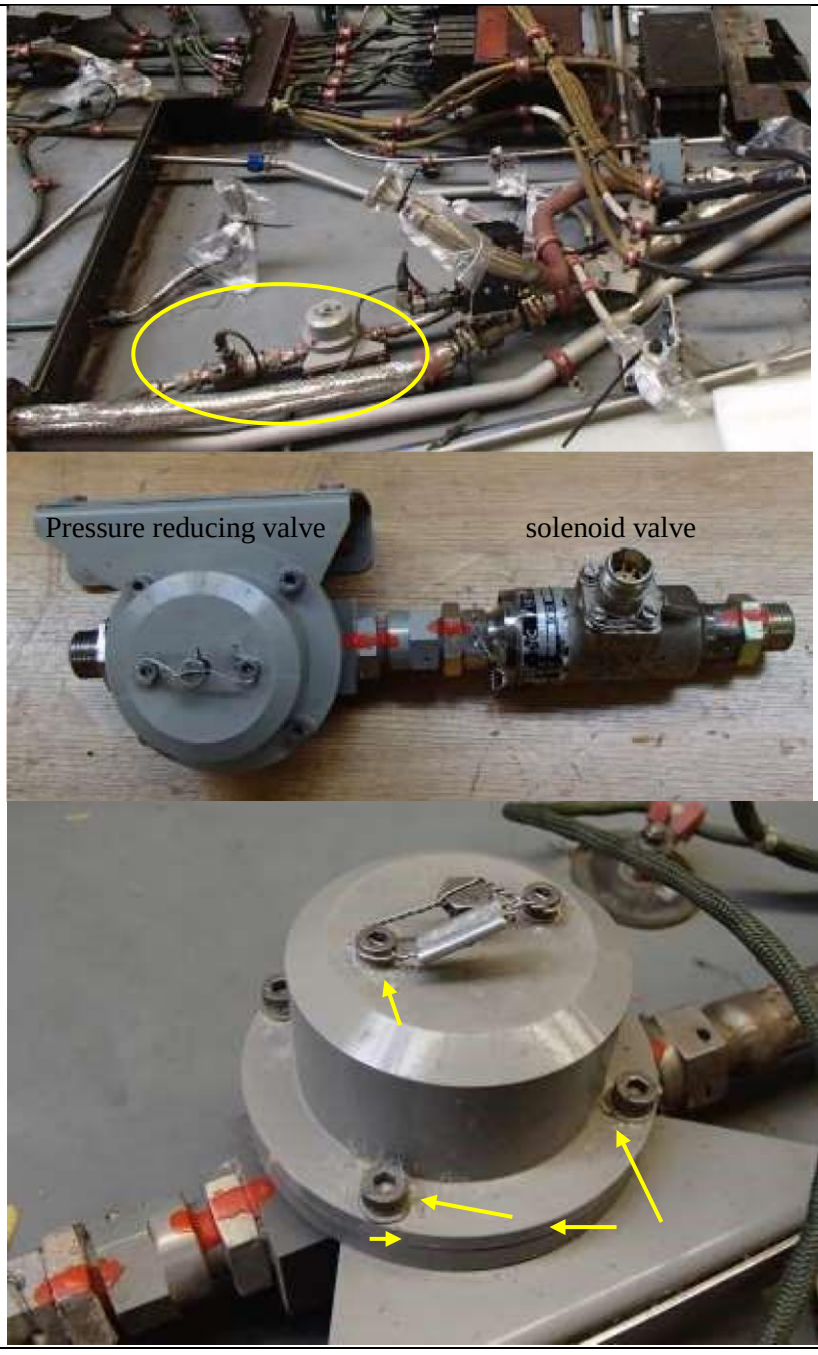
Tail number	N227
ATA nr	49-11
NCage code	S491A1001100:F0210

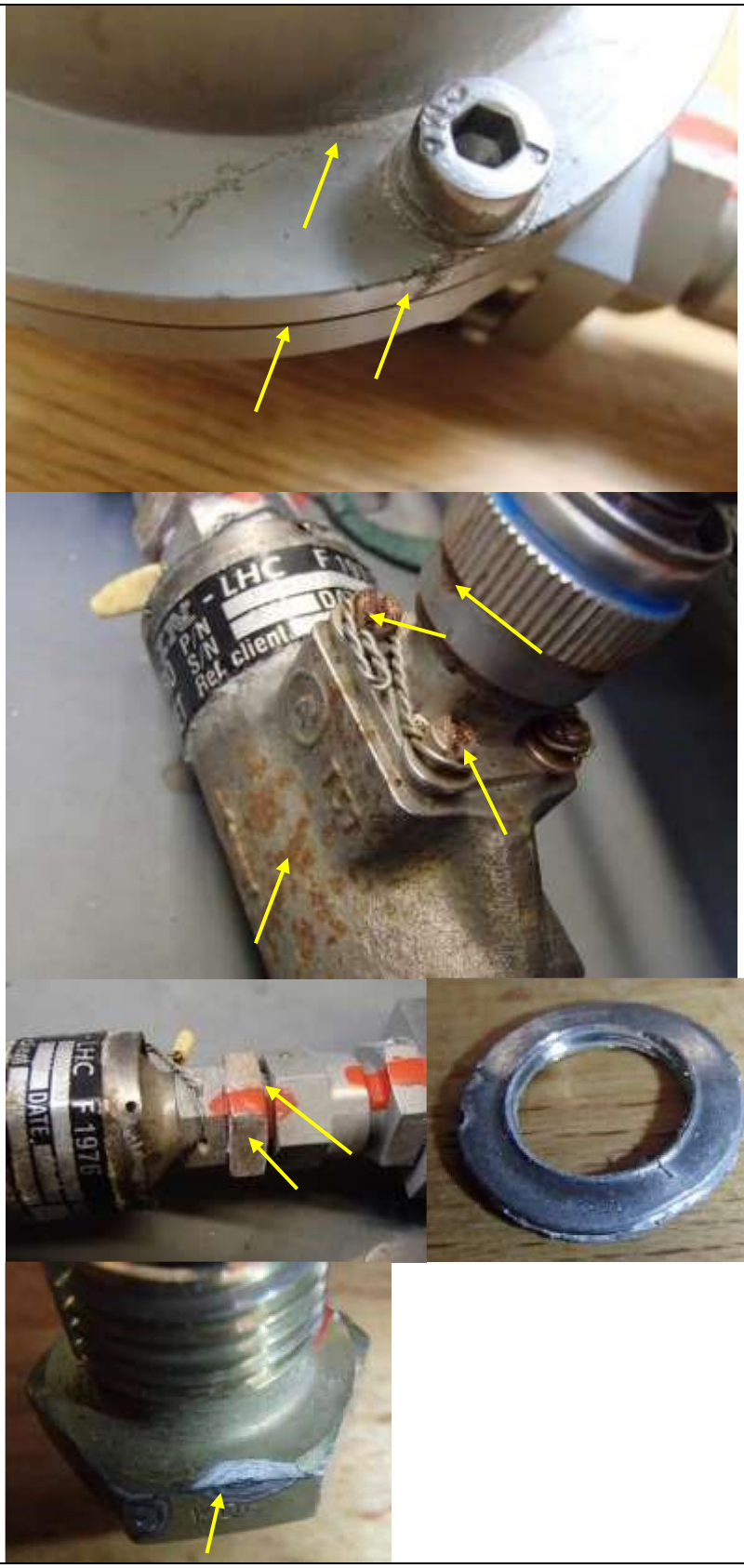
Picture(s)	
Corroding component	Bracket of engine mount, APU fitting

Component coupled to	CFRP fuselage

Preliminary analysis	Failure cause	Pitting corrosion of the steel occurs predominantly in the fastener holes. Crevice corrosion occurs in the crevices between parts of the bracket. One crack of about 1.3 mm is found near one of the attachment holes. The location of the crack and the presence of corrosion products in the crevice suggest that corrosion plays a role in the initiation of the crack.
	Corrective and/or preventive measures	Avoid water entry in the crevices of the bracket by using sealant, jointing compound or grease between the components when assembling the bracket. Apply a hard film CPC to the bracket to avoid water entry in the crevices. Redesign the bracket, thereby avoiding the many crevices present in the bracket shown.
	SR / SB ?	SR 1-11200315
	Classification	Wrong design

Tail number		N227
ATA nr		80-15
NCage code		S801A5021053:F0210
Picture(s)		
Corroding component		Start resistor assembly
Component coupled to		CFRP
Preliminary analysis	Failure cause	Corrosion of the resistor plate itself, corrosion between the resistor plate and the riveted terminal connector plate and corrosion of the rivets occurred due to the presence of salt water/moist air. The corrosion between the resistor plate and the connector is most probably crevice corrosion. The corrosion may/will lead to a high contact resistance and failure of the component.
	Corrective and/or preventive measures	Use dry air for cooling of the start resistor assembly. Apply a metallic corrosion protective coating over/on the joint to prevent crevice corrosion in the joint.
	SR / SB ?	SR 1-11355483
	Classification	Insufficient corrosion protection

Tail number	N227, N233
ATA nr	30-81
NCage code	Pressure reducing valve: 2416AC020101:F1958 Solenoid valve: 3089-100:F1976
Picture(s)	



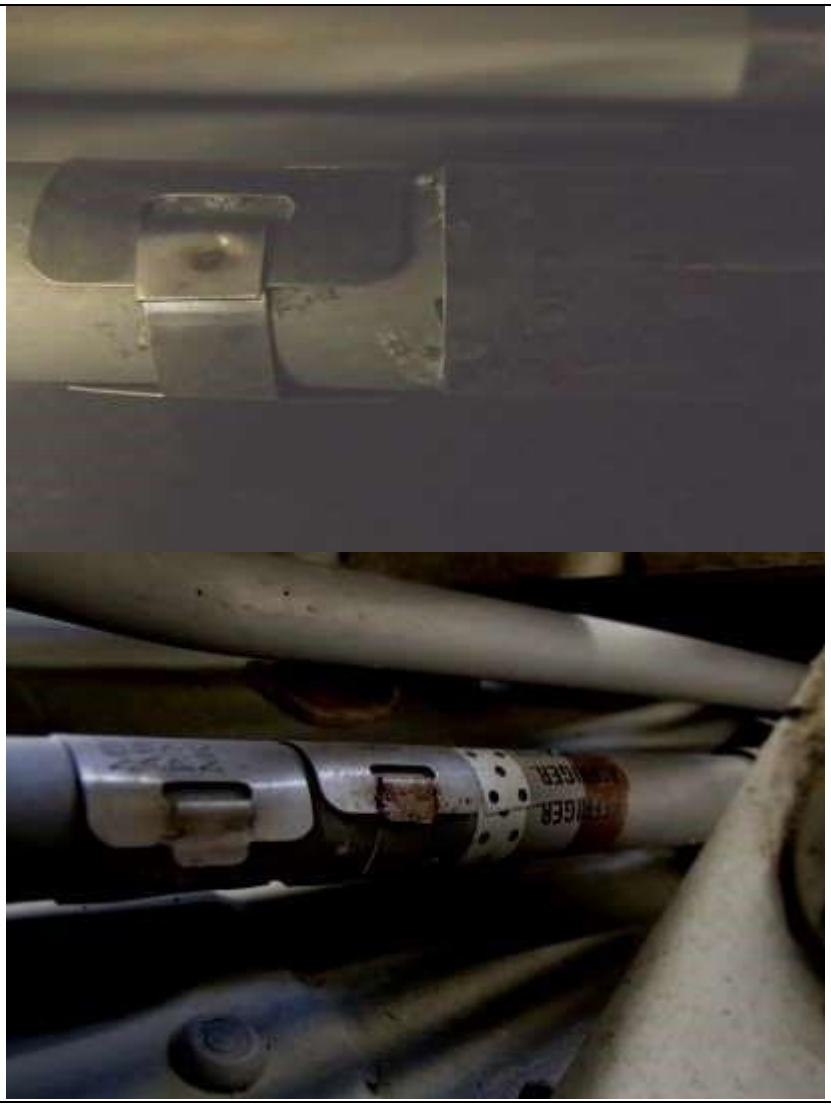
		
Corroding component		Pressure reducing valve and solenoid valve
Component coupled to		CFRP structure
Preliminary analysis	Failure cause	The pressure reducing valve shows corrosion at the location of the fasteners and in the crevice between the mating surfaces. The fasteners may have damaged the paint on the aluminium housing. Galvanic coupling accelerated the corrosion. Water could enter the crevice between the two parts and caused accelerated crevice corrosion. The solenoid valve is corroded on the inside, at the couplings. The (cadmium) coating shows poor adhesion at a few locations. Salt air passed through the valve and caused corrosion. Many components of the solenoid valve show corrosion. Coupling to the CFRP structure of the upper deck and to more noble metallic parts accelerated the corrosion that was initiated by the salt air that could enter the upper deck.
	Corrective and/or preventive measures	Replace the valves. Electrically insulate the different metals from each other and from the CFRP structure. Sealing of the fasteners and crevice of the pressure reducing valve to prevent contact with water. Apply sealant, CPC or grease to the valve-assembly to avoid contact with water.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number	N227, N233
ATA nr	21-54
NCage code	A154330-1:A0076 A154330-2:A0076
Picture(s)	Not available
Corroding component	The filler connector of the air conditioner
Component coupled to	CFRP structure

Preliminary analysis	Failure cause	Air containing salts and high humidity passes by the filler connector and causes corrosion. Galvanic coupling to the CFRP structure may have accelerated the corrosion.
	Corrective and/or preventive measures	Replace the connector. Insulate the connector from the CFRP structure with jointing compound or sealant. Protect the connector with a cap to prevent wetting with salt water.
	SR / SB ?	SR 1-11531430 (air conditioning flash tanks, including filler connector)
	Classification	Insufficient corrosion protection

Tail number		N227, N233
ATA nr		21-00
NCage code		24540-150:F0210
Picture(s)		
Corroding component		Corrosion of aluminium tubing under grooved clamp
Component coupled to		Not applicable
Preliminary analysis	Failure cause	The waffle structure of the grooved clamp traps water, thereby allowing stagnant water and corrosion of the tubing. The grooved clamps are used for damping.
	Corrective and/or preventive measures	Replace the grooved clamps with solid rubber fasteners that do not allow water entrapment in the rubber. Replace grooved clamps with vibration damping clamps that to not have water entrapment features.
	SR / SB ?	
	Classification	Wrong materials selection

Tail number	N227, N233
ATA nr	21-44
NCage code	Not applicable

Picture(s)		
Corroding component		Tubing under ID tags on the upper deck
Component coupled to		ID tags
Preliminary analysis	Failure cause	Crevice corrosion occurs between the ID tags and the tubing when water enters. The corrosion is enhanced by the crevice and possibly by galvanic coupling of the aluminium tubing to more noble materials like the steel ID tags.
	Corrective and/or preventive measures	Use a sealant or jointing compound between the ID tags and the tubing to prevent crevice corrosion.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number	N227
ATA nr	21-54
NCage code	155099-1:A0076

Picture(s)		
Corroding component		Aluminium rivets used for mounting the CFRP plates to the steel grid of the fan impeller guard of the environmental control system (ECS)
Component coupled to		Steel and CFRP
Preliminary analysis	Failure cause	Humid air containing salts passes through the grid and causes corrosion of the least noble metallic component, the aluminium rivets. Galvanic coupling of the aluminium rivets to the steel grid and CFRP plates accelerated the corrosion and led to failure of the rivets.
	Corrective and/or preventive measures	Application of grease or a CPC to the rivets prevents corrosion of the rivets. Note that the back side of the rivets should be protected as well, but cannot be reached easily. Use of stainless steel rivets that have a lower galvanic couple with CFRP. Use of sealant or jointing compound between the different materials when assembling the grid & plate.
	SR / SB ?	
	Classification	Insufficient corrosion protection Wrong materials selection

Tail number		N233, N227
ATA nr		21-54
NCage code		S216A10A2001:F0210
Picture(s)		Not available
Corroding component		Temperature control regulating computer housing in front of the fan on the upper deck
Component coupled to		CFRP structure, steel and/or titanium fasteners
	Failure cause	Humid and salt containing air passes by the computer housing. Damage of the paint on the computer housing allows corrosion that is accelerated by the galvanic coupling to more noble materials (CFRP and titanium/steel)

Preliminary analysis	Corrective and/or preventive measures	Use wet installation of fasteners and sealant or jointing compound between the computer housing and the CFRP structure to prevent galvanic corrosion. Apply a hard film CPC to the housing for additional protection.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number		N233, N227
ATA nr		25-97
NCage code		S533M0013212:C0418
Picture(s)		Not available
Corroding component		Spring of the hoist actuator
Component coupled to		Stainless steel, CFRP
Preliminary analysis	Failure cause	The spring of the hoist actuator is in direct contact with the outside environment that contained salt water, which resulted in severe corrosion of the spring. The spring is galvanically coupled to several components that are more noble, which accelerate the corrosion.
	Corrective and/or preventive measures	Use a more corrosion resistant material for the spring (preferably the same material as to which it is coupled, to prevent galvanic corrosion). Apply a soft film CPC to the spring. Electrically insulate the spring from the CFRP structure of the helicopter.
	SR / SB ?	SR 1-9797345
	Classification	Wrong materials selection

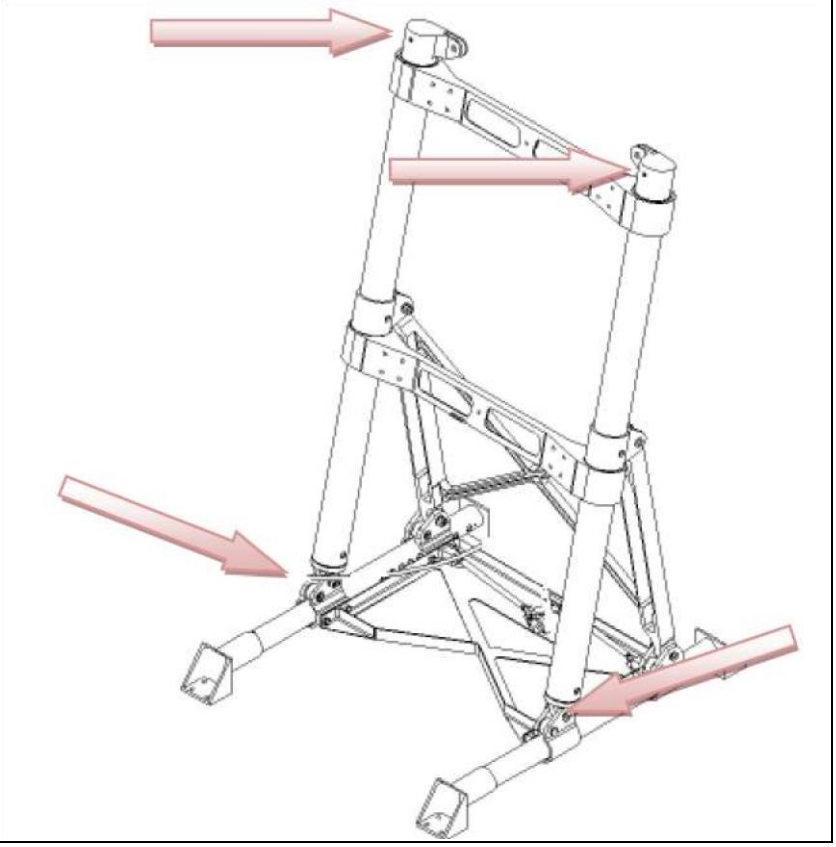
Tail number		N227, N233
ATA nr		21-54
NCage code		DIN912-M5X16-A2-70:D8286
Picture(s)		Not available
Corroding component		Fasteners of the fan casing (bolt and nut corrode)
Component coupled to		CFRP
Preliminary analysis	Failure cause	On the N227 all fasteners are corroding. On the N233 all but the lower fastener are protected with grease, and only the lower, unprotected fastener is corroding. A result of the protection of allbut-one of the fasteners is that the aluminium fan casing itself starts corroding near the joint where it is fastened (connected to more noble materials).
	Corrective and/or preventive measures	Application of grease or sealant to all fasteners protects them from corrosion. To prevent galvanic corrosion of the fan casing the fasteners should be installed wet and a sealant or jointing compound should be applied in the joint of the fan casing, so that it is electrically insulated.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number		N227, N233
ATA nr		71-30
NCage code		S713A1000001:F0210 S713A1000051:F0210 S713A4000000:F0210
Picture(s)		Not available
Corroding component		Rivets of the fire shields are corroding
Component coupled to		Stainless steel fire shields connected to CFRP
Preliminary analysis	Failure cause	Galvanic coupling of the rivets to more noble stainless steel and CFRP resulted in galvanic corrosion of the rivets (green corrosion products are visible on all rivets)
	Corrective and/or preventive measures	Protect the rivets with jointing compound. Grease will not work because the temperature may become too high. Replace the rivets periodically to prevent (almost) simultaneous failure of the rivets.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number		N227
ATA nr		63-61
NCage code		N636G10B1033:A0126
Picture(s)		
Corroding component		Pitting corrosion of steel driveshaft in air intake of oil cooler fan
Component coupled to		
Preliminary analysis	Failure cause	Moist air passes along the driveshaft. The moisture may contain salt as well, hence enabling corrosion. The material used is not resistant to pitting corrosion in salt water environment.
	Corrective and/or preventive measures	Replace steel pin with pin from material that is more resistant to pitting corrosion in saline environment. Apply a coating to the shaft to prevent corrosion.
	SR / SB ?	
	Classification	Wrong material selection
Tail number		N227
ATA nr		25-97
NCage code		S259M7001000:C0418
Picture(s)		Not available
Corroding component		Corrosion of the lower pivot pin of the hoist

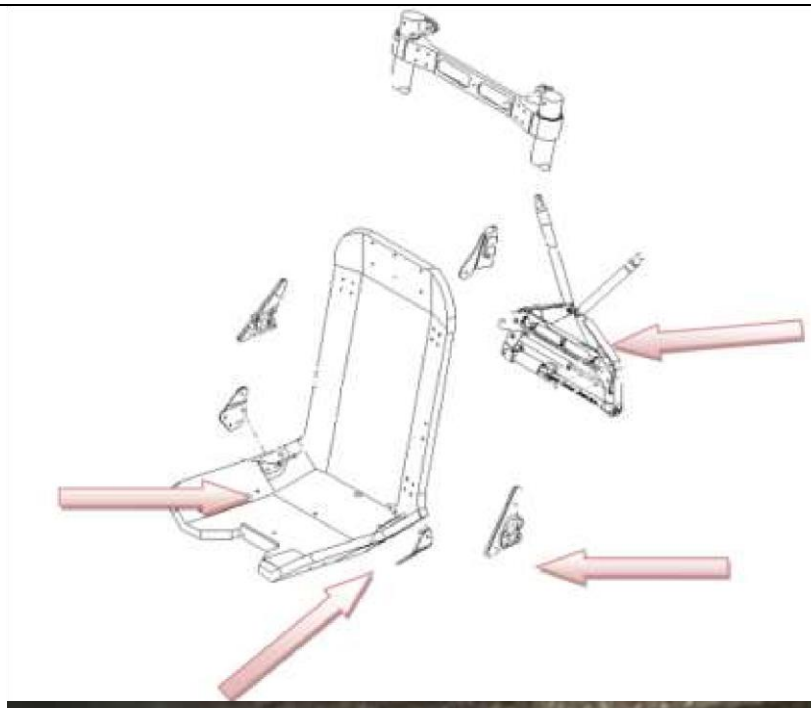
Component coupled to		CFRP
Preliminary analysis	Failure cause	The de-aeration hole of the hoist pin should have been sealed to prevent water entry, but it was left open. This allowed water to enter. Draining of the water was not foreseen because it should not have entered in the first place. The stagnant water caused corrosion, possibly accelerated by galvanic coupling to the CFRP structure.
	Corrective and/or preventive measures	Seal the hole as intended in the design.
	SR / SB ?	SR 1-9838627 RDAS_S_M_53_0222 Issue 1 gives solution
	Classification	Wrong manufacturing

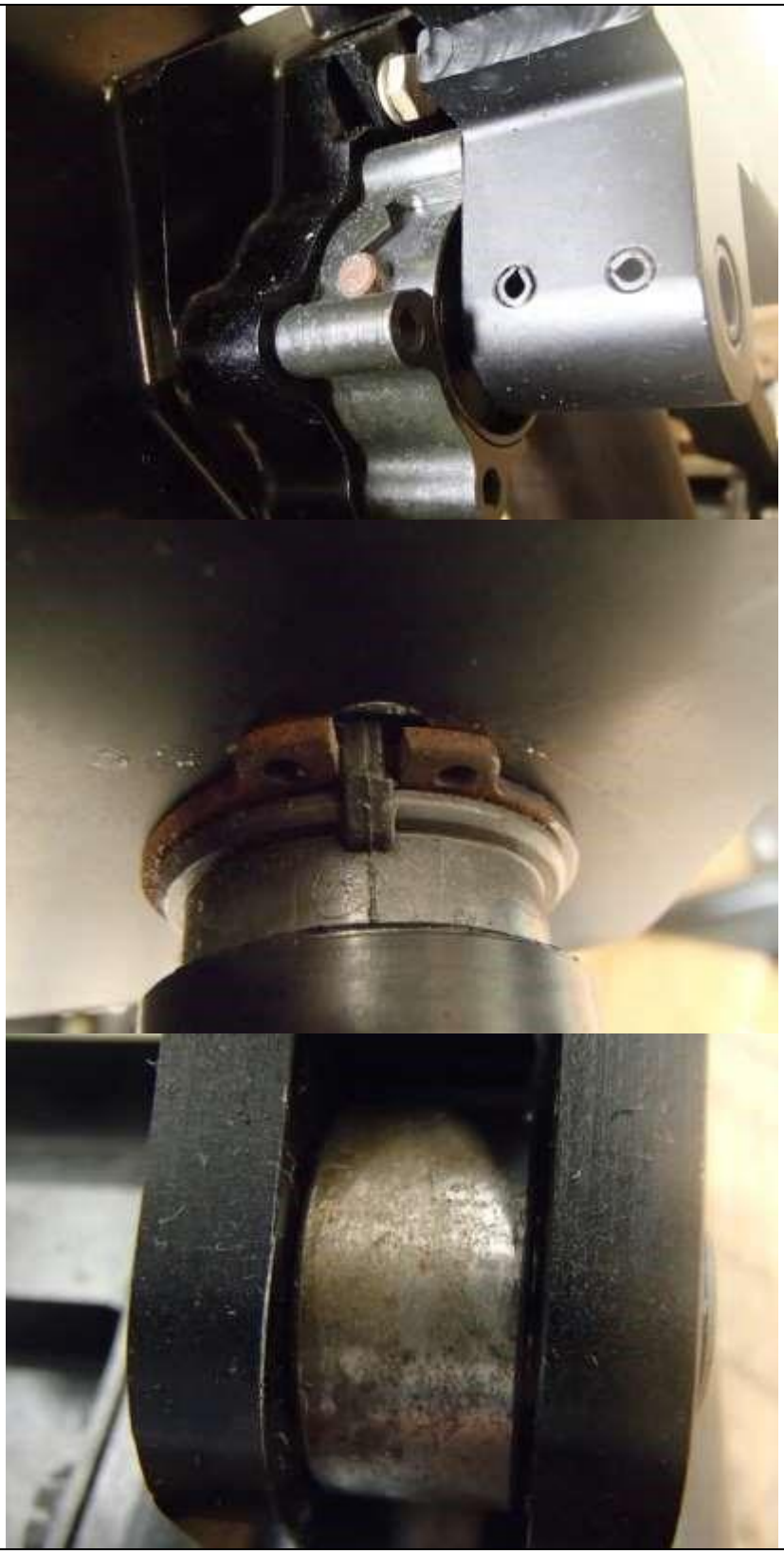
3 Cockpit: zone 200

Tail number	N233, N227
ATA nr	25-12
NCage code	S251A20A1002:F0210
Picture(s)	 

		
Corroding component		Dowel pins in cockpit seats
Component coupled to		Several materials
Preliminary analysis	Failure cause	Dowel pins are used to assemble the cockpit seats. These pins are not corrosion resistant and are unprotected. Note that these pins are used on several locations in the helicopter and all of them are corroding.
	Corrective and/or preventive measures	Use dowel pins with better corrosion resistance. Painting of the pins will not solve the problem because the paint will be scraped off partially during installation. Sealing is unwanted because the sealant hinders visual inspection for corrosion. Apply a transparent soft film CPC to the dowel pins after installation.
	SR / SB ?	
	Classification	Wrong materials selection

Tail number	N233, N227
ATA nr	25-12
NCage code	S251A20A1002:F0210

Picture(s)	 



		
Corroding component		Cockpit seats, several steel parts
Component coupled to		Several materials
Preliminary analysis	Failure cause	Several bare steel components in the cockpit seats show corrosion. The seats are bolted onto the CFRP cockpit floor. Exposure to salt water is not anticipated in the design, but occurs when flying above sea with the sliding door open.
	Corrective and/or preventive measures	Protect the bare metal components with a CPC (hard film can be used on non-moving parts, soft film should be used for moving parts). Mount the cockpit seats with jointing compound to prevent galvanic coupling with the CFRP floor.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number	N227
ATA nr	67-71
NCage code	S677A1010000:F0210

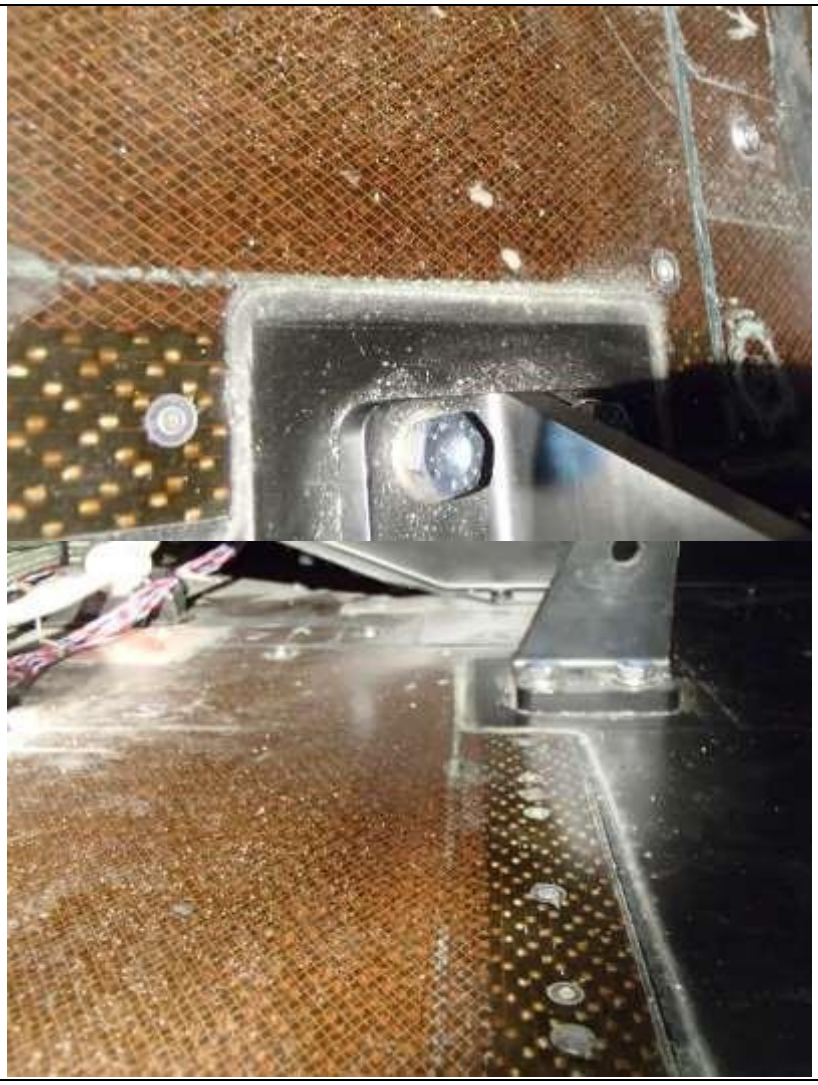
Picture(s)		
Corroding component		Spring in the cyclic stick
Component coupled to		Not applicable
Preliminary analysis	Failure cause	Salt water spray caused water on the spring of the cyclic stick. This water was trapped and caused corrosion of the spring. The spring has little to no corrosion protection, most probably because salt water spray was expected to be absent.
	Corrective and/or preventive measures	Apply CPC to the spring to protect it from corrosion.
	SR / SB ?	SR 1-11070181
	Classification	Insufficient corrosion protection

Tail number	N227 (very little on N233)
ATA nr	Depends on component
NCage code	Not applicable

Picture(s) Only a selection of the pictures is shown.	

		
Corroding component		Bolts and nuts fastening the instrument panels, protections caps and switches on the instrument panel
Component coupled to		CFRP fuselage structure
Preliminary analysis	Failure cause	Water spray enters the cockpit during operations above sea with the (right-hand) sliding door open. This leads to corrosion of the fasteners and switches of the instrument panel. Corrosion may be accelerated by galvanic coupling to the CFRP structure of the helicopter. The air circulation system circulates air that contains (some) salt. This adds in the corrosivity of the environment.
	Corrective and/or preventive measures	Protect the bolts and nuts with a hard-film CPC or paint after mounting of the instrument panels. Install bolts wet.
	SR / SB ?	SR 1-11069371
	Classification	Insufficient corrosion protection

Tail number	N227
ATA nr	25-12
NCage code	No item number for attachment brackets:F0210

Picture(s)	

		
Corroding component		Cockpit floor where seats were bolted
Component coupled to		CFRP support structure, metal seat and fasteners
Preliminary analysis	Failure cause	Corrosion of fastening materials (bolts and nuts) and bushings due to salt water spray and galvanic coupling to more noble CFRP cockpit floor.
	Corrective and/or preventive measures	Installation of metallic bolts into CFRP should be done wet, with sealant, CPC or jointing compound to insulate the metal from the CFRP.
	SR / SB ?	
	Classification	Insufficient corrosion protection

4 Aft section: zone 300

4.1 Intermediate structure: zones 310, 330

Tail number	N227
ATA nr	53-51

NCage code		S535M14530:C0418
Picture(s)		
Corroding component		Aluminium frame in intermediate structure
Component coupled to		Titanium fasteners and CFRP skin
Preliminary analysis	Failure cause	Sealant is placed next to the joint instead of over the joint. This allowed corrosion to start when water could reach the joint. Galvanic coupling of the aluminium frame to the CFRP skin accelerated the corrosion. Water was present because draining of water is not ideal in the intermediate structure
	Corrective and/or preventive measures	Apply sealant at the correct place, namely over the joint. Improve draining of water.
	SR / SB ?	
	Classification	Wrong manufacturing

Tail number		N227
ATA nr		33-42
NCage code		S334A2001051:F0210
Picture(s)		Not available
Corroding component		Aluminium components of the anti-collision light
Component coupled to		Titanium fasteners and CFRP skin
	Failure cause	Water collected at the connection of the light at the inside of the intermediate structure, because raised rims prevented draining of water to the drainage holes. The water caused corrosion that may have been accelerated by galvanic coupling of the aluminium to titanium fasteners and CFRP skin.

Preliminary analysis	Corrective and/or preventive measures	Fill up all recesses with sealant to prevent water collection. Install fasteners wet. Use sealant or jointing compound between the aluminium components and the CFRP fuselage to electrically insulate the metal parts.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number		N227
ATA nr		93-94
NCage code		N939G40A4001:A0126
Picture(s)		 
Corroding component		Antenna (sonobuoy)
Component coupled to		CFRP intermediate structure
Preliminary analysis	Failure cause	Water collected in the tail at the location of the antenna, because this is the lowest point. This stagnant water caused corrosion of the antenna mounting plate. The corrosion may be accelerated by galvanic cou0pling or by the presence of the crevice between the skin and the mounting plate. The drainage hole in the tail is at a higher location than the antenna mounting location. The drainage hole may be in the right location when the tail is folded.
	Corrective and/or preventive measures	Replace corroded antenna. Fill up the recess where the antenna is mounted (the stained area) with sealant to prevent water collection. Apply self-levelling green in the interface when mounting the antenna at the outer surface.
	SR / SB ?	

	Classification	Wrong design

Tail number	N227
ATA nr	43-42
NCage code	S434A2031102:F0210

Picture(s)	 

Corroding component		Copper antenna bonding strip
Component coupled to		CFRP intermediate structure
Preliminary analysis	Failure cause	Water ingress along joint led to galvanic corrosion of copper bonding strips coupled to CFRP fuselage.
	Corrective and/or preventive measures	Replace copper strip. Use sealant (self-levelling green) to prevent water ingress along fasteners and along the lap joint of the antenna connection Check sealant integrity (presence of cracks in the paint) on a regular basis, especially in hot climates. Apply a soft film CPC to prevent moisture ingress if the sealant is cracked
	SR / SB ?	
	Classification	Insufficient corrosion protection
Tail number		N227
ATA nr		43-31
NCage code		S433M1050101:C0418 S433M1050102:C0418
Picture(s)		Not available

Corroding component		Antenna connections of the HF antenna (mounting plates)
Component coupled to		CFRP intermediate structure and tail
Preliminary analysis	Failure cause	Water could enter the recess between the connection mount and the intermediate structure because the paint was cracked at the joint line. Water collected in the recess between the bracket and the helicopter tail because the drainage hole was not at the lowest location. Stagnant water caused corrosion of the copper strips in the antenna connection. Corrosion will shows as pillowing of the connection mount. This is not yet visible on the N233.
	Corrective and/or preventive measures	Corrective measure issued by the industry is to mount the antenna connections with sealant such that the drainage hole is at the lowest location. This should prevent the corrosion. Care should be taken that the drainage hole is not blocked by the sealant.
	SR / SB ?	
	Classification	Wrong design

Tail number		N233
ATA nr		66-21
NCage code		S662A10T1002:F0210
Picture(s)		Not available
Corroding component		Automatic Tail Locking Actuator (ATLA)
Component coupled to		Not applicable
Preliminary analysis	Failure cause	Fretting corrosion between the steel locking pin and the bronze bushing in the aluminium beam is possible due to too spacious fit of the locking pin, probably in combination with some movement that was possible in the tail folding hinge.
	Corrective and/or preventive measures	Use tighter fit of the locking pin and the hinge assembly to prevent fretting.
	SR / SB ?	
	Classification	Wrong design

Tail number		N227
ATA nr		53-51
NCage code		Frame 14A
Picture(s)		
Corroding component		Corrosion of aluminium lower hinge beam
Component coupled to		Bronze bushing and steel pins
Preliminary analysis	Failure cause	Galvanic coupling of the aluminium beam to more noble steel pins and bronze bushings lead to accelerated corrosion of the beam next to the bushings. Installation of the bushings leads to electrical contact between the bushing and the frame. Damage to the coating on the aluminium frame enables galvanic corrosion.
	Corrective and/or preventive measures	Application of a sealant over the paint to protect the paint from chipping and to seal the contact area between the beam and the bushing.
	SR / SB ?	
	Classification	Insufficient corrosion protection

4.2 Tail: zones 340, 350

Tail number	N233
ATA nr	53-51
NCage code	S535M1095102:C0418 S535M1096102:C0418
Picture(s)	Not available

Corroding component		Tail folding hinge bolt and frame
Component coupled to		Steel bolt coupled to aluminium frame
Preliminary analysis	Failure cause	The bolt has been submerged in stagnant water, which led to corrosion of te bolt and the frame. Water could collect when the tail was folded.
	Corrective and/or preventive measures	Use jointing compound when installing the bolt to prevent coupling of the bolt to the frame. Allow drainage of the water. Seal the bolt after installation to prevent contact with water.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number		N227
ATA nr		66-32
NCage code		Not available
Picture(s)		
Corroding component		Corrosion of connectors in tail pylon
Component coupled to		CFRP structure, titanium fasteners
Preliminary analysis	Failure cause	The connectors are coupled to the CFRP structure which results in galvanic corrosion if the connectors get into contact with water.
	Corrective and/or preventive measures	Apply a soft film CPC on the connectors and install them with sealant between the connectors and the CFRP. Protect the connectors with a cap.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number		N233, N227
ATA nr		55-31
NCage code		S553F1150000:H1822
Picture(s)		Not available
Corroding component		Internal structure of the tail (vertical) shows water stains
Component coupled to		Metal and CFRP in close contact
Preliminary analysis	Failure cause	Water drainage holes are located for draining of the structure in operational geometry. When the tail is folded the drainage holes are not anymore at the lowest location, which results in water being trapped in the tail. This stagnant water results in staining and eventually corrosion of metallic components (predominantly fasteners in the tail pylon, but also the aluminium frames and brackets).

	Corrective and/or preventive measures	Application of a CPC or jointing compound to reduce the risk of corrosion. It is preferred that rinsing of the helicopter after a mission on sea is done before folding the tail. However, procedures prescribe that the rotor blades and tail are folded within 20 minutes after landing on a ship (at high sea state). Additional drainage holes should have been implemented to allow draining of water when the tail is folded.
	SR / SB ?	
	Classification	Wrong design Insufficient corrosion protection
Tail number		N227
ATA nr		55-31
NCage code		S553F1150000:H1822
Picture(s)		
Corroding component		Fasteners in tail pylon
Component coupled to		CFRP tail structure

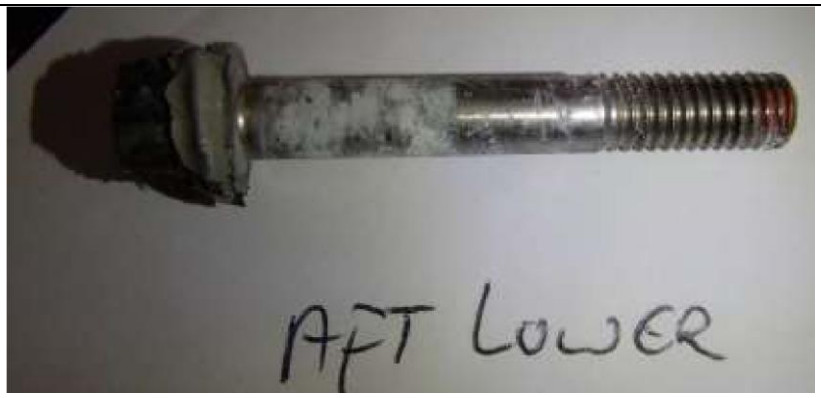
Preliminary analysis	Failure cause	Galvanic corrosion of part of the fastener led to cracking of the washers. The head of the fastener is sealed to prevent corrosion, but the remainder is unsealed and water could enter. This resulted in galvanic corrosion. Built-up of corrosion product resulted in cracking of the washers.
	Corrective and/or preventive measures	Seal the whole fastener instead of only the head to prevent water ingress in the fastener and subsequent corrosion. Use wet installation of the fasteners (it is unclear if this has been done). Apply jointing compound between CFRP structure and the washers and fasteners when installing the fasteners.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number	N227, N233
ATA nr	55-31
NCage code	S553F1150000:H1822

Picture(s)	Aft upper and lower attachment tail pylon   – reasonable corrosion  Aft upper (l) and lower (r) attachment inboard view moderate corrosion)

FWD attachment outside (l) and inside (r) tail pylon

FWD upper attachment tail pylon with jammed bolt (r)

	 AFT LOWER

		 Tail pylon attachment bolts after removal
Corroding component		Attachment assembly (bolts and lugs) of horizontal stabilizer – tail pylon side
Component coupled to		Aluminium lug coupled to steel bolts and CFRP structure
Preliminary analysis	Failure cause	Three of the four bolts were jammed in the lugs due to corrosion. Crevice corrosion of the aluminium lug is accelerated by galvanic coupling of the lug to steel bolts and possibly also to the CFRP structure of the tail and the horizontal stabilizer. Sealant was applied on the bolt head, but not the whole circumference of the bolt was covered. The sealant showed cracking. The incomplete sealing and cracks in the sealant allowed water to enter the area between the bolt and the lug, which led to corrosion of the lug.
	Corrective and/or preventive measures	The manufacturer should decide whether the lugs can be cleaned and fitted with a bushing or oversized bolt or that the whole parts need to be replaced. Application of jointing compound in the hole of the lug, to prevent electrical contact between the steel bolt and the aluminium lug and to prevent water ingress in the area between bolt and lug. Proper sealing of the bolt heads to prevent water ingress along the bolt.
	SR / SB ?	SR 1-10549293
	Classification	Insufficient corrosion protection Wrong manufacturing (sealant)

Tail number	N227, N233
ATA nr	55-11
NCage code	S551F0000000:H1822

Picture(s)	 Overview horizontal stabilizer – attachment holes  FWD upper attachment

		 Aft attachments
Corroding component		Attachment assembly (bolts and lugs) of horizontal stabilizer – horizontal stabilizer side
Component coupled to		Aluminium lug coupled to steel bolts and CFRP structure
Preliminary analysis	Failure cause	Three of the four bolts were jammed in the lugs due to corrosion. Crevice corrosion of the aluminium lug is accelerated by galvanic coupling of the lug to steel bolts and possibly also to the CFRP structure of the tail and the horizontal stabilizer. Sealant was applied on the bolt head, but not the whole circumference of the bolt was covered. The sealant showed cracking. The incomplete sealing and cracks in the sealant allowed water to enter the area between the bolt and the lug, which led to corrosion of the lug.
	Corrective and/or preventive measures	The manufacturer should decide whether the lugs can be cleaned and fitted with a bushing or oversized bolt or that the whole parts need to be replaced. Application of jointing compound in the hole of the lug, to prevent electrical contact between the steel bolt and the aluminium lug and to prevent water ingress in the area between bolt and lug. Proper sealing of the bolt heads to prevent water ingress along the bolt.
	SR / SB ?	SR 1-10549293
	Classification	Insufficient corrosion protection Wrong manufacturing (sealant)

Tail number	N233, N227
ATA nr	55-11
NCage code	S551F0000000:H1822

Picture(s)		
Corroding component		Rivet lock nuts closing the hatch in the horizontal stabilizer; the panel edge
Component coupled to		CFRP skin
Preliminary analysis	Failure cause	Water could enter the horizontal stabilizer and caused corrosion. The galvanic coupling of steel lock nut and its aluminium attachment pins to the CFRP structure accelerated the corrosion. The corrosion led to weakening of the attachment pins and eventual shearing of the pins when it was tried to open the hatch for maintenance. The paint on the edge of the hatch was damaged, which led to corrosion of the exposed aluminium.
	Corrective and/or preventive measures	Apply sealant or jointing compound between the nut and the CFRP structure and apply sealant over the nut to protect it from salt water.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number	N227
ATA nr	55-11
NCage code	S551F0000000:H1822

Picture(s)		
Corroding component		Rivet in the horizontal stabilizer
Component coupled to		CFRP skin
Preliminary analysis	Failure cause	Steel of the rivets started to corrode when the protective coating is damaged/consumed. Coupling to the CFRP structure enhanced the corrosion.
	Corrective and/or preventive measures	Replace the corroded rivets. Install the rivets wet and protect them with sealant or a CPC.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number	N227
ATA nr	55-11
NCage code	S551F1102053:H1822

Picture(s)	 
	

Corroding component		Fasteners in the horizontal stabilizer
Component coupled to		CFRP horizontal stabilizer
Preliminary analysis	Failure cause	Moisture ingress into the horizontal stabilizer resulted in galvanic corrosion of the least noble parts of the fasteners. The washers are cracked most probably due to overload by stresses induced by corrosion products. The socket head of the fasteners is sealed to prevent water collection and subsequent corrosion.
	Corrective and/or preventive measures	Sealing of the whole fasteners to prevent corrosion, instead of sealing of the fastener top only. Wet installation of the fasteners. Application of jointing compound between the washer of the fasteners and the CFRP skin.
	SR / SB ?	Replace broken fasteners with oversized fasteners or use bushings to accommodate the possibly increased hole size. Install the fasteners wet and seal the whole fastener instead of the top only. Replace horizontal stabilizer if corrosion is severe. Apply a hard film CPC on the inside of the new horizontal stabilizer.
	Classification	Insufficient corrosion protection

Tail number	N227
ATA nr	55-11
NCage code	S551F0000000:H1822

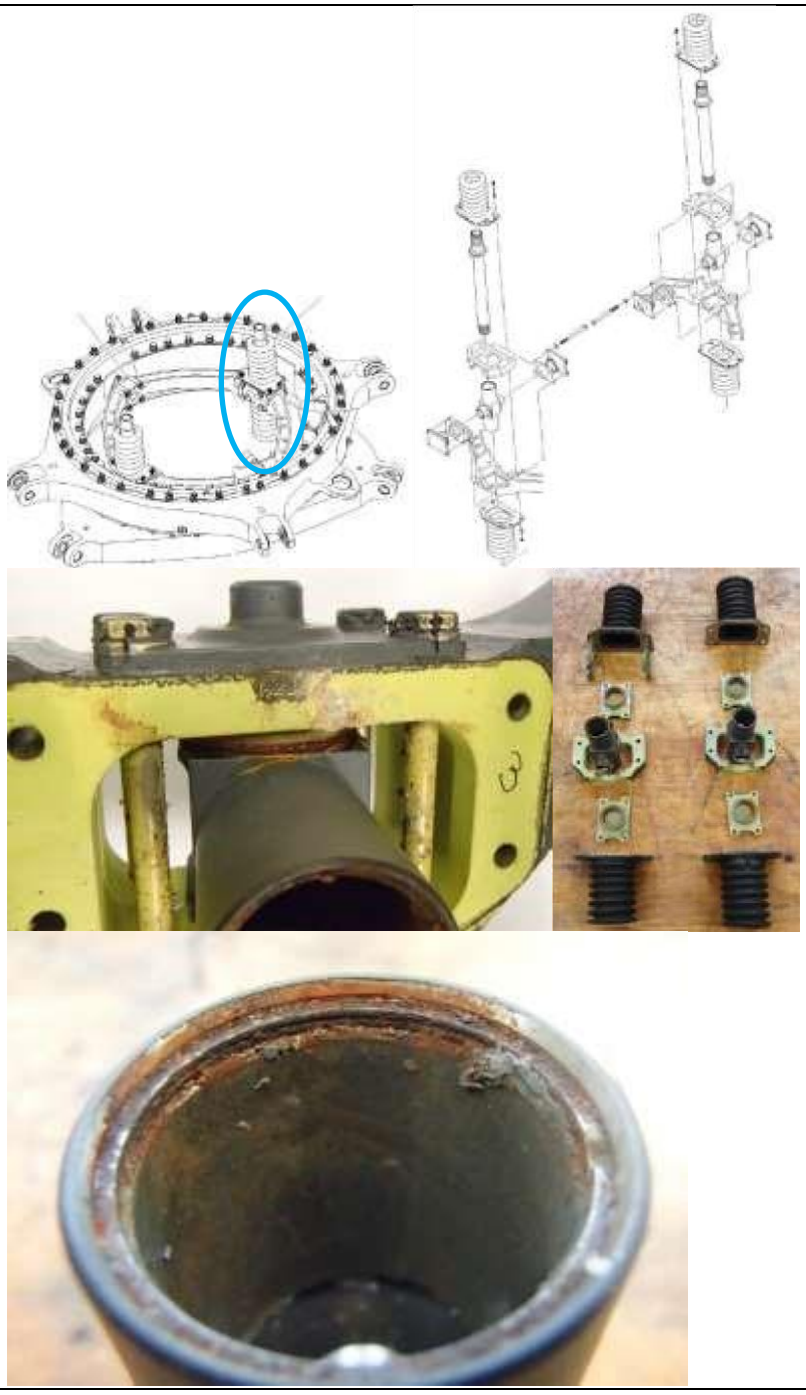
Picture(s)		
Corroding component		Steel nuts in the horizontal stabilizer
Component coupled to		CFRP structure and titanium bolts
Preliminary analysis	Failure cause	The top of the bolts are protected by sealant but the nuts are left unprotected while they are coupled electrically to the CFRP structure. Entry of salt water resulted in galvanic corrosion of the steel components. The detail photograph of the bolt & nut shown in the right hand image indicates that silver plated nuts are used. However, the silver plating is damaged and the steel nut underneath corrodes preferentially. The corrosion is accelerated by galvanic coupling of the steel nut to the silver plating and the CFRP structure.
	Corrective and/or preventive measures	Apply sealant over the whole assembly instead of the bolt end only. Use jointing compound between the washers and the nuts and the CFRP skin.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number	N227
ATA nr	55-31
NCage code	S553F1150000:H1822

Picture(s)		
Corroding component		Hi-loks (large) in tail at folding hinge
Component coupled to		CFRP
Preliminary analysis	Failure cause	Cadmium plated steel rings that accommodate tapers have white corrosion product. The components are coupled to the CFRP tail skin. Water could easily enter the area of the tail where the Hi-loks are mounted. Galvanic coupling of the cadmium plated steel rings to the CFRP skin lead to galvanic corrosion of the cadmium plating.
	Corrective and/or preventive measures	Electric insulation of the steel by using jointing compound or sealant when installing the high locks. Seal the Hi-loks.
	SR / SB ?	
	Classification	Insufficient corrosion protection

5 Power plant, transmission and rotor: zone 400

Tail number		N227
ATA nr		71-72
NCage code		S717A20T1011:F0210
Picture(s)		Not available
Corroding component		Engine rinsing connector hose
Component coupled to		Titanium deck
Preliminary analysis	Failure cause	The last step in the engine washing procedure is a water rinse. The connector for the water supply is corroding. The connector is mounted onto the titanium deck without electrical insulation (sealant). The galvanic coupling may have caused more severe corrosion than anticipated.
	Corrective and/or preventive measures	The industry has selected a more corrosion resistant material to replace the initially selected material for the engine rinsing connector hose. Use sealant between the connector and the deck to prevent galvanic coupling. Protect the connector from the salt water environment with a cap.
	SR / SB ?	
	Classification	Wrong materials selection

Tail number	N227
ATA nr	62-32
NCage code	S623A2002051:F0210
Picture(s)	

		
Corroding component		Swash plate component: column body
Component coupled to		Not applicable
Preliminary analysis	Failure cause	All steel components show signs of rust. The components have remnants of the self-lubricating coating that is used to reduce maintenance on the rotor head. The steel placeholder ring is corroding. The self-lubricating coating provides insufficient corrosion protection to the ring. Water can enter and cause corrosion of the steel ring. The water may also result in degradation of the self-lubricating coating.
	Corrective and/or preventive measures	Use grease in addition to the self-lubricating coating to prevent water entry and corrosion of the steel placeholder ring. Use more corrosion resistant steel for the placeholder ring.
	SR / SB ?	
	Classification	Wrong materials selection

Tail number		N233
ATA nr		65-11
NCage code		Not yet available
Picture(s)		Not available
Corroding component		coupling plates in the transmission (FOC helicopter only)
Component coupled to		Not applicable
	Failure cause	Water can enter the drive train area and causes corrosion of the coupling plates. The plates consist of a flex-pack of spring steel plates bolted together. The spring steel plates are coated but friction causes wear of the coating. This resulted in crevice corrosion of the steel plates when water enters.

Preliminary analysis	Corrective and/or preventive measures	Use a more wear resistant coating on the spring steel coupling plates. Apply a soft film CPC on the coupling plates to prevent water entry. Prevent water entry into the drive train area.
	SR / SB ?	
	Classification	Wrong materials selection

Tail number		N227, N233
ATA nr		53-73
NCage code		S537M3001000:C0418
Picture(s)		Not available
Corroding component		Quick release fasteners of the drive train shaft fairing
Component coupled to		CFRP
Preliminary analysis	Failure cause	Water seeps along the fasteners into the nuts and causes corrosion of the nuts. Corrosion is accelerated by galvanic coupling to the CFRP structure.
	Corrective and/or preventive measures	Prevent water entry by changing the orientation of the interface where the nuts are embedded from horizontal to vertical. Apply excess soft film CPC in the nuts
	SR / SB ?	
	Classification	Wrong design

Tail number		N227
ATA nr		63-12
NCage code		S631A2011201:F0210
Picture(s)		
Corroding component		Fretting corrosion of steel reaction torque housing (RTH) pin
Component coupled to		Aluminium housing
Preliminary analysis	Failure cause	Hard particles have most probably been trapped in the area between the bearing steel pin and the lug, causing fretting corrosion on the pin. The hard particles may have been sand or alumina corrosion product from corrosion of the lug.
	Corrective and/or preventive measures	Prevent water and sand entry into the area between pin and housing to prevent corrosion of the housing and fretting of the pins. This may be achieved by application of jointing compound, sealant or grease on the pins, but the jointing compound, sealant or grease must be temperature-resistant. Lock-tight anti-seize may work.
	SR / SB ?	SR 1-10692003 The corrosion must be removed. No further actions are required.

		Replace the pin if corrosion is deeper than the clean-up limit.
	Classification	Wrong design

Tail number	N227
ATA nr	65-31
NCage code	S653F1000000:H1632

Picture(s)	

		  
Corroding component		Intermediate tail gearbox output flange
Component coupled to		Aluminium coupled to steel
Preliminary analysis	Failure cause	Small movements of one flange with respect to the other caused breakdown of the protective oxide layer of the stainless steel flanges. The presence of water between the flanges caused corrosion when the protective oxide layer was damaged. The presence of corrosion products assisted in the fretting damage of the stainless steel flange.
	Corrective and/or preventive measures	Apply a grease or sealant between the two flanges to prevent fretting and corrosion.
	SR / SB ?	M5 number 10160851
	Classification	Insufficient corrosion protection

Tail number	N227, N233
ATA nr	65-20
NCage code	S652A0000051:M0294

Picture(s)	

Corroding component		Magnesium tail gear box (TGB) housing
Component coupled to		Steel bracket, steel and titanium fasteners and CFRP tail
Preliminary analysis	Failure cause	Galvanic corrosion of the magnesium housing occurs as soon as the protective paint is damaged. Coupling of the magnesium gearbox to more noble metals like steel and titanium accelerates the corrosion. During blending of the corrosion it turned out that the corrosion had progressed under the coating.
	Corrective and/or preventive measures	Use jointing compound to prevent galvanic coupling, so that corrosion is less severe when the coating is damaged. Use a barrier seal under the paint to reduce the risk of paint damage.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number		N233
ATA nr		65-20
NCage code		S652A1080201:F0210
Picture(s)		Not available
Corroding component		Washers and nuts of tail gear box fasteners
Component coupled to		CFRP tail pylon
Preliminary analysis	Failure cause	The bolts are connected to the magnesium gearbox, but also to the CFRP tail structure. The bolt heads themselves are sealed, but the washers and nuts are not sealed. If (salt) water can reach the washers and nuts corrosion will start, accelerated by galvanic coupling with the CFRP tail structure. When the paint on the magnesium TGB becomes damaged corrosion will shift to the magnesium,
	Corrective and/or preventive measures	Jointing compound between the washer, nut, bolt and CFRP fuselage will reduce the corrosion risk
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number		N227, N233
ATA nr		62-33
NCage code		S623A3010101:F0210
Picture(s)		
Corroding component		The inside of the pitch rods
Component coupled to		Internal galvanic coupling of several materials, amongst which aluminium and steel
Preliminary analysis	Corrosion cause	Water entered the internal of the pitch rod via the bleeding hole and caused corrosion of the anodised aluminium fork and the steel bar. Only the fixed (yellow) rod is not corroded because the sleeve prevented water entry. On the N233 only the steel bolts in the fork of the pitch rod are corroded
	Corrective and/or preventive measures	Cover the threaded part of the pitch rods with a sleeve or with sealant to prevent water entry. This is issued already as a solution by the industry.
	SR / SB ?	SR 1-10985303 SB JA-A-62-33-00-02A-A-A-001: sealing of the pitch rod to prevent water ingress
	Classification	Wrong design

Tail number	N227, N233
ATA nr	63-31

NCage code		S633A1010101:F0210 S633A1010102:F0210 S633A 1050101:F0210 S633A 1050102:F0210
Picture(s)		Not available
Corroding component		Suspension bar bearing
Component coupled to		Not applicable
Preliminary analysis	Failure cause	One of the suspension bar bearings is corroded severely and movement is around the pin instead of the bearing. Some of the other bearings are corroding as well (corrosion product can be seen), but are not yet stuck. The cause of corrosion may be insufficient grease applied during assembly or the use of a hygroscopic grease .Water spray is present in the area of the suspension bars during flight over sea and will cause corrosion if the bearing steel is not covered in excess grease. It is not sure what exactly is stuck. The autoliner may also be the cause of the problem.
	Corrective and/or preventive measures	Replace the bearing and use excess grease on the new one, to prevent direct contact with water.
	SR / SB ?	
	Classification	Wrong manufacturing

Tail number	N227
ATA nr	66-14
NCage code	S661A1004051:F0210

Picture(s)		 
Corroding component		Main rotor safety lock assembly (MRSLA) roller bearings (improved version of MRSLA)
Component coupled to		Not applicable
Preliminary analysis	Failure cause	The roller bearings show rust. Some of the bearings are severely corroded, which resulted in blocking of the bearing and sliding stickslip contact instead of rolling contact. Corrosion in roller bearings may be caused by insufficient grease in the bearing.
	Corrective and/or preventive measures	Replace bearing with new bearing that is filled with grease for lubrication and corrosion protection. Change from ML3 to ML2 solution is requested so that RNLAF personnel are authorized to replace the bearing. This request is not granted.
	SR / SB ?	
	Classification	Wrong manufacturing

Tail number	N227
ATA nr	62-25

NCage code	S622A5007102:F0210, S622A5008102:F0210
Picture(s) Only a selection of the pictures is shown.	

		
Corroding component		Fretting corrosion of bushings in blade folding hinge fitting
Component coupled to		Steel pins
Preliminary analysis	Failure cause	Almost all the steel bushings of the four blade folding hinge fittings show fretting corrosion signs. Hard particles that can enter between the pin and the bushing and damage the protective oxide film, thereby allowing corrosion to occur. The hard particles may be corrosion products or sand. Additionally the mating surfaces of the aluminium hinge with the blade show many corrosion pits. The pitting is most severe at the outer circumference of the surface, but has progressed inward on several of the surfaces. The location of the corrosion suggests that water can enter from the outside. Crevice corrosion and the presence of stainless steel bushings and pins may have accelerated the corrosion of the aluminium hinge.
	Corrective and/or preventive measures	The use of tough grease like TP42 may prevent corrosion and sand entering the area between pin and bushing. If it is applied onto the aluminium surface it prevents corrosion there. Tough grease is required to prevent it from being removed by centrifugal forces during operation of the rotor.
	SR / SB ?	

	Classification	Wrong design

Tail number		N227
ATA nr		62-25
NCage code		S622A5012201:F0210
Picture(s)		
Corroding component		Fretting corrosion on blade folding hinge pins
Component coupled to		Aluminium fitting, steel bushings
Preliminary analysis	Failure cause	Hard particles can enter the area between pin and bushing and cause fretting. The fretting damages the protective layer on the stainless steel pin, and subsequent corrosion of the pin is possible. The hard particles may be either sand entering from outside or corrosion product. The outermost pins have most damage, which indicates that high loading increases the damage.
	Corrective and/or preventive measures	Replace the pin. Apply superfluous lubrication under the head of the pin as well as on the shaft (jointing compound or TP42 paste should work without being removed by the centrifugal forces during operation). Check the space between pin head and sleeve surface. This space should be minimized to avoid entry of hard particles
	SR / SB ?	
	Classification	Wrong design

Tail number	N227
ATA nr	62-25
NCage code	S622A4012210:F0210

Picture(s)		
Corroding component		Corrosion on lower stops
Component coupled to		Steel pins
Preliminary analysis	Failure cause	Corrosion occurs above the thread and on the upper turn of the thread. Grease is applied to the thread area and above. The bolts are fastened to a specified wet torque. On three of the four lower stops the torque was too high (bolts were fastened during manufacturing). These lower stops show corrosion above the thread. Corrosion is found under the grease and the grease seems to have a different texture than freshly applied grease. The most probable cause of corrosion is galvanic corrosion of the

		aluminium lower stop in contact with steel pins. The water that entered in the grease acts as corroding media that also leads to galvanic coupling.
	Corrective and/or preventive measures	Use another grease that is not hygroscopic, thereby preventing corrosion and galvanic coupling.
	SR / SB ?	
	Classification	Wrong materials selection Wrong manufacturing (overtorque)

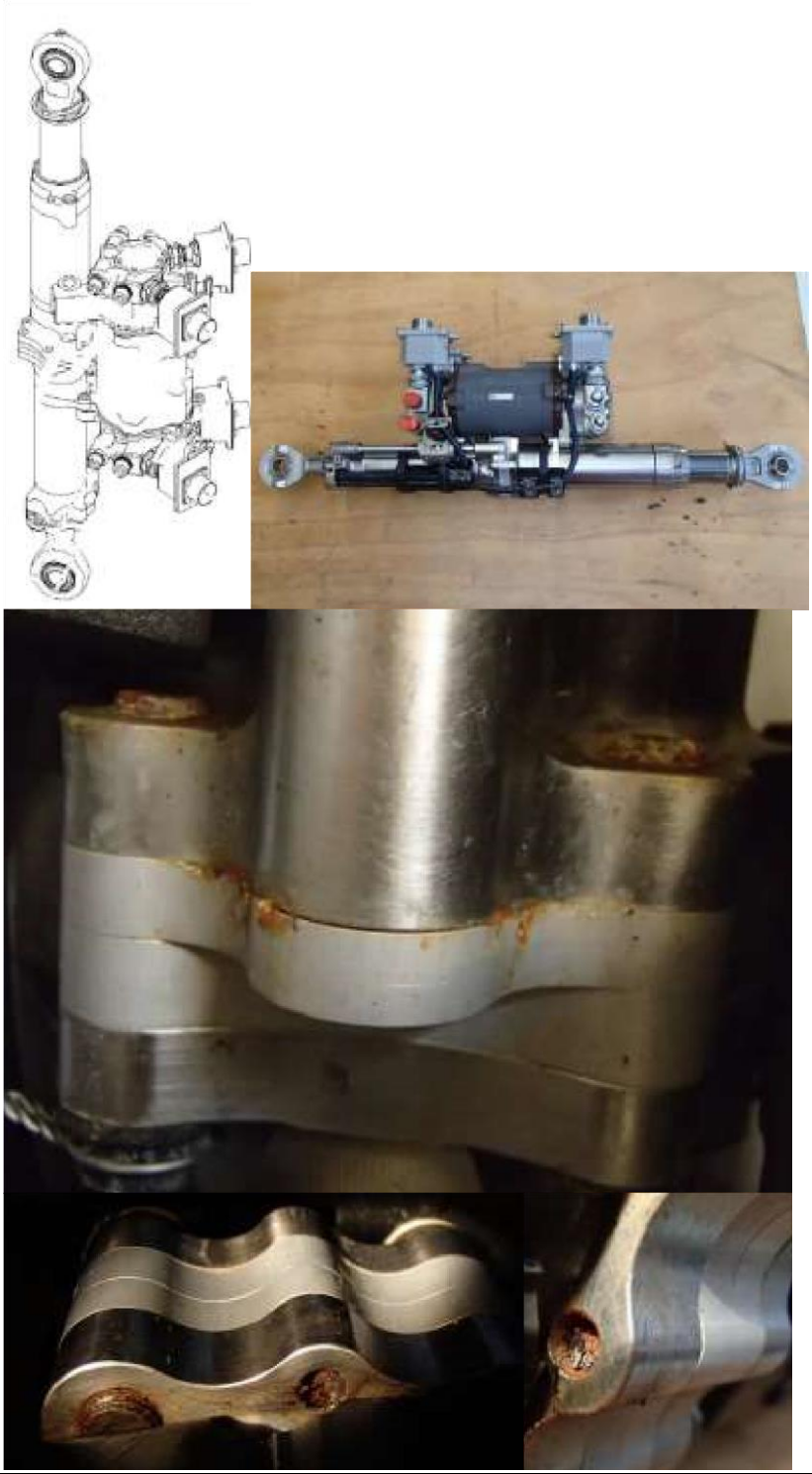
Tail number		N227, N233
ATA nr		66-15
NCage code		S661A50T7101:F0210 S661A50T8101:F0210 S661A50T6101:F0210 S661A50T5101:F0210
Picture(s)		 
Corroding component		Corrosion on aluminium main rotor blade folding actuator (MRBFA)
Component coupled to		Fasteners (steel, titanium)
	Failure cause	If the coating is damaged near the fasteners galvanic corrosion of the aluminium MRBFA housing can start. Galvanic coupling of the housing to the steel and/or titanium fasteners leads to accelerated corrosion. The paint may be damaged by erosion as well as by tooling.

Preliminary analysis	Corrective and/or preventive measures	Use a barrier seal to reduce the risk of paint damage and subsequent corrosion. Remove corrosion, reapply paint and apply sealant around fasteners after mounting them.

	SR / SB ?	SB: use caps to prevent water ingress when helicopter is on ship. The caps cover the manual folding actuator.
	Classification	Insufficient corrosion protection

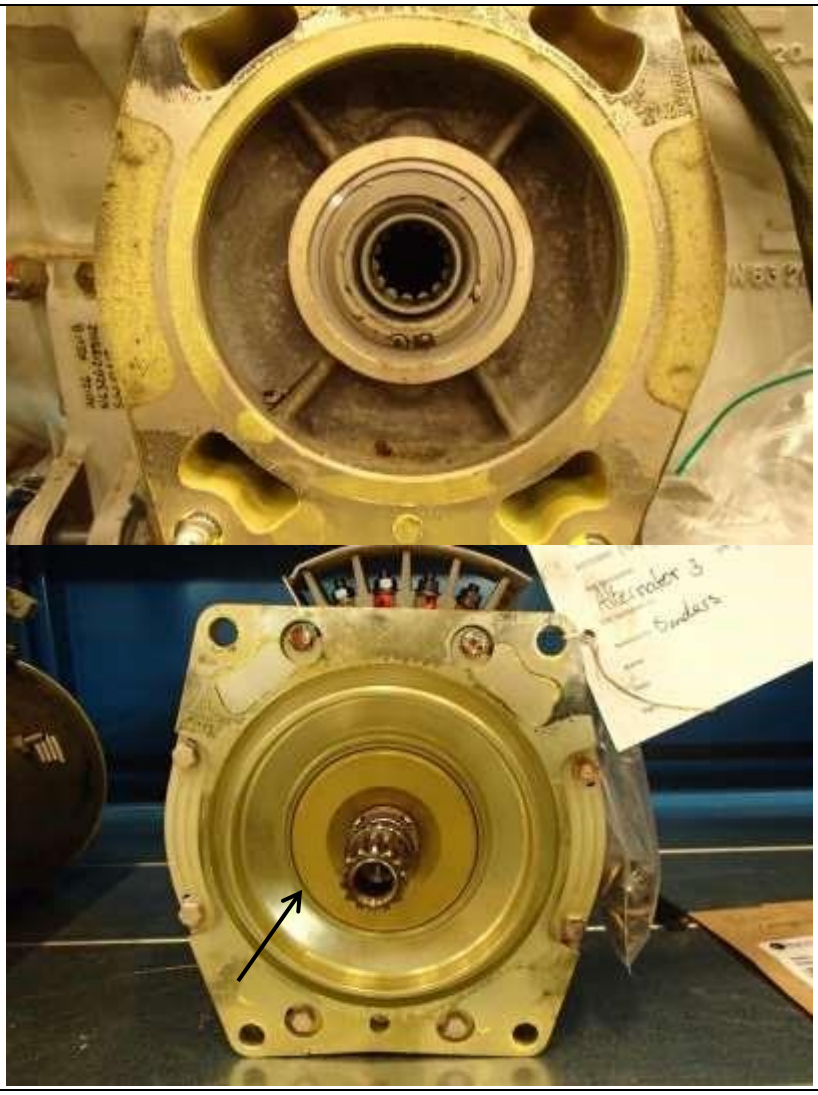
Tail number		N227, N233
ATA nr		66-15
NCage code		S661A50T7101:F0210 S661A50T8101:F0210 S661A50T6101:F0210 S661A50T5101:F0210
Picture(s)		
Corroding component		Corrosion on the safety mass housing of the MRBFA
Component coupled to		steel
Preliminary analysis	Failure cause	If the coating is damaged near the fasteners galvanic corrosion of the aluminium safety mass housing of the MRBFA can start. Galvanic coupling of the housing to the steel and/or titanium fasteners leads to accelerated corrosion. Corrosion is much less on the N233 than on the N227 due to application of grease to many of the components.
	Corrective and/or preventive measures	Apply barrier seal before painting to reduce the risk of corrosion when the paint is damaged. Apply grease or a soft film CPC on the safety mass as additional corrosion protection.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number	N227
ATA nr	67-33
NCage code	S673A30A3000:F0210

Picture(s)	

		
Corroding component		Main rotor actuator (MRA) / main servo assembly electrical
Component coupled to		Several materials coupled (stainless steel, steel,...)
Preliminary analysis	Failure cause	The MRA is protected against high temperatures by a blanket that collects water and contains the water once collected. The water facilitates: • Crevice corrosion in crevices between mating surfaces of the actuator, causing separation of the surfaces. • Corrosion of most of the steel fasteners. • Pitting corrosion of stainless steel components
	Corrective and/or preventive measures	Apply jointing compound on faying surfaces to prevent galvanic and crevice corrosion. Apply sealant or grease to the steel fasteners. Use a fire blanket that does not contain water if water spray is allowed to enter. Apply a hard film CPC to the stainless steel components to prevent pitting corrosion in salt water environment. Select a stainless steel with better resistance to pitting corrosion in salt water environment.
	SR / SB ?	

	Classification	Insufficient corrosion protection Wrong materials selection

Tail number	N227
ATA nr	24-21
NCage code	S242A1001051:F0210
Picture(s)	

		
Corroding component		Corrosion of FWD alternator
Component coupled to		Steel coupled to stainless steel
Preliminary analysis	Failure cause	Water ingress that should not have occurred caused corrosion of the steel component (lower picture). Water entry occurred most probably through a grid on the back of the alternator and enters the area between the surfaces indicated in the middle image.
	Corrective and/or preventive measures	Prevent water ingress by using better sealing, or by covering the grid from direct water spray.
	SR / SB ?	
	Classification	Wrong design

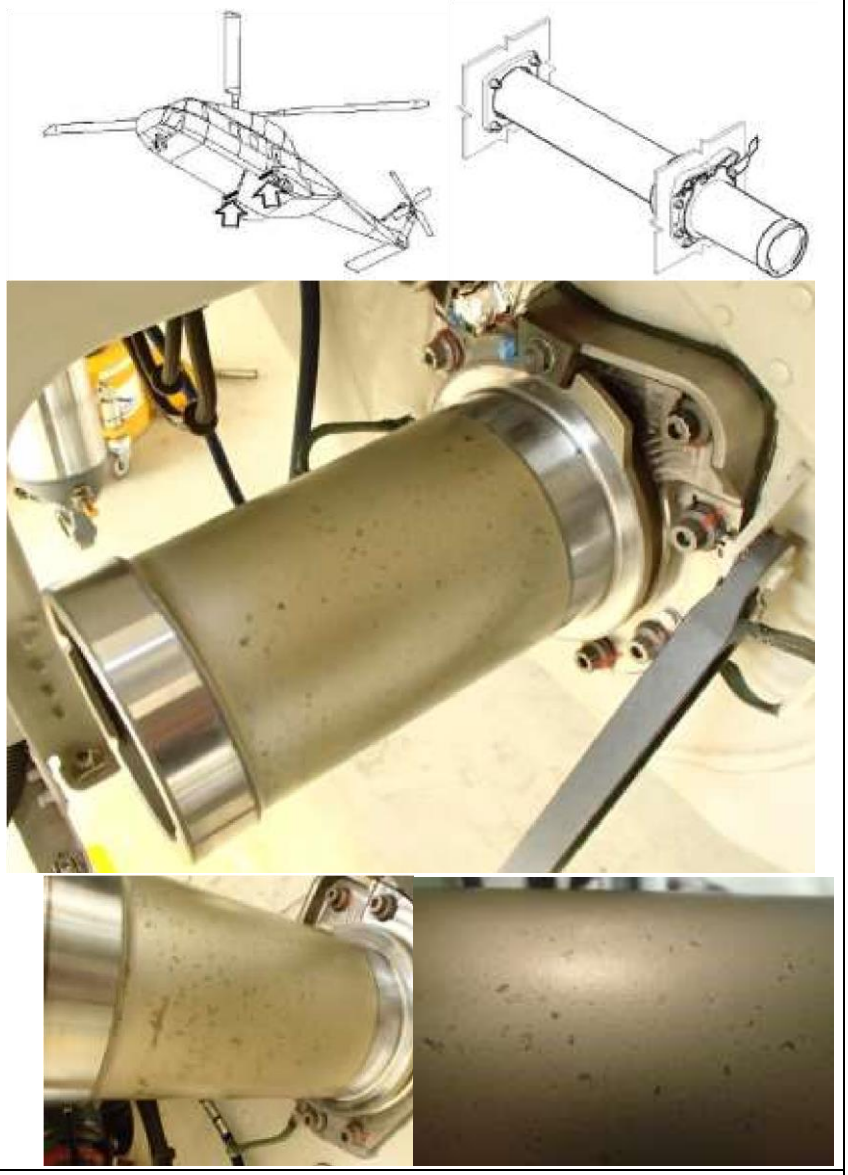
Tail number	N227
ATA nr	63-31
NCage code	S633A1010101:F0210

Picture(s)		
Corroding component		Main gearbox support strut (suspension bar)
Component coupled to		Not applicable
Preliminary analysis	Failure cause	Paint is hard and inflexible, which leads to cracking and chipping of the paint. Corrosion has not started yet.
	Corrective and/or preventive measures	Select paint with higher flexibility and better adhesion. Apply a thinner paint film, because thinner paint films have better flexibility than thicker paint films.
	SR / SB ?	
	Classification	Wrong materials selection

Tail number		N227
ATA nr		66-10
NCage code		S661A0000051:F0210
Picture(s)		Not available
Corroding component		Corrosion of trim taps
Component coupled to		CFRP blade and titanium fasteners
Preliminary analysis	Failure cause	Erosion of the paint leads to exposure of the aluminium. The aluminium is in contact with more noble CFRP, which leads to galvanic corrosion.
	Corrective and/or preventive measures	Remove corrosion locally and re-apply the paint. Replace the trim taps if corrosion is beyond repair. Insulate the trim tap from the CFRP blade by using an adhesive in addition to the fasteners to attach the trim taps to the blade. Jointing compound is not advised because it may impair adhesion of the paint.
	SR / SB ?	

	Classification	Insufficient corrosion protection

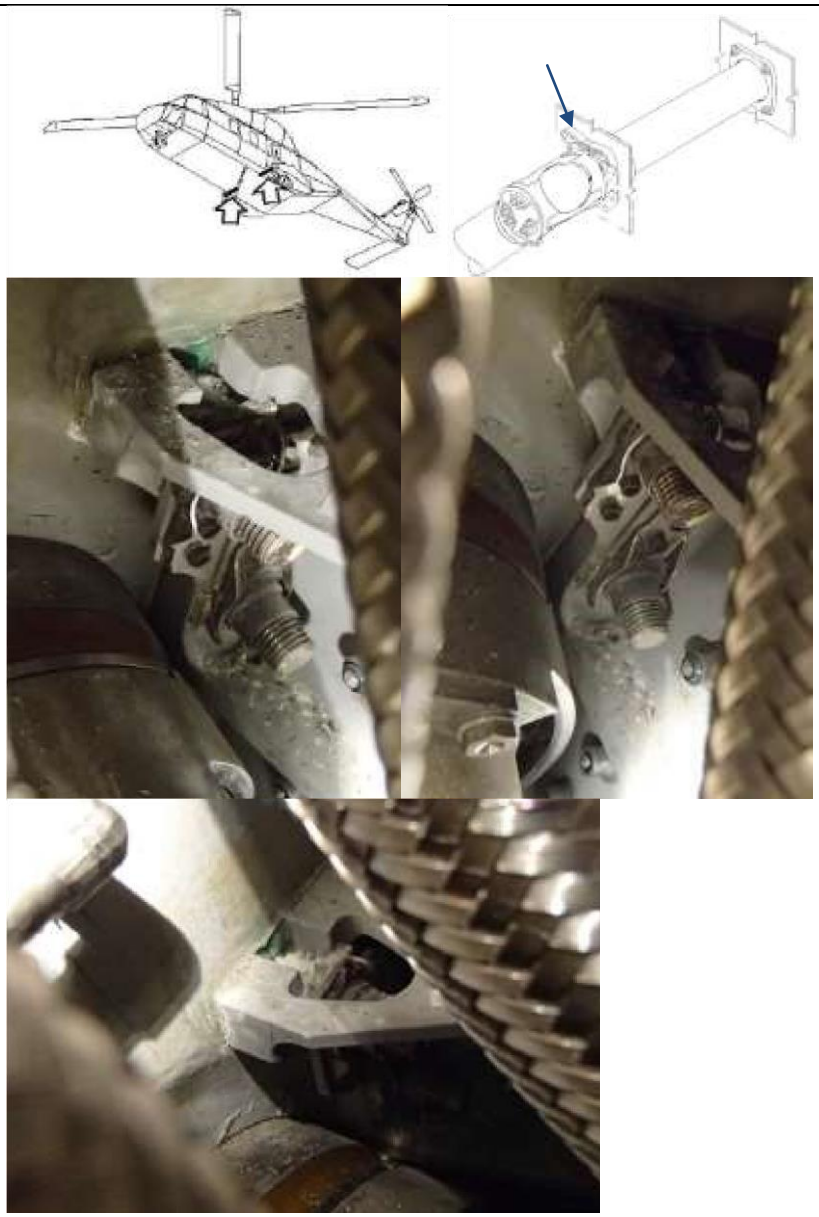
6 Landing gear area: zone 700

Tail number		N227, N233
ATA nr		32-13
NCage code		S321F3010101:H1822
Picture(s)		
Corroding component		Landing gear pintle axle (anodised aluminium)
Component coupled to		Hard chrome tread for landing gear trailing arm, steel coupling plate and CFRP fuselage
Preliminary analysis	Failure cause	Salt water sprays onto the pintle axle and causes degradation of the anodic layer followed by pitting corrosion of the aluminium. The area that is shielded from salt water spray by the trailing arm shows no pitting corrosion. Static electricity may have accelerated the corrosion. The bonding lead connecting the pintle axle to the helicopter shows light

		corrosion while the bonding lead connecting the pintle axle with the trailing arm is heavily corroded and often broken. Hence the static electricity is building up on the pintle axle. The presence of a salt water film may result in conduction of the static electricity away from the pintle axle, leading to stray current corrosion of the pintle axle.
	Corrective and/or preventive measures	Sealing of the anodic layer after anodising (if this has not been done). Rinsing of the pintle axle after each flight. This does not prevent salt water spray on the axle when the helicopter is on the deck in high winds. Application of (some) grease or soft film CPC on the pintle axle to seal small pinholes in the anodic layer.
	SR / SB ?	
	Classification	Wrong design

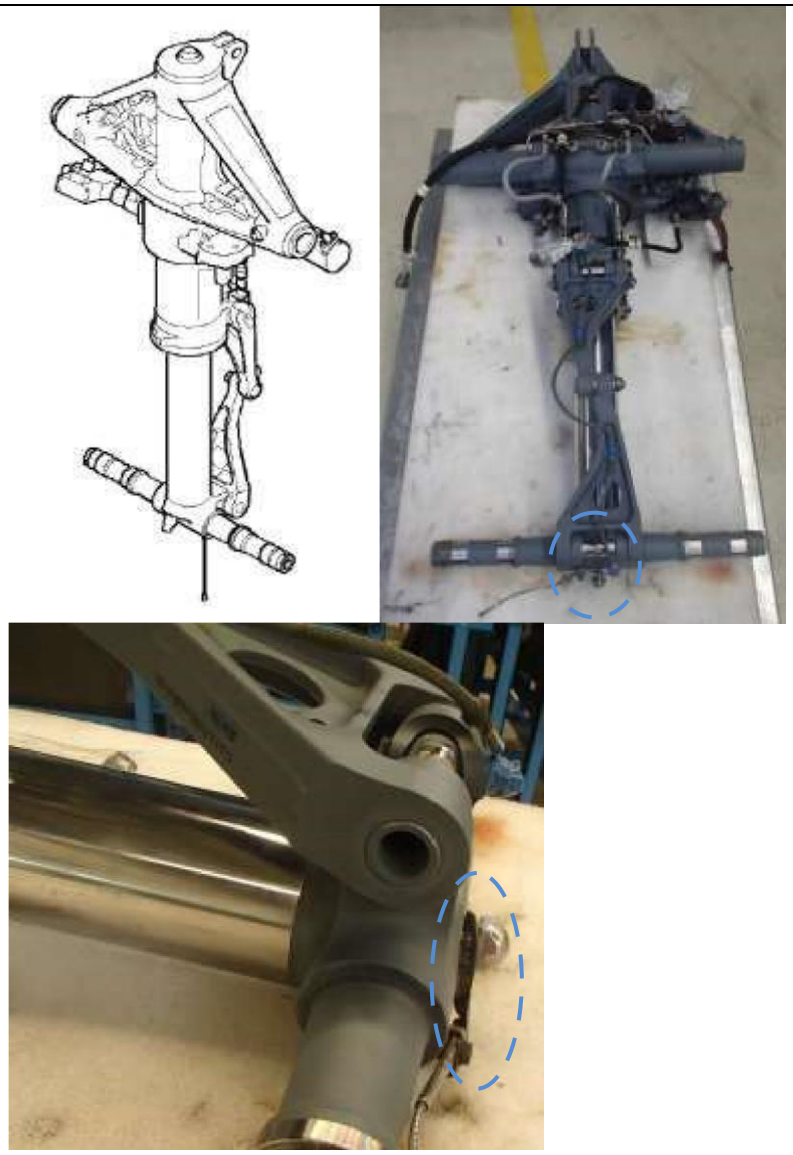
Tail number		N227
ATA nr		32-13
NCage code		S533M6001231:C0418
Picture(s)		
Corroding component		Main landing gear inner rib (RH)
Component coupled to		CFRP, titanium
Preliminary analysis	Failure cause	Water could enter the right hand shell of the subfloor through the gaps between the floor panels, because the floor panels were not sealed. Stagnant water caused corrosion of the bracket. It should be noted that the titanium installation bolts of the pintle axle are not sealed, although sealing is prescribed in the install procedure. Only very light corrosion is seen on the bolts.
	Corrective and/or preventive measures	Sealing of the floor panels to prevent water entry. Spray application of a hard film CPC to prevent corrosion in the case water enters the area even though the floor panels are sealed. Sealing of the titanium bolts.
	SR / SB ?	
	Classification	Wrong design Wrong manufacturing

Tail number	N227

ATA nr		32-13
NCage code		S533M6001218:C0418
Picture(s)		
Corroding component		Main landing gear outer bracket (RH)
Component coupled to		CFRP
Preliminary analysis	Failure cause	Water could enter most probably through the opening in the frame at the position of the pressure refuel valve actuator and cause corrosion of the main landing gear outer bracket.
	Corrective and/or preventive measures	Close the opening at the position of the pressure refuel valve actuator with a transparent window. Apply a CPC to the inside of the door post.
	SR / SB ?	
	Classification	Insufficient corrosion protection

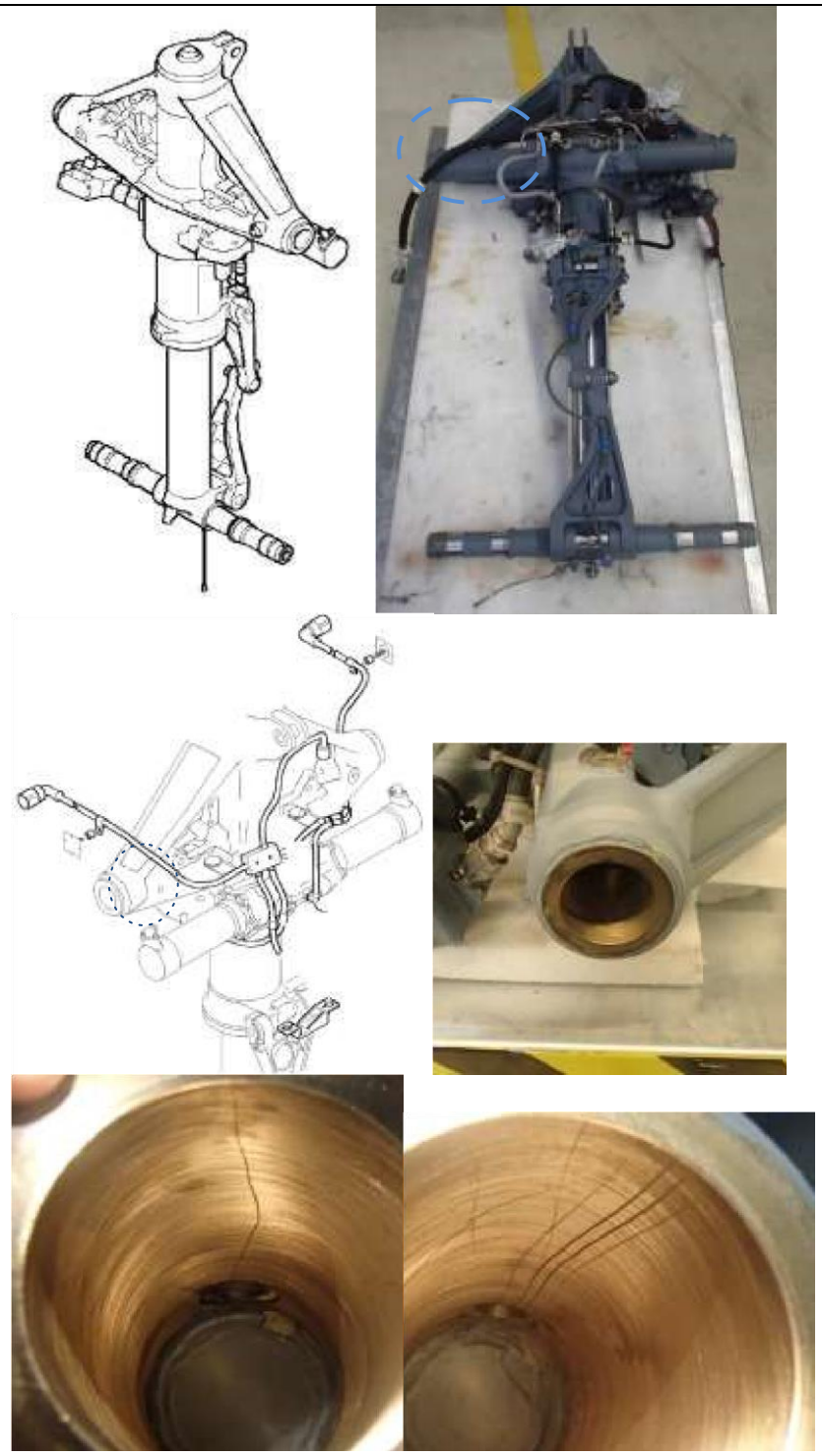
Tail number		N233
ATA nr		32-13
NCage code		EN3196-080:I9005
Picture(s)		Not available
Corroding component		Silver-plated nuts in the landing gear lock disk
Component coupled to		CFRP, steel plate
Preliminary analysis	Failure cause	Silver-plating is damaged by tooling. This exposes the steel bolt. Galvanic coupling of the steel to the more noble silver plating leads to corrosion of the steel under the plating.
	Corrective and/or preventive measures	Use of stainless steel bolts. Use of thicker silver plating that is more resistant to tooling damage. Use of cadmium plating instead of silver plating. Cadmium plating protects the steel even if the plating is damaged because cadmium is less noble than steel. NB Coupling to CFRP may lead to accelerated corrosion of the cadmium plating and subsequent corrosion of the steel bolt. Apply grease to seal damages of the silver plating. Jointing compound should have been applied to the bolt heads to prevent galvanic coupling, but seems to be absent. Jointing compound should have been applied to the self-locking nuts as well.
	SR / SB ?	
	Classification	Wrong materials selection Wrong manufacturing

Tail number	N227
ATA nr	32-21
NCage code	S322F1501105:H1632

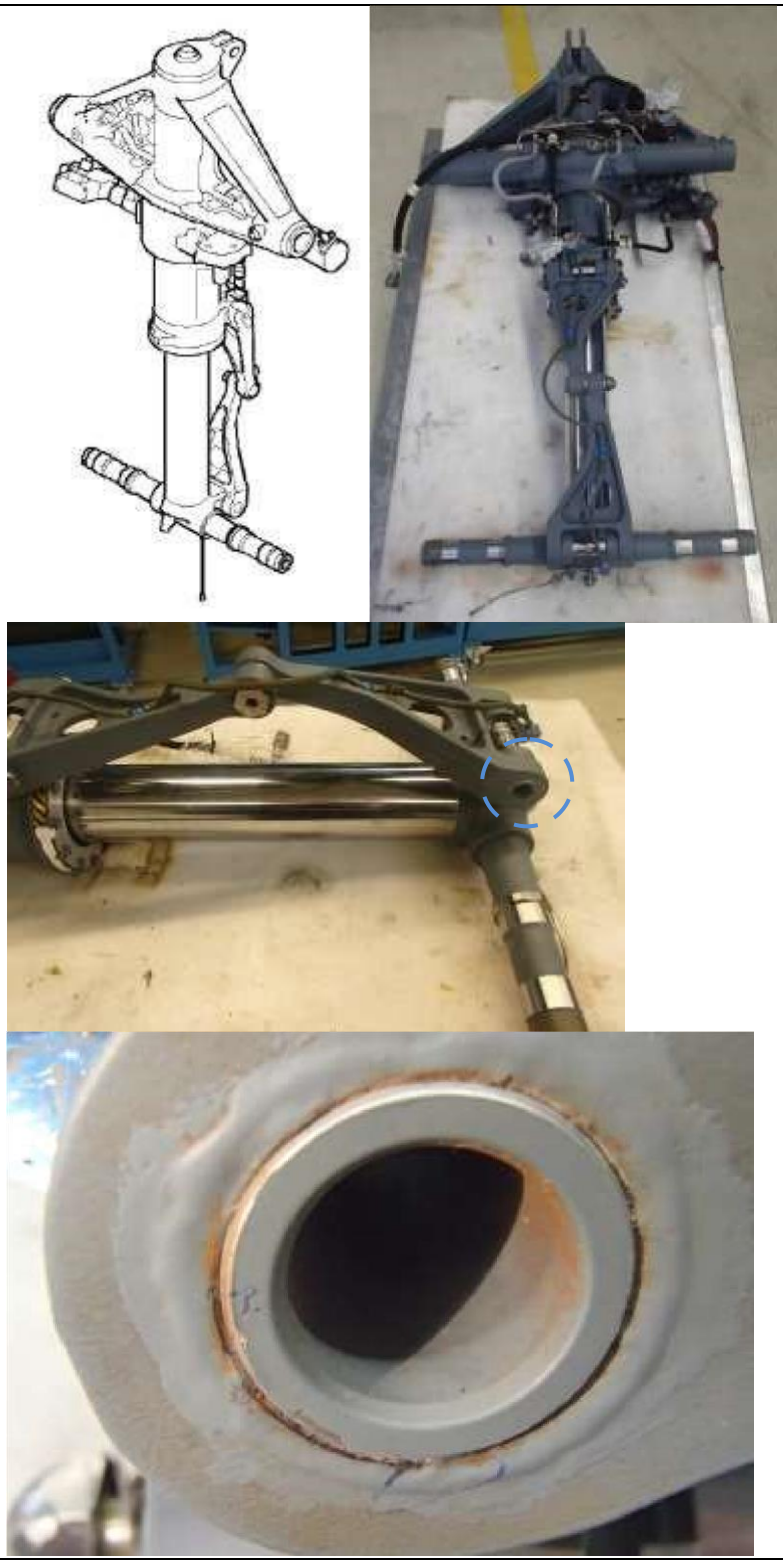
Picture(s)	

		 
Corroding component		Nose landing gear (NLG) shockstrut – NFH
Component coupled to		
Preliminary analysis	Failure cause	Corrosion of the aluminium of the shockstrut where the cable for discharge of static electricity is connected. The paint is damaged which allowed corrosion to start. The corrosion may be accelerated by galvanic coupling.
	Corrective and/or preventive measures	Use a flexible sealant to seal the aluminium in order to prevent damage of the paint. Sealing of the bronze bushing is not possible because static electricity must be conducted to the cable.
	SR / SB ?	
	Classification	Insufficient corrosion protection

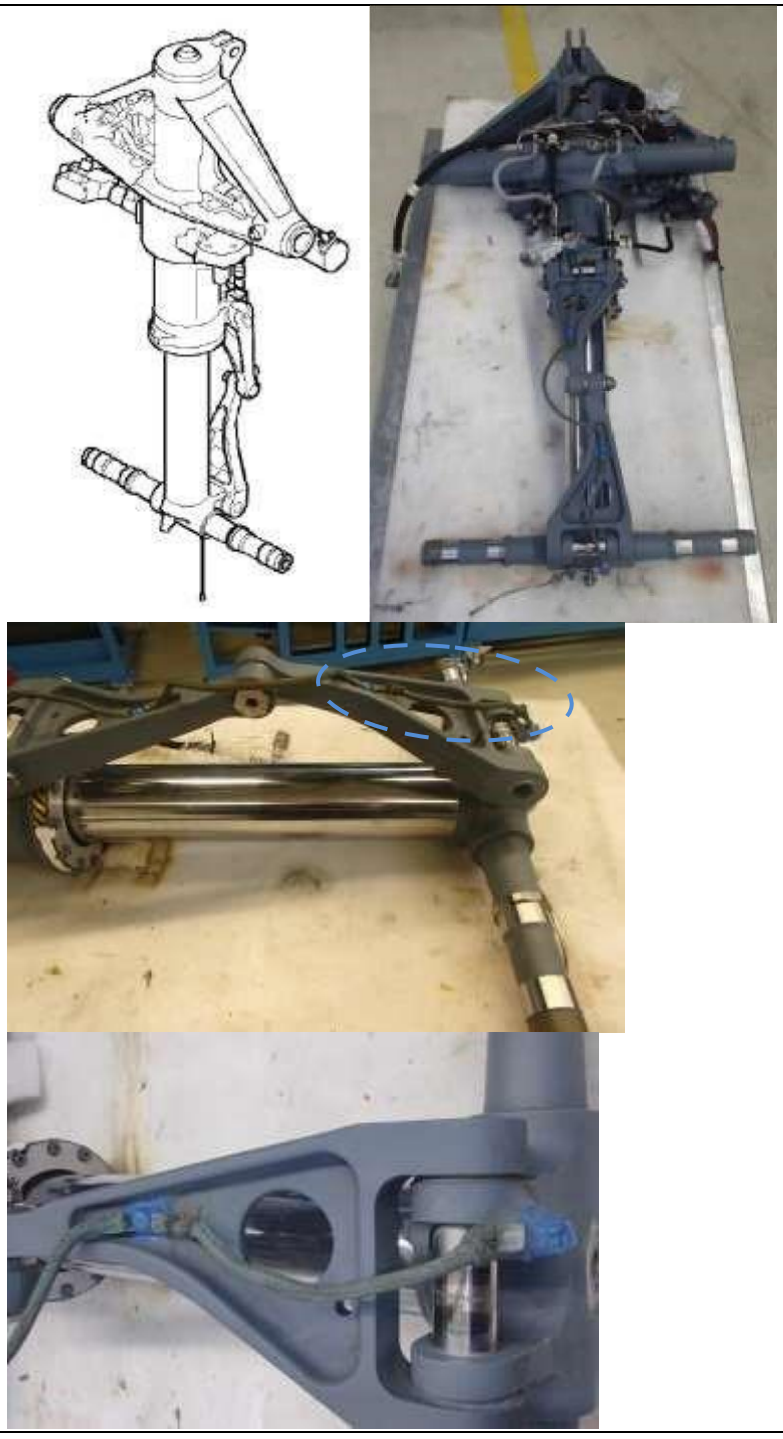
Tail number	N227
ATA nr	32-21
NCage code	S322F1501105:H1632

Picture(s)		
Corroding component		NLG shockstrut – NFH
Component coupled to		Not applicable
	Failure cause	Hard particles were drawn into the tube and caused scratches along the inside of the tube. This happened when disassembling the landing gear.

Preliminary analysis	Corrective and/or preventive measures	Avoid entry of hard particles into the tube when disassembling the landing gear, for instance by sealing the hole from the outside (if possible).
	SR / SB ?	
	Classification	Wrong design

Tail number	N227
ATA nr	32-21
NCage code	S322F1351105:H1632
Picture(s)	

Corroding component		NLG locking mechanism
Component coupled to		Not applicable
Preliminary analysis	Failure cause	Corrosion between pin and torque link lug is caused by water that can enter the crevice between the pin and the lug. The inside of the pin shows brown corrosion product as well, indicating that the paint inside the pin provides insufficient corrosion protection.
	Corrective and/or preventive measures	Sealing of the crevice between bushing and lug with a soft film CPC or grease. Use an additional CPC on top of the paint inside the pin.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number	N227
ATA nr	32-21
NCage code	S322F1351105:H1632
Picture(s)	

		
Corroding component		NLG locking mechanism
Component coupled to		CFRP
Preliminary analysis	Failure cause	Corrosion of the bonding lead and fracture of the wires in the braid upon bending after they have become brittle by severe corrosion.
	Corrective and/or preventive measures	Periodic inspection of the bonding leads for corrosion and replacement if corrosion is severe. Additionally they may be protected against corrosion by a sleeve or rubber tubing, but then sealing of the end of the tubing must be done to prevent water entry. Application of a soft film CPC may also reduce corrosion.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number	N227
ATA nr	32-21
NCage code	S322F1071201:H1632

Picture(s)		
Corroding component		NLG pintle pin
Component coupled to		Not applicable
Preliminary analysis	Failure cause	Cracking of the paint allowed water to enter the pin-lug coupling of the pintle pin and caused corrosion of the steel.
	Corrective and/or preventive measures	Prevent cracking of the paint by use of more flexible paint. Use a highly flexible sealant under the paint in the radius to prevent sharp radii in the paint that are prone to cracking.
	SR / SB ?	
	Classification	Wrong materials selection

Tail number	N227, N233
ATA nr	95-61

NCage code		S538A1111203:F0210
Picture(s)		
Corroding component		Right hand sponson immersion sensor cover grid
Component coupled to		CFRP cover, steel bolts
Preliminary analysis	Failure cause	The aluminium grid is most probably painted at the outside only. Water can spray through the grid and salt deposits can form on the inside. Salt water on the inside leads to corrosion that is accelerated by galvanic coupling of the aluminium grid to the CFRP cover.
	Corrective and/or preventive measures	Paint the grid on both sides before installing it on the cover. This ensures electrical insulation of the aluminium from the more noble CFRP cover and steel bolts and also prevents corrosion of the grid on the top surface when salt water entered through the grid. Use another material for the grid, like CFRP, plastic, glass fibre reinforced plastic.
	SR / SB ?	
	Classification	Wrong materials selection

Tail number	N227, N233
ATA nr	33-46
NCage code	S334A60A1012:F0210

Picture(s)		
Corroding component		Search light assembly
Component coupled to		Several materials are coupled to each other
Preliminary analysis	Failure cause	Several components start corroding after contact with salt water. The components are not electrically insulated from each other and not protected from the salt water. As a result corrosion can start and is accelerated by galvanic coupling.
	Corrective and/or preventive measures	Apply sealant or jointing compound between the different materials. Apply paint, sealant or grease to protect the bare metal components.
	SR / SB ?	
	Classification	Wrong materials selection

Tail number	N227
ATA nr	32-42
NCage code	S324F2000000:H1632
Picture(s)	

Corroding component		Corrosion of brake disks
Component coupled to		
Preliminary analysis	Failure cause	Salt water environment leads to severe corrosion of steel brake disks.
	Corrective and/or preventive measures	Rinsing of the brake disks may reduce the severity of corrosion. Apply black oxide to the brake disks as protective coating. The black oxide will be removed from the parts that take place in the braking, but the remainder of the brake disks will be protected against corrosion by the coating.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number		N227
ATA nr		32-42
NCage code		S324F2000000:H1632
Picture(s)		Not available
Corroding component		Corrosion of aluminium brake disk housing
Component coupled to		Steel bolts and locking wire
Preliminary analysis	Failure cause	Coating on housing is locally damaged. Sometimes by locking wire, sometimes at the sharp edges in the housing. Filiform corrosion starts from these locations.
	Corrective and/or preventive measures	Check coating integrity after installation of the brake housing. Use of scratch and impact resistant coating. Apply a barrier seal before painting as additional protection for parts that are prone to damage upon installation of the housing.
	SR / SB ?	
	Classification	Wrong manufacturing (paint damaged) Wrong design (sharp edges)

Tail number		N227
ATA nr		32-41
NCage code		214-11000:33269 214-11200:33269
Picture(s)		Not available
Corroding component		Corrosion of main landing gear wheel bearings
Component coupled to		Not applicable
Preliminary analysis	Failure cause	The bearings of the main landing gear were corroding because the grease used to seal the bearings was hygroscopic. The grease attracted water that caused corrosion of the corrosion-sensitive bearing steel.
	Corrective and/or preventive measures	Now another type of grease is used. This grease is not hygroscopic and seems to work well.
	SR / SB ?	
	Classification	Wrong materials selection

Tail number		N227
ATA nr		95-61
NCage code		S956A20A1000:F0210
Picture(s)		
Corroding component		Corrosion of water immersion sensor and a dummy connector next to it
Component coupled to		CFRP sponson
Preliminary analysis	Failure cause	Water could enter the area and caused corrosion of the sensor and galvanic corrosion of the connector.
	Corrective and/or preventive measures	Use a hard film CPC on the sensor to avoid direct contact with water. Place a cap over the connector to prevent contact with water. Insulate the connector and sensor from the CFRP sponson by using a sealant between the connector and the skin and use sealant or jointing compound when installing the fasteners.
	SR / SB ?	
	Classification	Insufficient corrosion protection

Tail number	N227
ATA nr	95-62
NCage code	218735-0:F6101

Picture(s)	 

Corroding component		Floatation gear bottle clamps
Component coupled to		Not applicable
Preliminary analysis	Failure cause	Long duration wetness in saline environment caused corrosion of the fasteners on the floatation bottles. Only those at the right hand side of the helicopter are affected. Those at the left hand side of the helicopter are in fine condition. The flotation gear is attached to the sponson attachment lug that shows corrosion as well.
	Corrective and/or preventive measures	Replace the clamps. Apply a hard film CPC to the clamps, in addition to the protective coating. Rinse periodically to remove the salt deposited on the clamps.
	SR / SB ?	
	Classification	Wrong design
Tail number		N227
ATA nr		32-91

NCage code		N329G10A3002:A0126
Picture(s)		Not available
Corroding component		Deck lock emergency manual release (Rosan coupling and coupling next to it)
Component coupled to		Not applicable
Preliminary analysis	Failure cause	The couplings show white corrosion products. Installing of the Rosan coupling leads to damage to the coating that is not properly corrected. The exposed bare metal comes into contact with salt water spray that causes corrosion.
	Corrective and/or preventive measures	Sealing of the Rosan coupling after installation to prevent contact with water (spray).
	SR / SB ?	
	Classification	Wrong design

7 Conclusions

The corrosion findings listed in this report show that a total of 92 different occurrences are found on two helicopters that have been operating on a ship in tropical seas. Each occurrence is analysed based on the visual appearance and material information available. The type and cause of corrosion and possible corrective measures are identified for each occurrence. Finally the occurrences are classified according to their probable cause of corrosion. Summarizing the number of occurrences for each classification leads to the following list:

- 52 occurrences due to insufficient corrosion protection
- 20 occurrences due to wrong material selection
- 20 occurrences due to wrong design
- 14 occurrences due to wrong manufacturing Fourteen occurrences have a double classification.

Acknowledgements

The assistance RNLAF personnel, in particular Aoo J.J.M.H. van Es, in finding the corrosion, supplying photographs and information regarding materials and part identification numbers and discussing the corrosion problems is greatly acknowledged.