Scientific Support for the Investigation of a Helicopter Collision

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ABSTRACT
This paper discusses some aspects of scientific support provided during the investigation of an accident in which two Black Hawk helicopters collided during an exercise; both helicopters were destroyed in the collision, with substantial loss of life. One aircraft was reconstructed at DSTO, with extensive analysis of parts, to allow determination of the collision mechanics. The investigation succeeded in its main aims of determining the location of the collision point, and the likely track of each aircraft, as well as the details of the collision. Extensive support was also provided on many other aspects of the accident. The investigation required development of several innovative approaches, including a way of analysing the wreckage distribution to establish the collision location, as well as producing some challenges in component failure analysis. This paper provides a brief discussion of the reconstruction and the wreckage analysis.

KEYWORDS
Aircraft, accident investigation, failure analysis, wreckage analysis.

INTRODUCTION

Six Black Hawk helicopters were involved in a practice assault on a hill top near Townsville; the critical part of the formation comprised a row of three aircraft flying abreast, with the lead aircraft (referred to as BLACK 1) located on the left. It was dark, and the aircrew relied on night vision goggles (NVGs) for visual clues; these significantly impair vision by reducing the field of view to approximately 40 degrees, less than half normal vision, and reduce the contrast of the terrain. During the final stages of approach to the target area, the lead aircraft and the aircraft to its immediate right (referred to as BLACK 2) collided in-flight. Both aircraft fell to the ground where they were consumed by fire. In all, 18 men lost their lives.

After initial investigation which did not identify a single most likely description of the accident, and was complicated by a multitude of witness statements, many apparently contradictory, the Board of Inquiry (BOI) ordered a supplementary technical investigation by RAAF and DSTO staff. The team was given one month to complete the investigations and report to the BOI. The Terms of Reference, in brief, were to establish

(a) the serviceability status of the aircraft before, during and after the accident,
(b) the flight paths of the aircraft before, during and after the collision,
(c) the crash sequence, and
(d) the point in space of the initial contact, with estimates of confidence

This was a major challenge given the extent of the destruction caused by the post accident fires, however, the deadline was met and a most probable scenario deduced.

This paper presents a brief summary of the wreckage which was recovered, and gives a few examples of techniques used to deduce information from the wreckage distribution.

WRECKAGE EXAMINATION

The wreckage was consolidated at the AMRL facility at Fishermans Bend, Melbourne. It included substantial sections of main rotor blades (MRBs) and tail rotor blades (TRBs) from both aircraft, and a range of components from BLACK 2 which had been flung away from the burning wreckage during the accident. Significant items included the severed tail assembly, the APU, DME antenna, aft sections of the engines, the right engine exhaust system and engine cover door, left cargo door, right side drive train access door and a pneumatic 'Buddy Start' fitting, all of which had blade impact witness marks. A three dimensional mock-up, as shown in Figure 1, was constructed in order to re-build what was left of BLACK 2. Because BLACK 1 was essentially complete when it impacted the ground, with the exception of its MRBs, very little physical evidence was available from it because of the intense fire which engulfed the wreckage and melted the aluminium components.

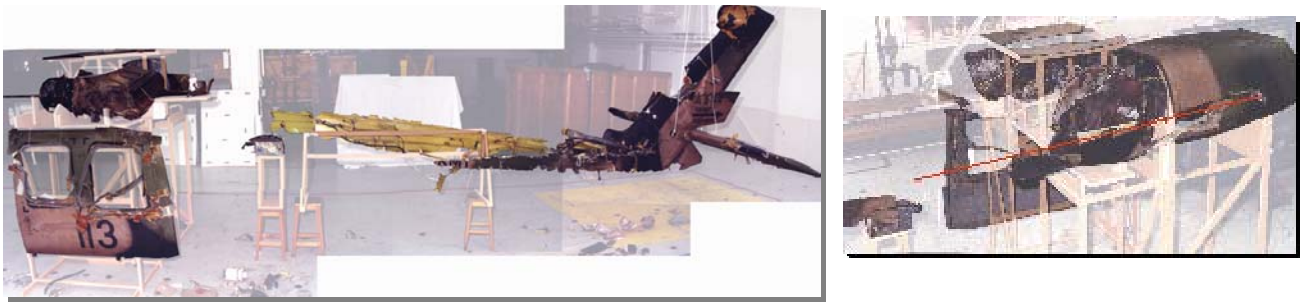

Figure 1 View of the recovered tail section along with other major components.

Figure 2 The reconstructed tail section of BLACK 2 looking in-plane with the upper cut through the tail section and the lower cut through the tail boom.

Assessment of BLACK 2 damage

Using the mock-up of BLACK 2 it became clear that a number of the cuts caused by the passage of MRBs began to line up. Reconstruction of the tail section of BLACK 2 as shown in Figure 2, revealed the alignment of rotor blade strikes in the fin and stabilator, and the tail boom and stabilator. The tail section had evidence of four MRB strikes. The first two were clearly identified from two cuts through the horizontal stabilator, one of which severed the tail rotor drive shaft, and a third from a blade tip penetration near the 45 degree gearbox. However, a fourth strike was not evident until a small fragment of the fin leading edge was replaced in its position on the fin. This strike was barely a glancing blow, and its discovery emphasises the need for thoroughness in parts recovery and airframe reconstruction. The horizontal stabilator actuator was recovered and, because it lost all inputs from the flight control system during the first MRB strike (severed hydraulic line), its configuration was able to determine the stabilator angle, which was then used to estimate the speed of BLACK 2.

Figure 3 Reconstructed left side cargo door from Black 2 showing three cuts.

Cargo Door

The left cargo door (Figure 3) had three distinct cuts/impact marks while the right cargo door had one impact mark. (The evidence for this section includes the cargo doors because they were open (slide to the rear) during the collision. In their closed position, they are part of the cargo area).

Cargo Area/Centre Fuselage.

Numerous fittings (including the pneumatic 'Buddy Start' fitting) and small access doors from the left side, the APU exhaust duct (located on the left side), GPS receiver, TACAN adapter Receiver/transmitter, the avionic bay air cleaner top and various smaller pieces of structure had MRB impact witness marks. Blade witness marks were also observed on or through upper panels, the APU, left and right engine exhaust system, the right engine cowl, seating framework, hydraulic lines and the GPS antenna.

Blade Strikes

After extensive examination, only **<u>four</u>** distinct MRB strikes could be identified - significantly fewer than initially thought. Because large sections of the four MRBs from BLACK 1 were found well clear of the wreckage, each blade passed through the fuselage of BLACK 2 only once before breaking away and being projected into the distance.

Hence it can be estimated that the collision took approximately 0.25 seconds to complete, ie four blade passes at 17.2 passes per second. This conclusion supported the views of several witnesses who described the impact as an explosion. The tracks of the four strikes are illustrated in Figure 4.

Figure 4 The port side of a Black Hawk showing the deduced positions of the mrb cuts/strikes on BLACK 2

The following key deductions could then be made:

Angle of Collision.
The MRB tracks through the airframe of BLACK 2 indicated that during the collision, BLACK 1 was inclined at 25 to 35^{o}, left side low, relative to BLACK 2. This can be most clearly seen from the cuts through the horizontal stabilator.

MRB Condition.
Almost all sections of the MRBs from BLACK 1 were recovered from the accident site. The blades bore a range of impact marks and embedded components which confirmed that they had cut through the fuselage of BLACK 2. Critical evidence included:

(a) a significant crushing indentation in an MRB titanium spar cap which matched the deformation to the rear of the APU,
(b) an impact mark which matched the pneumatic ‘Buddy Start’ fitting,and
(c) a piece of fuselage structure from the transition area which was recovered from the leading edge of one MRB.

MRB Impact Sequence.
Matching witness marks were then used to identify key points of intersection. At least two points on each MRB could be related to specific points the BLACK 2 airframe which enabled simple triangulation to be used to identify actual blade tracks through the structure. The value of this analysis lies in being able to identify the rotor disc movement during the collision, and hence the track of the closing aircraft relative to BLACK 2.

Approach Velocity.
By using the aircraft centres of gravity (CoG) obtained from triangulating back from the known points of impact, a relative movement of BLACK 1 to BLACK 2 could be estimated (Figure 5). Given the normal blade pass frequency was known (17.2 blade passes per second) and the relative movement of the CoGs, the approach velocity could be estimated. Over the four MRB strikes, the centre moved longitudinally along the fuselage of BLACK 2 by approximately 4.6 metres.

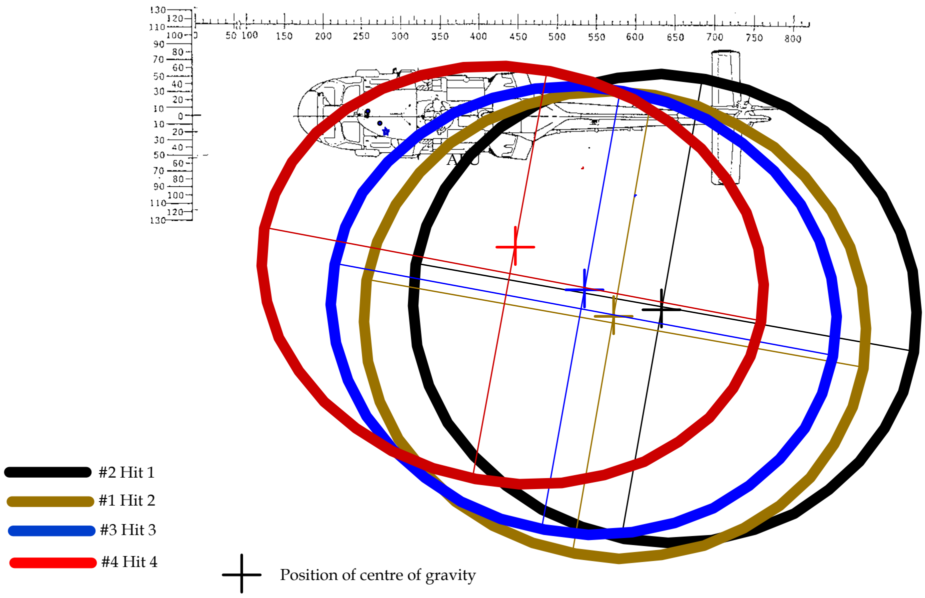

Figure 5 The estimated rotor disc sizes and locations, and the progression of the BLACK 1 centre of gravity through the collision. Note that the angle of bank has been increased from 25 to 35 as the collision progressed, corresponding to the physical evidence from the cuts.

Given that the horizontal stabilator actuator setting indicated that BLACK 2 was travelling at between 50 and 70 kt, BLACK 1 appeared to travelling at a speed of between 70 and 114 kt. The resultant approach angle when viewed from the ground was approximately 14°.

In an effort to understand the dynamics of the rotor disc during manoeuvres, the AMRL Black Hawk simulator was used to explore ways in which a 25° to 35° angle of bank could be generated by BLACK 1 on its approach to BLACK 2. A range of simulations of BLACK 1 was conducted which sought to combine the deduced approach speed towards BLACK 2 and expected evasive manoeuvres by BLACK 1. The first simulation modeled a 65 kt speed and full left cyclic input. This demonstrated that the energy of the manoeuvre during the first approximately 10 blade passes is consumed in rotating the aircraft. By this point, the blades have achieved a bank angle of approximately 20° assuming a rigid rotor (Figure 6). Thereafter, the aircraft commences to move to the left. When an 8 m/sec side speed is introduced to the simulation and the blade tracks are superimposed on an adjacent aircraft, ie BLACK 2, a clear correlation with the MRB witness marks through BLACK 2 was clear.

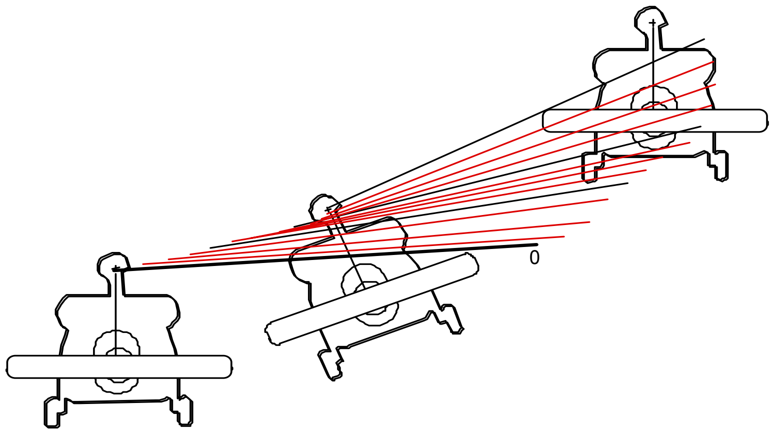

Figure 6 Full left cyclic applied at blade pass 0, moving 8m/s to right, 2m/s climb, relative to other aircraft.

Wreckage Plot

The wreckage plot developed by the initial AIT revealed that parts were widely scattered around the site, many travelling for several hundred metres. Conventionally, analysis of wreckage distributions supports a trajectory analysis which itself will identify the point in the sky where separation occurs; many tools are available for assessing the effect of prevailing weather on the distribution of parts. In this case, however, the collision occurred at low level, and weather was not a major factor. Unfortunately, the complexity of the distribution made it difficult to identify any overall pattern with any certainty, and this prevented any direct approach to determining the impact location. Accordingly, an alternative approach was required. The method developed proposed that the areas of probable impact could be estimated by analysing groups of wreckage types, and that repetition of this process would

(a) lead to identification of the impact site, and to
(b) preparation of a contour plot representing overlapping areas of probability that the contour enclosed the impact location.

Five main groups of wreckage were identified, from each of which some estimate of the collision region could be obtained; two such groups consisted of fuel-impregnated foam pieces (and areas of spot fires), and light perspex pieces from the LH cargo door of BLACK 2. These parts were considered likely to have been ejected to the left of BLACK 2 at collision.

Based on the height of trees at the accident site, the assumption was made that the minimum height of the collision was 11 metres, which equates to a 1.5 second fall time in a vacuum ie the minimum time for an object in free fall. From the evidence of the horizontal stabilator actuator, the forward velocity of BLACK 2 at the time of the collision was approximately 50 to 70 kt. Using computer modeling of a small piece of perspex (representative of a window fragment from BLACK 2) and the assumed ground speed range of 45 to 75 knots for BLACK 2 (a greater range than indicated by the stabilator), the minimum and maximum throws were estimated to be 20 metres and 45 metres respectively. Therefore, 20 metres was identified as the threshold distance from the light debris field on the ground back to the point of the collision.

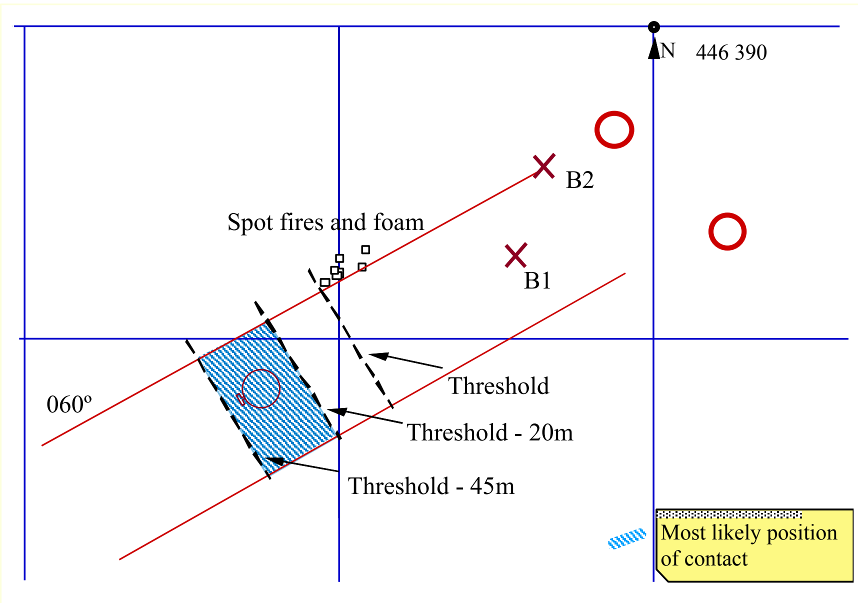

Figure 7 Location of spot fires, light foam material, and likely location of collision.

Spot Fires and Fuel Cell Foam from BLACK 2.
Given the extremely light weight of the fuel cell foam and the relatively tight grouping of the foam and spot fires, a probable area of collision could be estimated using the 20 metre and 45 metre limits identified by trajectory analysis. The width of the area was estimated as 45 metres for the same reason. Figure 7 shows the overall area, with the airframe ground locations B1 and B2, as well as some target revetments shown as circles. The shaded area represents an estimate of the likely position of BLACK 2 at the time of collision.

Probable Area of Collision.
The crucial feature of this approach is to increase confidence in the estimate of collision position by superimposing several estimates. Figure 8 shows the superposition of five separate estimates of the location in this accident; a most likely area of probable impact was defined based on the area common to all five estimates. A lower probability was given to areas which were contained in only four of the five estimates, and so on. In this way, a contour map of probable likely location was generated. The result was a high level of confidence that the location had been identified to within one rotor diameter. Furthermore, placing the two aircraft at this location then effectively identified the tracks of the two aircraft, and met the requirements of the Board of Inquiry.

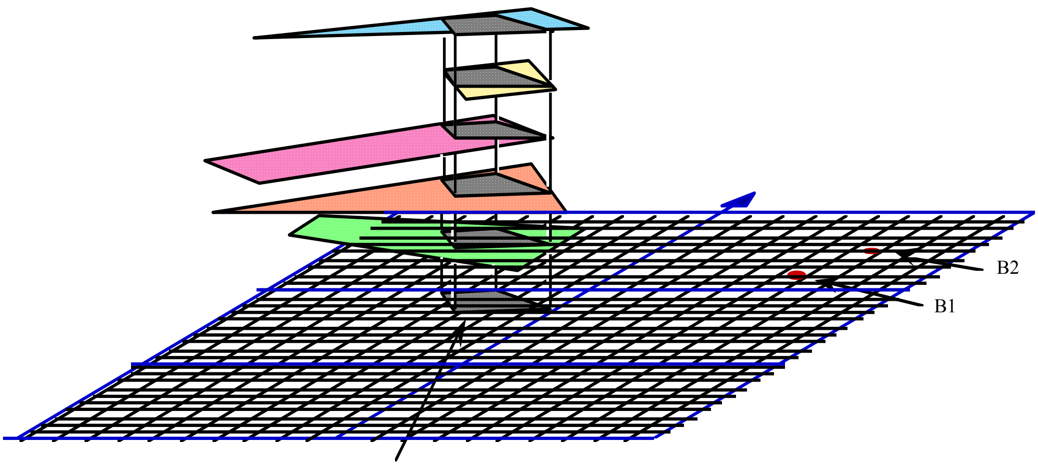

Figure 8 Identification of the most probable area of contact by superimposing best estimates of contact regions.

CONCLUSIONS
The development of innovative ways of assessing wreckage distributions allowed the team to identify the location of the collision point. The use of aircraft reconstruction, extensive parts examination, coupled with simulation, provided a high level of confidence in the identification of the collision sequence, collision mechanics, post-collision behaviour, and the tracks of the two aircraft at the time of collision. The investigation also used damage assessment and modelling to conclude that just before impact with BLACK 2, BLACK 1 banked sharply to the left during which time its main rotor blades passed through the aft section of BLACK 2.

This paper has sought to summarise the investigation of the Black Hawk accident and, as such, has sought only to summarise the key points. More detailed reports were tabled to the Military Board of Inquiry and later released by AMRL under DSTO-DDP-0190 dated 21 May 97.

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