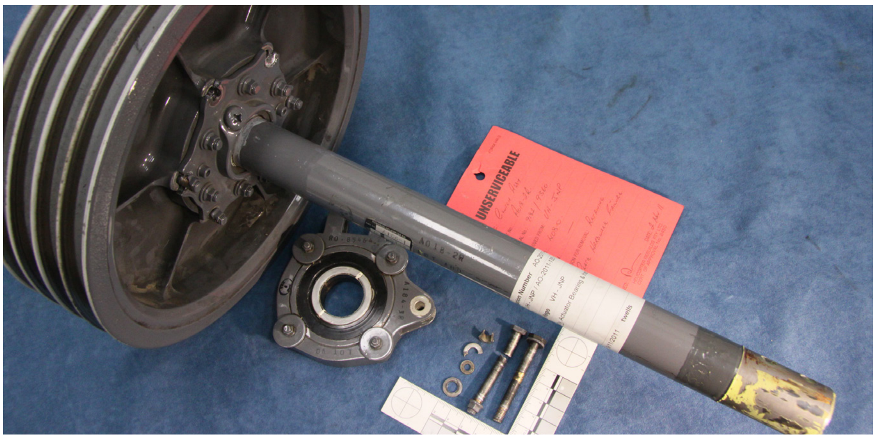
Australian Government
Australian Transport Safety Bureau

Embrittled nut and related failures Robinson R22 Beta helicopter, VH-JNP

22 km N of Saxby Downs, Qld | 12 October 2011



Investigation

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Postal address: PO Box 967, Civic Square ACT 2608
Office: 62 Northbourne Avenue Canberra, Australian Capital Territory 2601
Telephone: 1800 020 616, from overseas +61 2 6257 4150 (24 hours)
Accident and incident notification: 1800 011 034 (24 hours)
Facsimile: 02 6247 3117, from overseas +61 2 6247 3117
Email: atsbinfo@atsb.gov.au
Internet: www.atsb.gov.au

Addendum

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Safety summary

VH-JNP post-landing

Source: Foxling Helicopter Services

What happened

On 12 October 2011, the pilot of a Robinson R22 helicopter, registered VH-JNP, was performing aerial work near Saxby Downs in Queensland, when he heard a rattling noise behind the cabin and noted that the clutch light had illuminated. The pilot opened the clutch actuator circuit breaker and, at the same time, noted a burning rubber smell, prompting him to make an immediate precautionary landing and shut down the helicopter.

What the ATSB found

The problems with the helicopter's drive system were traced to the clutch assembly where a group of MS21042L-4 locking nuts on the drive belt upper sheave had cracked and fractured. This premature nut failure had stemmed from the likely embrittling effect of residual hydrogen generated during the cadmium electroplating process applied during manufacture. The nut failures consequently led to a series of mating part failures and a breakdown of the clutch assembly, producing the symptoms experienced by the pilot and prompting the precautionary landing.

Importantly, after recognising the aural and visual warnings of problems developing with the helicopter's drive system, the pilot followed the required emergency procedures and made an immediate and safe precautionary landing. Taking this prompt, prescribed action limited the damage sustained and very likely prevented a more serious outcome.

What was done as a result

At the time of this occurrence, the brittle failure of MS21042L-series nuts was an emerging airworthiness issue and several associated safety actions had already been implemented. In August 2011, 2 months before this occurrence, the helicopter manufacturer issued Service Letters alerting owners, operators and maintenance personnel to the potential for cracking of MS21042L-series self-locking nuts and requiring the immediate replacement of any cracked nuts found during inspections. The service letters had been issued in response to reports of cracked nuts being discovered on Robinson and other helicopter types.

On 12 October 2011 (the date of this occurrence), the Australian Civil Aviation Safety Authority (CASA) issued an Airworthiness Bulletin (AWB 14-002), alerting pilots and maintenance personnel of the need to closely monitor the condition of high-strength steel hardware (such as these nuts) with a view to identifying any failures that may have resulted from hydrogen-induced cracking.

On 4 April 2012, the manufacturer of the specific MS21042L-series nuts in question issued a *Technical Quality Notice Bulletin,* addressing in detail many procedural improvements that were being introduced to reduce the potential for hydrogen-related failures of this nut type.

Safety messages

A potentially serious accident was avoided by the prompt actions of the pilot, who recognised the symptoms of a drive system malfunction and promptly followed the emergency procedure requirements by landing immediately.

This occurrence highlights the importance of maintained vigilance during pre-flight and maintenance inspections, where close attention must be paid to the condition of all components within the helicopter's critical flight systems. It also highlights the importance of pilots and maintenance personnel remaining attentive to the release of any information regarding new or emerging airworthiness issues that may affect the safety of their flight operations.

Contents

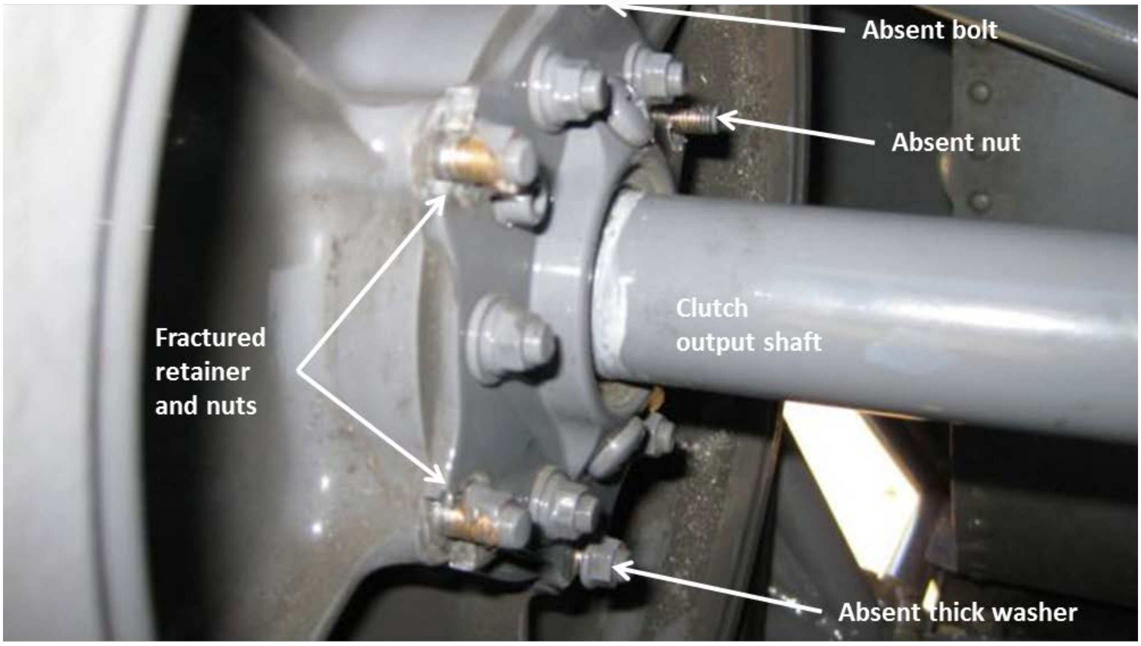
The occurrence

History of the flight

On 12 October 2011, the pilot of a Robinson R22 Beta helicopter, registered VH-JNP, was performing aerial work near Saxby Downs in the gulf country of North Queensland. During cruise flight, approximately 10 minutes after lifting off, the pilot reported hearing a rattling noise behind the cabin, followed by the illumination of the clutch light. Responding, the pilot opened the clutch actuator circuit breaker and, at the same time, noted a 'burning rubber smell', prompting him to make an immediate precautionary landing and shut the helicopter down.

An inspection by the operator later that day identified damage to the helicopter's main rotor drive clutch assembly. Several retention nuts from the upper drive pulley (sheave) had failed (Figure 1), with corresponding lobes of the retainer having broken away beneath the nuts. The clutch actuator drive motor had also sustained some visible damage.

Figure 1: In-situ photograph of the damaged clutch assembly



Source: Foxling Helicopter Services

Context

Aircraft information

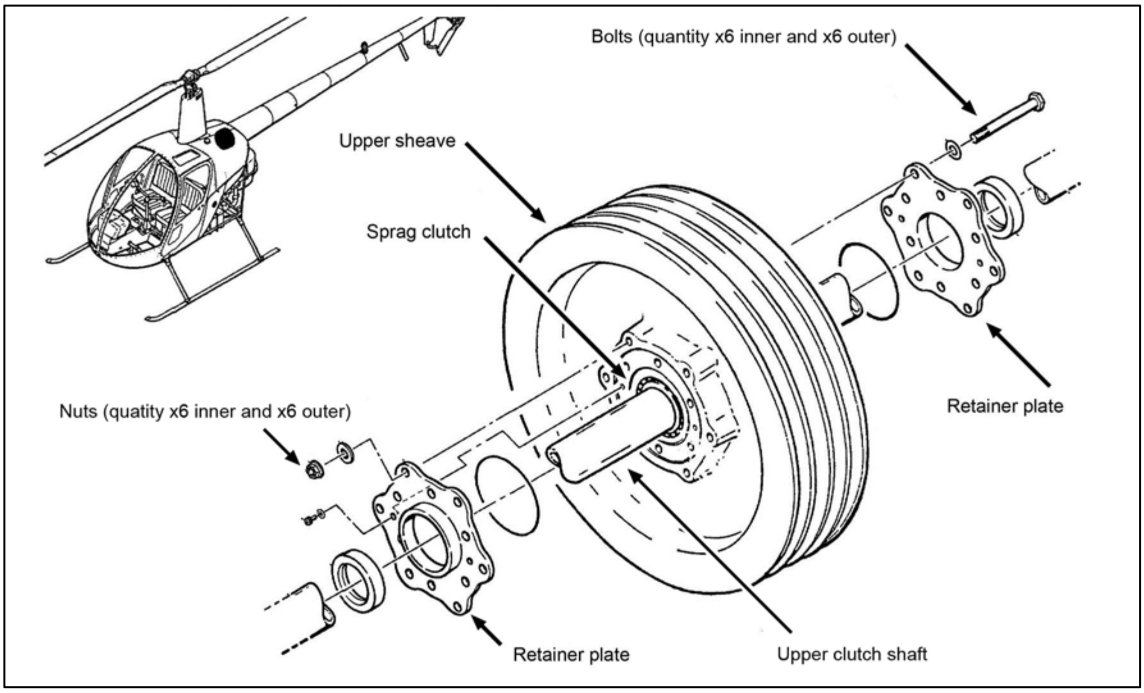
VH-JNP was a Robinson Helicopter Company (RHC) model R22 Beta helicopter, serial number 1121. The helicopter was manufactured in the United States in 1989 and first registered in Australia in October of that year. In April 2011, at 6,149.3 hours total time in service (TTIS), the helicopter underwent a major refit and overhaul, during which the clutch assembly was replaced with a factory-overhauled unit (serial number 9182/9360). A factory-overhauled clutch actuator was also installed. Since that overhaul and up until the time of the incident, the helicopter had operated for a further 408 hours.

Clutch assembly functional description

The Robinson R22 helicopter is a two-seat, light utility helicopter powered by a horizontally-mounted, rearward-facing, piston engine. Power is transmitted to the rotor system through two dual-banded, rubber v-belts running on matching, multi-grooved sheaves (pulleys). The upper drive sheave was mounted on the clutch shaft and could be moved relative to the engine drive sheave by an electric clutch actuator, allowing control of the belt tension.

Figure 2 illustrates the R22 helicopter clutch assembly. Along with the clutch shaft, a free-running sprag clutch and two oil seals were secured centrally to the upper sheave by opposing retainers, using an array of six outer and six inner bolts and nuts.

Figure 2: R22 clutch assembly location and exploded view



Source: Robinson Helicopter Company

Inspection and maintenance

The helicopter *Pilot's Operating Handbook* specified a series of checks and inspections to be carried out daily before the commencement of flight. Those checks were aimed at providing a reasonable opportunity for the identification of any damage or problems that may have been sustained or developed during the previous flight/s. The handbook required checks of the sprag clutch assembly; however, there was no specific requirement for the inspection of the clutch retainer fasteners.

The manufacturer's maintenance schedule for the helicopter prescribed a regime of periodic inspections and preventative maintenance activities aimed at ensuring the continued safety and airworthiness of the helicopter. In the clutch assembly context, during each 100-hourly/12-monthly inspection, the maintenance manual required the maintainer to *'inspect the condition and verify the security of all fasteners'*. Additionally, Service Letter R22 SL-58 (issued 18 August 2011, Appendix B) raised the issue of cracking within MS21042L-series nuts (although directed inspections for this issue were not specified in the Service Letter).

A review of the maintenance documentation for VH-JNP (post-installation of the overhauled clutch assembly) found records of the 100-hourly maintenance having been carried out in June 2011 (6,249.3 hours TTIS), July 2011 (6,348.4 hours TTIS), August 2011 (6436.3 hours TTIS) and October 2011 (6,536.3 hours TTIS). Service Letter R22 SL-58 was not listed in these maintenance records as having been embodied during the October 2011 maintenance activity.

Clutch assembly examination

Following commencement of the ATSB investigation, the operator submitted the helicopter's clutch assembly for examination (Figure 3). Preliminary visual examination of the components noted the following:

- The upper sheave did not reveal any uneven wear, damage or other indications of misalignment or abnormal operation.
- The outer lobe portions of both retainers had fractured (Figure 4).
- All six *inner* bolts/nuts/washers that secured the two retainers onto the sprag clutch housing were intact (Figure 4).
- The self-locking nuts and respective washers from five of the six retainer outer bolts had fractured (Figure 6).
- One of the outer, retainer bolts had fractured through the shank. Its self-locking nut remained whole and attached (Figure 5).

Key component identification

Table 1 presents the component details for the helicopter's clutch assembly.

Table 1: Clutch assembly component detail

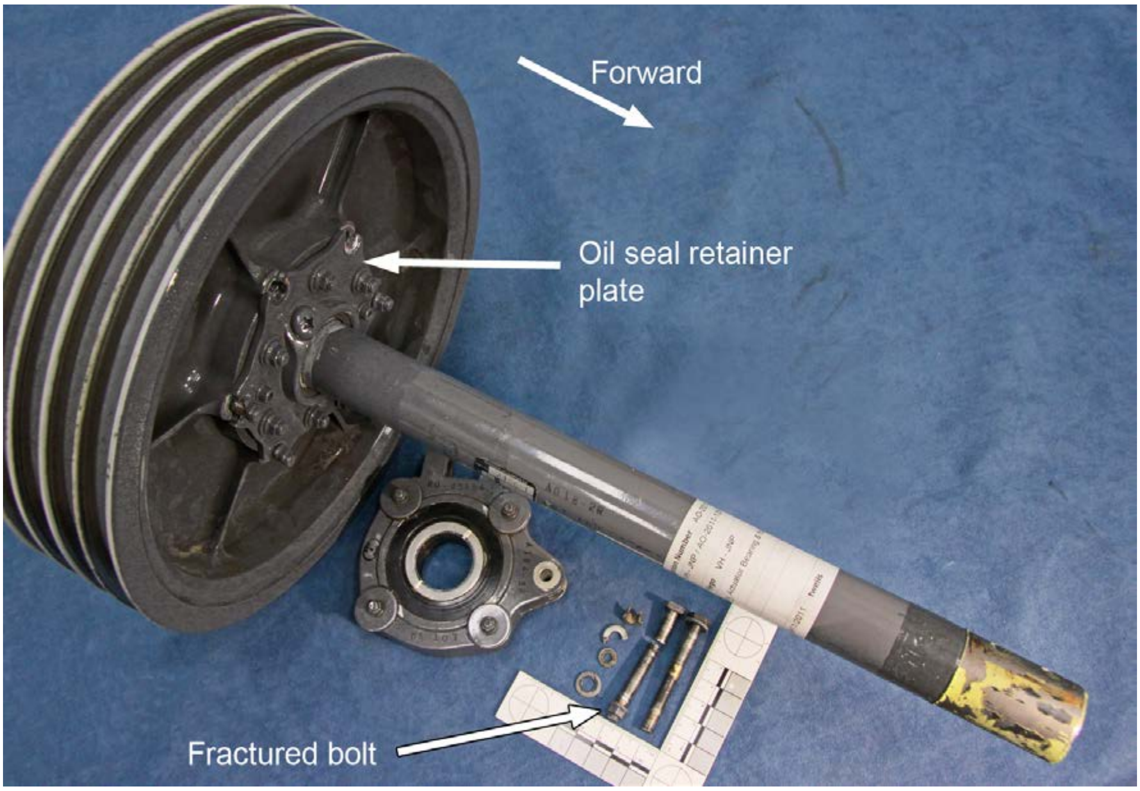
Item	Specification Document	Part Number/Description
Retainer bolts	NAS1302 - 1320[1] (now NAS6603 thru 6620)	Drawing requirement: NAS 6604-30 Bolt Hex head, tension, close tolerance alloy steel, 2.3 in (58mm) length, 0.25 in (6.35mm) diameter, .2500-28 thread, grip length 1.875 in (47.6mm), cadmium plated
Washers	AN960[2] (now NAS 1149)	Drawing requirement: NAS1149 F0462P & F0463P 0.5 in (12.5 mm) outer diameter 0.032 or 0.064 in (0.8 or 1.6 mm) thickness, carbon steel
Nuts	MS21042[3]	Drawing requirement: MS21042L4

[1] National Aerospace Standard, *NAS 1303 - 1320, "Bolt, Tension, Hex Head, Close Tolerance, Alloy Steel, Long Thread, Reduced Major Diameter, Self-Locking and Non-locking, 160 KSI Ftu"*

[2] Air Force-Navy Aeronautical Standard, *AN960, "Washer, Flat*"

	(now NASM 21042)	Self-locking reduced hexagon (thin wall) reduced height, ring base, .2500-28UNJF-38 threads Cadmium plated to QQ-P-416F type II, Class 2 [4] and dry-film lubricated
Retainers	Not available	RHC part no. A168-3 (aft) & -4(fwd.)
Upper sheave	Not available	RHC part no. A188-2
Clutch shaft	Not available	RHC part no. A166-1
Actuator bearing	Not available	RHC part no. A184-3R

Figure 3: As-received clutch assembly when viewed from the forward end.

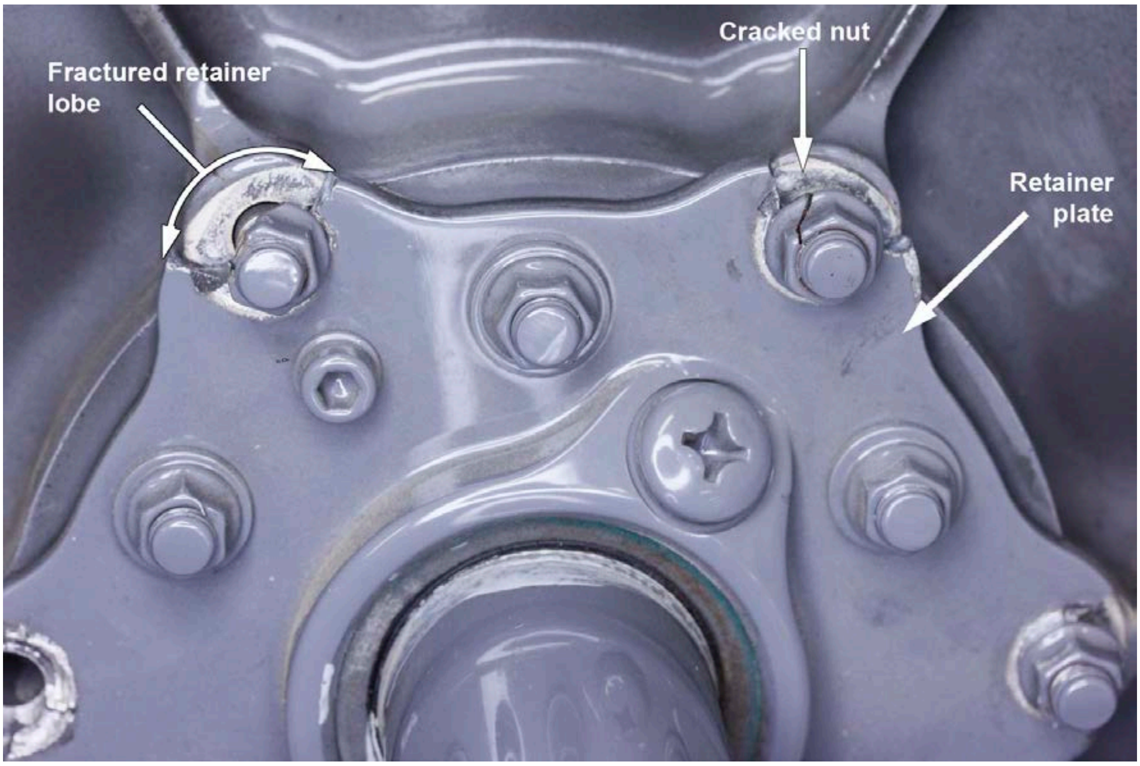


Source: ATSB

[3] Military Specification, *MS-21042, "Nut, Self-locking, 450°F, Reduced Hexagon, Reduced Height, Ring Base, Non-Corrosion-Resistant Steel"*

[4] Federal Specification, *QQ-P-416F , "Plating, Cadmium (Electrodeposited)"*

Figure 4: Close view of the clutch assembly damage. Five of the nuts had either cracked or had fractured.



Source: ATSB

Figure 5: The as-received, loose outer, retainer fasteners.

Source: ATSB

Component examination

Fractured nuts

After controlled disassembly of the clutch, the fractured retainer outer locking nuts were examined visually and microscopically. All five fractured nuts presented two opposing cracks or fracture surfaces (Figure 6). Characterisation of the fracture morphology under stereomicroscopic examination showed at least one fracture on each nut to have originated at the junction of the bearing surface and the start of the internal thread (Figure 7) – those origin regions typically presented macroscopic chevron patterning consistent with a brittle fracture mechanism.

Figure 6: Nuts from the outer fasteners (labelled to relative positions on the 'clock face')

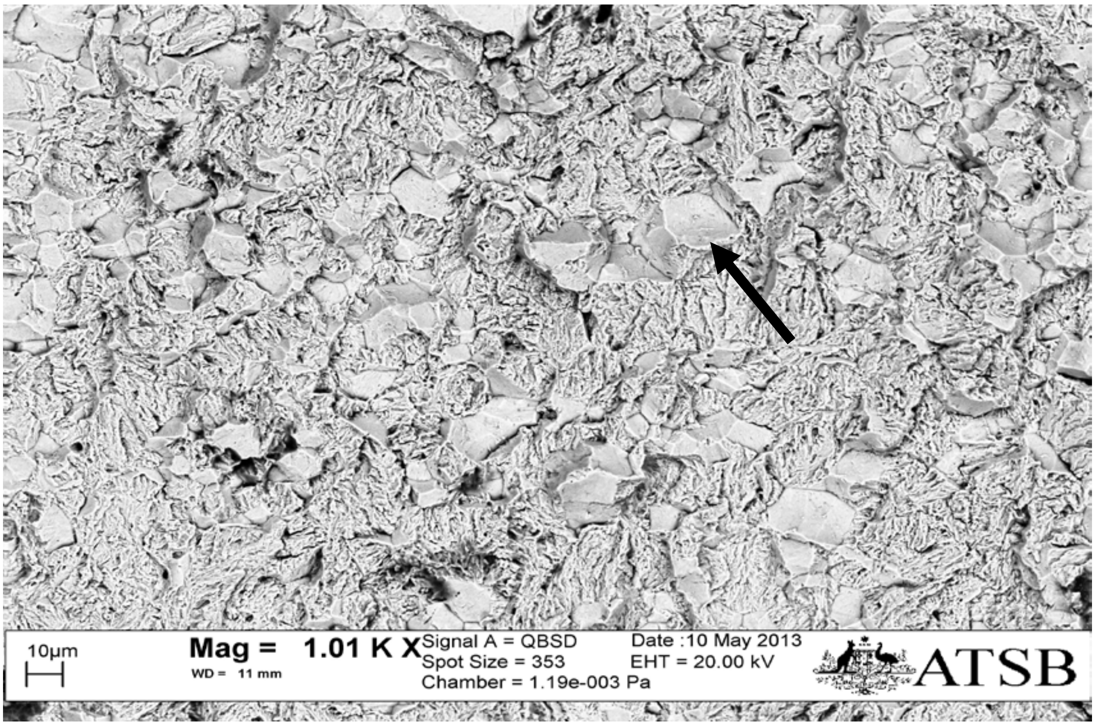
Source: ATSB

Figure 7: Typical, axially-orientated nut fracture surface; note the reflective grain facets

Source: ATSB

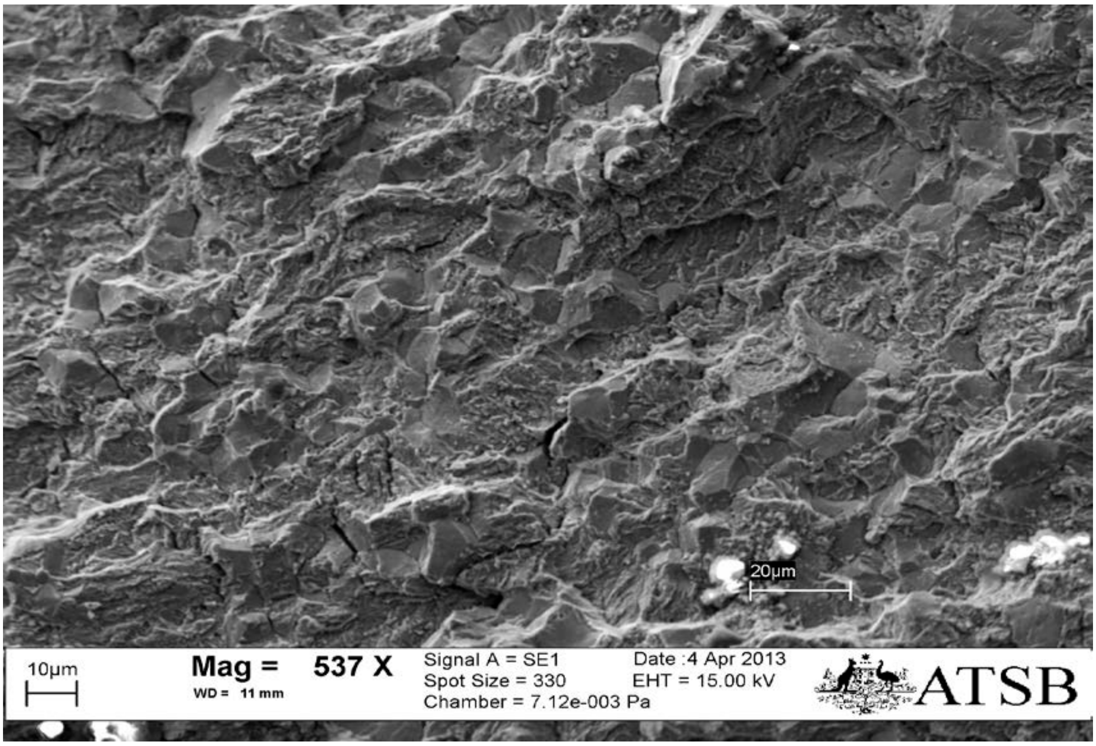
Across the fracture surfaces of four nuts were areas of bright, crystalline, reflective features – further indicative of a brittle fracture mechanism. Higher magnification examination of those areas under the scanning electron microscope found characteristic evidence of a mixed-mode failure, with areas of intergranular fracture (i.e. fracture following the grain boundaries) intermixed with regions presenting a more transgranular form. Figure 8 shows an area adjacent to one of the internal corners, while Figure 9 shows an area below a thread root; intergranular characteristics can be seen in both.

Figure 8: Fracture surface of a nut with initiation at an inner corner. The areas of smooth faceted appearance (example arrowed) are indicative of intergranular fracture.



Source: ATSB

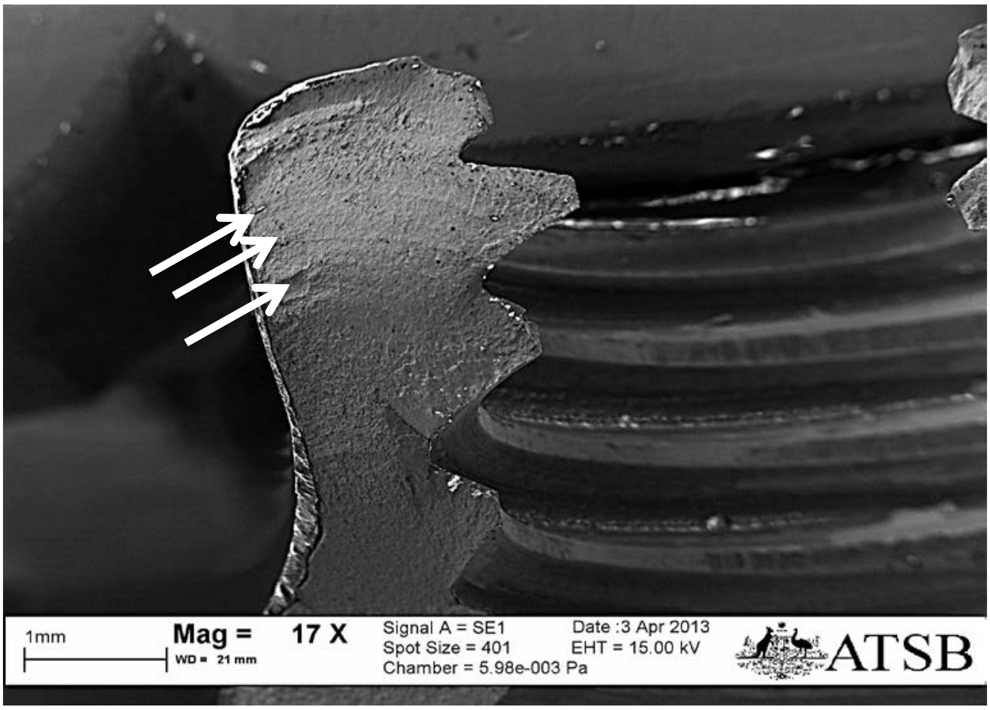
Figure 9: Intergranular cracking below the threads adjacent to the nut flanged surface.



Source: ATSB

Away from the regions of intergranular/transgranular failure, the fracture surfaces presented areas of repeating crack progression markings; a characteristic of fatigue failures (Figure 10). In these regions, crack growth was almost completely transgranular, which is also typical of fatigue in ferrous materials.

Figure 10: Beach marks (indicative of fatigue) extending away from the nut bearing face.

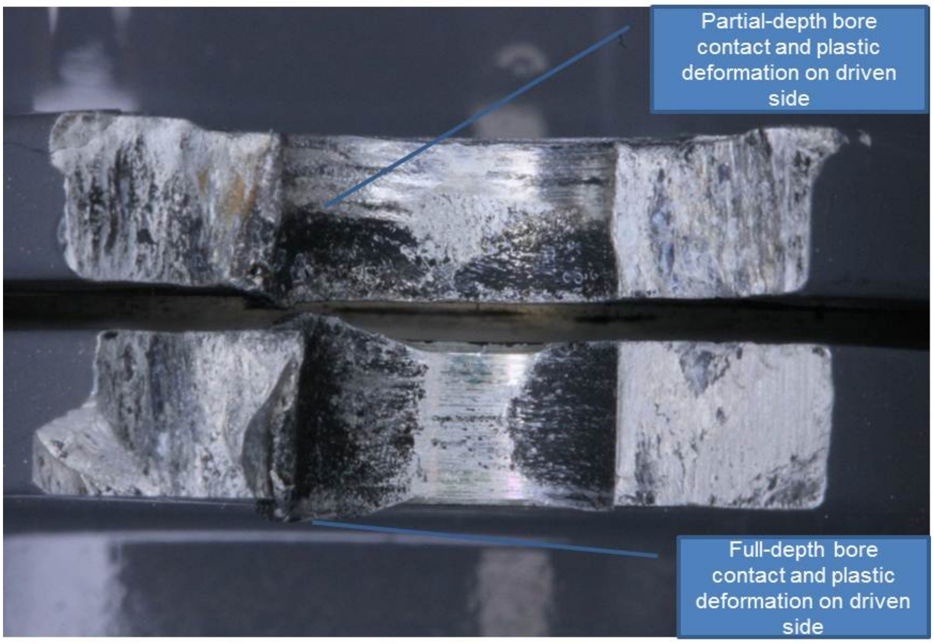


Source: ATSB

Examination of the nut mating components (washers and retainer lobes) identified features typical of overstress fracture. Many of the retainer lobe fractures showed areas of adjacent plastic deformation around the bolt hole bores, with the location and orientation of these areas being typical of sideways shear loading by the respective sheave-driven mating bolt (Figure 11). Wear and compressive deformation of up to 2.5mm was present on the retainer faces beneath the nut and washer stack, suggesting a period of significant axial movement between the components before the complete breakdown of the assembly.

As shown in Figure 5, one nut had fully fractured and separated from its mating bolt, allowing the bolt to migrate axially out of position to a point where the head came in contact with the clutch actuator bearing's fixed journal. This rotating contact during operation produced the gross angular wear observed on the bolt head surface (Figure 12).

Figure 11: Lobe fractures of retainers; the forward retainer is uppermost.



Source: ATSB

Figure 12: Worn head of a retention plate outer bolt from contact with the clutch actuator fixed bearing journal.

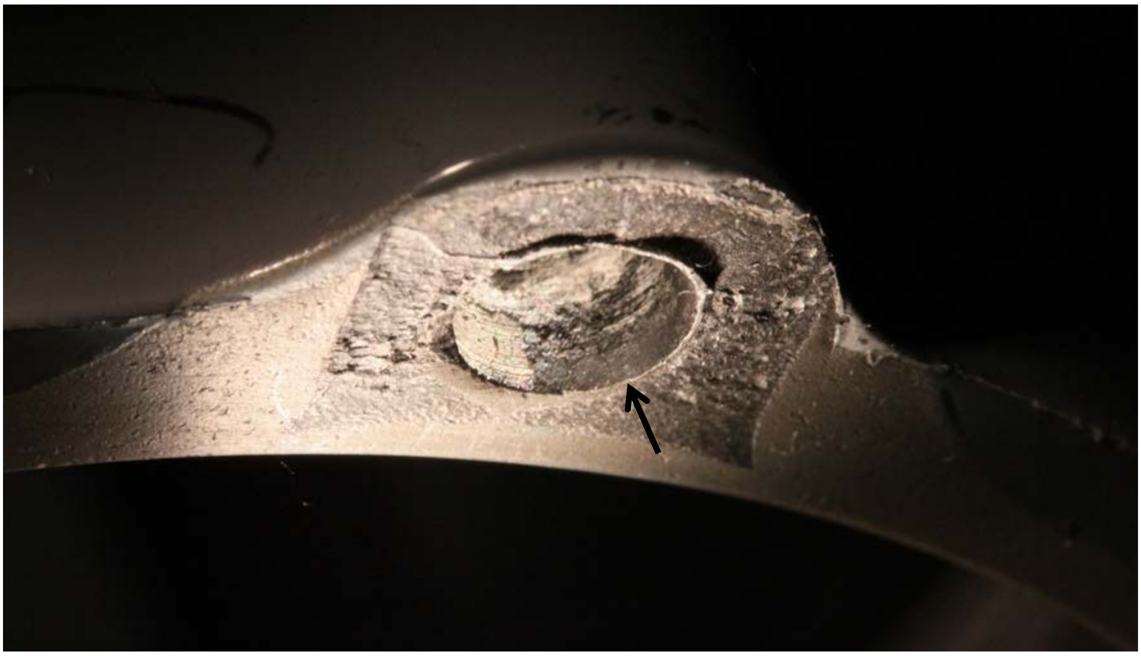
Source: ATSB

Fractured bolt

One of the six retainer outer bolts had fractured transversely through the plain shank section, approximately 20 mm from the head underside (Figure 5). The associated nut was intact and in position, and the two assembly washers both presented with single chord-wise cracks through the full width.

The bolt shank surfaces showed varying levels of surface fretting and light wear, consistent with repetitive rotational movement against the bore of the sheave through-holes. The bore surfaces also presented corresponding levels of wear, fretting and deformation – with a bias in the level of damage shown to one side that was consistent with the transmission of bearing loads in the direction of sheave rotation (Figure 13).

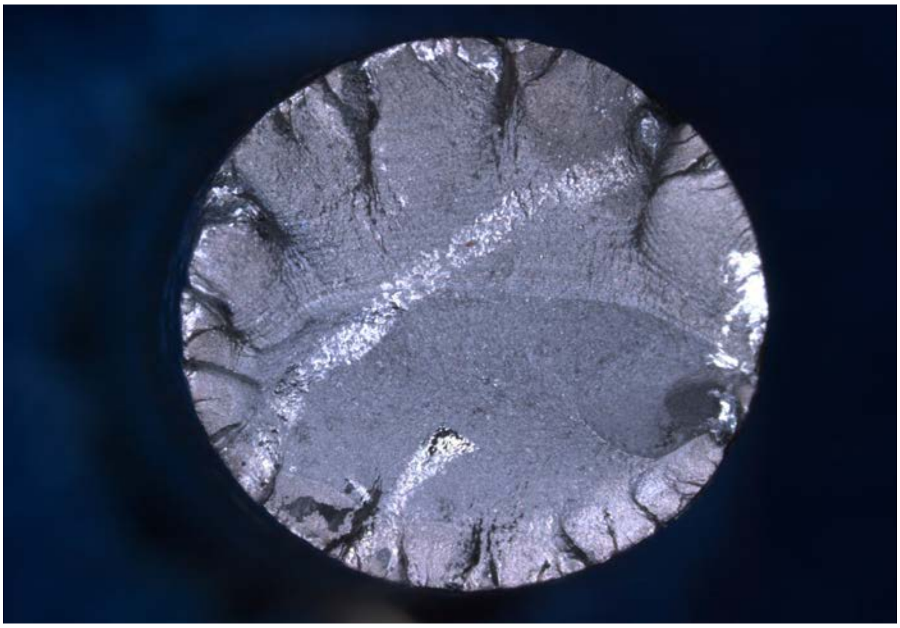
Figure 13: Sheave/retainer bolt hole bore showing associated driving-side wear and deformation (arrowed) from contact with the bolt shank.



Source: ATSB

The bolt fracture surfaces showed multiple, radially-orientated ratchet marks extending around the circumference, with clear, bending fatigue crack progression marks between the ratchet marks, extending part-way across the bolt diameter (Figure 14). A small, offset zone of final ductile overstress failure was evident to one side of the central section.

Figure 14: Bolt fracture surface with fatigue steps around the perimeter and linked beach marks progressing from top to middle. Final overload is the dark grey remainder.



Source: ATSB

Torque measurements

The six intact *inner* retainer bolts were removed in the as-is condition i.e. with primer and topcoat remaining on the exposed bolt threads. The averaged maximum disassembly torque was 129 in.lb

(14.6 N.m); slightly higher than the manufacturer's specified installation torque[5] of 120 in.lb on unpainted fasteners.

Dimensional tests

Key dimensions relating to the fit of the retention bolts (diameter and grip length) and washers (thickness) were measured. All conformed with their specifications, with the exception of the shank diameter of the five unfractured outer, retainer bolts, which all exhibited levels of wear down to a minimum of 0.2455 in (6.07 mm) at retainer-mating surfaces. The specified bolt shank diameter was 0.2485 – 0.2495 in (6.31 – 6.34 mm).

Metallurgical testing

The core and surface hardnesses and the microstructure of the fractured bolt met the nominal manufacturing specification requirements. The Vickers hardness (HV) of the cracked nut (arrowed in Figure 4) was measured, as were three of the inner nuts; the measured results are tabled below along with their conversion to the specified unit of Rockwell C (HRC). All recorded values were typical of the nuts being produced from high-strength alloy steel.

Table 2: Nut hardness

Nut	Measured Hardness (HV)	Converted Hardness (HRC)
Cracked Outer Nut	437 & 437HV10	44
Inner Nut A	429 & 437HV10	43.5
Inner Nut B	466HV20	46.5
Inner Nut C	463HV20	46.5

Self-locking nuts

Military Standard, MS 21042, specified the manufacture of compact, thin-wall self-locking nuts for use in aerospace applications. To ensure satisfactory load capacity, the nuts were to be produced from medium-carbon or alloy steels and heat-treated to achieve the necessary strength levels. The specification provided for a maximum hardness limit of 49 Rockwell C (HRC). For corrosion resistance, the specification required cadmium plating and a passivating chromate surface treatment.

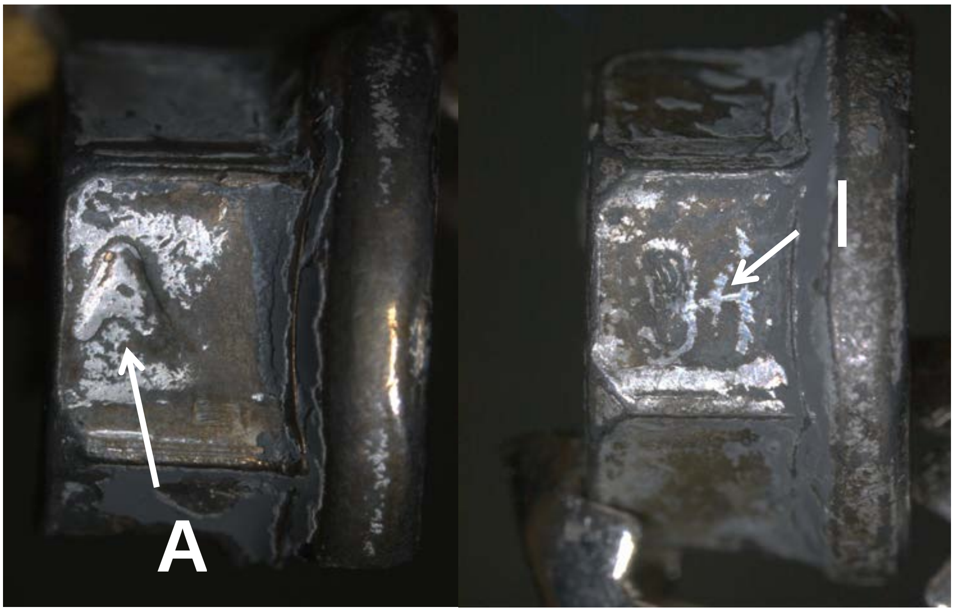
The standard provided for the nut manufacturer's identification to be recorded on each item for -08 [6] sizes and larger; smaller sizes may include identification at the manufacturer's discretion. Typically, identification is achieved through the use of a unique hallmark embossed into the nut's hexagonal flats.

All of the retainer's outer nuts showed hallmark features comprising either an 'A' and/or or an 'I' on their lateral faces. Referring to the US Department of Defence Handbook MIL-HDBK-57F(IS) - 2011, this combination of identifiers was attributed to Airfasco Industries Fastener Group of Canton, Ohio, USA (Figures 15 and 16).

5 This is a combination of the specified bolting torque (100 in.lb) plus the nominated value of the self-locking nut torque of 20in.lb; however, the limit is 30in.lb maximum in the nut's detail specification noted below.

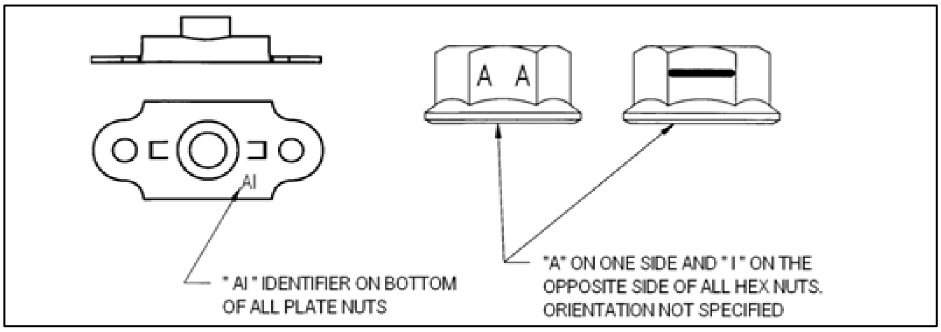
6 A Size -08 nut is approximately 0.22in (5.5 mm) across the hexagonal flats.

Figure 15: Manufacturer's hallmark on the flanks of two MS21042L-4 nuts from the clutch assembly/retainer outer fasteners.



Source: ATSB

Figure 16: Manufacturer's hallmark attributed to Airfasco Industries Fastener Group.



Source: MIL-HDBK-57F(IS)–2011, page 11

Hydrogen embrittlement / hydrogen-assisted cracking

During both the acid pickling/descaling and electro-deposition stages of the cadmium plating process, atomic hydrogen can be generated at the metal surfaces. Hydrogen atoms are inherently small, very mobile and diffuse easily into the metallic structure. Subsequent release of the hydrogen from the component may be inhibited by the newly-plated surface coating.

Under conditions of applied stress that can occur when the component is later placed into service, the inter-atomic hydrogen can migrate to locations of higher stress concentration, creating internal stress levels that can produce brittle, intergranular cracking or fracture at grain boundaries, impurities or other metallurgical features. This phenomenon is known collectively as hydrogen embrittlement, hydrogen-assisted or hydrogen-induced cracking. High strength, alloy steels are known to be particularly susceptible to this behaviour; affected components can exhibit delayed cracking and related brittle failure phenomena well after introduction into service.

Cadmium plating

To reduce the effect of hydrogen adsorption and the risk of subsequent cracking, the cadmium plating specification[7] required the parts to undergo heat treatment to relieve residual stresses before plating, if required, and to drive out any adsorbed hydrogen after plating. The plating specification also provided for a hydrogen embrittlement relief test as a default for higher-strength parts with a hardness of 36 HRC or above. The ATSB investigation was unable to determine whether the particular production lot or lots of MS21042L-4 nuts in question had been subject to the test for hydrogen embrittlement.

Also reflecting the susceptibility of higher-strength parts to hydrogen embrittlement, the plating specification made a general statement:

> *Unless otherwise specified, parts having an ultimate tensile strength of greater than 200 ksi (or HRC 43) shall not be plated in accordance with this specification.*

Other occurrences

A search of accident and incident databases maintained by the ATSB, the Civil Aviation Safety Authority (CASA) and the US National Transport Safety Board found no other reports of clutch assembly bolt failure or similar events for either Robinson R22 or R44 helicopter models.

The cracking and failure of MS21042L-series self-locking nuts had, however, been previously identified and reported to both the ATSB and CASA. In most instances, these failures had resulted from the effects of hydrogen adsorption during cadmium plating; producing almost wholly intergranular fracture features. The loss of an MS21042 nut was identified during the ATSB's investigation of a loss-of-control accident involving a Robinson R44 helicopter near Cessnock, NSW[8] in 2011; however, the inability to examine that nut prevented any absolute confirmation of the loss mechanism.

During the course of the subject investigation, several examples of cracked nuts from other helicopters were supplied to the ATSB for examination. The failures of all were consistent with the effects of hydrogen embrittlement. CASA Airworthiness Bulletin 14-002 was subsequently published; alerting aircraft owners, operators and maintainers of the potential for MS 21042 nut failure.

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[7] Federal Specification, *QQ-P-416F, Plating, Cadmium (Electrodeposited) [now SAE-AMS-QQ-P-416]*

[8] ATSB Aviation Safety Investigation, AO-2011-016, *Loss of control – Robinson R44 helicopter, VH-HFH, Cessnock Aerodrome, NSW, 4 February 2011*

Safety analysis

Occurrence flight

The ATSB's investigation found that, following indications of a developing problem with the helicopter's main rotor drive system, the pilot appropriately and proficiently managed the response by isolating the clutch actuator and conducting an immediate precautionary landing. The pilot's actions reflected the guidance presented in the Pilot's Operating Handbook and Robinson Helicopter Company's Safety Notice SN-28 – ensuring that the problem did not escalate into an emergency situation involving the complete loss of drive to the main and tail rotors.

Clutch assembly failure

The breakdown of the helicopter's clutch assembly was attributed directly to the premature failure of five nuts from the outer row of six retainer fasteners that surround the sprag clutch mechanism. The progressive loss of clamping load resulting from the nut failures allowed relative movement, wear and overstressing of the lobes on both retainers, producing the series of fractures evident around the forward retainer periphery. With this loss of uniform retainer clamping load, it is likely that the bolts were subject to oscillating and variable bending stresses, producing the fretting and deformation damage to the shank and bore surfaces and the initiation and propagation of bending fatigue cracking within the one bolt that did not lose integrity through the cracking and failure of its associated nut.

Nut failure

The ATSB's metallurgical examination found that, in all five MS21042L-4 locking nuts, cracking had initiated at the corner of the bearing surface and the thread origin. Fracture within these lower body regions was predominantly brittle in nature, with a significant proportion of intergranular morphology evident throughout. Increasing evidence of fracture propagation by fatigue was evident away from the nut base, with growth occurring roughly along an axial plane.

Intergranular fracture in high-strength steels is atypical and generally indicative of an environmental or pre-existing embrittlement mechanism. Contextually, the MS21042L-4 nuts in question are produced at strength/hardness levels that strongly predispose them to the embrittling effects of hydrogen adsorption during cadmium electroplating. Production of a structurally sound and embrittlement-free nut is highly dependent on the efficacy of the prescribed pre- and post-plating heat treatment processes. Indeed, the cadmium plating procedure (QQ-P-416F) makes particular mention of the risks of embrittlement, specifying embrittlement relief evaluative tests for components of hardness greater than 36 HRC and recommending that components produced to hardness levels greater than 43 HRC not be plated.

In this instance, the mixed intergranular / transgranular (fatigue) fracture suggests that nut failure had arisen from the synergistic effects of cyclic operational stresses acting upon a base material partially embrittled by the effects of hydrogen adsorption. The range of measured nut hardness (44 – 47 HRC) confirmed the components' susceptibility to hydrogen embrittlement, and the stress concentration effects produced by the nut geometry and any incipient hydrogen-induced cracking would certainly have promoted the development of fatigue cracking under conditions of cyclic stress associated with clutch assembly operation.

Bolt failure

Detailed analysis of the complex stress state developing within the nuts as cracking initiated and progressed was beyond the scope of this investigation; however, it was likely that the bending fatigue failure of the single bolt shank among the set of outer fasteners was a result of transferred loads stemming from the progressive nut failures. The widespread evidence of fretting, wear and other evidence of relative movement between the assembly components was further evidence of this.

Maintenance and inspection

Given that the nut failures at the centre of this occurrence had occurred from the effects of hydrogen embrittlement and fatigue, it was likely that nut cracking had first begun to develop well before the occurrence flight on 12 October 2011. In terms of a developing failure, while the nuts would likely have presented visible evidence of cracking well before their final failure, positive identification of that cracking during the prescribed daily inspections would have been very unlikely, given the affected area was not clearly examinable without inspection aids and crack identification would have required a level of close, detailed scrutiny that is not generally undertaken at this time.

Four, 100-hourly maintenance inspections had been carried out on the helicopter during the interval between installation of the overhauled clutch and the in-flight failure, with the last inspection (5 October 2011) performed 6 days before the event. While that inspection presented an appropriate opportunity for the identification of nut cracking, it would again have required close and focussed attention to ensure positive identification of the fine developing cracks associated with this type of progressive cracking problem.

Despite the manufacturer's publication of R22 Service Letter SL-58 which directed broad attention to the possibility of MS21042L-series nut cracking, without the assistance of more directed instructions or targeted guidance material, the ATSB considers it likely that any general inspections associated with the completion of a 100-hourly maintenance activity may not detect all instances of such nut failures – particularly within those nuts fitted in obscured or difficult-to-access locations.

Other embrittlement-related nut failures

The ATSB has examined six separate instances of embrittlement failures of cadmium-plated nuts; five of those studies since 2011 have involved nuts made to the same MS21042 specification as the nuts implicated in this occurrence. The significant majority of the twelve cracked nuts from those instances carried the same identification hallmarks as the nuts in this investigation, and thus were likely to have been produced by the same manufacturer.

Unlike the mixed-mode failure of the nuts in this investigation, the previous nut failures examined by the ATSB were more directly the result of hydrogen-induced cracking under the static nut stresses associated with installation and applied tension. No crack propagation by a fatigue mechanism was evident in those instances.

Findings

From the evidence available, the following findings are made with respect to the failure of the clutch assembly from a Robinson R22 helicopter, VH-JNP, which occurred north of Saxby Downs, Queensland on 12 October 2011. The findings should not be read as apportioning blame or liability to any particular organisation or individual.

Safety issues, or system problems, are highlighted in bold to emphasise their importance. A safety issue is an event or condition that increases safety risk and (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operating environment at a specific point in time.

Contributing factors

- Military Specification MS21042L-4 self-locking nuts employed in the design of the Robinson R22 clutch assembly were predisposed to the effects of hydrogen embrittlement / hydrogen-assisted cracking, should the particular embrittlement control processes used during manufacture of the nuts be inadequate or ineffectively carried out.
- **The nut manufacturer's quality control processes failed to prevent the release of a lot or lots of MS21042L-4 nuts that remained in a partially-embrittled state after cadmium electroplating. [Safety Issue]**
- When overhauled in 2011, the clutch assembly (later fitted to VH-JNP) was re-built using MS21042L-4 nuts that had been released from the manufacturer in a partially-embrittled state.
- During subsequent operational service, four of the six clutch assembly retainer's outer nuts began to crack and fail from the effects of fatigue cracking initiating within, and propagating through, a partially-embrittled base material.
- **At the time of the occurrence, there was limited advisory material available to owners, operators and maintenance personnel to alert them to the possibility of MS21042L-series nut failure and to assist with appropriately detailed inspections aimed at identifying affected items. [Safety Issue]**
- Cracking and failure of the clutch assembly's oil seal retainer nuts was not identified during the periodic pre-flight and maintenance inspections prescribed by the helicopter manufacturer.
- As a result of the retainer nut failures, the structural integrity of the assembly became compromised, producing the consequential component fatigue failures and the final breakdown that led the pilot of VH-JNP to conduct the precautionary landing on 12 October 2011.

Other findings

- The pilot's prompt and appropriate response to the onset of the helicopter's drive system problems minimised the extent of the damage sustained and prevented the development of a serious accident.

Safety issues and actions

The safety issues identified during this investigation are listed in the Findings and Safety issues and actions section of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisations. In addressing those issues, the ATSB prefers to encourage relevant organisations to pro-actively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

Depending on the level of risk of the safety issue, the extent of corrective action taken by the relevant organisation or the desirability of directing a broad safety message to the aviation industry, the ATSB may issue safety recommendations or safety advisory notices as part of the final report.

Production release of partially-embrittled MS21042L-4 nuts

Number:	AO-2011-135-SI-01
Issue owner:	Airfasco Industries Fastener Group
Operation affected:	Aviation – General and air transport – all operations
Who it affects:	All owners and operators of aircraft using MS21042 and related nuts

Safety issue description:

The nut manufacturer's production control and quality control processes failed to prevent the release of one or more lots of MS21042L-4 nuts that remained in a partially-embrittled state after cadmium electroplating.

Safety action taken by: Airfasco Industries Fastener Group

On 4 April 2012, Airfasco Industries issued a Technical Quality Notice Bulletin covering *MS 21042 Thin-Wall Hex-Flange Nuts*. The bulletin listed six specific issues relating to the structural integrity of the nut type, including several new measures to more effectively manage the risk of product remaining in the embrittled or partially-embrittled state upon release. Although Airfasco has designed an alternative 'hydrogen embrittlement negative (HEN)' thermal diffusion coating for MS21042/NAS1291nuts, replacing the cadmium electroplated finish, this is not yet specified in NASM21042. This bulletin was subsequently revised and re-issued on July 16, 2012.

Action number: AO-2012-135-NSA-064

ATSB comment

The ATSB is satisfied that the actions taken by the above organisation should reduce the risk of future manufacturing deficiencies with the MS21042L-series nut product.

Current status of the safety issue

Issue status: Adequately addressed

Justification: The nut manufacturer's Technical Quality Notice Bulletin demonstrates a level of understanding of the issues that should be sufficient to ensure that the risks of future hydrogen embrittlement of the MS21042L-series nut and related products are minimised. Nevertheless, given the widespread use of this nut type across a variety of aviation and aerospace applications, the ATSB will continue to monitor reported safety occurrences and service difficulty events for any further indication of nut embrittlement issues.

Awareness of the potential for nut failure

Number:	AO-2011-135-SI-02
Issue owner:	Manufacturers of aircraft using MS21042 and related nuts, and relevant regulatory agencies
Operation affected:	Aviation – General and air transport – all operations
Who it affects:	All owners and operators of aircraft using MS21042 and related nuts

Safety issue description:

At the time of the occurrence there was limited advisory material available to owners, operators and maintenance personnel to alert them to the possibility of MS21042 nut failure and to assist with appropriately detailed inspections aimed at identifying affected items.

Safety action taken by the Australian Civil Aviation Safety Authority (CASA)

On 12 October 2011, the Australian Civil Aviation Safety Authority (CASA) issued *Airworthiness Bulletin 14-002,* recommending that pilots and maintenance personnel closely monitor aircraft hardware (such as nuts) during installation and thereafter at pre-flight and periodic inspections. Any cracked MS21042 and related nuts were to be reported to CASA via their Service Difficulty Reporting (SDR) system.

Action number: AO-2012-135-NSA-065

Safety action taken by: New Zealand Civil Aviation Authority (CAA)

On 2 December 2011, the New Zealand Civil Aviation Authority (CAA) issued *Continuing Airworthiness Notice 14-001* requiring operators and maintainers to inspect all standard aircraft hardware, including MS 21042 nuts, after installation and thereafter at every daily/pre-flight inspection and every periodic inspection.

Action number: AO-2012-135-NSA-066

Safety action taken by: Transport Canada

On 24 September 2013, Transport Canada issued *Civil Aviation Safety Alert CASA 2013-04*, advising the aviation community of the potential hazard resulting from the potential failure of MS21042 series nuts manufactured by Airfasco Industries (Canton, Ohio, USA).

Action number: AO-2012-135-NSA-067

Safety action taken by: European Aviation Safety Agency (EASA)

On 20 September 2013, EASA issued Emergency Airworthiness Directive AD 2013-0225-E, to visually inspect for cracked MS21042L4 nuts on Agusta Westland helicopter tail rotor drive shafts before the next flight. Cracked nuts are to be replaced before the next flight and all MS21042 nuts on the drive shafts are to be replaced with a different part number within ten flight hours or 30 days. The AD applies to particular helicopter models and serial numbers.

Action number: AO-2012-135-NSA-068

Safety action taken by: Federal Aviation Administration U.S.A. (FAA)

On 3 October 2013, the FAA issued Airworthiness Directive AD 2013-20-51 to visually inspect for cracked MS21042L4 nuts on Agusta Westland helicopter tail rotor drive shafts before the next flight. Cracked nuts are to be replaced before the next flight. Within ten flight hours or 30 days, all such MS nuts on the drive shafts are to be replaced with a different part number. The AD applies to particular helicopter models and serial numbers.

Action number: AO-2012-135-NSA-069

ATSB comment

The ATSB is satisfied that the actions taken by the above organisations will adequately address the safety issue.

Current status of the safety issue

Issue status: Adequately addressed

Justification: Many civil aviation regulatory agencies and original equipment manufacturers have now produced and disseminated advisory material on this issue, providing appropriate background information and guidance on the identification of defective components.

General details

Occurrence details

Date:	12 October 2011	
Occurrence category:	Serious incident	
Primary occurrence type:	Powerplant / propulsion event	
Type of operation:	Aerial work	
Location:	22km N of Saxby Downs Qld	
	Longitude :19° 50’ S	Latitude: 142° 30’ E

Aircraft details

Manufacturer and model:	Robinson Helicopter Company R22 Beta	
Registration:	VH-JNP	
Operator:	Foxling Helicopter Services	
Serial number:	1121	
Persons on board:	Crew –1	Passengers – 1
Injuries:	Crew – 0	Passengers – 0
Damage:	Minor	

Sources and submissions

The sources of information during the investigation included:

- Foxling Helicopter Services Pty Ltd
- Civil Aviation Safety Authority
- Robinson Helicopter Company
- Heli-Engineering Pty Ltd
- Helicopter Rebuilds Pty Ltd
- National Transportation Safety Board
- Civil Aviation Authority of New Zealand
- Airfasco Industries Fastener Group
- European Aviation Safety Agency

References

MIL-HDBK-57F, Department of Defence Handbook: *Listing of Fastener Manufacturers' Identification symbols,* 21 June 2011

ASM Handbook, Volume 2, *Properties and Selection: Non-Ferrous Alloys and Special Purpose Materials,* ASM International

ASM Handbook, Volume 4, *Heat Treating,* ASM International

ASM Handbook, Volume 11, *Failure Analysis and Prevention,* ASM International

ASM Handbook, Volume 12, *Fractography,* ASM International

Robinson Helicopter Company, *Model R22 Maintenance Manual and Instructions for Continued Airworthiness,* March 2004

Robinson Helicopter Company, Process Specification RPS – 16 *Bolt and Nut Torque – General Use*

Robinson Helicopter Company, Safety Notice SN-28, *Listen for impending bearing failure,* July 2012

Robinson Helicopter Company, Service Letter SL-58, *Cracked MS21042L-series nuts,* 18 August 2011

NATO Science and Technology Organization, RTO-AG-AVT-140 - Corrosion Fatigue and Environmentally Assisted Cracking in Aging Military Vehicles, Chapter 20, *Prevention of Hydrogen Embrittlement in High-Strength Steels, with Emphasis on Reconditioned Aircraft Components.* R. Wanhill, S. Barter, S. Lynch & D. Gerrard

Robinson R22 Pilots Operating Handbook

Robinson Illustrated Parts Catalog Model R22

National Aerospace Standard, *NAS 1303 - 1320, "Bolt, Tension, Hexagon Head, 160 KSI Ftu"*
National Aerospace Standard, *NAS 6603 thru 6620, "Bolt, Tension, Hex Head, Close Tolerance, Alloy Steel, Long Thread, Reduced Major Diameter, Self-Locking and Non-locking, 160 KSI Ftu"*

Air Force-Navy Aeronautical Standard, *AN960, Washer, Flat*
National Aerospace Standard *NAS1149 Washer, Flat*

Military Standard, *MS21042, Nut, Self-locking, 450°F, Reduced Hexagon, Reduced Height, Ring Base, Non-Corrosion-Resistant Steel*

National Aerospace Standard NASM*21042, Nut, Self-locking, 450°F, Reduced Hexagon, Reduced Height, Ring Base, Non-Corrosion-Resistant Steel*

Federal Specification, *QQ-P-416F, Plating, Cadmium (Electrodeposited)*

MIL-DTL-25027H Detail Specification Nut, Self-Locking, 250°F, 450°F and 800°F

Australian Transport Safety Report AO-2011-016 *Loss of control Cessnock aerodrome, New South Wales 4 February 2011 VH-HFH Robinson Helicopter Company R44 Astro*

Maintenance Log Book VH-JNP

Robinson Helicopter Company *Clutch Assembly Order Serial Number 9182/9360*

Robinson Helicopter Company *Blade & Spindle Assembly Order Serial Number 8577 & 8591*

Airfasco *Technical Quality Notice Bulletin MS21042 & NAS1291 450F Steel (Thin-wall Hex, lightweight hex flange nuts) April 4 and July 16 2012 (appended)*

EASA *Safety Information Bulletin 2012-06R1 Defective Standard Hardware – MS21042, NAS1291 and LN9338 Self-locking Nuts and NAS626 Bolts (appended)*

CASA *Airworthiness Bulletin AWB 14-002 Cracked MS21042 / NAS1291 Series Nuts – Hydrogen Embrittlement*

CAA *Continuing Airworthiness Notice – 14-001 MS21042 and NAS1291 Series Nuts – Cracks due to Hydrogen Embrittlement*

EASA *Emergency Airworthiness Directive AD No.: 2013-0225-E*

Transport Canada *Civil Aviation Safety Alert CASA 2013-04 Defective Standard Aircraft Hardware – Self-Locking Nuts – MS21042*

Federal Aviation Administration *Airworthiness Directive AD 2013-20-51*

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003*, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to:

- The Australian Civil Aviation Safety Authority (CASA)
- The US National Transportation Safety Board (NTSB)
- The US Federal Aviation Administration (FAA) – via the US National Transportation Safety Board (NTSB)
- Robinson Helicopter Company – via the NTSB
- Foxling Helicopter Services Pty Ltd
- Helicopter Rebuilds Pty Ltd
- Steven Hegarty Aircraft Maintenance Pty Ltd

Submissions were received from the Civil Aviation Safety Authority and the Robinson Helicopter Company. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

Appendices

Appendix A – EASA Safety Information Bulletin

EASA SIB No: 2012-06R1

EASA Safety Information Bulletin

SIB No.: **2012-06R1**
Issued: **07 August 2012**

Subject: **Defective Standard Hardware – MS21042, NAS1291 and LN9338 Self-Locking Nuts, and NAS626 Bolts**

Ref. Publications:
- CAA Israel AD 57-10-06-18, dated 27 July 2010.
- Gulfstream Aerospace LP Service Bulletin (SB) 200-51-366, dated 30 March 2010.
- AgustaWestland Information Letter GEN-11-024, dated 20 July 2011.
- Bell Helicopter Textron Operation Safety Notice GEN-11-43 Revision A, dated 16 September 2011.
- Robinson Helicopter Company Service Letters R22 SL-58, R44 SL-38 and R66 SL-01 (single document), dated 18 August 2011
- L-3 Communications, Aviation Recorder Alert Bulletins FA2100CVDR SB 015, dated 10 January 2011, FA2100CVR SB 018, dated 14 January 2011 and FA2100FDR SB 020, dated 14 January 2011.
- CASA Airworthiness Bulletin 14-002, dated 12 October 2011.
- CAA New Zealand Continuing Airworthiness Notice 14-001, dated 2 December 2011.
- Australian Transportation Safety Board (ATSB) Investigation Report AO-2011-016, dated 30 April 2012.
- Airfasco Industries "Technical Quality Notice Bulletin MS21042 & NAS1291 450 F Steel" dated 16 July 2012, which is attached as pages 4 through 8 of this SIB.

Applicability: The Part Numbers of the affected hardware are MS21042, NAS1291 and LN9338 self-locking nuts, and NAS626 bolts.

The identified defective hardware is known to have been installed on rotorcraft, aeroplanes, appliances and engines.

Reason for revision: Revision 1 of this SIB is issued to recommend a torque check before new lot acceptance, incorporate a reference to an ATSB investigation report, and to include information received from Airfasco Industries (Canton, Ohio, USA), prompted by the original release of this SIB (see pages 5 through 8 of this SIB); the illustration mentioned on page 4 of the Airfasco bulletin (page 8 of this SIB) has not been provided to EASA at time of publication.

Description: Several manufacturers (see ref. publications above) have received numerous reports of defective standard hardware installed on different areas of their products. In particular, many self-locking

This is information only. Recommendations are not mandatory.

nuts have been found cracked, parallel to the nut axis, in some instances only a short time after installation. Broken bolts have also been found.

At this time, apart from the specific case of the Gulfstream 200 and GALAXY (Israel Aircraft Industries) aeroplanes, insufficient evidence is available to determine whether an unsafe condition exists that would warrant the issuance of an AD under EC 1702/2003, Part 21A.3B.

EASA, in cooperation with other aviation authorities and a number of aircraft, engine and equipment manufacturers, is currently investigating the reported occurrences to determine whether (and if so, what) further action is necessary.

Recommendation: Manufacturers, aircraft owners, operators and maintenance staff, are recommended to subject the standard hardware (as identified in the Applicability paragraph of this SIB) to a close visual inspection for surface irregularities, such as gouges or cracks, as illustrated in Figures 1 and 2 of this SIB, before being installed on a product.

In addition, it is recommended to subject incoming lots of self-locking nuts (as identified in the Applicability paragraph of this SIB) to a torque check and inspection, before receiving them in stock, as follows: Install the nuts on the appropriate bolts, with spacers as required, and keep them torqued (see relevant torque values in Table 1 of this SIB) for 1 week. For statistical reasons, a quantity of 1% (round up) or 20 nuts of one manufactured batch – whichever is less – should be tested. After the test period, visually inspect the nuts for cracks on the bearing surface or longitudinally as illustrated in Figure 3 of this SIB.

Suspect parts should be quarantined until conformity to the manufacturing standard is verified.

As not all non-conformities to the manufacturing standards can be visually detected, the importance of quality acceptance criteria for standard parts is also emphasized.

Occurrences of cracked nuts or bolts should be reported through the established channels, as well as to the Agency Occurrence Reporting System, here.

Of particular interest are the hardware Part Number, manufacturer (or markings), lot number, location on the product and time since install.

Contact: For further information contact the Safety Information Section, Executive Directorate, EASA. E-mail: ADs@easa.europa.eu.

This is information only. Recommendations are not mandatory.

Figure 1: Example of surface irregularities observed on a nut. Overall view.

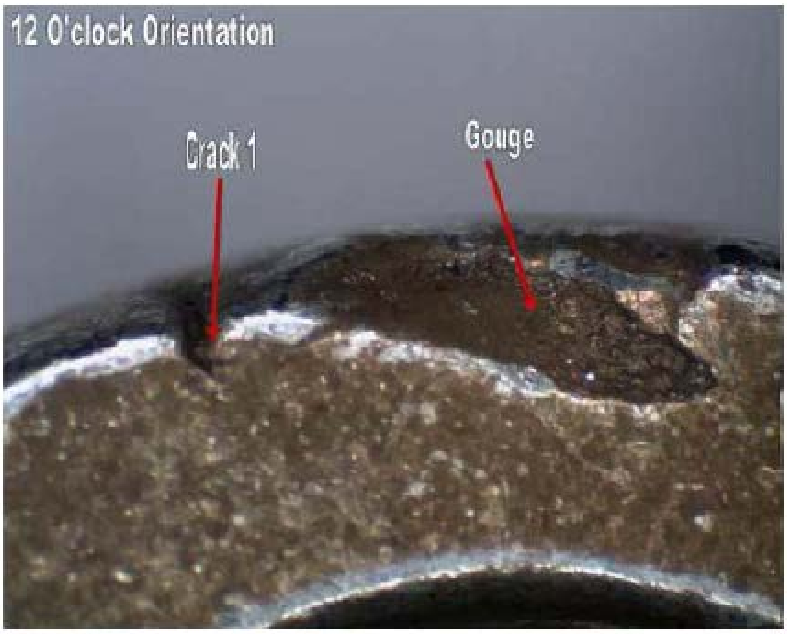

Figure 2: Example of surface irregularities observed on a nut. Detail

This is information only. Recommendations are not mandatory.

Table 1: Torque to be applied during the torque check

Size Dash No.	Thread	Wrenching Torque Test Value		Wrenching Torque Test Value for steel A286 (NAS1291C)	
		in-lb	Nm	in-lb	Nm
-02	.0860-56 UNJC-3B	5	0.6	3	0.4
-04	.1120-40 UNJC-3B	10	1.1	7	0.8
-06	.1380-32 UNJC-3B	20	2.3	15	1.6
-08	.1640-32 UNJC-3B	30	3.4	20	2.4
-3	.1900-32 UNJF-3B	60	6.8	40	4.7
-4	.2500-28 UNJF-3B	150	17	105	12
-5	.3125-24 UNJF-3B	330	37	230	26
-6	.3750-24 UNJF-3B	530	60	370	42
-7	.4375-20 UNJF-3B	825	95	575	65
-8	.5000-20 UNJF-3B	1125	125	780	85
-9	.5625-18 UNJF-3B	1550	175	1075	120
-10	.6250-18 UNJF-3B	2000	225	1390	155

Note: The nut should be tested for wrenching torque by the use of a box or a socket wrench.

Figure 3: Example of longitudinal crack.

This is information only. Recommendations are not mandatory.

AFC X AIRFASCO® INDUSTRIES
2655 Harrison Ave SW
Canton, Oh. 44706
(330)430-6190 Office
(330)430-6199 Fax
www.Airfasco.com

July 16, 2012

TECHNICAL QUALITY NOTICE BULLETIN MS21042 & NAS1291 450 F STEEL: (THIN WALL HEX, LIGHTWEIGHT HEX FLANGE NUTS)

The MS21042 and NAS1291 steel design is a very thin wall, lightweight hex flange design (LMC drawings attached) along with the wide range of available torque values and high tensile heat treat values. These nuts are susceptible to galling and post torque ductile overload failure. We have seen the use of high speed air assembly tools which increase the galling process. The steel MS21042 and NAS1291, 450 F nuts have a higher axial strength pound minimum requirement from the procurement standard of 125,000 PSI minimum per NASM25027.

Through our customers, Airfasco has become aware that a few MS21042 and NAS1291 steel nuts have cracked. Other manufacturers of nuts have had similar reports. Airfasco has not verified the installation or the class 3A thread pitch diameter of the male mate(s) and has not confirmed whether the failure resulted from high over values from galling leading to ductile failure from installation. The customer's evaluation and analysis reflected classic failures of hydrogen embrittlement (HE). Hydrogen assisted cracking (HAC) of alloy steel, high tensile strength and electrodeposited cadmium plated hardware has been an ongoing quality issue in the industry for over 50 years.

The specifications for the nuts were intended for weight saving applications and have relatively thin walls. There are many alternate forms of hardware choices that are designed, manufactured and suitable for critical applications. Airfasco has published a weight and least material condition (LMC) selection guide. The original nut this series replaced was the NAS679, 125,000 PSI minimum which was only intended primarily for shear applications. The MS21042 and NAS1291 steel thin wall hex flange nut was designed for a replacement with a higher axial tensile strength for both shear and tensile applications.

Designers and Engineers are advised to check with Airfasco to determine availability of torque value ranges and hardness ranges along with new improved technical designs for special applications to improve the use of these nuts. Airfasco has authorized distributors that offer managed inventory programs for OEM's.

Before installation, verify and assure the correct pitch diameter of the male mate(s), the appropriate assembly torque range and the hardness of the male mate(s). Assemble using calibrated hand tools for the installation as RPM speed and torque pressures of air tools can readily gall and damage the nuts if out of calibration tools are used.

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Galling is a form of adhesive wear that can occur in fasteners as they are tightened. Galling is most prevalent in fasteners made from corrosion resistant materials that self-generate a protective oxide surface film [such as stainless steel, aluminum, titanium and nickel based alloys]. As contact pressure increases on the sliding surfaces of the threads during tightening, the oxide layer is stripped off high points on the mating surfaces and the bare unprotected surfaces 'cold weld' together. As the fastener tightening continues, these localized cold welded joints shear, tearing off metal particles. Debris from the stripped oxide film and particles from the sheared joints are entrained in the sliding surfaces which exacerbate the adhesive wear. The process can ultimately lead to seizing of the fasteners and breakage if tightening continues. Seizing can even occur during the loosening process.

Galling is best avoided by: (1) Installation using calibrated hand tools to slow down the RPM tightening process since increased speed generates greater heat from friction and heat accelerates the 'cold weld' process; and/or (2) Providing lubrication, either solid film or anti-galling compound to the threads prior to assembly (see SAE J2270 for additional information); (3) Carefully evaluating the thread fit of the male mate(s) threads. The MS21042 and NAS1291 specify a class 3B thread fit and at maximum material condition with a class 3A male mate(s) thread, there is zero clearance between mating threads. Using a class 2A external thread with these nuts provides some clearance between threads, even at maximum material condition. When design considerations dictate the use of materials for which there is no experience, an evaluation of the material couple's resistance to galling should be made to assess the risk of failures during installation. ASTM G 98 provides a test method for evaluating the galling resistance and determining threshold galling stress. This threshold can then be compared to analytically determine contact pressures of the threaded joint during tightening to provide an assessment of the fastener design. (4) Selecting different alloys with different hardness values or different strengths of the same alloy, thereby providing different hardness values in the threaded joint.

Require all electro-platers to initiate a hydrogen embrittlement prevention (HEP) requirement making it mandatory for plating processors to begin baking immediately after plating and not to exceed one (1) hour for the twenty three (23) hours minimum baking requirement temperature of 375 F degrees +/- 25 F (190 C +/-14 C). This will reduce the possibility of hydrogen embrittlement (HE) and post hydrogen assisted cracking (HAC).

The use of the electro-plating process with any anode base metals on this type of thin wall nut hardware will cause the classic effects of hydrogen embrittlement (HE). Following hydrogen embrittlement prevention (HEP) techniques will minimize the amount of hydrogen embrittlement (HE) and reduce post hydrogen assisted cracking (HAC), but not remove all concentrations of hydrogen content because of the cadmium electro-plating process.

Page 2 of 4

The electro-plating finish of anode cadmium metal along with a post chromate finish treatment are both considered a candidate of "Substance of Very High Concern" (SVHC) with the European Chemicals Health Agency (ECHA) located in Helsinki. These metals and chemicals are <u>NOT</u> compliant with the "Registration, Evaluation, Authorization and Restriction of Chemical" (REACH) substances and the directive "Restriction of Hazardous Substances" (RoHS). REACH in brief calls for the progressive substitution of the most dangerous chemicals when suitable alternatives have been identified. Aerospace is no longer exempt and Article 33 (1) REACH may allow the recipient of the nut provided the concentration of (SVHC) is less than 0.1% weight/weight (w/w) and sufficient information is submitted to determine safe application and installation use. To plate 4,536 kg (10,000 lbs.) of bare steel nuts requires approximately 14 kg (31 lbs.) of cadmium metal and approximately 2 liters (2.12 quarts) of post treatment chromate.

Airfasco suggests an additional hydrogen embrittlement wedge testing (HEWT) of 85% tensile strength for a minimum of 72 hours with a 10 degree wedge test fixture for additional rigorous testing as well as the required standard parallel fixture per NASM1312-5, T=KD/W.

Torque specification range of NASM25027 has a very wide tolerance that can affect final assembly depending on the matting fasteners being used. We have developed a lower torque (LT) series which conforms to lower allowable range of NASM25027 torque specifications. We feel using a lower torque range will create more of an allowable tolerance for the use of dissimilar metals and coatings used in final assembly. We conducted conformance testing and have reduced the hardness range and torque values for use with lower tensile matting fasteners such as the AN bolts and standard 125,000 PSI minimum machine screws. Included in this bulletin is the lower torque (LT) series of MS21042 and NAS1291 steel product line that is recommended.

It should be noted that many distributors sell standard hardware purchase to the minimum sampling plan. It has been brought to our attention that many of the OEM's require additional flow down quality requirements such as C=0 and the standard sampling plan of ANSI/ASQZ1.4-2003 is not acceptable. Many of our OEM's will assign additional flow down quality requirements when purchasing standard AN, MS or NAS hardware and have them 100% NDT Magnaflux tested per ASTM E 1444-11 for their critical applications. NDT per ASTM E 1444-11 sample lot testing is only required on nuts .1900-32 inch (4.83 mm) and larger and not a requirement for the smaller nuts sizes per NASM25027, 4.5.4.1.

Any products manufactured in quantity from all of the manufacturers will always have a very small percentage of fallout when 100% NDT testing is performed. Airfasco does offer and can provide 100% NDT, C=0 for the nuts at an additional cost and reject on any imperfections which exceeds the minimum inspection requirements of NASM25027 Table VII (7) allowing limits of .010" (.25 mm) depths for laps, seams and inclusions.

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With reported problems from various manufacturers we feel there are many variables that can cause these problems. The use of out of calibrated hand tools or the use of high RPM assembly of non calibrated lower cost air tools without certified regulated air pressure can readily gall and damage the nuts. If too long of a bolt or screw with a shoulder is used this can create a wedge effect and crack the nut. A high 3A pitch diameter makes for a zero clearance between mating threads and can cause galling during assembly with failure due to over torque or ductile failure. We do recommend anti-galling compound to the male threads prior to assembly per SAE J2270. This will slow the tightening process since increased speeds generate greater heat from friction and heat accelerates the "cold weld" process. We feel the use of lower torque nuts may help this problem and we have attached drawings in the report.

MS21043 and NAS1291C stainless A286 nuts of the same thin wall, light exact design and weight have lower axial tensile strengths of 125,000 PSI minimum and should be considered when design application permits. NAS1291- Rev 13 steel sizes less than .375-24" (9.525 mm) and under axial tensile strengths are crossed off the current drawing and inactive for new design. Airfasco has published a design selection guide referencing the different thread sizes, weights, torque value ranges, axial tensile strength, plating finishes and least material condition (LMC). An illustration of all the sizes for least material condition (LMC) is attached for reference.

Airfasco has designed a hydrogen embrittlement negative (HEN) series of the MS21042 and NAS1291 450 F steel thin walled hex flange nut that is a cadmium replacement, RoHS and REACH compliant finish. The nut meets all the physical, chemical and mechanical properties of the specification except for the improved finish which far exceeds the cadmium salt spray requirements. Totally chrome free finish that exceeds > 2,000 hours salt spray corrosion. The process is a thermal diffusion coating (TDC) at 400 C (752 F) which eliminates any chances of hydrogen embrittlement by process application per ASTM A1059. This finish has the same friction factor (K) as cadmium and provides the same natural lubricant for installation assembling and removal.

Key Words: European Chemicals Health Agency (ECHA), Hydrogen Assisted Cracking (HAC), Hydrogen Embrittlement (HE), Hydrogen Embrittlement Negative (HEN), Hydrogen Embrittlement Wedge Testing (HEWT), Least Material Condition (LMC), Lower Torque (LT), Non Destructive Testing (NDT), Registration, Evaluation, Authorization and Restriction of Chemical (REACH), Restriction of Hazardous Substances (RoHS), Substance of Very High Concern (SVHC), Thermal Diffusion Coating (TDC), Weight to Weight (W/W).

Please contact Dennis Dent Dennis.Dent@Airfasco.com if you have any questions or need any additional information or assistance.

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Appendix B – Robinson Helicopter Company Service Letters

ROBINSON
HELICOPTER COMPANY

2901 Airport Drive, Torrance, California 90505 Phone (310) 539-0508 Fax (310) 539-5198

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R22 SERVICE LETTER SL-58

R44 SERVICE LETTER SL-38

R66 SERVICE LETTER SL-01

DATE: 18 August 2011

TO: R22, R44 & R44 II, and R66 owners, operators, and maintenance personnel

SUBJECT: Cracked MS21042L-series Nuts

BACKGROUND: RHC has received two reports of cracked MS21042L4 self-locking nuts. Other helicopter manufacturers have received similar reports. A possible cause for cracking nuts is hydrogen embrittlement, which can be introduced during hardware manufacturing. Manufacturing processes for government- and industry-standard hardware are not controlled by RHC.

COMPLIANCE PROCEDURE:

Pilots and maintenance personnel are reminded that hardware condition is equally important as hardware security. Cracked or corroded nuts require replacement.

Contact RHC Technical Support at techsupport@robinsheli.com if cracked nuts are found.

Australian Transport Safety Bureau

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The Bureau is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

Australian Transport Safety Bureau

24 Hours 1800 020 616
Web www.atsb.gov.au
Twitter @ATSBinfo
Email atsbinfo@atsb.gov.au

Investigation

ATSB Transport Safety Report
Aviation Occurrence Investigation
Embrittled nut and related failures Robinson R22 Beta helicopter
VH-JNP, 22 km N of Saxby Downs, Queensland, 12 October 2011

AO-2011-135
Final – 22 January 2014