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Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY INVESTIGATION REPORT

Aviation Occurrence Report 200405511

Final

Independent Technical Review of Gyrocopter Hub Bar Failures



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**Independent Technical Review of
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Independent Technical Review of Gyrocopter Hub bar Failures

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Abstract

Following a fatal accident near Thargomindah, Queensland, and a series of other serious gyrocopter accidents and incidents involving the cracking or failure of the rotor hub bar component, a review of the available information and understanding of the failure mechanism was undertaken on behalf of the Charleville Qld coroner, to assist in his preparation for an inquest into the Thargomindah accident.

The review examined the mechanism of hub bar failure and the influence of flight loads, maintenance activities and design. Historical, current and possible future safety action was outlined, as were avenues for future investigation of the relevant safety issues.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal Bureau within the Australian Government Department of Transport and Regional Services. ATSB investigations are independent of regulatory, operator or other external bodies.

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. Accordingly, the ATSB also conducts investigations and studies of the transport system to identify underlying factors and trends that have the potential to adversely affect safety.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and, where applicable, relevant international agreements. The object of a safety investigation is to determine the circumstances to prevent other similar events. The results of these determinations form the basis for safety action, including recommendations where necessary. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations.

It is not the object of an investigation to determine blame or liability. However, it should be recognised that an investigation report must include factual material of sufficient weight to support the analysis and findings. That material will at times contain information reflecting on the performance of individuals and organisations, and how their actions may have contributed to the outcomes of the matter under investigation. 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.

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. While the Bureau issues recommendations to regulatory authorities, industry, or other agencies in order to address safety issues, its preference is for organisations to make safety enhancements during the course of an investigation. The Bureau is pleased to report positive safety action in its final reports rather than make formal recommendations. Recommendations may be issued in conjunction with ATSB reports or independently. A safety issue may lead to a number of similar recommendations, each issued to a different agency.

The ATSB does not have the resources to carry out a full cost-benefit analysis of each safety recommendation. The cost of a recommendation must be balanced against its benefits to safety, and transport safety involves the whole community. Such analysis is a matter for the body to which the recommendation is addressed (for example, the relevant regulatory authority in aviation, marine or rail in consultation with the industry).

INTRODUCTION

Background

On 13 October 2004, the pilot of an autogyro aircraft (gyrocopter) conducting mustering operations on Norley Station, near Thargomindah Qld, was fatally injured when the aircraft departed controlled flight and impacted the ground.

Accident site investigations by the Queensland police service found that the main rotor hub bar had failed, resulting in the separation of both rotor blades from the aircraft during flight. Subsequent forensic study of the failure confirmed the presence of pre-existing fatigue cracking through approximately half of the hub bar cross-section at a location immediately adjacent to the central (teeter) mount. Separation of the hub bar and release of one rotor blade followed the ductile overload and fracture of the remaining un-cracked section, whereupon the resulting gross imbalance in the rotor system likely caused the separation of the remaining blade and hub bar from the rotor head assembly.

Following the Thargomindah accident, several subsequent gyrocopter accidents and incidents that involved cracking or failure of the hub bar were reported to the ATSB and/or the Australian Sports Rotorcraft Association (ASRA). As a result, the ASRA issued a series of Airworthiness Directives (AD) to address the risk of further hub bar failures.

Investigation brief

On 24 December, the Charleville (Queensland) coroner requested the assistance of the ATSB in preparation for an inquest into the Thargomindah accident. To that end, the ATSB initiated an investigation under the *Transport Safety Investigation Act 2003* for the purposes of examining the available information relating to the development of cracking and failure within gyrocopter hub bar components.

Information provided

The following documents were received and considered during the course of this review (in no particular order).

- [1] Letter from the Operations Manager, ASRA to the Coroner, dated 13 December 2005
- [2] ASRA Airworthiness Directive 02/2004
- [3] ASRA Airworthiness Directive 05/2005
- [4] Copy of e-mail cancelling AD's 'Rotor blade failure' and 02/2004.
- [5] Letter from the Coroner, to a Senior Constable, Thargomindah Police, dated 23 December 2005.
- [6] Letter from the Coroner, to the Operations Manager, ASRA, dated 23 December 2005.
- [7] Aerospace NDI Pty Ltd inspection reports 01/05, 02/05, 03/05, 04/05.
- [8] AlfaTest Pty Ltd inspection report A2005329N01.
- [9] Forensic Services Australia (Qld) Pty Ltd report BK05057.
- [10] ATSB database summary of reported gyrocopter accidents from 1 Jan 2000 to 12 April 2006.
- [11] Letter from the Vice President, ASRA, to the Coroner, dated 31 December 2005.
- [12] Letter from the acting manager Corporate Relations, Civil Aviation Safety Authority, to the Coroner, dated 6 March 2006.
- [13] Metlabs hub bar cracking / failure examination report No's. 6A21/MET1,2,3.

For investigatory purposes, reference was also made to the following publications.

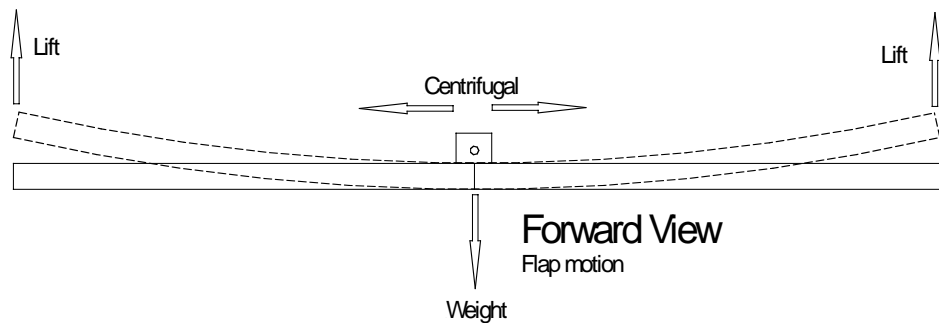
- [14] Smithells Light Metals Handbook, E.A. Brandes & G.B. Brook, editors. 1998, ISBN: 0 7506 3625 4
Table 3.2 'Aluminium and Aluminium Alloys – Mechanical Properties at Room Temperature'.
- [15] ASM Handbook, Volume 2: Properties and selection: Nonferrous Alloys and Special Purpose Materials. 1993, ISBN: 0 87170 378 5
pp. 70, 102

FACTUAL INFORMATION

Hub bar operation

The function of the hub bar in a typical gyrocopter rotorcraft is to mechanically link the two rotor blades and provide for control of the aircraft via the movement of the rotor plane relative to the fuselage. In flight, the entire static weight of the rotorcraft and occupant/s is carried by the rotors and transferred through the hub bar and rotor head to the fuselage. Any flight manoeuvring will generate additional dynamic loads, as will landing and taxiing. A further source of loading arises from the spinning rotor, which produces a tensile stress along the bar axis in response to the centrifugal loads from the rotating blade masses. Drag and inertial loads acting on the individual advancing and retreating rotor blades may also induce bending in the rotor plane as the rotorcraft moves forward through the air. Figure 1 presents some of the basic loads sustained by the typical hub bar when in flight.

Figure 1: Hub bar ‘flap’ loads carried in steady flight



Materials

It was noted from the documentation examined that the gyrocopter hub bars in question are commonly produced from a wrought aluminium alloy; either an AS/NZS 1866 /ASTM B221 grade 6061-T6 [Ref. 13] or 2024-T3 [Ref. 2]. Table 1 summarised the typical mechanical properties [Ref. 14,15] of both alloys.

Table 1: Nominal mechanical properties of hub bar alloys

Alloy	0.2% Proof Stress (MPa)	Ultimate Tensile Stress (MPa)	Elongation % over 50mm	Hardness Brinell	Fatigue Stress (over 5×10^8 cycles)
6061-T6	280	310	13	90	97
2024-T3	345	485	18	120	140

Failure mechanisms

The study commissioned by the Queensland Police Service [Ref. 9] determined that failure of the hub bar in the Thargomindah accident had arisen as a direct consequence of fatigue crack initiation and growth through the bar section, coincident with one of the central hub block bolt holes. Similarly, the examinations conducted subsequently for the ASRA [Ref. 13] also identified fatigue cracking in three other hub bars.

Typically, fatigue cracking will initiate and propagate through a structural section in response to the accumulation of stress cycles induced during dynamic loading (such as occurs during gyrocopter flight). The initiation of fatigue cracking in any particular location is governed by a number of factors:

- Magnitude of the applied loads and hence the net section stress created during manoeuvring / handling and loading of the rotorcraft
- Load spectrum – the number and length of flight cycles, type of flights undertaken
- Presence of stress-raising features such as service damage, maintenance damage, design features, corrosion damage
- Strength and mechanical properties of the base material – relates to the selection of materials as nominated by the design of the hub bar.

Appendix 1 presents a logic diagram examining the development of hub bar cracking. In all cases, the examinations referenced at [9] and [13] identified the presence of stress raising defects at the crack origins – features such as mechanical indentations produced by fastener clamping or surface fretting between the hub bar and fixtures.

Fracture control

For all critical components (i.e. those components, if they were to fail, would result in the loss of the aircraft), the aircraft engineer typically implements a design-level plan to address the risk of failure by fracture. The '*fracture control plan*' as such, will examine of the possible failure mechanisms and establish controls to limit the influence of each. In the case of dynamically loaded structures such as the hub bar, the plan may require the design to call for strong materials and large sections to lower the net stresses to a level where fatigue is unlikely to occur for the foreseeable life of the item. Alternately, '*life-limiting*' may be implemented to ensure that critical components are removed from service before a pre-established fatigue life is exhausted. Periodic non-destructive inspection also finds application in monitoring the performance of a structure during its service life to ensure that cracking is detected and the component retired before the cracking reaches critical size.

It was not known whether the designs of rotorcraft that have sustained recent hub bar cracking and failures had incorporated a fracture control plan for the hub bar or other flight-critical components.

Historical safety action

Following the Thargomindah accident, the ASRA issued an airworthiness directive (AD) [Ref. 2], prohibiting the further flight of gyrocopters fitted with a specific make of hub bar, until such time as the hub bar was replaced and the replacement approved by an ASRA Technical Officer. That directive was subsequently rescinded in October 2005 [Ref. 4] when AD 05/2005 was introduced. AD 05/2005 implemented requirements for owners and operators of gyrocopters to periodically inspect the hub bar component in accordance with an ASRA procedure, and to retire the hub bar from service after the accumulation of a defined flight time. The AD cited two further accidents associated with hub bar cracking and several instances where cracking was detected before flight.

The inspection procedure called by AD 05/2005 was a surface and bolt-hole eddy-current inspection technique (ECI), backed up with fluorescent liquid penetrant inspection (FPI). The inspection intervals specified by the AD were related to the type and operation of the rotorcraft, with two-seat and single-seat type approved gyrocopters and single-seat gyrocopters involved in high-energy manoeuvres¹ requiring inspection at 100 hourly intervals after 500 hours service, and hub bar replacement after 800 hours. Single-seat gyrocopters used for sport and recreation only were required to have hub bar inspections carried out at 100 hourly intervals after 800 hours service and hub bar replacement after 1000 hours.

The methodology employed by the ASRA in determining the inspection intervals and retirement lives of the gyrocopter hub bars was not documented.

¹ Typical of usage for mustering operations or related aerial work.

ANALYSIS

Crack origins

The mechanical indentations and surface fretting damage identified in the cracked or failed hub bars examined for the ASRA [Ref. 13], was likely to have been a significant contributing factor in the initiation of fatigue cracking. Heavy tightening of the hub bar securing bolts had produced plastic deformation and crushing of the parent alloy, thus providing for localised stress concentration and creating ideal sites for fatigue crack initiation. The design of the hub bar/s did not appear to have provided for the use of a clamping plate or other mechanism for the distribution of the clamping loads more evenly across the under-surfaces of the bar. Of the two instances of cracking found at the blade attachment points, both were associated with surface fretting damage created by the repeated movement between the mating surfaces of the hub bar and blade attachment fittings. Fretting damage was also identified in the examination of the Thargomindah accident hub bar failure [Ref. 9].

Bolt tension

In all instances of failure examined in References 13 and 9, bolt tension was identified as a safety factor. Inadequate bolt tightening (torque) or undetected loosening in service will allow the movement of clamped surfaces and the generation of fretting damage as observed. Over-tightening of bolts can lead to damage of the underlying material or the bolt itself and can produce the damage noted in Ref. 13.

Periodic checking and maintenance of bolt tension and joint condition is a maintenance activity and is particularly relevant in dynamically loaded structures. Joint movement and fretting is sometimes visibly evident by the formation of an oxide product that may be visible alongside the joint or emanating from the region. The narrative to ASRA AD 02/2004 discusses this.

Flight loads and rotorcraft maintenance

The magnitude of the loads placed upon the gyrocopter rotor structure will often contribute significantly to the extent to which a problem such as fatigue cracking develops. Rotorcraft used for aerial work involving regular and repeated heavy manoeuvring will be at a higher level of risk of cracking or defect development, than comparable craft employed for recreational or transport purposes. Regular inspection and maintenance thus becomes more critical in maintaining the airworthiness of frequently used or more highly loaded rotorcraft. The nature of the maintenance is similarly important and should take into account all components and systems known to have a propensity for defect development or failure.

Examination of the prescribed maintenance regime for gyrocopters in Australia was outside the scope of this review.

Design

The hub bar design (materials, physical form and construction) is implicitly linked to its service performance, and as such, its resistance or otherwise to the development of fatigue cracking. Any given design of component will have a fatigue strength definable in terms of the number and magnitude of stress cycles required to initiate cracking under any particular loading spectrum. It is in the interests of safety and reliability for the fatigue behaviour of any flight-critical component design to be predicted and subsequently established by testing. Maintenance and inspection programs may then be implemented around the expected life and behaviour of the component/s.

Changes to a 'proven' design must be evaluated in terms of their likely impact on fatigue performance – possibly necessitating re-testing of the changed design to establish the continued suitability of the design for the intended purpose.

SAFETY ACTION

Airworthiness directive

At the time this review was being prepared, the governing document addressing the issue of hub bar failure was the ASRA airworthiness directive 05/2005 [Ref. 3]. That directive implemented a defined program of maintenance for the hub bars, incorporating periodic inspection and life-limiting.

Further investigation

Given that the hub bar failures to date have resulted, at least in part, from damage induced during, or as a result of, work carried out on the rotorcraft, it may be prudent for a responsible body to examine further the circumstances surrounding the known instances of cracking and failure. Aspects such as the requirements for tightening and checking the tightness of hub bar bolts should be examined, as should the operational and maintenance history of those rotorcraft known to have sustained hub bar cracking.

An evaluation of the hub bar design process may also be applicable to investigate the suitability of the various hub bar and rotorcraft designs for high load aerial work activities such as mustering.

Safety advisory notice

SAN20060016

The Australian Transport Safety Bureau advises owners, operators, maintainers and manufacturers of autogyro rotorcraft (gyrocopters) of the potential for premature failure of the rotor hub bar or related components as a result of fatigue cracking developing from bolted connections within the hub bar assembly.

Appendix 1: Development of gyrocopter hub bar cracking, including possible contributory factors.

