行政院及所屬各機關出國報告
（出國類別：進修）
ASC-TRT-03-09-001

赴美參加南加州飛安學院 直昇機事故調查訓練課程

報告

服務機關：行政院飛航安全委員會
出國人職稱：調查官
姓名：張文環
出國地區：美國新墨西哥州阿柏克基市
出國期間：民國九十二年九月五日至九月十四日
報告日期：民國九十二年十月二十八日

行政院及所屬各機關出國報告提要　　系統識別號 C09204049

出國報告名稱：赴美參加南加州飛安學院失事調查訓練課程報告

頁數：118 頁含附件：是

出國計畫主辦機關：行政院飛航安全委員會

聯絡人：黃佩蒂　　　　　　電　話：(02) 2547-5200 分機 154

出國人員姓名：張文環

服務機關：行政院飛航安全委員會

職稱：調查官　電話：(02) 2547-5200　分機 160

出國類別：□1 考察■2 進修□3 研究□4 實習□5 其他

出國期間：民國九十二年九月五日至九月十四日

出國地區：美國新墨西哥州阿柏克基市

報告日期：民國九十二年十月二十八日

分類號/目

關鍵詞：直升機失事調查、訓練、南加州飛安學院

內容摘要：（二百至三百字）

本項課程本班次授課期間、共完成直升機失事調查介紹（Investigation）、直昇機相關技術簡介（Technology）、人為因素（Human Factors）、案例討論及殘骸區實習等五門課程。直昇機失事調查課程內容包括飛安失事之背景介紹、相關法規介紹、直升機失事調查之準備工作、調查安全注意事項、調查相關細節及注意事項；如蒐證、飛機性能及特性、飛機操作、飛機系統、人機介面、飛行作業、維修作業、飛機結構、電器系統、傳動系統、旋翼系統、火燒軌跡、電器系統、儀表、發動機及飛航紀錄資料之簡介等。並對飛機失事重要影響因素如風場、滯空效應、旋翼失速、載重限制、重心與控制、動態飛操效應、發動機失效、傳動系統（齒輪箱）失效等現象均有重點介紹。另外針對直昇機之空氣動力、旋翼之振動、結構疲勞、飛機安定性及控制等對飛安之影響及關係等均為教授之範圍，但因時間關係，無法針對相關細節深入介紹。

本文電子檔已上傳至出國報告資訊網

行政院及所屬各機關出國報告審核表

出國報告名稱：赴美參加南加州飛安學院直昇機失事調查訓練課程報告
出國計畫主辦機關名稱：行政院飛航安全委員會

出國人姓名：張文環
職稱：調查官
服務單位:行政院飛航安全委員會

出國計畫主辦機關審核意見:

□1.依限繳交出報告
□2.格式完整
□3.內容充實完備
□4.建議具參考價值
□5.送本機關參考或研辦
□6.送上級機關參考
□7.退回補正,原因:
  □(1)不符原核定出國計畫
  □(2)以外文撰寫或僅以所蒐集外文資料為內容
  □(3)內容空洞簡略
  □(4)未依行政院所屬各機關出國報告規格辦理
  □(5)未於資訊網登錄提要資料及傳送出國報告電子檔
□8.其他處理意見：

層轉機關審核意見:

□同意主辦機關審核意見
  □全部 □部份_________(填寫審核意見編號)
□退回補正,原因:_________(填寫審核意見編號)
□其他處理意見:

目　　　　　錄

壹、目　　的

本次赴美南加大飛安學院受訓之目的：

- 接受直昇機飛安專業調查基本訓練，獲取飛安調查基本知識。
- 瞭解國際飛安調查技術之發展及現況，提昇本會飛安調查之能量。

貳、受訓過程紀要

一、受訓行程

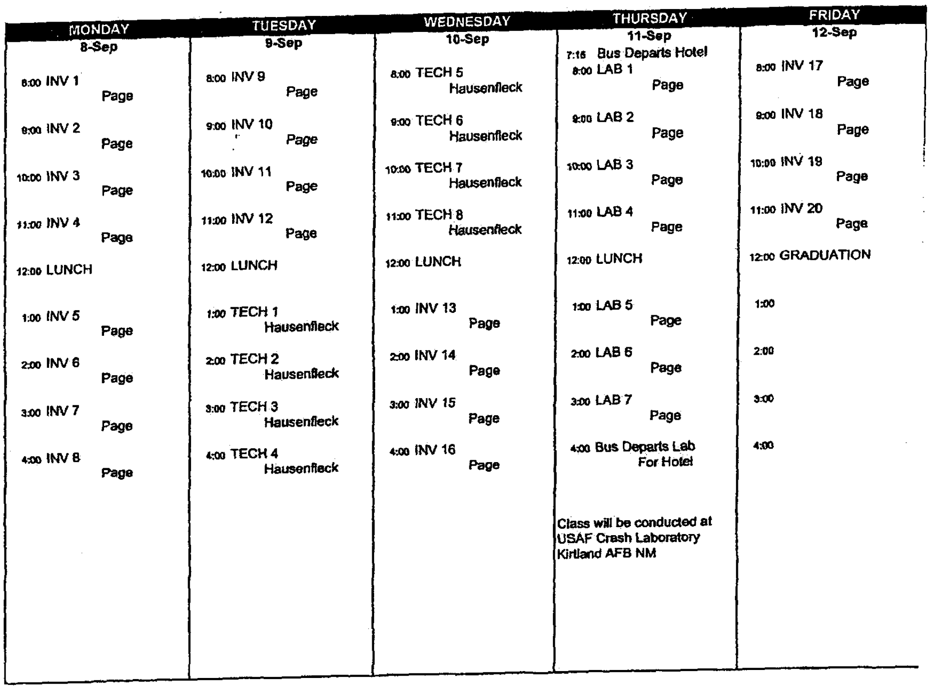
本次受訓行程自民國九十二年九月五日至九月十四日，共計十日，詳細行程表如表一：

日期	起訖地點	行程紀要	備考
9/5	台北-舊金山	出發	
9/6	舊金山-阿柏克基	行程中	
9/7 ~9/12	阿伯克基	受訓	
9/13	阿柏克基-舊金山	返程中	
9/14	舊金山- 台北	返回	

表一：行程表

二、受訓課程表

本次訓期共計36小時，如表二



MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
8-Sep	9-Sep	10-Sep	11-Sep	12-Sep
			7:15 Bus Departs Hotel	
8:00 INV 1 Page	8:00 INV 9 Page	8:00 TECH 5 Hausenfleck	8:00 LAB 1 Page	8:00 INV 17 Page
9:00 INV 2 Page	9:00 INV 10 Page	9:00 TECH 6 Hausenfleck	9:00 LAB 2 Page	9:00 INV 18 Page
10:00 INV 3 Page	10:00 INV 11 Page	10:00 TECH 7 Hausenfleck	10:00 LAB 3 Page	10:00 INV 19 Page
11:00 INV 4 Page	11:00 INV 12 Page	11:00 TECH 8 Hausenfleck	11:00 LAB 4 Page	11:00 INV 20 Page
12:00 LUNCH	12:00 LUNCH	12:00 LUNCH	12:00 LUNCH	12:00 GRADUATION
1:00 INV 5 Page	1:00 TECH 1 Hausenfleck	1:00 INV 13 Page	1:00 LAB 5 Page	1:00
2:00 INV 6 Page	2:00 TECH 2 Hausenfleck	2:00 INV 14 Page	2:00 LAB 6 Page	2:00
3:00 INV 7 Page	3:00 TECH 3 Hausenfleck	3:00 INV 15 Page	3:00 LAB 7 Page	3:00
4:00 INV 8 Page	4:00 TECH 4 Hausenfleck	4:00 INV 16 Page	4:00 Bus Departs Lab For Hotel	4:00
			Class will be conducted at USAF Crash Laboratory Kirtland AFB NM	

表二：航空器失事調查課程

三、受訓情形說明

（一）受訓學院及環境

本次受訓單位為美南加州飛安學院（Southern California Safety Institue），受訓地點位於美國中部新墨西哥州（New Maxcio）阿帕克奇市（Albuquerque），當地夏日天氣炎熱，日平均溫度介於華氏 85 度至 95 度間。受訓教室使用當地 Hilton 旅館之會議室舉行，該館為一新建之房舍，設施完整良好。

（二）課程內容

本班次授課期間、共完成直升機失事調查介紹（Investigation）、直昇機相關技術簡介（Technology）、人為因素（Human Factor）、案例討論及殘骸區實習等五門課程。

直昇機失事調查課程內容包括飛安失事之背景介紹、相關法規介紹、直升機失事調查之準備工作、調查安全注意事項、調查相關細節及注意事項；如蒐證、人員訪談及證詞、飛航軌跡、飛機殘骸及撞擊點之判斷等。同時介紹調查之分工及專業；如飛機性能及特性、飛機操作、飛機系統、人機介面、飛行作業、維修作業、飛機結構、電器系統、傳動系統、旋翼系統、火燒軌跡、電器系統、儀表、發動機及飛航紀錄資料之簡介等。並對飛機失事重要影響因素如風場、滯空效應、旋翼失速、載重限制、重心與控制、動態飛操效應、發動機失效、傳動系統（齒輪箱）失效等現象均有重點介紹。另外針對直昇機之空氣動力、旋翼之振動、結構疲勞、飛機安定性及控制等對飛安之影響及關係等均為教授之範圍，但因時間關係，無法針對相關細節深入介紹。

人為因素課程部分之教授重點為介紹人為因素於失事調查之重要性、飛行員及維修人員易產生之疏忽及錯誤、督導人員易犯之錯誤

及疏失、人為因素之調查方式、組員資源管理及人為失事肇因模式分析等。

此外航空人員之心理及生理之介紹包括障礙區飛行、夜航、空間迷向、夜視裝備之使用等之人員適應狀況，本項專業因與牽涉部份醫學專業，僅止於概念介紹。

事故案例部份，教官例舉之案例包括普通航空業（General Aviation）直昇機及軍用直昇機之失事；事故原因範圍涵蓋空中起火、飛行操作錯誤、飛機性能衰減、飛機動力失效、飛機結構失效、飛機系統失效、夜間飛行操作錯誤、維修人員疏失、人員空間迷向、人員航空生理、心理、天候不良、人員資格與訓練不足及管理等案例，包括之範圍甚廣，並有許多圖片及影片做為輔助教材，可惜許多直昇機事故之案例，教官列為補充教材，未發給書面參考資料，影片亦因著作權之關係不能提供。

南加州飛安學院與美空軍協議，有權使用其位於柯藍空軍基地（Kirtland AFB）內之飛機殘骸存放場。本訓練課程安排8小時實地於該區實施殘骸調查實習課程，於實際飛機殘骸存放區將學員編成不同分組進行實地調查訓練工作。計有UH-1H型直昇機殘骸兩具，由教官提示事故之飛航背景、人員背景及失事過程，並複習完整之直昇機事故調查必須注意事項後，將學員分三組，實際於殘骸區依現場殘

骸分部狀況蒐集事實資料，據以分析並找出事故之原因。該項實習因殘骸為實際飛機事故之實體，故幾乎與實際現場調查類似，對受訓學員實際經驗之獲得助益良多，亦受限於時間因素，無法針對事故細節深入研究及討論。

該空軍基地之殘骸存放區內，有一直昇機旋翼展示間，存放主旋翼之組成及結構，包括主支撐軸、旋翼葉片、變向盤、角度控制連桿及平衡桿等，教官於現場展示及說明主旋翼各組成之外型及功能，便於學員了解旋翼之旋轉及控制等實際狀況。

現場殘骸中，有許多不同型別之發動機，其中數具為事故直昇機所使用之噴射發動機殘骸，為渦輪軸式之發動機，於殘骸實驗課程時，教官對其中一具直昇機發動機殘骸之破壞情形、結構、事故當時運轉情形、動力輸出，作了一概略敘述，表示針對發動機有一特別課程，因此未作詳細介紹。

另外學院找來乙具近期內發生車禍，車首遭重創之小客車殘骸，存放於空軍基地殘骸實習現場，用於展示及計算撞擊力教學之用，使學員對撞擊之影響及結果印象深刻，並可據撞擊之痕跡及深度計算受力情況，極具教學意義。

與本次受訓相關之書面資料含美空軍直昇機調查手冊及案例等如附錄一。

（三）教官背景

本班次授課之教官計兩員；失事調查（Invesigation）、人為因素（Human factor）、案例研討（Case Study）及殘骸實習等部份由 Mr. Jim Page 擔任。Mr. Page 為美空軍退休之直昇機飛行員，任職於美空軍長達 25 年，期間擔任飛安主管職務達 20 年，曾任美直昇機聯隊副聯隊長，對飛安調查及管理之經驗豐富，並曾任美空軍副督察長。

科技簡介（Technology）之教官為 Mr. Charles Hausenfleck，亦為美軍除役之飛行員，飛行機種含定翼機及旋翼機，飛行經驗豐富。曾擔任美空軍飛安調查委員會委員及美空軍航空研發部門主管，亦曾任美空軍作戰測試評估聯隊聯隊長，具豐富之飛安調查、管理經驗及航空專業知識。

（四）參訓學員背景

參與本班次訓程之學員共計九員，分別來自加拿大、英國、冰島、荷蘭、美國陸軍、美國國家運輸安全委員（National Transportation Safety Board，NTSB）會及中華民國。（參訓人名冊如附錄二）參訓學員中有四位來自軍方單位（美國陸軍及荷蘭皇家海軍），其餘五位則來自各國之飛安調查單位。其中來自冰島之學員 Mr. Thormodor Thormodsson 為該國失事調查局之首席調查官。來自 NTSB 之 Mr.

Edward Malinowski 為 NTSB 派駐芝加哥之地區代表，對普通航空業（General Aviation）航空器之調查，經驗豐富。南加州飛安學院當地之負責人 Mr. Gary Morphew 表示：NTSB 係首次派員參與該院辦理之訓練班次，非常難得，並感謝 NTSB 對該院之肯定。

參、心　　得

本項課程提供學員對直昇機事故調查所須具備之基本知識；包括飛航作業（含調查前準備、人員訓練、操作程序及技巧、天候、航管、場站設施、航空生理等）、飛航專業（含空氣動力、性能、發動機、安定性與控制、火警、飛航系統等之專業）。因事故調查程序並無機種之分別，所以本次直昇機調查訓練多偏重於直昇機之專業及特性，以下為個人於參訓過程中之心得：

一、專業部份

- 直昇機事故發生後，需事前蒐集該型直昇機之規範、結構及系統相關資料，以利於現場調查時參考。
- 事故調查前之準備工作很重要；包括專業知識、裝備、文件、參與人員之素質等及行前之任務提示與溝通、任務分工、通聯管道等，於事前如能充分之準備，事故調查必能收事半功倍之效。
- 如直昇機之事故與飛機之操作相關，其操作邏輯雖與定翼機相似，但操作技巧卻與定義機迥異，負責飛航操作之調查人員必需具備直昇機之操作經驗且能充分了解直升機之操作程序、操作特性、系統與性能，方能精準蒐集事故

現場之事實資料。

- 事故現場之座艙檢查必須完整且仔細，任何一電門、儀表指示、開關位置及斷電器等均可能為事故原因判斷重要線索，此點授課教官於現場殘骸實習時，特別示範其容易疏忽但非常重要之現場證據。
- 由事故現場之座艙現況可判斷飛機撞擊之痕跡及方向；如駕駛員座椅受擠壓程度、擠壓方向、集體桿及駕駛桿（又稱迴旋桿）之變形狀況、儀表板之變形狀況、機門之損壞狀況等，均為重要之參考。
- 如直昇機之起落架為滑橇式，則可根據滑橇及尾桁彎曲/折斷之形狀/方向或斷裂之狀況，判斷飛機墜落之方向、角度及速度。
- 事故現場如有火燒現象，則可依據火燒痕跡（Fire Pattern）、機上可燃物及飛機結構燒毀之形狀及顏色，判斷係空中起火或地面起火及起火之順序，亦可根據火燒之遺跡看出起火之原因。
- 直昇機具許多特殊之飛行特性；如地面震動，共振、蜂鳴、主旋翼失速、傳動系失效、齒輪箱超溫、飛操系失效、發動機失效、供油系統失效、飛機落地時動態翻滾（Dynamic

Rollover)、自動旋轉（Autorotation）等，於事故現場，殘骸如未燒毀，均有其殘骸分佈之特徵及證據，所以必須瞭解直昇機上述特性，才能於事故之調查中抽絲剝繭，找出失事之原因。

- 直昇機因其旋翼系統、傳動系統及操控系統與定翼機不同，所以熟悉其專業系統及原理並具實際經驗，於執行事故調查時必定能得心應手。
- 由於主旋翼旋轉之特性，可由殘骸之旋翼組成件如主支撐軸、變向盤、襯筒、連桿等磨損痕跡判斷主旋翼於事故當時旋轉情形。
- 直昇機因於運轉時連續震動之關係，許多直昇機事故中，結構疲勞及失效亦為常發生之因素，於課堂間教官展示許多結構失效之樣品，使學者對結構失效之模式有一定程度之了解。
- 於殘骸實習區，因具有直昇機主旋翼運轉相關組件之實體，可實際體會其運轉間之關係，與理論相結合，可明顯增加學習效果。
- 於授課期間，教官依其經驗教授許多對事故系統之檢查方法，於實習時可於實地驗證，可加深學者對系統之深入了

解，效果甚佳。

- 依美方對直昇機事故原因調查結果統計，因直昇機運作時噪音大，於低空及夜間操作機會多，所以許多人員生理問題常是失事之主要原因，例如人員疲勞，視覺誤差，空間迷向等問題。
- 直昇機因其機動性高，經常執行障礙區搜救、吊掛、高山飛行等任務，於上述地區常見之事故原因則為飛機載重過重、吊掛失控、重心計算錯誤、山區氣流不穩、飛機性能衰減及於不平坦地區落地不當，未注意當地地形或當地斜坡坡度超出限制等問題。
- 有關失事人為因素部份之教學，飛航人員、維修人員、督導及管理人員均為事故人為因素探討之主題。舉凡公司（單位）之政策、管理方式、工作環境、人員負荷、工作壓力、個人情緒等因素如無法於執行相關任務時有效消除，便有飛安事故發生之潛在危險。
- 依美方直昇機事故之統計數據，直昇機如因失去動力或動力發生問題而失事，則飛機墜毀後，結構及人員之損害必定非常嚴重，所以直昇機結構設計時對墜機存活率之考量特別謹慎。

- 有關飛機具單發動機與雙發動機間之安全問題，與發動機本身之可靠度有關，與失事本身無直接關係。

- 就美國之環境及觀點而言，因直昇機具備上述設計及特性，於美國海軍、美國空軍、南加州飛安學院、南加大及聯邦航空局（Federal Aviation Administration，FAA）等機關均設有定期直昇機訓練之班隊，受訓之學員包括國內外軍、民方之學員。

- 軍用直昇機與民用直昇機除因任務不同而配備不同之裝備外，其餘系統與飛行特性完全相同。

- 據與參訓之美陸軍學員面談及交換經驗結果：美陸軍之直升機多達兩仟架，平均五年來之年事故發生率約為0.005%（與飛行架次比較），比例上來較歷年之數字高，大略原因為接受新型之夜視裝備有關。

- 此次訓練，美軍方之同學表示，美國軍方非常重視飛行風險管理，強調飛行安全應首重預防，良好之組織管理與人員之訓練為保障飛安之不二法門。

- 依來自加拿大運輸安全局本次參訓同學 David Ross 說法，其曾分別於 1998 年及 2000 參加此同一直昇機訓練班次，含此次已為第三次參訓，其表示依其重複參加同一

課程之經驗，幾乎每次授課之教官均不同，教材除有些調查基本原則相同外，大部份之課程內容都不同，尤其是案例及實習，每次題材均為前次上課所沒有的。所以重複參加同一課程並不代表所學習之內容相同，當然其效果為除複習部份調查邏輯外，最大之收穫為可獲得許多不同之事故調查經驗。

- 授課教官 Mr. Page 曾參與五十餘次直昇機事故調查，依其經驗，認為現場蒐証之完整最重要，其於執行現場調查時，通常於現場至少連續停留三日以上，必要時並於當地紮營，以重複觀察現場殘骸及軌跡，以免遺漏重要證據。另外主任調查官尤需不斷充實一己之專業知識及經驗，以利於事証不足時，對事故原因之分析及判斷能接近事實。對教官上述經驗之看法，筆者深感認同。

二、生活部份

- 本次訓期雖短，與來自其他國家之受訓學員相處融洽，尤其於實習時與來自冰島及 NTSB 之學員同組，於相互討論中學習及交換彼此之經驗，也建立起良好之個人及國際友誼。
- 冰島之飛安調查局組織目前為 10 人，負責全國所有航空

器之事故調查工作，亦為一小規模，任務範圍大之組織。

- NTSB 地區之代表負責之工作為所有該地區 GA 之事故調查。
- 有關受訓期間日常生活部份，與同班學員間之相處及互動良好，尤其可與來自美國以外國家之學員相處，藉以了解其國家之飛安調查組織及概況，機會難能可貴。另關於受訓期間日支費用問題，以當地之生活水平，每日之住宿、餐飲、租車等，以較節省之方式，花費約在 140 至 160 美元左右。

肆、結　　論

一、 本課程教授之內容符合直昇機調查訓練之需求，但受訓之訓期稍短，規劃之課程內容無法完全講授完畢。

二、 本課程整體安排，除讓學員學習專有之調查技術外，尚可實際體驗現場殘骸檢視之環境，有效增加學習效果，可惜受限於受訓時間，多數課程內容均無法深入說明及討論。

三、 殘骸實習場之實體教材內容豐富，具備實際學習效果及意義。

四、 受訓學員無法獲得完整於課堂上講授之輔助教材，增加日後複習之困難。

五、 受訓當地之日支生活費有不足現象。

伍、檢討與建議

一、南加州飛安學院部份：

（一）考量增加本項課程訓練時數。

（二）發給學員完整之訓練教材

（上項建議已於結訓時填寫意見調查表）

二、本會部份：

（一）考量派員參加該院發動機部份之調查訓練。

（二）視需要執行本課程之複訓工作。

（三）利用年度複訓時間，與同仁交換參訓心得及經驗。

（四）國外訓練旅費受八折規定限制，有不足現象，建議以實報實銷原則，增列國外受訓人員之住宿及租車費用。

陸、附　　錄

附錄一　　訓練教材

附錄二　　參訓人員名冊

附錄一　Training Materials

Chapter 13

HELICOPTER INVESTIGATIONS

by

Mr. Lester R. Kerfoot, Jr.

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Section A—General Information

Section B—Operational Mishaps

Section C—Inflight Power Train Failures

Section D—Inflight Breakups

Section E—Summary and Conclusions

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Section A—General Information

13-1. Introduction To Helicopter Mishaps:

a. Helicopter mishaps provide many new challenges for the investigator principally because of the dynamic factors involved in helicopter performance. Most of the systems on helicopters are the same as those found on the typical fixed wing aircraft. The primary differences are the rotor systems which are quite complicated and provide many unique investigation problems. This chapter assumes a fundamental knowledge of investigation techniques and a basic understanding of helicopter operations.

b. The approach to helicopter mishap operations and investigations is best summed up by "Harry Reasoner's Comments" on ABC radio circa 1970:

> "The thing is, helicopters are different from planes. An airplane by its very nature wants to fly, and if not interfered with too strongly by unusual events or by a deliberately incompetent pilot, it will fly. A helicopter does not want to fly. It is maintained in the air by a variety of forces and controls working in opposition to each other, and if there is any disturbance in this delicate balance the helicopter stops flying immediately and disastrously. There is no such thing as a gliding helicopter.
>
> "This is why being a helicopter pilot is so different from being an airplane pilot, and why, in general, airplane pilots are open, cleareyed, buoyant extroverts, and helicopter pilots are brooders, introspective anticipators of trouble. They know if something bad has not happened, it is about to."

c. The US Army has an excellent manual, Fundamentals of Flight (FM 1-203), which provides complete information on helicopter operations. It covers theory, practical experience, and applications.

13-2. Helicopter Aerodynamics:

a. General. The majority of mishap investigators are familiar with fixed wing investigative techniques, but to understand helicopter investigations, it is necessary to understand some of the differences between the two types of aircraft. Both derive lift the same way, i.e., by moving air over an airfoil. The difference is that in a fixed wing aircraft, the entire airframe is moved through the air to develop lift on the wings. In the helicopter, the wings are moved independently of the fuselage to develop the lift. A helicopter is flying when the main rotor system is at operating revolutions per minute (r/min). A turbine engine propels a small volume of air at high velocities to achieve thrust for the aircraft. The helicopter rotor system propels large volumes of air at low velocities to provide the thrust.

b. Flight Controls. There are three flight controls for a helicopter: cyclic pitch, collective pitch, and antitorque.

(1) The cyclic pitch is controlled by the control stick which is located between the pilot's legs. It controls the main rotor disk in pitch and roll attitudes, i.e., horizontally. In forward flight, the main rotor blades constantly change their angle of attack as they rotate. To provide symmetry of lift, the advancing blade, i.e., the one moving toward the front of the helicopter, has a lesser angle of attack than the retreating blade. If this were not true, on achieving translational lift, the advancing blade would provide more lift than the retreating blade, and the helicopter would roll to the left and onto its back. The differential (cyclic) pitch occurs at the swashplate, which is the point at which linear control from the pilot is changed to rotational control and transmitted to the main rotor blades.

(2) Collective pitch is controlled by a lever on the pilot's left side. Collective pitch increases or decreases a marginally equal amount of pitch, or angle of attack, simultaneously into the main rotor system. In effect, it controls the thrust of the main rotor system. In most helicopters the control is through a collective pitch sleeve located below the nonrotating swashplate. The collective pitch raises or lowers the nonrotating swashplate.

(3) The antitorque is controlled by pedals at the pilot's feet. On single-rotor helicopters manufactured in the United States, the main rotor system rotates counterclockwise as viewed from above. To prevent the fuselage from rotating clockwise, as in Newton's Third Law (for every action there is an equal and opposite reaction), a tail rotor is installed which is actually an antitorque rotor. The tail rotor provides directional control in a hover, and antitorque and directional control in flight. The tail rotor is geared to the main rotor and maintains a constant proportional r/min.

c. Airflow through the main rotor system. There are generally five different types of flow through the main rotor system in helicopters.

(1) In hovering, the airflow is downward and consistent. While hovering in ground effect, that is with the rotor system generally within one rotor disk diameter of the ground, less power is required than hovering out of ground effect (HOGE). HOGE is using the brute power of the helicopter and is limited by density altitude. This results in significantly increased fuel consumption.

(2) At a climb or while in forward flight, the airflow is generally down through the rotor system, however the forward airspeed permits more air to pass through the rotor system and thus reduces the power required for forward flight.

(3) In a slow descent, the air still passes down through the main rotor, however, there is an additional upward factor that effects the performance of the helicopter to reduce the power required.

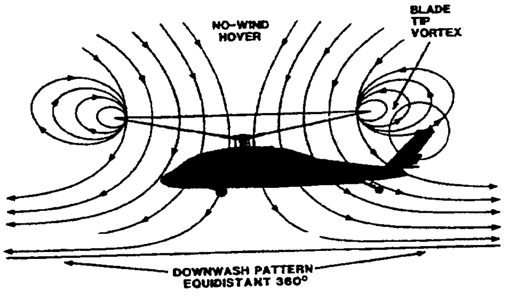

Figure 13-1. Hovering in Ground Effect.

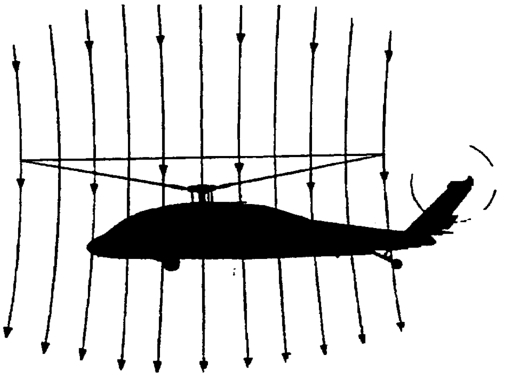

Figure 13-2. Climb or Forward Flight.

(4) Autorotation is a maneuver wherein the airflow is entirely upward through the rotor system. It is used when there is an engine failure and is, in effect, a forced-landing state. The inner 25 percent to 70 percent of the rotor diameter, as measured from the hub, provides the lift and enables the rotor r/min to be maintained at the operating level by means of the upward flow.

(5) The last airflow state is an aberration, and is known variously as settling with power, power settling, or more properly, as vortex ring state. The vortex is similar to that found in fixed wing wingtip vortices, but is much more dangerous to the helicopter. This occurs when the helicopter is descending at speeds greater than 300 ft/min, and flight is near or slightly above translational lift. Vortices form first at the rotor tips and then progress inward. In effect, the helicopter is flying in its own downwash of disturbed air. The characteristic symptoms of this condition is an increased vibration level, pitch and roll motions, and an increase of the rate of descent with an increased application of collective pitch. The proper recovery procedure is to reduce collective pitch and increase forward airspeed, thus flying out of the disturbed air.

d. Airflow through the tail rotor is essentially the same as for the main rotor system in a climb or hover. It must constantly produce positive thrust to perform its antitorque role. However, even the tail rotor can experience vortex ring state. When this occurs, there is no antitorque thrust provided, and the helicopter will rotate to the right since the thrust required exceeds thrust available. This phenomenon is termed tail-rotor-stall, or loss of tail rotor effectiveness. It can be aggravated when the wind is from certain directions and, in the worst case, when the normal main rotor vortices impinge on the tail rotor. The critical wind speeds seem to be 10–30 knots quartering left crosswinds for vortex ring state. The flight manual should be consulted to determine the critical relative wind azimuths for a specific helicopter when loss of tail rotor per-

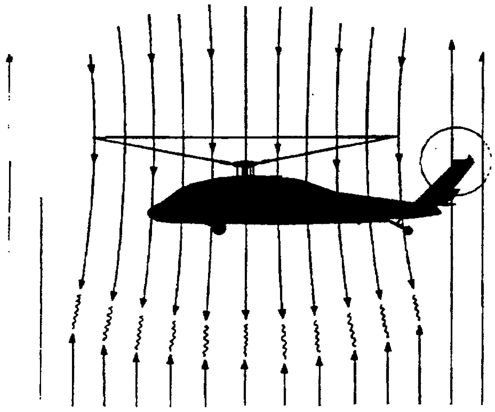

Figure 13-3. Slow Descent Airflow.

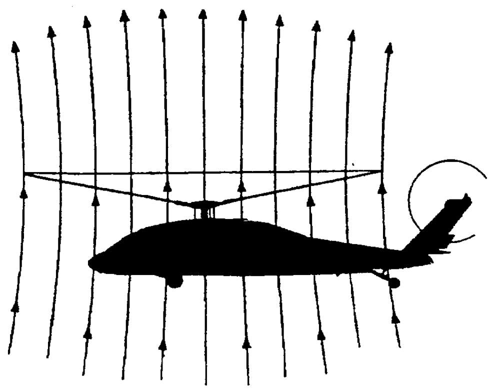

Figure 13-4. Autorotation Airflow.

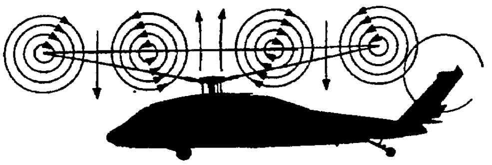

Figure 13–5. Settling With Power Airflow.

formance is suspect.

Section B—Operational Mishaps

13–3. Landing and Takeoff Mishaps:

a. Ground Resonance. This is a potentially destructive coupling of blade lead-lag motion with the aircraft rocking in its landing gear.

(1) As the name implies, ground resonance occurs when the helicopter comes in contact with the ground, either during takeoff or landing, and ground contact is not firm. There are several conditions which must be present to initiate the sequence.

(a) The helicopter must have a fully articulated head, such as the H–3, as opposed to a teetering rotor head found on the UH–1s. In the fully articulated head, each blade is free to lead-lag, flap, and feather in its own axes. Ground resonance is most common to three-bladed helicopters having landing wheels.

(b) The landing gear must be dampened, i.e., an oleo strut is fitted with a shock-absorber-type damper.

(c) Inflatable tires should be present, although this is not a necessity for the phenomenon to manifest itself.

(2) A series of shocks can be imparted to the rotor system through the landing gear which cause the lead-lag dampers to lose their alignment. For example, the normal blade separation in the UH–60 is 90°. Under ground resonance conditions they become unbalanced to a greater or lesser degree, so that the angle between blades is no longer symmetrical. This shift causes a change in the normal center of gravity of the helicopter. As this occurs, the helicopter will oscillate. If the oscillations are not stopped immediately, either by fully cutting power or, if at operating r/min immediately taking off, structural failure can occur within a few seconds.

(3) Ground resonance mishaps essentially have one of three cause factors: crew induced, maintenance procedures, and material malfunction.

(a) *Crew Induced.* There must be firm contact with the ground during helicopter landings. If it is eased down to contact, and held just lightly on the landing gear, the oscillation, or whirling motion, can be initiated. This is not to imply that the contact should be hard. An unusually hard landing can also displace the blades and initiate ground resonance. The same phenomenon can occur when taking off to a hover, i.e., too slow to apply collective pitch and remaining "light on the skids or landing gear." A sideward jolt while landing can displace the proper spacing of the blades and induce ground resonance.

(b) *Maintenance Procedures.* The main landing gear (oleo) struts and the tires must be serviced exactly as stated in the maintenance manual. Specifically, ground resonance has occurred when the strut was inflating it to the correct extension with inert gas rather than the proper fluid-air mix. Typical maintenance procedures require the fluid level to be checked before inflating the strut with inert gas. Manufacturers design helicopters to provide a mutual dampening between the main rotor system and the alighting gear. Anything which upsets this mutual dampening can excite ground resonance. Tire inflation to the proper pressure is equally important for this very same reason.

(c) *Material Failure.* The freedom of the rotor blades about the vertical drag hinges requires a mechanical damping device for each blade to maintain a nearly equal angular relationship between rotor blades in the plane of rotation, thus preventing excessive oscillation and geometric unbalance.

1. The most common type of damping device is the viscous- or orifice-type hydraulic damper.

2. Dampers are temperature compensated to maintain the proper damping rate at all times.

3. Damper malfunctions during landing or takeoff conditions can result in disrupted angular blade displacement, center-of-gravity shift and structural failure. Malfunctions during flight are usually not very noticeable except for slight increase in airframe vibrations.

(4) Ground resonance mishaps can usually exhibit the following characteristics:

(a) Structural failure during landing or takeoff phase of flight.

(b) Pilot reports of unexpected onset of severe airframe vibrations followed by structural failures.

b. Dynamic Rollover. Contrary to popular belief, dynamic rollover is not limited to helicopter slope operations. It can, and has, occurred on level terrain when a roll rate developed by the helicopter which could not be controlled by the lateral cyclic trim. In these instances, however, the effect is the same — destruction of the aircraft. Dynamic rollover mishaps have resulted when attempting to lift to a hover a helicopter with skids frozen to the ground, the alighting gear stuck in the mud, sideward drift into a macadam ridge, or contact with corrugated matting.

(1) In slope operations, which accounts for the majority of the dynamic rollover mishaps, the critical rollover angle is the slope angle which would require the maximum lateral cyclic input to trim the alighting gear level. This may require adjustment for wind speed. However, by no means should a helicopter ever exceed or even meet the critical angle. For some examples of the operational helicopters the critical angles are:

Aircraft	*Critical Rollover Angle*
UH-1	17°
CH-3	17°
CH-53	15°
UH-60	15°

(2) The critical rollover angle is reduced under high gross weights, conditions when right lateral center of gravity is present, if there is a crosswind from the left, when hovering with only the right skid or wheel in contact with the surface, and if the thrust (left) is approximately equal to the weight and very little right roll is correctable for any given bank angle.

13-4. Inflight Operating Guidelines:

a. Flight Within the Height-Velocity Envelope:

(1) The Federal Aviation Administration (FAA) defines the height velocity diagram shaded area (or avoid area) as those altitude-airspeed combinations from which it would be nearly impossible to successfully complete an autorotative landing. The US Army further states that "The Height-Velocity diagrams show the combinations of speed and wheel height which should be avoided during normal operations, to provide for safe landing if a single-engine failure or excessive maneuvering to reach a suitable landing area reduces the probability of a safe touchdown."

(2) Figure 13-7 provides an additional example of one such diagram. The flight manual should be consulted for the helicopter involved in the mishap.

b. Autorotations. The rotor system is turned by airflow and not by engine power. The airflow is produced by movement through the air.

(1) The pilot must react quickly to a power loss to prevent the rapid decay in rotor r/min

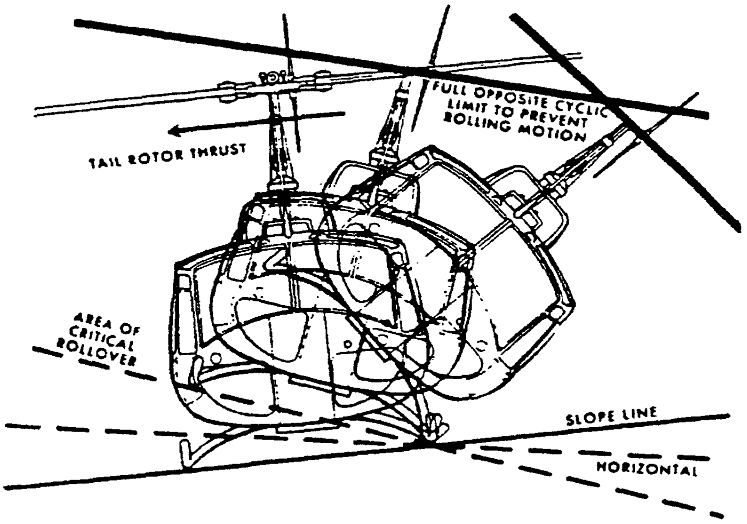

Figure 13-6. Upslope Rolling Motion. Excessive application of cyclic into the slope, in coordination with collective pitch application. During landings or takeoffs, this condition results in the downslope skid raising sufficiently to exceed lateral cyclic control limits and an upslope rolling motion occurs.

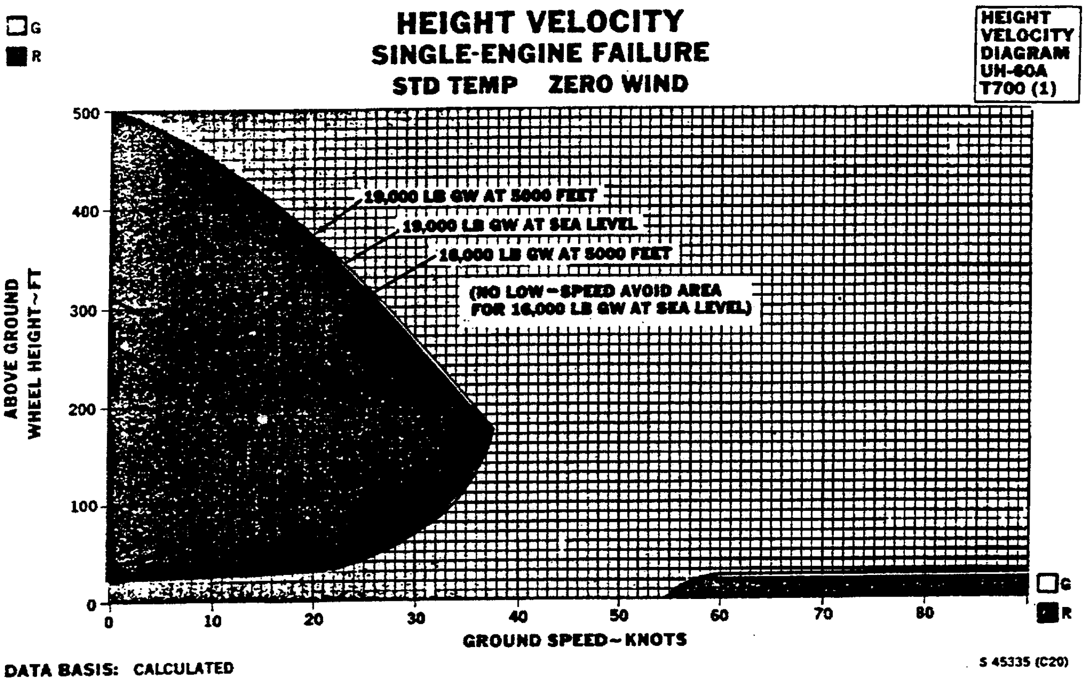

Figure 13-7. Height-Velocity Deagram.

which can quickly reach a minimum safe range.

(2) The r/min must be established as prescribed in the flight manual. This is normally a few turns higher than the normal operating r/min.

(3) The last 100 feet is critical, since there must be a smooth transition from autorotation descent to a power-off landing situation. The deceleration must be turned and applied so that the rate of descent and the forward speed are reduced just before touchdown to the slowest rates possible for the existing conditions.

(4) An unsuccessful power-off landing can lead to major aircraft destruction and is analogous to a very hard landing in a fixed wing aircraft.

Section C—Inflight Power Train Failures

13-5. **Power Train Failures.** Engine failures are recognizable by essentially the same factors as for fixed wing aircraft. The engine(s) are frequently sent to the respective tear-down and analysis facility for examination when a major power loss is suspected. The quickest way to determine the possibility of an engine failure in a helicopter is to examine the turbine blades for obvious damage. Internal engine failures frequently result in excessive heat or distorted flame patterns which cause major damage to turbine blades. Other possibilities are turbine damage or molten metal in tail pipe. If there is no evidence of any rotational blade damage, engine failure or malfunction should immediately be suspected. In the event of a suspected failure, the following procedures should be followed.:

a. Check for fuel. If fuel is present in the aircraft, take samples and forward them, in the proper quantity, for analysis. If fuel is present in the aircraft but not in the fuel control or lines adjacent to the engine, the firewall shutoff valve should be evaluated.

b. Ensure an adequate oil supply. Oil samples should be forwarded for spectrometric analysis and to ensure it is the proper specification for the engine. The prior spectrometric oil analysis program (SOAP) samples may reveal a failure trend.

c. While the engine is still on the aircraft, the continuity of controls from the cockpit to the engine should be checked. The control positions and connector noted and photographed at the engine, i.e., linear actuators, etc.

d. Field disassembly of a suspect engine is usually not recommended. When removing the engine from the helicopter, ensure all connecting fuel, oil, and other lines and connections are protected with plugs or caps.

e. Inspect and preserve airframe fuel filters and pumps for laboratory examination.

13-6. Main Drive Shaft Failures or Malfunctions. The main drive shaft, or shafts, transmit power from the engine to the transmission. They may go directly into the transmission from the engine, as in a single-engine and some multiengine helicopters, or they may go through intermediate gearing, as in a combining transmission, before connection to the main transmission. In the event of a failure or malfunction of a main drive shaft, the first indication to the pilot may be a low r/min warning. The warning can be misinterpreted as an engine out condition. Another indication would be a loud noise or bang when the shaft in the engine disconnected. Engine r/min is generally taken at a point before the output shaft.

a. Items to be examined in a mishap where main drive shaft failure is suspected include the lubricants, bearing, and gears. If a clutch is part of the power train and internal to a combining transmission, it too should be examined.

b. The power train shafts should be carefully examined.

(1) Tail rotor drive shafts will exhibit a torsional buckling and an ultimate tensile failure. To determine if the failure was initiated by stoppage of the main rotor or the tail rotor, place a cigarette parallel to the shaft after determining the direction of rotation. The cigarette should be rotated in the same direction. The rotation should be stopped on one end and then on the other. The buckling on the cigarette will be in the same direction as indicated on the drive shaft, depending on which rotor made contact first. Document this photographically with arrows showing the direction of rotation and the forward direction of the shaft.

(2) Fasteners and bolt holes in the "thomas" couplings should be inspected. Distortion of a "thomas" coupling is associated with impact damage. The absence of a bolt and a lack of distortion indicates that the bolt was missing at impact or, more probably, that it was not installed. These couplings are normally used to join drive shaft sections, and continuity should be established.

(3) Inflight shaft failures will be obvious. The driving end of the shaft will flail and damage the surrounding cowling and structure.

(4) Where shaft couplings are greased, look for the presence of heat and old grease. Heat does not have time to build up in a crash sequence, and may indicate bearing problems. Old grease is indicative of a seal failure. Splined couplings are intended to permit pylon and tail boom movement while maintaining continuity of the drive train.

(5) Some drive units contain splined couplings. If so, these should be checked for damage and excessive wear.

13-7. Transmission Failures. The failure of a main transmission will have catastrophic results. As with other rotating components, lubrication by quantity and type must be checked. Beyond that, it is necessary to forward the transmission to a laboratory for teardown analysis. In the past, transmissions have failed internally because of improper overhaul procedures. Transmission failure should be suspected when there is very little or no rotational damage to the main rotor blades and when there are high-impact forces.

a. Where there are gear and shaft driven accessories, i.e., generators, inspect both gears and shafts. Although there are shear features built into these components, there have been instances of bearing failures in generators and the shaft did not fail in shear. The result is a transmission failure. Determine the direction of the shear as in the discussion of tail rotor drive shaft failures.

b. Intermediate gear boxes and tail rotor transmissions may not necessarily end in a catastrophic mishap, however their failure or malfunction should be treated the same as the main transmission. These components should be disassembled under sanitary conditions, i.e., not in the field. Examine the internal gears and determine the presence of lubricant. There have been instances where sight gauges were discolored, to give the impression of oil being present, whereas, in fact, none was.

13-8. Sprague Clutches. Rotate sprague clutches in both directions to determine proper function. This will indicate the operation of the free wheeling feature as well as the driving function.

a. With main rotor sudden stoppage from impact, the individual spragues will roll forward if the engine is still operating. There will be a signature on the individual spragues in the outer race of the housing.

b. Inspect the assembly of the clutch. They

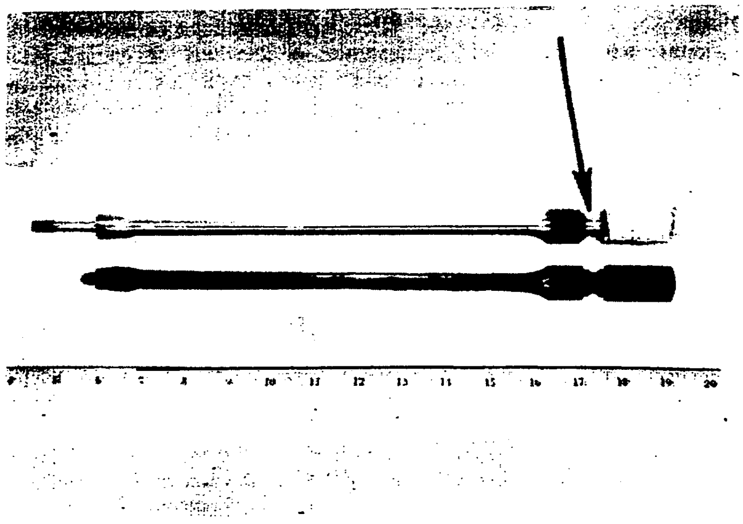

Photo A. Fractured generator shaft is shown at the bottom of photograph. A new shaft is also shown. Arrow indicates the area required by design to fail when the shaft is overloaded.

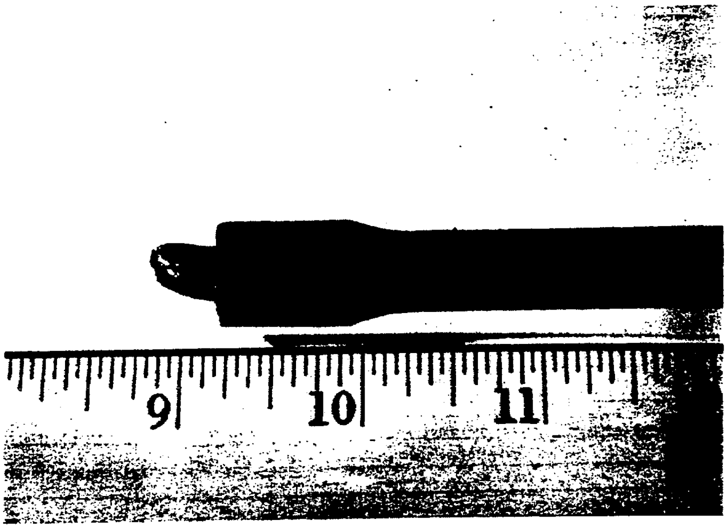

Photo B. Close-up of drive shaft fracture. Note ductility and melting at break area.

Figure 13-8. Failed Generator Shaft.

have been misassembled in the past. Improper assembly can cause misalignment of drive shafting and attendant failure of the shaft.

13-9. Rotor Brakes. Rotor brakes have been unintentionally activated. This slowed down the main r/min to a point where flight could not be sustained. Inspect for an overheating condition, however; by their very nature, rotor brakes will have some heat discoloration.

Section D—Inflight Breakups

13-10. Main Rotor Separations. Since 1967 a great deal more has been learned about main rotor separations in flight. New helicopters have been introduced with new systems that may affect the susceptibility to separation. Actually, the phenomenon is not unique to the UH-1/B205 family of helicopters. It can, has, and will probably continue to occur in teetering rotor systems in general, irrespective of the manufacturer, and particularly in systems in which the main rotor mast itself acts as the principal static stop. This section goes beyond main rotor separation to deal generally with helicopter breakups in flight. The purpose is to provide guidance for the safety investigator approaching this kind of mishap. Understanding the underlying causes which can lead to inflight breakup helps focus the thrust of the investigation on areas with higher probabilities of success.

a. Causes of Helicopter Inflight Breakups. The inflight breakup of a helicopter is one of the most difficult mishaps to investigate. The sequence in which separated components are found along the flight path may or may not be indicative of the actual breakup sequence, due to the centrifugal force of rotating parts. Furthermore, the first significant part found may have separated as a result of vibrations originating elsewhere in the aircraft. For example, imbalance in the main rotor system—for any number of reasons—may literally shake off the tail boom. In another scenario, the separated part of a previously weakened tail rotor blade may act as a projectile anywhere in its plane of rotation; when it strikes the main rotor controls or a fuel tank, the subsequent events may obscure the primary event. Finally, a post-crash fire that ignites the magnesium alloy parts of engine and transmission tends to obliterate critical control components.

b. Since the term "mast bumping" will be used in the text that follows, this phenomenon will be discussed first. Mast bumping occurs in teetering rotor systems (H-1 and similar helicopters) when the flapping angle of the main rotor exceeds its design limits (approximately 12°). In that case, the rotor head static stops will contact the mast. If this occurs gradually—as may be the case in a slope landing—the results are not necessarily catastrophic. However, abrupt displacement of the main rotor disk well in excess of the flapping angle may cause the static stops to strike the mast with enough force to deform it to the point of failure. Typically, the cross-section of a mast that failed as a result of mast bumping has an oval or rectangular appearance at the fracture site.

c. In mishaps involving mast bumping followed by main rotor separation, the basic question is not WHAT caused the mast failure, but WHAT caused the violent displacement between main rotor disk and mast? Due to the unpredictable gyrations of a separated main rotor system, a fuselage strike may result in separation of the outboard portion of a main blade as a result of inertia forces when the inboard portion comes to a sudden stop in the fuselage.

d. In addition to catastrophic mast bumping, there are numerous other types of inflight breakups. There causes can be conveniently grouped into ten categories, which are not necessarily mutually exclusive, but will suffice for the purpose of this chapter:

(1) Pilot induced (volitional action).
(2) Control failure at or below hydraulic servos (may not result in breakup in big helos).
(3) Transmission mount failure.
(4) Control failure above the hydraulic servos.
(5) Tail rotor failure or malfunction.
(6) Synchronized elevator disconnect.
(7) Electronic flight control system malfunction.
(8) Pilot's improper reaction to emergency condition.
(9) Weather-induced problems.
(10) Loss of a main rotor blade.

13-11. Pilot Induced (Volitional Action). Other than in emergency situations (which will be discussed later), there are four principal categories of maneuver by which pilot inputs induce violent main rotor disk excursions:

a. Flight at Near-Zero "G". Primarily a problem in teetering rotor systems, which is a two-bladed rotor with a single horizontal hinge for flapping. The problem derives from a "push-over" maneuver which "unloads" the main rotor system. This reduces the aerodynamic loading on the blades so they produce zero lift. However, a tail rotor thrust is still effective and rolls the helicopter to the right (US direction of rotation assumed). Because it is unloaded, the main rotor system still responds to cyclic pitch control inputs, but the response is not transmitted to the fuselage. Therefore, if the pilot initially attempts to correct the roll excursion with cyclic input, which is a "normal" response, the flapping angle may increase enough to permit the static stops to contact the mast. The proper corrective action for the pilot is first apply aft cyclic to reload the rotor, then to correct the roll after attaining a positive "G" condition.

b. Excessive Bank Angle. At bank angles approaching 90 degrees the rotor system may be unloaded by the pilot's failing to maintain positive "G" throughout the maneuver and recovery.

c. Excessive Rapid Control Movements. Rapid roll or pitch (cyclic) reversals can displace the rotor disk plane faster than the fuselage can respond, leading to blade-to-fuselage contact.

d. Exceeding the Design Envelope. At excessive forward speeds in certain helicopter designs, retreating blade stall can progress to main rotor blow-back, resulting in blade-to-fuselage contact if not arrested immediately. Excessive lateral speed (sideslip) will also contribute to large flapping angles. In these instances, there will normally be a blade to fuselage contact, with the main rotor blade penetrating the fuselage.

13-12. Control Failures at or Below the Hydraulic Servos. This type of failure occurs in the lower flight controls, and can be caused by disconnection or rupture of control linkages, such as: push-pull or torque tubes, bellcranks and walking beams, or rod end bearings. Failures of this type have occurred after nuts have backed off connecting bolts, either when self-locking nuts were improperly installed or reused, or when cotter keys were omitted from castellated nuts. Servo malfunction can occur because of an internal failure; e.g., a broken internal component, or contamination of hydraulic fluid. If the servo malfunction is such that control from the cockpit is lost, uncontrolled excursions of the rotor disk are probable.

13-13. Transmission Mount Failures:

a. The main transmission on some helicopters is attached by means of a three-point mount. Each forward side mounts a spindle which is bolted to a pylon support link and attached by clevis arrangements to the cabin roof. At the rear it is supported and attached by means of an elastomeric isolation mount which also dampens the pylon-to-fuselage vibrations and limits pylon rocking. Movement of the transmission and isolation mount is limited by a drag pin ("spike") which extends downward into a plate in the transmission deck. Out-of-phase rocking between the transmission and the fuselage may result in contact between the drag pin and its static stop, a phenomenon known as "spike knock." This may lead to failure of the pylon support links in the vicinity of the pylon support bearing at the apex of the support link. When this has occurred in flight, the results have been catastrophic.

b. On a helicopter with more rigid mounting, i.e., 4, 5, or more mounts, the first indication to the pilot will be a lateral vibration. If allowed to continue to failure, there will be an indication or wrenching of the initially unfailed mounts, with the failed mount indicating little or no wrenching.

13-14. Control Failures Above the Hydraulic Servos. The flight controls above the servos are subject to greater aerodynamic loads than those below the servos, which act to dampen the loads on the lower controls. Failure of the flight controls above the hydraulic servos will result in an uncontrollable rotor disk. Failures have been known to occur because of improperly manufactured, installed, or maintained components, and loss of fasteners. Overtorquing has caused failures at the pitch change link clevis bolts at the spherical bearing on the outer (rotating) swashplate, or at the pitch change horns at the rotor head. Failures have occurred on the trunnions of both the rotating and nonrotating swashplates.

13-15. Synchronized Elevator Disconnect, Stabilator Failure or Malfunction:

a. The aerodynamic download on the tail boom caused by the synchronized elevator increases with forward airspeed. If the elevator becomes disconnected at high forward speed the download is immediately relieved. The resulting nose-down pitch of the helicopter, coupled with the pilot's instinctive aft cyclic input, can provide enough tilt to the main rotor so it strikes the tail boom. It is not uncommon to find the synchronized elevator itself severed spanwise by a main rotor blade strike.

b. There are no recorded mishaps in either H-3 or H-53 helicopters wherein loss of the horizontal stabilizer was causative to the mishap. In those mishaps where the stabilizer separated from the airframe, they were secondary, or impact, failures.

c. In the UH-60B, malfunction of the stabilator can have similar, catastrophic results. In this instance, however, if the malfunction occurs in the trailing-edge-down mode, the immediate response is aft cyclic input with constant collective, and simultaneous manual upslew of the stabilator. If acceleration is continued with the stabilator in the fully down position, longitudinal control will be lost, the helicopter will pitch over and nose into the ground.

13-16. Tail Rotor Failure:

a. Separation of the tail rotor gearbox from the airframe results in a nose-down pitching moment similar to the synchronized elevator disconnect because of the immediate shift in center of gravity. Should the pilot respond with a rapid aft cyclic input in an attempt to control the helicopter's attitude, a blade-to-tail boom strike is likely.

b. The tail rotor gear box is bolted to the tail boom. The typical gear boxes have "ears" for the bolts. The structural failure of the ears or the loss of a single attaching bolt can lead to tail rotor gear box separation. The failures should be evaluated as outlined in the structural chapter of this pamphlet.

13-17. Malfunction of an Electronic Flight Control System. Modern helicopters are often equipped with an electronic flight control system, variously called "Stability Control Augmentation System (SCAS)," "Automatic Flight Control System (AFCS)," or "Stability Augmentation System (SAS)." Malfunction or failure in a SAS or AFCS increases pilot workload with little additional effect. The SCAS system, however, is different.

a. In the SCAS system electric solenoid-activated hydraulic actuators are located below the flight control servos in the control hydraulic system; i.e., they are schematically between the pilot's flight controls and the flight control system hydraulic servos. Transducers located on the flight control push-pull tubes sense their movement and transmit electrical signals to the SCAS amplifier, which in turn relays signals to the solenoid-actuated hydraulic actuators.

b. In normal operation the amplifier responds to excursions caused by gusts, etc., to dampen extraneous movement in the aerodynamic rotor head components and ease the pilot's workload. However, when they malfunction it is most often to a full-throw condition, known as a "hardover." For instance, in one type helicopter the SCAS has 25 percent (plus or minus 12½ percent) of total control authority in all three channels of motion (pitch, roll, and yaw) in normal operation.

c. In a "hardover" the servos often migrate to nearly full throw, without pilot input and without any motion of the cockpit controls. If the SCAS cannot be disabled immediately the helicopter will likely exceed design maneuver limitations.

13-18. Improper Pilot Reaction To Emergency Conditions. Improper pilot reaction to emergency conditions occurs most frequently in four situations: engine failure, loss of tail rotor thrust, malfunction of the SCAS, and topside governor failure.

a. Engine Failure. When a helicopter's engine fails the aircraft yaws left, rolls right, pitches nose-downward, and the main rotor r/min decreases. (Again, US direction of rotation is assumed.) The left yaw and right roll place the helicopter into a sideslip, increasing the flapping angle. If collective pitch is not lowered immediately, and the pilot compounds the error by attempting to correct the roll with cyclic, the flapping angle will be increased further and mast bumping may occur. (Proper corrective action in this situation is to lower collective pitch and correct the yaw with pedal, *then* establish the proper glide pitch attitude with cyclic.)

b. Loss of Tail Rotor Thrust. This situation creates an attitude condition similar to engine failure; however, yaw is to the right, with left roll. Once again, if the pilot attempts to correct the roll with cyclic before reducing collective pitch and correcting the yaw, cumulative sideslip can increase the flapping angle sufficiently to result in mast bumping.

c. SCAS Malfunction. If the SCAS malfunction results in a "hardover" the helicopter will enter gyrations in the axis of the malfunction. The pilot's first action must be to disable the SCAS either by the quick disconnect (usually on the cyclic pitch control grip), the SCAS power switch or the individual channel switches on the SCAS control head. The SCAS circuit breakers would be a last resort. (There have been cases reported in which the SCAS could not be disabled after a "hardover," with catastrophic results.)

d. Topside Governor Failure. Inability to maintain throttle control over engine r/min is unusual in a turbine-powered helicopter. However, there is no manual fuel control in the Bell 206. At least one mishap has been recorded in which the engine surged as a result of a topside governor failure. The resulting main rotor r/min surge caused excessive flapping leading to mast bumping, blade-to-fuselage contact and inflight breakup.

13-19. Weather-Induced Problems:

a. At least one case is known in which a pilot flew into an area of thunderstorms in which turbulence was severe enough to initiate mast bumping. Severe turbulence such as might be associated with mountain waves would be equally conductive to violent rotor excursions. "A pilot who is not qualified or proficient for flight into IMC could be subject to spatial disorientation severe enough to permit the aircraft to attain an unusual attitude which can exceed the design limits of the helicopter."

b. When contact is made with the water, the blade contacting the water will be swept aft, and the other blades swept forward. The blade which contacts the water will normally have its blade tip swept upward. The angle described by the upward sweep will approximate the aircraft attitude at the time of the main rotor blade impact. There may be additional indications on the mast of stops where the other main rotor blades were displaced in their path of rotation.

13-20. Loss of a Main Rotor Blade. Loss of a main rotor blade will result in a totally unpredictable track of the remaining blades. It is likely that the dynamic imbalance of the rotor system will result in divergent flapping of the remaining blades. It has been reported that blade loss in a Hughes 269/300 (which has a very low inertia main rotor system) resulted in a complete stoppage of the remaining blades, with the helicopter rolling inverted because of the weight moment of the transmission. Loss of one blade in a two-blade system may result in loss of the transmission assembly.

a. Some main rotor blades are attached to the hub by a tension torsion strap ("T-T strap") consisting of multiple wrappings of wire, similar to piano wire, encased in a plastic housing. Other helicopters use different methods for main rotor blade retention, including lead-lag bolts, stainless steel strap packs, and threaded fittings. Documented cases exist in which unreported main rotor overspeeds initiated fatigue failures in blade retention bolts which subsequently failed at later dates. In the case of the Boeing-Vertol tandem-rotor helicopter, the remaining blades will continue for approximately an additional 2/3 rotation, after which the entire pylon will separate from the airframe. In a four-blade rotor system, loss of one blade near the hub may result in the simultaneous overload separation of the two blades perpendicular to it.

b. Helicopters may receive lightning strikes when operating near thunderstorms. These usually do not critically damage the helicopter and it can be safely recovered.

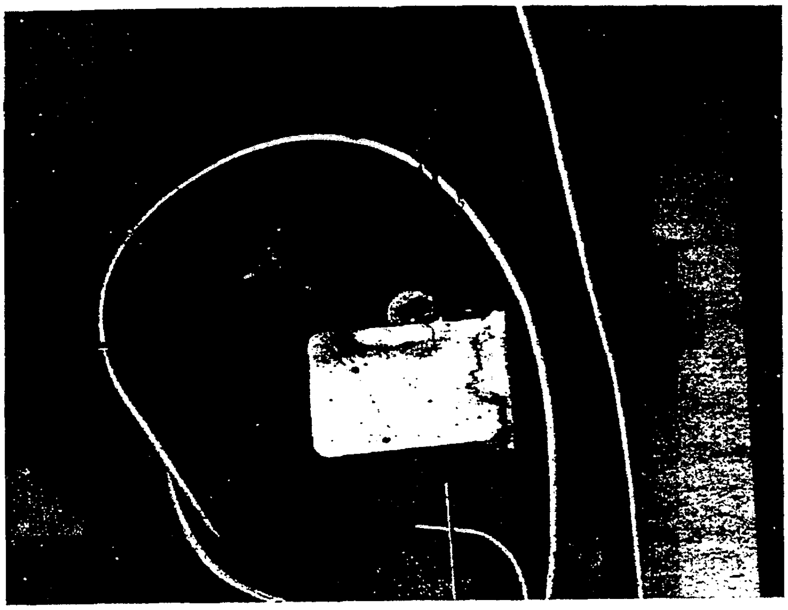

Figure 13-9. Classic Helicopter Blade Lightning Strike.

13-21. Investigative Procedures and Techniques:

a. The mast control components between the swashplate and the main rotor blades ensure symmetry of the main rotor blade pitch angles. Failure anywhere among these components destroys the symmetry and results in an uncontrolled blade. It has been speculated that a mast fracture under those conditions may occur in as little as 180 degrees of rotation in a teetering rotor system—approximately 0.10 second. The stops may strike the mast so violently that one strike on each side of the mast may be sufficient to cause failure. Mast failures from unusual attitudes may result in several strikes on each side of the mast. The services of a competent metallurgist may be required to obtain a reliable analysis.

b. To appreciate the complexity of this type of mishap it must be understood that main rotor separation also implies severing of the main rotor control tubes. If damper assemblies are installed on the helicopter these also will be severed. These failures may in turn cause secondary failures lower in the system which would be almost coincidental with the beginning of the breakup sequence. As a result, pieces found along the flight path can be misleading if taken in isolation.

c. It is virtually impossible to list and discuss all individual flight control components; therefore a general listing and discussion follow:

(1) Check the condition of all bearings. Even a portion of a bearing race may be adequate to establish its condition before disintegration.

(2) Be suspicious of all open connections; e.g., rod end bearings, clevises, etc., especially if one or both sides of the disconnection shows no sign of distortion.

(3) Be alert for impact marks on control tubes. When dampers are installed, damper bracket adapter failure may cause a damper to be flung against a control tube (or tubes). Con-

Figure 13-10. Rotor Head Witness Marks.

sequent crippling and failure of the tube(s) can result in loss of control of the main rotor. (Mast distortion or failure can initiate damper bracket failure, in which case the bracket failure would be secondary to the principal failure.)

(4) Pay special attention to the mast support and collective pitch sleeve, and their associated bearings. Look for marks which cannot be explained by a one-time impact.

(5) Check for servo failure. If a servo failure is suspected, pack the servo(s) carefully in an as-found condition and take by a knowledgeable person to a competent laboratory. **Do not permit the laboratory to flow-check a servo before its being x-rayed.** Flow-checking can dislodge foreign objects which might otherwise show up in the radiograph. The second step—after scribing witness marks—should be to disassemble the servo to determine the presence of contamination or internal failure. Only after these examinations have proved negative should the servo be reassembled, using the original parts, and flow-checked. When flow-checking the servo, be sure to install a fine filter (no greater than 5 microns) in the return outlet to capture possible contaminants.

(6) Account for all cowlings and doors, and the damage sustained thereby. A similar approach should be taken for cargo compartment items found along the flight path. Bear in mind that a loose item flung from another aircraft in formation can cause catastrophic failure if it contacts a critical flight control component. The possibility of a bird strike should also be considered.

(7) Check disconnected parts. In general, any part which failed or became disconnected without evidence of any force causing the failure or separation should be subject to suspicion and scrutiny.

(8) Examine fuselage strikes. There is no specific pattern to be found in fuselage strikes following mast bumping and main rotor separation, although strikes on the left side appear to predominate. Portions of a left skid, cockpit door, crew seat, cargo door, cockpit roof or left synchronized elevator may be found along the flight path. If more than one fuselage strike occurs, there will generally be a substantial angular difference between successive strikes consistent with increasing flapping angles. (In the UH-1 it is common to find the initial strike on the tail rotor drive shaft cover near the 42-degree gearbox, the next strike near the sync elevator, and the next about 3 feet forward of the sync-elevator.)

13-22. Wreckage Search and Diagramming. The importance of an accurate wreckage distribution diagram cannot be overemphasized. The remark "See Photos" in a mishap report is not the mark of a good investigator. The wreckage distribution pattern may not be significant until it is interpreted by someone with adequate knowledge and experience; therefore, it is incumbent on the investigator at the scene to get it accurate. No wreckage diagram can be considered complete without *all* critical and dynamic component positions plotted accurately. More than one organized search may be necessary, and careful inventory must be taken after each search is "complete." If critical components are missing, search again!

Section E—Summary and Conclusions

13-23. Summary:

a. The helicopter is a fatigue-producing machine. No other aircraft has such a large number of components with a finite life, nor does any other aircraft have so much rotating machinery. This means that maintenance and aircrew inspections are very critical. The investigation of helicopter mishaps is not easy, in fact, it is often considered to be more complicated than any other type investigation. Those principles which have been brought out in other parts of this pamphlet which are not covered in this chapter are equally valid to helicopter mishap investigations. To reiterate, though, a thorough investigation must include an inspection of all helicopter's historical records to determine the time life on all components, along with their overhaul record. A careful examination and inspection of the records before looking at the crashed helicopter many times will lead the investigator into a suspect area. (Good luck on your first!)

13-24. About the Author:

Lester R. Kerfoot, Jr., is a lecturer in the Extension and In-Service Programs Directorate, Institute of Safety and Systems Management, University of Southern California. He teaches helicopter accident investigation. He actively consults in aircraft accident investigation, reconstruction and analysis, specializing in helicopters, and has authored many technical articles on helicopter accident investigation.

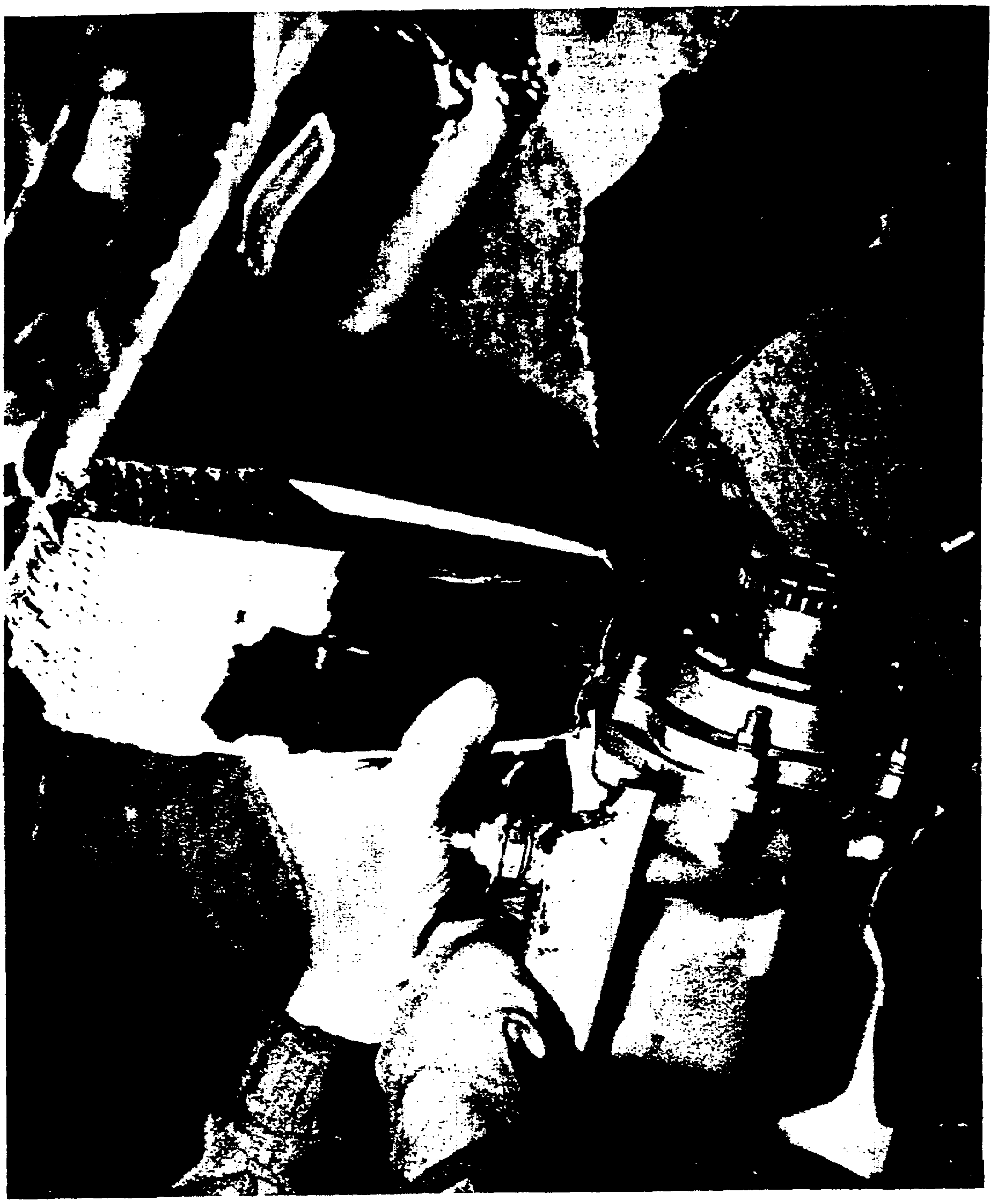

Figure 13-11. 42° Gear Box Showing Main Strike From Rotor Blade Leading Edge.

He received his Bachelor's Degree from the University of Santa Clara and a Master of Science Degree in Aerospace Operations Management from the University of Southern California. He is a member of the International Society of Air Safety Investigators, the American Helicopter Society, Helicopter Association International, and the Association of Aviation Psychologists.

He served in the US Army for over 26 years as an aviator and was Chief, Central Aircraft Accident Investigation and Assistant Director for Plans and Operations at what is now the Army Safety Center. He has participated in over 200 accident investigations, approximately 100 as president of the accident investigation board or investigator in charge, primarily involving helicopter, both military and civil, and has served as a consultant on many others. He has over 3,000 hours, primarily helicopter, in a variety of aircraft, including reciprocating and turbine powered, single and multiengine helicopters, both single and tandem rotor, varying in weight from 2,000 to 33,000 pounds.

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REVIEW OF ACCIDENT INVOLVING AS 350 BA SQUIRREL HELICOPTER A22-004

'Hydraulics-off' accident at RAAF Base Fairbairn, ACT on 10 March 1997

FACTUAL INFORMATION

History of the flight

On Monday 10 March 1997, Australian Army AS 350 BA Squirrel helicopter A22-004, took off from RAAF Base Fairbairn in order to conduct a loadmaster training mission as part of a *Loadmaster Rotary Wing Basic Course*. During loadmaster training missions, the aircraft would normally be crewed by one pilot in the right front crew seat, a Qualified Loadmaster Instructor (QLI) in the right rear seat and a loadmaster trainee in the left rear seat. Frequently, an additional loadmaster trainee would be carried in the left front crew seat, in order to gain maximum training benefit.

Coincidentally with the loadmaster training, on this mission, a staff pilot from Loadmaster Training Troop required assessment, at the request of the base Medical Officer, by a Qualified Flying Instructor (QFI), of her physical ability to control the aircraft following a return to flying duties from injury to her right ankle. Consequently, the left front crew seat was occupied by a QFI and the right front crew seat by the staff pilot under assessment. The pilot was briefed by the QFI to act in command under supervision for the purposes of the dual check, however, the QFI was the aircraft captain for the mission.

At the conclusion of the 1.4 hr sortie, the QFI initiated a hydraulics failure emergency practice with the flying pilot, with the intention of terminating in an in-ground-effect hover, prior to landing in helicopter lane 3 (landing direction 300°M) at RAAF Base Fairbairn. The approach to landing appeared normal until shortly before termination in the hover, at a height of 10-15 ft above the ground and approximately 1630 hrs local time, when the flying pilot (in the right front crew seat) assessed that application of right pedal to control the left yaw was ineffective and communicated that fact to the QFI.

The QFI took control of the aircraft as it was yawing rapidly to the left, at approximately 40° to the left of the intended landing direction. The QFI was unable to correct the rapidly increasing left yaw and subsequent nose down pitch and left roll. The aircraft rotated approximately 280-290° in a severe nose-down and left roll attitude when the main rotor contacted the ground, followed by the left skid toe and the lower left side of the nose. The aircraft came to rest on its right side, in a position indicating a left rotation through approximately 300° from the intended landing direction and displaced laterally 30 m to the left of the intended termination point. The QFI shut down the engine using the fuel cut-off lever. There was no fire and all crewmembers egressed the aircraft unaided.

Damage and injuries

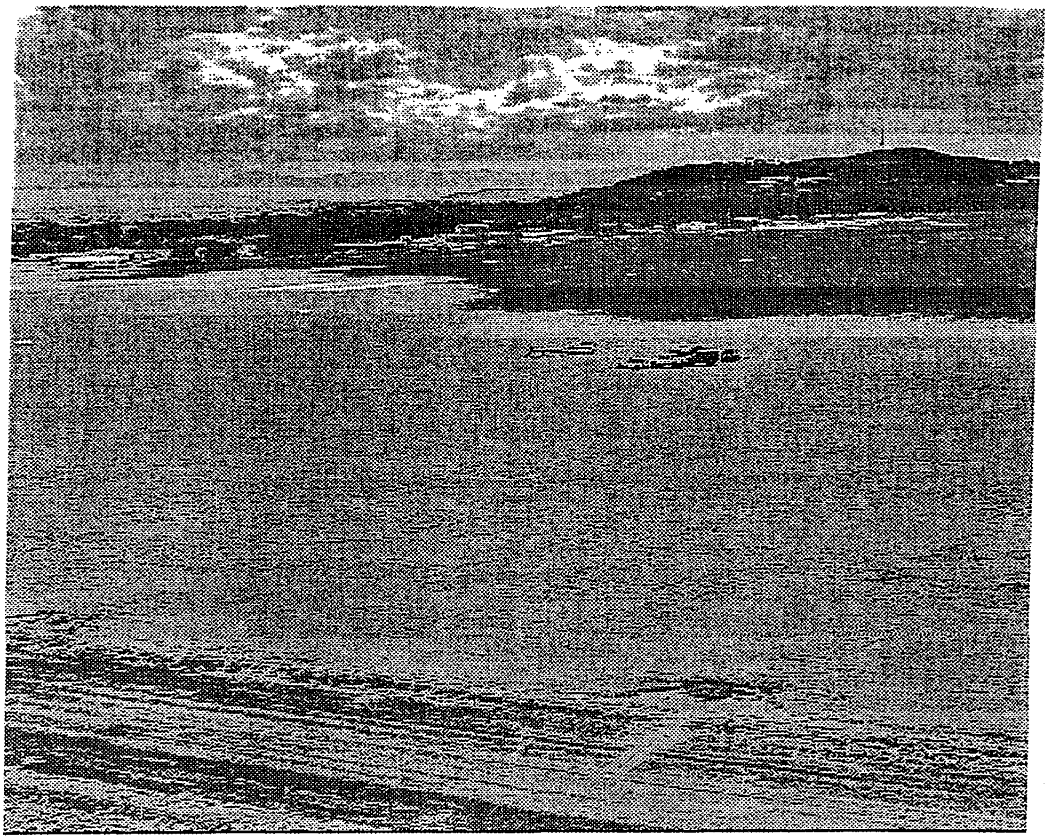
The aircraft was destroyed. The four crewmembers suffered minor injuries. Soft tissue bruises, abrasions, and lacerations were the only documentable injuries. Collateral damage was occasioned to the airfield which consisted of impact marks and fuel, oil and hydraulic fluid spillage to grass lanes 2 and 3 (in Rwy 30 direction).

Personnel involved

The aircraft captain, a Category A2 QFI, graduated from No 104 Pilots Course in December 1978 and commenced operational flying tours. In August 1986, he graduated from the RAF Central Flying School Helicopter Instructors Course and was posted as a staff instructor at No 5 Squadron and the Australian Defence Force Helicopter School (ADFHS), until the end of 1989. He then returned to operational flying in Australia and New Zealand, prior to returning to ADFHS as the Senior Naval Officer and his current appointment as Senior Instructor, Instructor Training Wing. At the time of the accident, he had accumulated a total of 4603.4 hrs flying experience, including 1550 hrs instruction on Squirrel aircraft and was in current flying practice. He was considered to possess above average flying skills, aviation knowledge and experience.

The pilot graduated from No 57 Army Pilots Course in November 1994, and was posted to 171 Operational Support Squadron to fly Iroquois aircraft. She returned to ADFHS in January 1997, completed transition to the BA model Squirrel aircraft and was posted as a Category C staff pilot, Loadmaster Training Troop. At the time of the accident, she had accumulated a total of 1140.0 hrs flying experience, including 182 flying hours on B and BA Squirrel aircraft. She had not flown for approximately three weeks due to an ankle injury.

The Loadmaster Instructor was a Category C QLI. At the time of the accident, he had accumulated a total of 2036 hrs flying experience on Iroquois, Black Hawk and Squirrel aircraft.



General view of accident scene.

The Loadmaster Trainee had a total of 19.6 hrs flying experience, at the time of the accident, on AS 350 BA Squirrel aircraft.

THE ACCIDENT

The mission

The mission was loadmaster consolidation training which was also to be used as a dual check flight for the pilot, who had not flown for three weeks. She had suffered an injury to her right ankle so the QFI was tasked to ensure that she was capable of controlling the aircraft in the most physically demanding configuration, which is a hydraulics-off approach to an in-ground-effect (IGE) hover.

Accident flight sequence

The mission proceeded normally for the loadmaster training portion. Whilst returning to RAAF Base Fairbairn and about five minutes from landing, the QFI initiated a simulated hydraulics failure by enabling the *Hyd Test* switch. The pilot carried out the correct hydraulic failure actions in accordance with the Flight Manual and was assisted by the loadmaster trainee, who was using the checklist. The QFI elected to leave the *Hyd Test* switch enabled after the hydraulics were isolated, as he believed that this would be more realistic of a real hydraulics failure and therefore a better test of the pilot's ankle. The sequence continued as expected, until the aircraft approached the hover at approximately 15 ft, when it started to yaw rapidly to the left.

The QFI took control as the yaw approached approximately 40° left and applied what he thought was sufficient right pedal to stop the yaw; however, the yaw continued to increase in rate. As the rate of yaw increased the nose also dropped and a left bank developed. The aircraft struck the ground with the main rotor first, after completing approximately 280° of turn. The aircraft was estimated to be approximately 40° nose-down and 30° banked left. After the main rotor hit the ground the aircraft moved backwards and the left skid toe skipped along the ground until it dug in and broke off, followed by the front left nose of the aircraft contacting the ground. The aircraft then rolled over gently onto its right side.

Previous similar occurrences

Two previous similar incidents have occurred:

1. On approximately 13 July 1995, during a maintenance test flight conducted by the civilian maintenance test pilot employed by ASTA Defence and whilst conducting a hydraulics-off test flight to the hover, the hydraulic test switch was inadvertently left enabled after isolating the hydraulics, contrary to the Squirrel Flight Test Schedule. As the aircraft approached the hover, it started to yaw left and the rate of rotation started to increase. The pilot attempted to stop the rate of yaw with right pedal but was unsuccessful. As the turn continued the hydraulic isolate switch was deactivated; however, the aircraft still failed to recover. While continuing to keep the aircraft away from the ground and scanning instruments, the pilot noticed the *Hyd* caption was still illuminated and realised that the hydraulic test was still enabled. The pilot asked the technician in the left seat to disable the test switch and the aircraft started to recover as hydraulics were restored. The C of G at the time of the incident was approximately 3.25 metres which is close to the middle of the C of G envelope.

2. A second incident occurred the week before the accident. Whilst hovering during a hydraulics-off test, the same civilian maintenance test pilot found that excessive force was required to move the tail rotor pedal. He found that he had left the hydraulic test switch enabled and, upon deactivation, the required pedal force decreased significantly. At no time was directional control lost. The C of G at the time was approximately 3.25 metres, which is near the middle of the flight envelope.

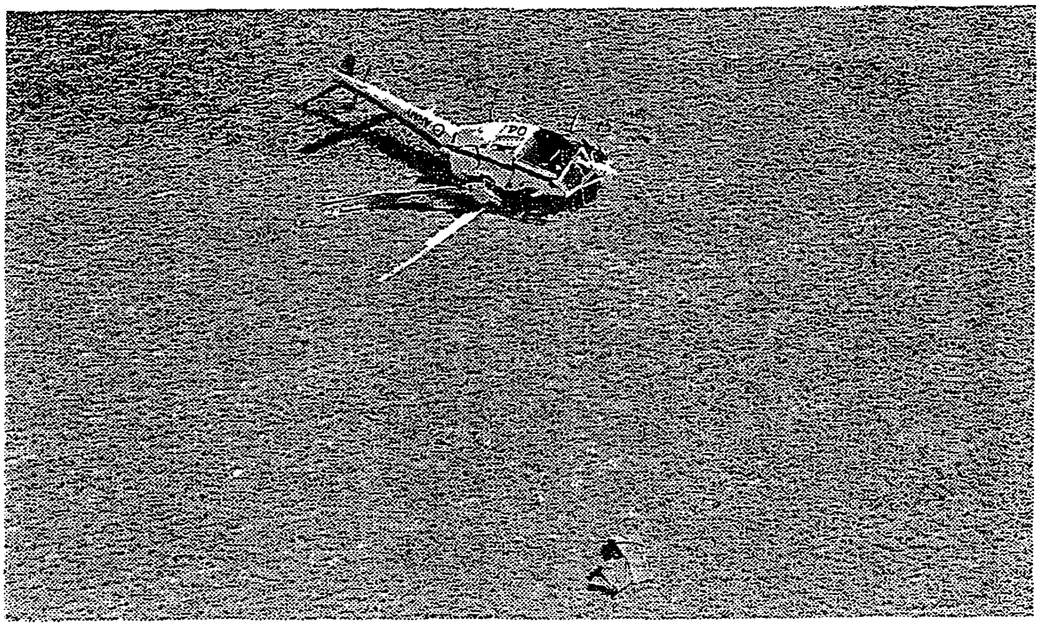
Neither of these incidents were reported in accordance with Army Flying Orders (AFO); however, at the time of the accident the ASTA Defence contract did not require civilian maintenance test pilots to report incidents or operate in accordance with AFO.

Environment

Meteorological observations 30 seconds prior to the accident indicated light northeasterly winds and a temperature of 25°C. There is no evidence to indicate that environmental factors contributed to the accident.

Operational documentation

The AS 350 BA Squirrel Flight Manual, ADFHS Mass Briefs, Unit Flying Orders, Standard Operating Procedures SOPs) and the Instructors Manual, have no warning with respect to control difficulties experienced with the hydraulic system inoperative and the *Hyd Test* function enabled. The manual also does not require or suggest that the QFI should disable the *Hyd Test* switch after initiating a hydraulics failure practice. The Squirrel Flight Test Schedule calls for the *Hyd Test* switch to be disabled prior to landing, although there are no warnings



Aerial view of accident scene.

to indicate that control difficulties may be experienced if the switch is left in the enabled position.

The aircraft

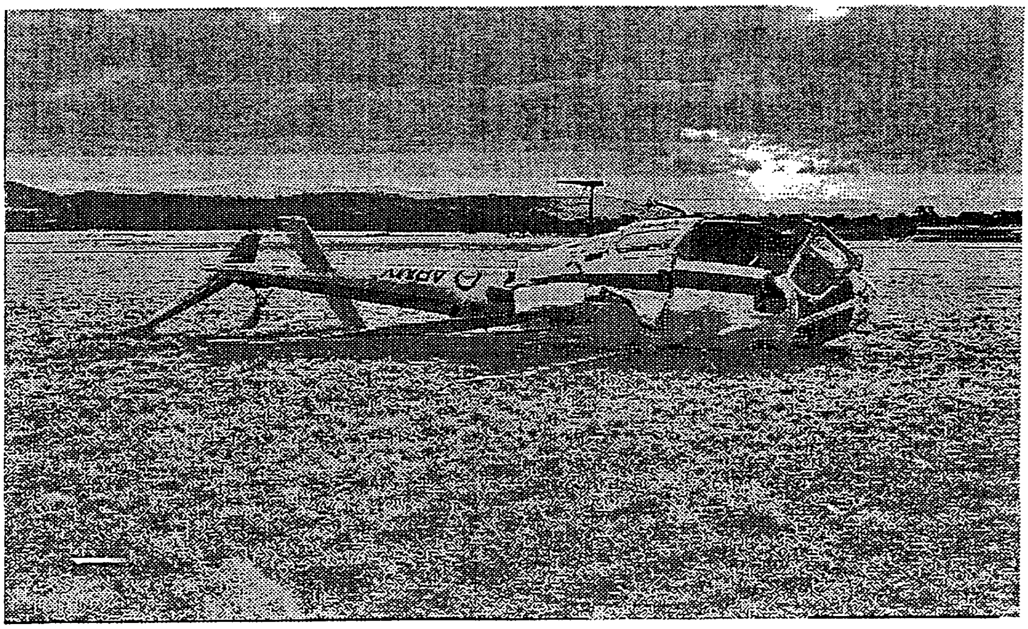
At the time of maintenance release for the accident sortie, AS 350 BA Squirrel helicopter A22-004 had flown a total of 4552.5 airframe hours (AFHRS). The flight time for the accident sortie has been estimated at 1.4 AFHRS. The aircraft was in a standard ADFHS training configuration, without a rescue hoist fitted. A physical inspection of the aircraft and its systems, and review of the aircraft maintenance documentation, did not reveal any unserviceabilities which would have contributed to the accident. The aircraft was serviceable when released for the accident flight and, from the evidence available, together with the testimony of the crew, aircraft A22-004 was considered to have been serviceable and operating correctly immediately prior to the accident.

AS 350 BA hydraulics-off performance

For type certification of the AS 350 BA upgrade modification, Army Aircraft Logistic Management Squadron raised a DT&E task through Headquarters Air Command for the conduct of performance flight trials. The RAAF Aeronautical Research and Development Unit (ARDU) was directed to complete the task, and subsequently produced ARDU report AR-007-219 AS 350 *Squirrel BA Upgrade Performance Validation* in January 1995. In addition, ADFHS completed similar performance flight testing and produced a report ADFHS-ITW/BA-2/94 of 12 December 1994 entitled *The ADF Helicopter School Qualitative Evaluation of the AS 350 BA.*

Both ADFHS and ARDU raised concerns in their respective reports regarding the control forces and handling characteristics of the AS 350 BA aircraft during performance flight testing. The ARDU report stated that for hydraulic-off operations the *'...gradient reversals and control force characteristics below 40 KIAS would significantly increase pilot workload...and could prove to be unsatisfactory in the training role'.* ARDU concluded that *'...it is recommended that a quantitative evaluation be conducted into the handling characteristics of the AS 350 BA following a hydraulic system malfunction'.* ARDU rated the recommendation as *'Highly Desirable'*, defining this deficiency as *'restricts aircraft operational capability or is liable to cause accidents unless significant restrictions are imposed'.*

The ADFHS report discussed some of the flight characteristics of the hydraulics-off approach to the hover, and the author stated that hydraulics-off approaches to the hover *'...required excessive pilot compensation to overcome the high control forces and step changes to the direction of the required applied force as the aircraft decelerated...delay in pilot compensation resulted in a significant...nose down pitch and resultant forward translation'.* Further, the *'...flying skill necessary to compensate for the poor handling qualities of A22-001 when attempting to terminate to a hover with-*



A22-004 as it came to rest after the accident.

A22-004 being inspected by accident investigators.

out hydraulic flight control assistance, exceeds that of a basic "ab initio" student'. Significantly, the ADFHS report concluded:

> *'Recommend ADFHS SOPs reflect that student emergency procedures be restricted to running landings in the event of loss of flight control hydraulic pressure in flight.'*

The Squirrel Airworthiness Board conducted on 28 October 1994 addressed the supplemental type certification of the AS 350 BA. The minutes of that meeting also addressed the ARDU findings in relation to hydraulics-off operations:

> *'Also, during simulated hydraulic failure, cyclic controls seemed heavy. These results, being obtained from only one aircraft, were not conclusive and were not seen as an impediment to certification'.*

Investigation could find no further reference to concerns regarding the aircraft characteristics during hydraulics-off operations after this time. The ADFHS report does not appear to have been formally released outside of the unit, although reference to the report was found in later RAN Aircraft Maintenance And Flight Trials Unit (AMAFTU) flight trials reports indicating that an informal copy was at least received from ADFHS. Although ADFHS was on the distribution, no record could be found that the ARDU report was received at the unit, and a copy of the report was not located during the investigation. The Airworthiness Board does not appear to have addressed the ARDU concerns any further and Army Aircraft Logistic Management Squadron advised ARDU that they were satisfied with the draft report, and that ARDU was to terminate the task. That minute states that:

> *'...ADFHS believes that an evaluation of handling characteristics following a hydraulic system malfunction is unnecessary. Current procedures ensure that students will only be required to terminate to a running landing'.*

To provide some indicative figures relating to hydraulics-off operations, the investigation conducted some static measurements of the AS 350 BA flight control system to compare control movement between hydraulics-on and hydraulics-off. Measurements (from a fixed arbitrary reference) were taken at the collective servo and the tail rotor pitch change shaft to estimate relative movement. The test results indicated that there is reduced movement in the collective servo and tail rotor pitch change shaft with hydraulics-off. The difference is in the order of 28.2 per cent for the collective servo and 16.3 per cent for the tail rotor pitch change shaft. The results indicate that full control surface deflection may not be available with hydraulics-off, leading to reduced effectiveness of both main and tail rotor control. These measurements are only indicative of possible control effectiveness in flight, and more substantial flight testing is required to quantify any actual control effectiveness reduction.

A tail rotor compensator is available for the AS 350 BA aircraft; this compensator is a pressure accumulator that is fitted in parallel with the tail rotor servo to reduce the muscular effort by the pilot in the event of the loss of hydraulic pressure. Fitment of this device may be necessary for the AS 350 BA to safely conduct hydraulics-off flight.

Performance conclusion

The increase in control forces during hydraulics-off flight, especially in an approach to the hover, was central to the accident investigation. ARDU, ADFHS, and the ASTA test pilot have either raised concerns or witnessed incidents involving difficulties experienced in hydraulics-off flight in the AS 350 BA, but these concerns have not been fully investigated and/or reported. The ability of the pilot to recover from a rapid yaw in the hover without hydraulic assistance may be limited due to reduced control movement, and hence reduced control effectiveness. This effect may be further exacerbated by extreme forward centre of gravity of the aircraft, and possibly differing flight characteristics of individual aircraft. Quantitative flight testing and evaluation of the AS 350 BA may be the only method to fully explain the aircraft characteristics that contributed to this accident.

TECHNICAL ANALYSIS

Aircraft mechanical malfunction

Engineering analysis was unable to detect any aircraft systems fault which could have either contributed to the accident, or impaired occupant survivability.

Loss of tail rotor effectiveness

Loss of tail rotor effectiveness (LTE) can be caused in helicopters by the main rotor shedding vortices which then interfere with airflow to the tail rotor. In the AS 350 BA the wind would have to be coming from the right between 045° and 075° relative to cause the main rotor vortices to interfere with the tail rotor. The AS 350 BA is also quoted as having very good tail rotor authority with no recorded cases of LTE. As the relative wind was coming from 108° right of the aircraft, it is extremely unlikely that main rotor vortices could have caused loss of tail rotor effectiveness and hence rapid yaw left.

Tail rotor vortex ring

The AS 350 BA Flight Manual discusses tail rotor vortex ring state in a limited fashion. The aircraft can experience tail rotor vortex ring when hovering with a wind from the right of about 15 kts or in right sideways flight at 15 kts in nil wind conditions. The relative wind causes the wake of the tail rotor to be recirculated through the tail rotor disc. The vortices are said to build rapidly and spread over the entire span of the tail rotor which causes a reduction in thrust. The vortices, however, are of short duration and rapidly dissipate allowing thrust to return to normal. This continual building and dispersing of vortices on the tail rotor results in a continual variation in tail rotor thrust. This variation in thrust makes accurate heading control difficult. Discussions with unit aircrew indicate that the heading phenomenon is often experienced but never leads to any significant rates of yaw developing.

The wind at the time of the accident was approximately 6 kts and may have gusted to 13 kts from 060° T (048°M). The aircraft was heading 300°M prior to the accident which means the relative wind was 108° from the right at possibly up to 13 kts. This approximates the criteria for tail rotor vortex ring state in the AS 350 BA.

If tail rotor vortex ring state had developed just prior to the accident, it is believed that it would not have had time to cause a rapid yaw rate to the left before the vortex dissipated. Whether hydraulics are on or off should have no effect on the development of tail rotor vortex ring. If tail rotor vortex ring state was going to present a problem to aircraft control, then it would have also have been experienced hydraulics-on. There was no evidence to suggest that vortex ring has ever caused control problems with hydraulics-on and therefore it may be assumed that it will not be a problem hydraulics-off.

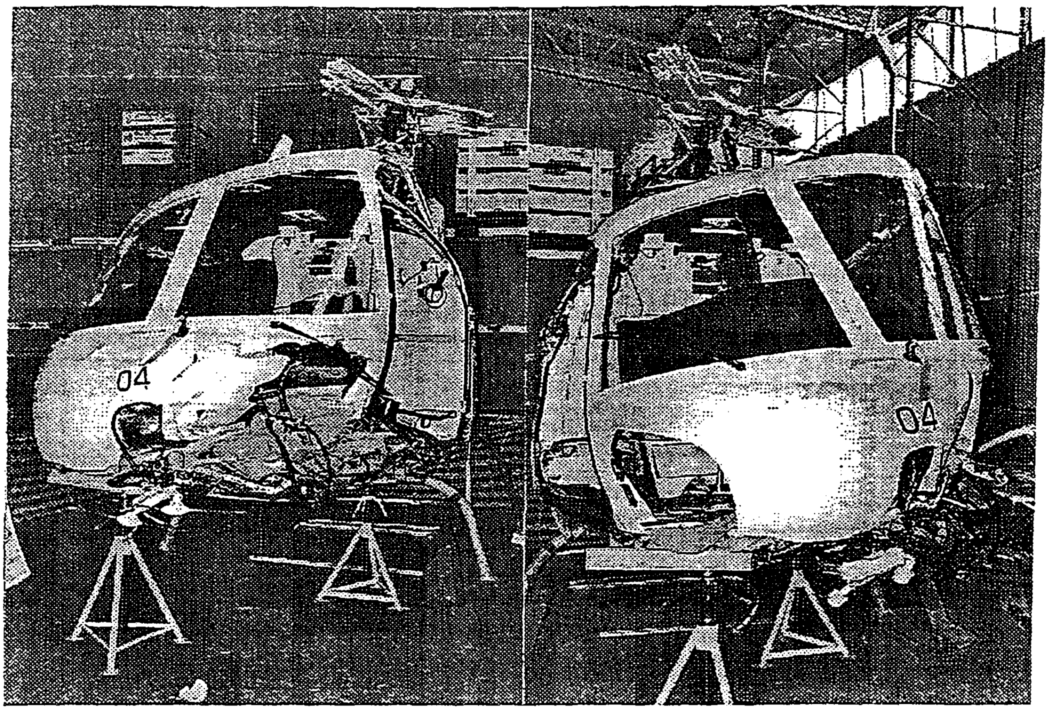
While it is possible that tail rotor vortex ring could set up a left yaw condition, it was considered extremely unlikely that it could have caused enough yaw to develop in the accident for loss of control of the aircraft to eventuate.

Control effectiveness hydraulics-off

Engineering analysis of the amount of control movement hydraulics-off and hydraulics-on was conducted on a static AS 350 BA with a hydraulic rig connected. The test revealed a reduction of approximately 16 per cent in the movement of the tail rotor pitch change shaft and a reduction of approximately 28 per cent in the movement of the collective servo (cyclic can not be tested without flight loads).

There is considerable difference in tail rotor pedal force depending on whether the aircraft is being flown with the hydraulic test switch enabled or disabled. The difference appears to be caused by some hydraulic assistance being still available to the tail rotor servo when the hydraulic isolate is activated and the hydraulic test switch is disabled. The hydraulic test switch enabled situation appears to more accurately simulate an actual hydraulics failure.

Hydraulic Isolate versus Hydraulic Test. The *Hyd Test* switch enabled scenario appears to allow a situation to develop where there is not enough tail rotor authority remaining in the hover to allow the pilot to stop a left yaw once it has developed. Once a rapid left yaw devel-



A22-004 after removal to a hangar at RAAF Base Fairbairn.

ops there is also a tendency for the aircraft to pitch down and roll left.

Weight and Balance

Fuel. *Discussions with crew members on the accident* flight indicated that the aircraft departed the training area with something less than 30 per cent fuel. The transit to RAAF Base Fairbairn from the training area can take from 15 to 20 minutes and with a possible fuel burn rate of 30 per cent per hour, the fuel could have been as low as 18 per cent on arrival at Fairbairn, although most crew members believe it was approximately 25 per cent.

Centre of Gravity (C of G). No C of G calculations had been carried out for this mission. Indeed it was evident that ADFHS personnel do not conduct C of G calculations for any flight. A number of C of G calculations were carried out by the AIT for the accident aircraft.

The forward C of G limit for the AS 350 BA at the accident operating weight is 3.17 metres aft of the datum. The C of G for A22-004 at the time of the accident was very close to the forward limit. There is no way to definitively quantify the effect of crew movement on C of G; however, a small movement forward by the loadmasters (as little as 20 cm) can put the aircraft out of the forward C of G limit. This C of G sensitivity also has implications on loadmaster training sorties where the QLI moves forward to observe the trainee loadmaster. In these instances the aircraft can possibly be placed in an out-of-C of G situation.

The position of the C of G on the accident flight is believed to have been contributory, especially when considered in conjunction with the reduced control effectiveness hydraulics-off and the encountered nose-down pitch. The AIT considered that, due to the forward C of G, once a pitch down moment started, there was insufficient cyclic control remaining to correct the aircraft attitude.

Corporate knowledge

ADFHS previously had C of G standard figures calculated for various aircraft loadings and configurations. These standard figures allowed crews to rapidly check that they were within C of G limits. Some time during the last five years the standard C of G calculations have been removed from ADFHS publications, resulting in an erosion of corporate knowledge of AS 350 forward C of G problems.

The ADFHS report previously discussed did not leave the unit, although an unofficial copy was found at

RAN AMAFTU. Therefore, in this case, corporate knowledge was not gained, although the opportunity existed. Consequently, a potential hazard did not gain command visibility outside ADFHS.

Additional corporate knowledge was not gained in the case of an AS 350 BA anomaly hydraulics-off when the civilian test pilot did not report, and was not required to report, the two previous air safety incidents.

Technical conclusion

When the aircraft approached the hover with hydraulics-off, it started to rotate to the left for an unknown reason. With the hydraulic test switch enabled, it appears there was insufficient tail rotor authority to stop the turn. As the rate of turn increased, so did the amount of pitch down and roll left. The C of G was very close to the forward limit and this, in conjunction with what appears to be reduced control effectiveness hydraulics-off, indicates that there was insufficient cyclic authority to prevent the main rotor blades from contacting the ground.

HUMAN FACTORS ANALYSIS

During the Human Factors analysis, a number of issues were addressed:

- Trans-cockpit authority gradient.
- Why was the hydraulics-off to the hover sequence chosen for the flight evaluation?
- Why was the pilot tested with other crewmembers in the aircraft?
- Did the pilot revert to an earlier aircraft type and use left pedal instead of right pedal?
- Did the pilot input sufficient right pedal?
- Was there an appropriate handover of the aircraft from flying pilot to QFI?
- Why did the QFI leave the *Hyd Test* function enabled?
- Why couldn't the QFI recover the aircraft from the yaw?

Human factors conclusions

Although Human Factors findings were made from the investigation, it was concluded that medical and psychological issues were not causative factors in this accident. Notwithstanding, the following human factors decisions were considered contributory:

- the decision to evaluate the pilot during a loadmaster training sortie, thus ensuring a forward C of G during a critical manoeuvre;
- the decision to perform a hydraulics-off approach to the hover; and
- the decision to leave the *Hyd Test* function enabled.

FINDINGS

The aircraft AIT found that significant factors contributing to the accident were:

- the lack of AS 350 BA loaded C of G calculations;
- the C of G near the forward limit;
- insufficient or ineffective right pedal input by the pilot;
- the onset of a rapid left yaw which the QFI was unable to effectively oppose;
- an apparent inherent AS 350 BA flight characteristic which is not widely known or published; and
- an apparent lack of control movement in the AS 350 BA with hydraulics-off.

RECOMMENDATIONS

The significant recommendations were that:

- a competent flight test agency conduct a quantitative evaluation of the AS 350 BA hydraulics-off flight characteristics, as soon as possible; and
- until the quantitative evaluation of the AS 350 BA indicated above is conducted, that:
  - where possible running landings be conducted when the hydraulic system is inoperative;
  - where landings to the hover are unavoidable, that:
    - the left yaw is not permitted to develop, and
    - a relative wind be used or artificially induced.
  - the *Hyd Test* function is disabled prior to landing; and
  - aircrew avoid conducting hydraulics-off flight with a C of G at the forward limit of the flight envelope; (unable to be quantified until the ARDU flight evaluation is complete).

EXECUTIVE REVIEW

Headquarters Aviation Support Group accepted the findings of the investigation and endorsed the aircraft AIT recommendations. As a result of the accident, Headquarters Aviation Support Group has imposed flight restrictions with respect to hydraulics-off flight. In addition, evaluation of the flight characteristics of the aircraft, with the hydraulics system inoperative, is continuing. ✈

REVIEW OF ACCIDENT INVOLVING BELL 206B-1 KIOWA HELICOPTER A17-021

'Loss of Tail Rotor Effectiveness (LTE)' accident at Gibb River, WA on 30 May 1995

FACTUAL INFORMATION

History of the flight

At 2337 hrs Coordinated Universal Time (UTC) on 30 May 1995, 161 Reconnaissance Squadron Bell 206B-1 Kiowa helicopter A17-021 departed Drysdale, Western Australia, for a field completion mission in support of 4 Field Survey Squadron. The sole crewmember was a Category D pilot. Passenger composition was a Survey Corps CPL in the front left copilot/passenger station and a Survey Corps SGT in the left rear passenger station.

The mission progressed as planned, including field completion tasks to the SE of Drysdale and the area between Drysdale and Gibb River. Up until 0100 UTC, the pilot had been maintaining communications with another 161 Recce Sqn Kiowa, flown by the Troop Commander. At that time the pilot indicated that he would be conducting operations SE of Gibb River and would re-establish communications at 0130 UTC. The pilot then continued with tasking. At approximately 0105 UTC the pilot was following a fence line, when an unmarked intersection was noted. The aircraft captain, at the request of the passengers, started to bring the aircraft to a hover over the intersection in order to gain a Global Positioning System (GPS) fix.

As the pilot approached the hover over the intersection, at 50 ft AGL and 1 380 ft AMSL, the aircraft began to rapidly rotate to the right. As initial control inputs failed to reduce the rotation, the aircraft captain closed the throttle. The aircraft then began to autorotate whilst continuing to spin, albeit at a reduced rate. The aircraft landed heavily in an upright position. The fuselage was significantly damaged, the roof partially collapsed on the port side and the tail boom and tail rotor blades detached. The three occupants egressed the aircraft unaided.

Damage and injuries

The aircraft was destroyed. The three occupants sustained minor injuries.

Personnel involved

The sole crew member was the 29 year old aircraft captain who had graduated as an Army pilot in November 1994. He was posted to 161 Recce Sqn in December 1994; however, as the sub-unit was in the middle of the move from Holsworthy to Darwin, he did not join the squadron until early January 1995. This meant that little consolidation of his flying training was completed until late February 1995. However, as tasking for 161 Recce Sqn had been embargoed until 1 May 1995 to allow adaptation to the Northern Territory, all squadron pilots were able to consolidate their flying in the NT before commencing tasking. Further, the accident pilot's consolidation training had been interrupted for two weeks in April 1995, due to a medical condition, and he had resumed flying only three weeks prior to the accident.

At the time of the accident, he had accumulated a total of 1604 flying hours, of which 1215.1 hrs were civil fixed wing, 70.4 hrs were military fixed wing, 148.6 hrs on the Squirrel and 169.9 hrs on the Kiowa. In the 14 days prior to the accident he had flown 36.1 hrs on the Kiowa, of which 8.4 hrs had been under supervision and 27.7 hrs had been as aircraft captain. This was his first supervised deployment.

THE ACCIDENT

The mission

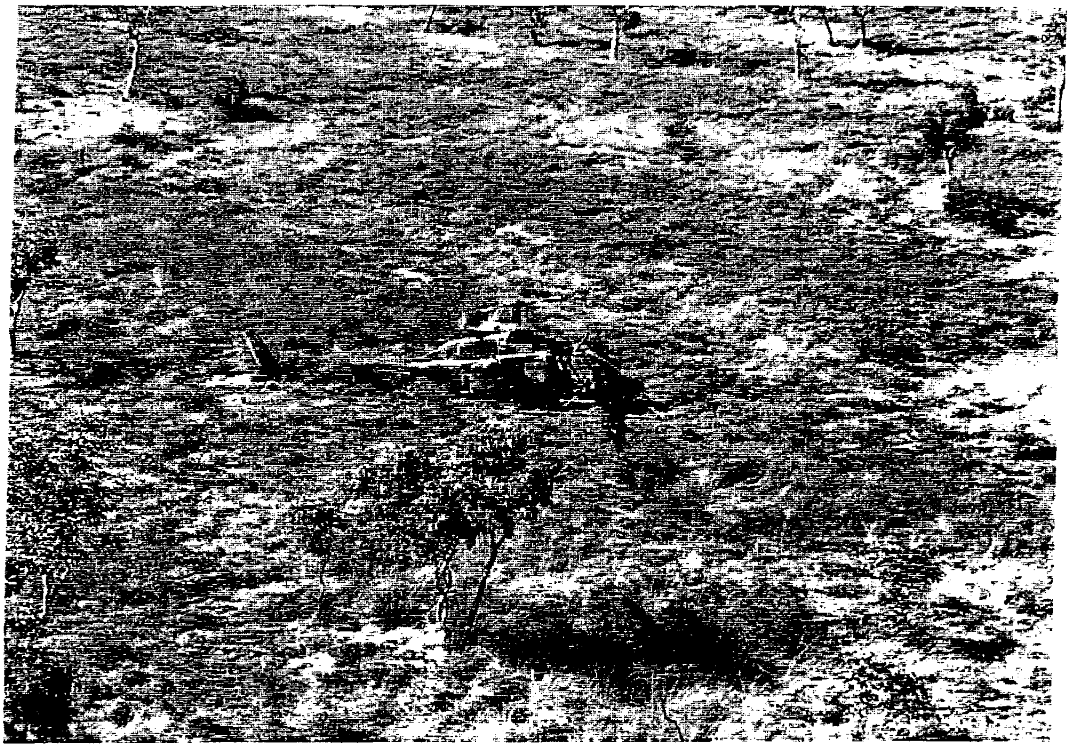
The mission being flown involved field completion to the SE of Drysdale and the area between Drysdale and Gibb River, in support of 4 Field Survey Squadron.

Previous similar accidents/incidents

A search of the Directorate of Flying Safety aircraft accident/incident data base revealed one other military accident which involved a loss of directional control. That accident, which occurred to Kiowa A17-042 near Bourke, NSW on 24 February 1980, was attributed to:

> *'a combination of factors acting in unison. The search for a triggering factor which caused the initial right yaw was exhaustive and discounted many popular technical considerations normally associated with incidents of this nature. Whilst the theory propounded is quite probably conjectural, in absence of other concrete evidence, the willy-willy phenomena must be selected as the most likely cause.'*

This accident, and advice from other Kiowa pilots regarding occurrences involving directional control, resulted in a program of flight trials into the directional



General view of the accident scene.

handling qualities of the Kiowa, being conducted by the RAAF Aircraft Research and Development Unit (ARDU).

There were no incidents recorded on the database; however, anecdotal evidence indicated that numerous other occurrences had taken place without damage to the aircraft. In some of those incidents, control was regained before rapid rotation could develop. In other cases, collective pitch was applied, altitude was increased and a successful recovery was made from a safe altitude. It was also noted that, in those cases, the yaw rate continued for several revolutions; however, the rotation did eventually subside of its own accord.

Environment

Observations by the aircraft captain after the accident indicated that the sky was clear of cloud, with an easterly wind which alternated in strength between calm and gusting strongly at 10-15 kts. The forecast weather conditions included southeasterly winds at 15 kts. Several grass fires were noted in the area of the accident, including a controlled burning-off program taking place in the Drysdale area. These fires may have contributed to the frequency and strength of the gusting wind conditions. The investigation determined that the prevailing environmental conditions were a contributing factor in the accident.

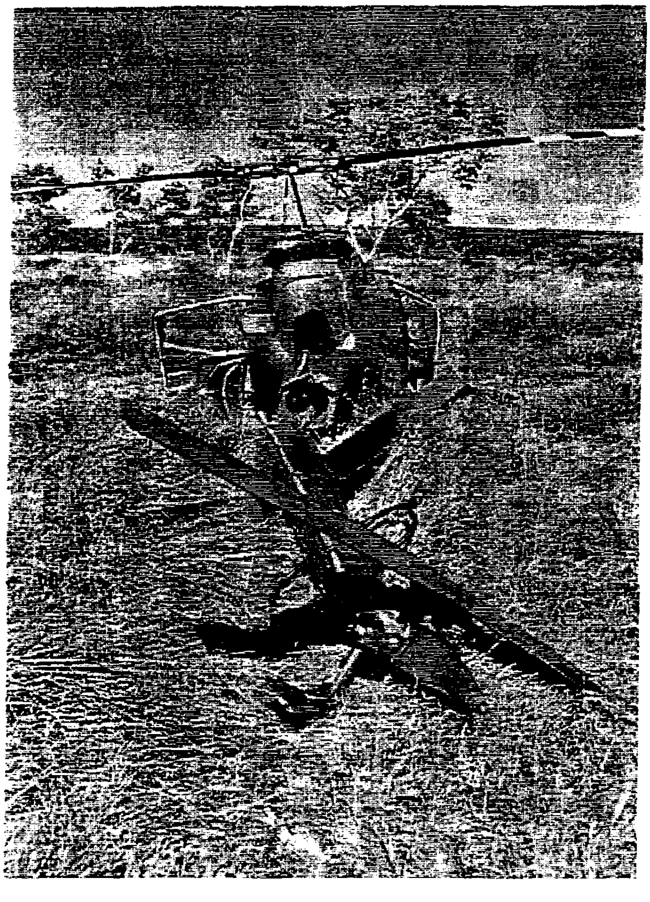
Emergency training

The main emphasis of emergency training during the Kiowa transition involved actions in the event of an engine failure. The training package including LTE was covered only in limited detail and was undergoing a rewrite at the time of the accident. Similarly, LTE emergencies were not a routine part of unit consolidation training. As a consequence, the aircraft captain had received little training in, and exposure to, the LTE phenomenon prior to the accident.

The aircraft

At the time of maintenance release for the accident mission, Bell 206B-1 Kiowa helicopter A17-021 had flown a total of 6 200.6 Airframe Hours (AFHRS). The aircraft was configured with pilot and copilot/passenger doors removed, dual controls removed and cargo platform installed. A physical inspection of the aircraft and its systems, and review of the aircraft maintenance documentation, did not reveal any unserviceabilities which would have contributed to the accident. The aircraft was serviceable when released for the accident flight and, from the evidence available, it was considered that aircraft A17-021 was serviceable and operating correctly immediately prior to the accident.

Basic Weight and Centre of Gravity (C of G). The basic weight of A17-021 was 2 062 lb with a C of G at 114.72 inches, calculated by Bell Helicopter Pacific on 20 June 1990. The aircraft was determined to be at an all up weight of 3 270 lb (maximum gross weight of the Bell 206B-1 Kiowa, internally loaded, is 3 200 lb) and at a C of G of 107.7 inches at take-off (allowable C of G being 106.0 to 112.2 inches at 3 200 lb). At the time of the accident the aircraft was at an all up weight of 3 050 lb and an arm of 107.1 inches (allowable C of G 105.8 to 112.6 inches at 3 050 lb). The aircraft was therefore above the allowable gross weight at the time of take-off, but within allowable C of G limits; however, at the time of the accident, the aircraft was within allowable weight and C of G limits.



Rear view of A17-021 revealing severe damage to tail boom assembly.

TECHNICAL ANALYSIS

Aircraft mechanical malfunction

Engineering analysis was unable to detect any aircraft systems fault which could have either contributed to the accident, or impaired occupant survivability.

Aircraft characteristics and features relevant to the investigation

Power turbine (N_2) governor RPM. The collective lever is mechanically connected via the linear actuator to the N_2 governor, which is linked to the power turbine through the output gear train. The N_2 governor senses compressor discharge pressure, N_2 turbine speed and the collective lever setting. It also determines the fuel required to meet actual power requirements and to maintain N_2 RPM, while sustaining the gas producer (N_1) turbine operation. An N_2 governor RPM switch is connected to the linear actuator. This switch, which is accessible to the pilot, permits small adjustments of the linear actuator which in turn alters the power turbine speed. During flight, the power turbine governor RPM will vary according to in-flight loads, control inputs and the rate of fuel scheduling to the engine. The pilot must therefore maintain the power turbine governor at the optimum RPM through the judicious use of the governor RPM switch and flight controls.

Loss of tail rotor effectiveness (LTE). LTE is a condition whereby the aircraft is subject to an uncommanded and rapid right yaw which does not subside of its own accord. If not quickly corrected the result can be a complete loss of aircraft control. The primary contributory causes of LTE are:

- encountering critical wind azimuths;
- ingestion of main rotor vortex;
- tail rotor precessional flapping;
- high gross weight;
- high density altitude;
- ground vortex interference;
- N_2 Governor RPM underspeed; and
- low forward airspeed.

Aircraft Research and Development Unit (ARDU) Technical Investigation No 721: *Bell 206B-1 Directional Control In Low Airspeed Flight.* ARDU Report No 721 was commissioned in 1981 following a number of incidents/accidents associated with directional control of the Bell 206B-1 helicopter.

The report cited several factors which:

> *'in some combination, may result in loss of directional control of the helicopter. Of these factors, operation of the tail rotor in the vortex ring state was considered most likely to be the trigger for loss of directional control.'*

Hover performance. Hover capability varies depending on whether the aircraft is in ground effect (IGE), or out-of-ground-effect (OGE), and is affected by outside air temperature, wind velocity, engine torque (power available) and gross weight of the helicopter. Examination of DI (AF) AAP 7210.010-1 Flight Manual, Bell 206B-1, indicates that at the gross weight of 3050 pounds, 67 psi torque is required to hover OGE, from an available torque of 74.3 psi. This represents a margin of 7 psi, which is considered adequate, for the aircraft to terminate to an OGE hover. It would however provide a minimal or zero margin in the event of the manoeuvre being mishandled.

Height vs velocity for safe autorotation. The coordinates of density altitude versus gross weight, indicate the range of various parameters from which a landing may be considered safely achievable ie, without aircraft damage, in the event of an engine failure.

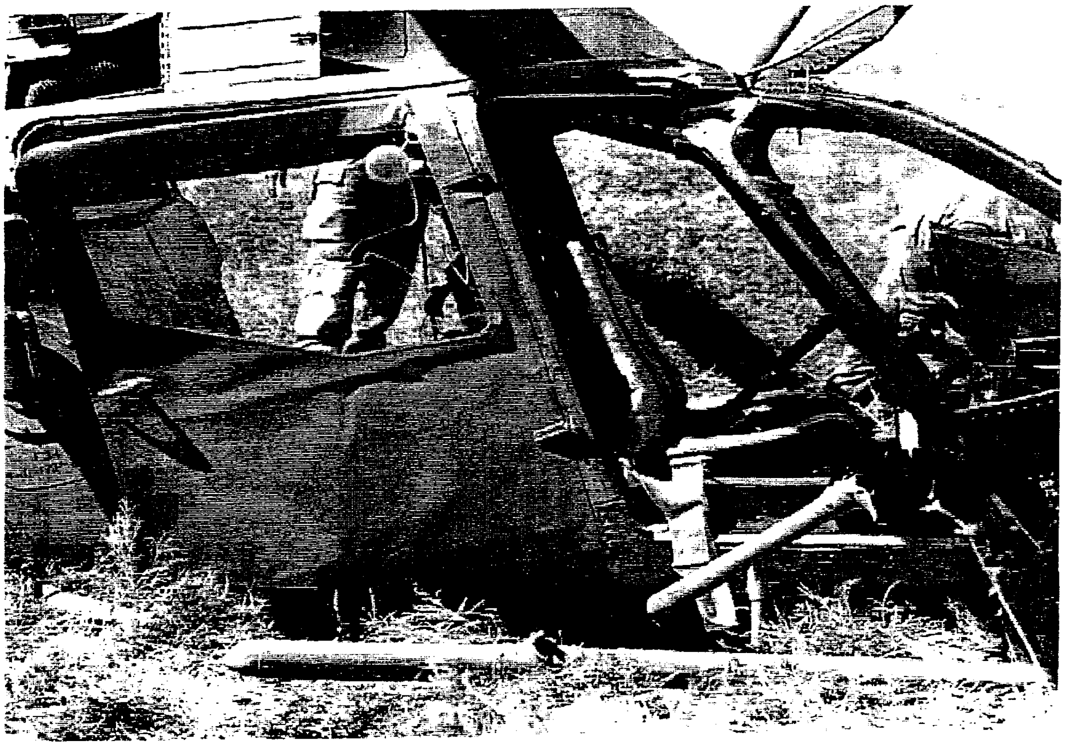
HUMAN FACTORS ANALYSIS

During the investigation, a number of Human Factors issues were addressed as follows:

- pilot workload;
- situational awareness (SA);
- assessment of wind effect;
- decision-making;
- stress; and
- organisational issues, which include training and supervision.

Pilot assessment of wind effect

The pilot assessed the wind direction to be from the east. The wind direction at the two nearest locations both indicated a prevailing wind direction of 070°. The manoeuvre conducted by the pilot placed the aircraft 90° out of wind at best (with a wind direction from the east) and possibly downwind (with a wind direction of 070°). These conditions coincided with that portion of the manoeuvre where the aircraft captain was applying power to arrest the rate of descent and to terminate to an OGE hover.



Human Factors conclusions

It was concluded that Human Factors issues were significant in this accident, specifically the pilot's:

- training, experience and supervision; and
- situational awareness and decision-making process, in particular his assessment of wind effect, which was possibly adversely affected by pre-existing and self-imposed stressors.

FINDINGS

The aircraft Accident Investigation Team found that significant factors contributing to the accident were that the aircraft captain:

- manoeuvred the aircraft into a situation which resulted in LTE; and
- subsequently retarded the throttle to idle, after control inputs to correct an LTE situation had failed, and, in doing so, accepted a landing over which he had little control.

Contributory to the above were:

- the pilot's training, experience and supervision;
- the pilot's SA and decision-making process, in particular his assessment of wind effect, which was possibly adversely affected by pre-existing and self-imposed stressors; and
- the prevailing environmental conditions.

RECOMMENDATIONS

The significant recommendation was that the content of training courses be reviewed with respect to the conduct of LTE emergencies. ✈

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REVIEW OF ACCIDENT INVOLVING S-70A-9 BLACK HAWK HELICOPTER A25-217

Controlled Flight into Terrain (CFIT) accident, near Oakey, Queensland on 29 June 1992.

FACTUAL INFORMATION

History of the flight

At 1552 hrs on 29 June 1992, School of Army Aviation (SAA) S-70A-9 Black Hawk A25-217 departed Oakey Army Airfield, Queensland, for a familiarisation mission in the Oakey local flying training areas. The crew comprised a Qualified Flying Instructor (QFI) as aircraft captain, a Qualified Loadmaster Instructor (QLI) as loadmaster and another QLI, in the copilot seat, assisting the captain in his piloting duties. Other non-crew occupants comprised an aircraft handler and five Specialist Service Officers (SSO) cadets. The purpose of the flight was to familiarise the SSO cadets, who were to commence basic flying training in July 1992, with Black Hawk operations.

The accident occurred at 1604 hrs when the aircraft entered a low-level right-hand break turn in training area Lima One, a promulgated low flying area 20 km north west of Oakey airfield. After the aircraft had turned through approximately 270°, the main rotor blades struck the ground. Immediately thereafter, the aircraft impacted the ground, bounced and rolled left through 720° (impacting the ground as it passed through the inverted attitudes) before coming to rest in an upright attitude.

Fatalities and injuries

Two personnel died as a result of the accident and seven survivors suffered injuries, ranging from lacerations, bruising and whiplash to extensive soft tissue contusions and dispersed minor fractures.

The aircraft captain, the QLI in the copilot seat and the four rearmost passengers were injured but egressed the aircraft without assistance. The loadmaster, who occupied the Row 1 left seat, was injured and required assistance to egress the aircraft. The aircraft handler and an SSO cadet, who occupied, respectively, the Row 1 right and middle seats were killed. These members were trapped under the aircraft and could not be freed by the survivors.

Damage

The aircraft was destroyed by impact forces. Damage to civilian property was limited to an area of some 2 500 square metres of sorghum crop and the cutting of several fences by rescue personnel.

Personnel involved

The aircraft captain was a 26 year old QFI with the SAA based at Oakey, QLD. He graduated as an Army pilot in June 1989 and then served for two and a half years as a staff pilot at 5 Avn Regt. He completed Black Hawk instructor training in the USA in March 1992 and commenced Black Hawk instructional duties at the SAA in May 1992. He was employed as a Category C QFI at the SAA at the time of the accident.

THE ACCIDENT

The mission

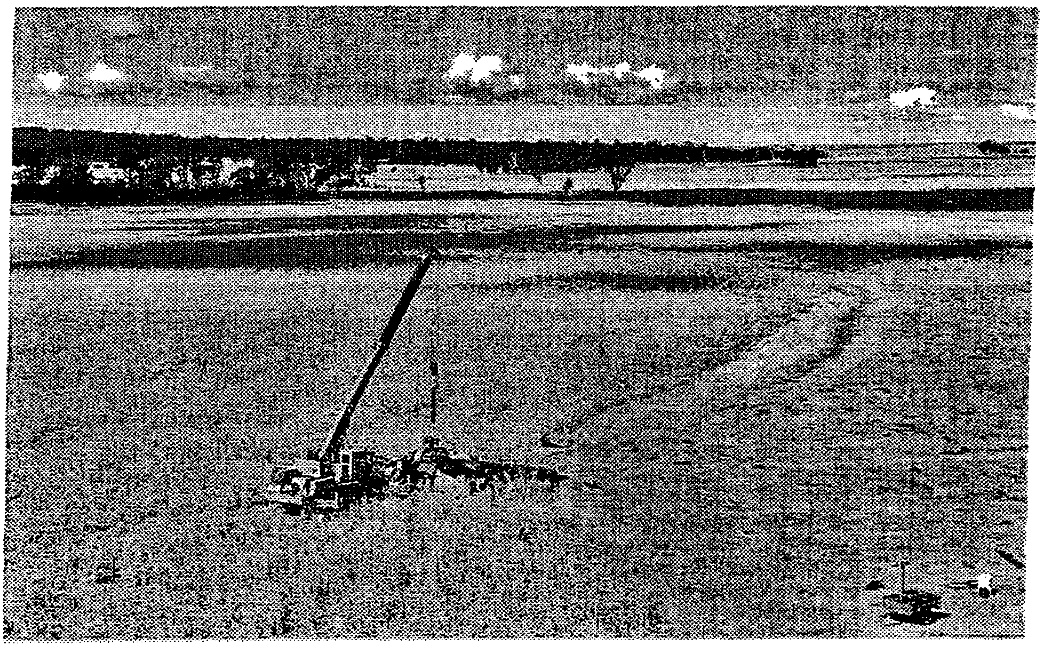
The purpose of the flight was to familiarise the SSO cadets, who were to commence basic flying training in July 1992, with Black Hawk operations. Given the nature and purpose of the flight, a detailed mission briefing was not conducted; however, a passenger briefing was conducted by the aircraft captain. In addition, the authorising officer had directed that the aircraft captain was to take due care and not do anything likely to induce airsickness in his passengers.

The captain could not recall the exact details of his briefing to the loadmaster occupant of the copilot seat. However, he indicated that his usual briefing to non-pilot crewmembers located in the cockpit included the operation of radios (including distress calls) and duties during emergencies (ie, switch selections, etc). The occupant of the copilot seat recalled that the briefing comprised the operation of radios and the actions he was required to perform during emergencies.

The aircraft captain had flown a mission similar to that during which the accident occurred on the morning of the same day. Break turns similar to the one during which the accident occurred had been executed several times during that mission.

The accident flight sequence

After the aircraft had turned through approximately 230° of the right-hand break turn (ie, as the aircraft passed through a heading of 007°M), the advancing main rotor blades on the right side of the aircraft began to strike the ground, the blade tip caps disintegrating at initial impact. The angle of bank at initial rotor blade strike was approximately 42° and the sideward velocity of the aircraft (to the left) was 22 kts.



General view of accident scene.

The aircraft then continued to drift on a bearing of 340° with the aircraft heading 025°. After 22 metres of travel from the rotor blade strike, the right main undercarriage struck the ground. This caused the main undercarriage to separate from the fuselage, taking the supporting box section with it. (The box section supports the cabin roof and ties the floor to the aircraft).

After a further four metres, the fuselage impacted the ground. The fuselage had now slewed to a heading of 084°. At this time, the tail wheel and left main undercarriage impacted the ground and the fuselage received significant damage to the left hand box section. The aircraft then became airborne and started a roll to the left with the stabilator remaining in contact with the ground. The tail rotor gearbox impacted the ground as the aircraft rolled through the inverted attitude. The aircraft briefly landed, inverted, after another 18 metres of travel on a bearing of 360° with the fuselage still heading 084°.

The aircraft then became airborne for a second roll to the left. At this point, the tail rotor gearbox and one main rotor blade separated from the aircraft. The aircraft again landed, inverted, after a further 13 metres of travel on a bearing of 357° with the fuselage heading 083°.

On the second inverted landing the remaining three rotor blades separated. The tail boom broke away from the fuselage but remained attached by electrical and control cables. At this point, the forward roof section collapsed onto the floor of the aircraft and the forward fuselage cowling separated.

The fuselage then commenced a final airborne roll to the left, dragging the inverted tail boom with it. This roll was on a bearing of 359° with the fuselage landing upright on a heading of 084°. The tail boom remained inverted, aligned on a heading of 015°.

Previous similar occurrences

A search of the (then) Directorate of Air Force Safety aircraft incident database, indicated one previous incident involving Australian Army Black Hawk aircraft which was considered relevant to the investigation. On 7 September 1990, Black Hawk A25-210 was conducting a right hand 270° turn on approach to a landing zone. The entry speed was 120 kts and height above ground was 50 ft. During the approach, the QFI looked outside the aircraft to check for orientation. Upon looking back inside the cockpit, he noted that the student had rolled the aircraft to 70° angle of bank and had allowed the nose to descend below the horizon. When the QFI drew the student's attention to the rate of descent, he (the student) increased the collective sharply but made no cyclic correction. As the descent continued, the QFI twice instructed the student to roll wings level. Upon taking control of the aircraft, the QFI found that the student had applied full left cyclic. Despite the full cyclic application, the aircraft began to roll only slowly towards wings level. Noting that rotor RPM was about 96-97 per cent, the QFI reduced collective slightly to regain rotor RPM, as a result of which roll rate improved slightly. The descent bottomed out approximately 10 ft above trees.

Following flight trials conducted by the unit QFI, the cause of the reduced control power was attributed to the effects of the 'four-per-revolution' vibration.

Relevant piloting practices

Interviews with Black Hawk pilots indicated that pilot monitoring of torque settings is not as rigorous in the Black Hawk as it is in other aircraft. In essence, given the high torque limits of the Black Hawk, pilots tend to apply collective inputs as required, without close reference to the torque instruments, in the belief that aircraft limits will not be exceeded.

Environment

Meteorological observations in the vicinity prior to the accident indicated light northeasterly winds and a temperature of 18°C. The sun position at the time of impact was bearing 300°M from the impact site and an elevation above the horizon of 12°. For the sun not to have been a distraction, the aircraft captain would need to have been looking through the side window, rather than through the front windscreen, during the latter stages of the turn. The investigation concluded that the sun would have inhibited an accurate perception of aircraft attitude during the latter stages of the turn.

Operational documentation

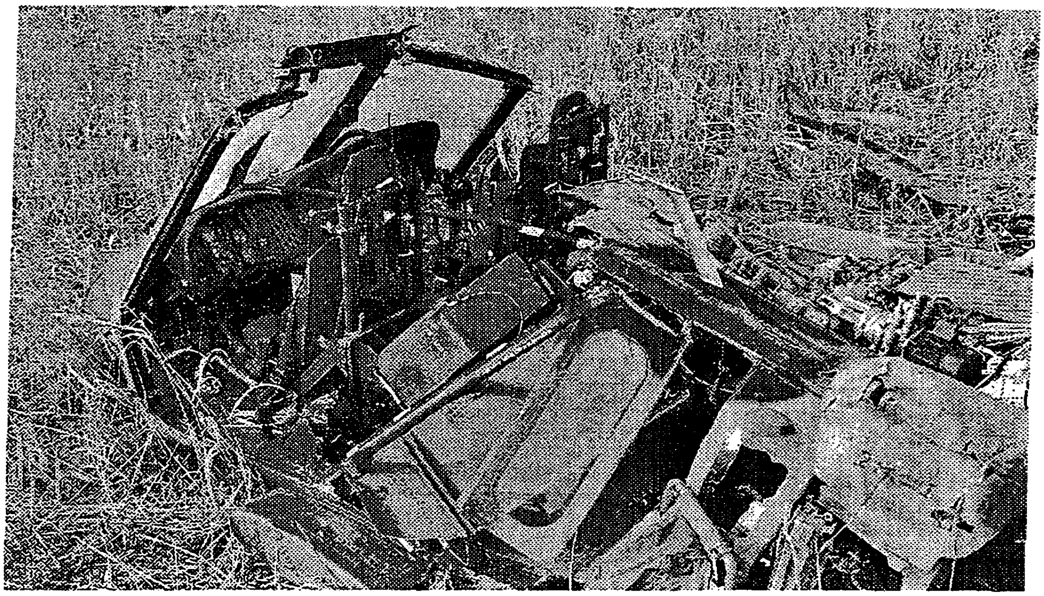
Minimum crew requirements. The Black Hawk Flight Manual, the only operational publication at that time containing information on minimum crew requirements in Australian Army Black Hawk aircraft, states:

> *'The normal crew required to fly the helicopter is pilot and copilot. Additional crewmembers may be added as required. The minimum crew requirement for visual flight rules (VFR) operations shall be a pilot trained and qualified in single pilot operations, and a trained observer (TO).'*

No documented training requirements existed in the Australian Army to train and qualify a pilot in 'single pilot operations' and there was no documented requirement to endorse aircrew documentation (eg, Pilots' Log Books, pilot categorisation records, etc) with such qualification. Similarly, no documented training or endorsement requirements existed for trained observers (TO), nor was there any document which specified those persons who may be employed as TO. Indeed, the term 'TO' or 'Trained Observer' (as opposed to the Aircrewman Observer) was not in general usage within the Australian Army.

SAA Mass Briefing Manual. The SAA Mass Briefing Manual is issued to instructors and students at the SAA. The document was not specified in Unit Flying Orders (UFO) or unit Standard Operating Procedures (SOP) as being authoritative, the only reference to it in SOP being on the matter of formation flying. On the matter of break turns, the manual states:

*'**Break Turns:** A break turn is used as a last resort to avoid a collision. The object is to turn the helicopter rapidly to avoid a midair or Air Defence System. In*



Cockpit area of A25-217 was extensively damaged during tumbling manoeuvres after initial impact.

practice, we turn through 180°. In order to do this, the procedure is to ROLL, POWER and PULL. That is, ROLL to the maximum AOB for level flight (generally about 70-80° AOB), apply maximum POWER (aim for 100 per cent) and PULL aft cyclic until the onset of the 4:1 vibration. This combination will give the maximum turn rate at current IAS and altitude. BEWARE that the nose does not get below the horizon and a rapid rate of descent allowed to develop. If this does happen, the recovery is to decrease the AOB until the nose recovers to the desired attitude. At the completion of 180° of turn, simultaneously roll wings level and reduce the power. During the turn, the copilot should monitor the power and inform the pilot of the amount applied.'

Of significance to the investigation was the procedure of applying aft cyclic until the onset of the 4:1 vibration, the admonition relating to the avoidance of a nose-low attitude and consequential high rates of descent, and the recovery procedure in such circumstances of decreasing the angle of bank until the 'nose recovers to the desired attitude'. Although this section of the manual does not constitute an SOP as such, its significance to the investigation was that, as an instructor at the SAA, the aircraft captain was required to be familiar with the content of the manual, was required to instruct students in accordance with the procedures documented therein, and thus could reasonably be expected to perform the manoeuvre in accordance with those procedures.

Relevant loadmaster duties. Annex A to Employment Specification ECN 004 (AIRCMAN LOADMASTER) lists one of the main job functions of loadmasters as providing the *'aircraft captain with clearances from obstacles'*. (It is generally understood that, for the purposes of this obstacle clearance responsibility, the ground itself constitutes an obstacle.)

The aircraft

The aircraft was a Sikorsky S-70A-9 Black Hawk, Australian Army serial number A25-217, which was accepted into service on 10 August 1990 and had accrued 490.8 airframe hours prior to the flight on which the accident occurred. The aircraft was configured without the External Stores Support System (ESSS). Examination of existing EE500 records revealed no unserviceability trends. There was no documentary evidence to indicate that A25-217 had ever exhibited adverse handling characteristics, and statements by SAA pilots who had flown the aircraft confirmed the documented record.

Black Hawk characteristics

Characteristics and features of the S-70A-9 Black Hawk relevant to the investigation were as follows:

Four-per-revolution vibration. Asymmetrical aerodynamic main rotor blade loading results in a vibration – capable of being felt in the cockpit – known as the *four-per-revolution* vibration. This vibration is most intense during low-speed flight and periods of high aerodynamic loading on the main rotor, a condition known as *high disc loading*. The significance of this vibration is that it reduces main rotor thrust and hence control power.

Flare effect. During normal power-on flight in any helicopter, airflow is induced down through the rotor disc. This is known as *induced flow*. However, during a decelerative manoeuvre or a turn, airflow also flows from below the rotor disc. This is known as an *autorotative* or *rate of descent flow*. Autorotative flow works to cancel out the induced flow, the effects being an increase in the angle of attack of the main rotor, increased thrust, decreased rotor drag and a decrease in torque. The net result of these effects are to increase main rotor RPM (N_R).

Transient droop. A condition whereby the power turbine RPM (N_P) and N_R temporarily decrease below optimum is known as transient droop. The condition is possible in all helicopters and is caused by large collective inputs, the degree of N_p and N_R reduction depending on the rate of collective application and the characteristics of the fuel governing system. Another cause of transient droop, and one which is peculiar to the S-70A-9 Black Hawk, is an ECU- commanded reduction in fuel flow followed by commanded flight loads on the main rotor (this can be in the form of a collective or cyclic input). The ECU commanded reduction in fuel flow is occasioned by reduced load demands on the engines arising from an N_R overspeed condition (only a marginal increase in N_R is required). This will occur regardless of Load Demand Spindle (LDS) position. In the Black Hawk, therefore, transient droop can occur whilst the aircraft is experiencing an N_R overspeed resulting from flare effect. The resulting transient reduction in N_p and N_R may be of such magnitude as to initiate low N_R audio and visual warnings. The aerodynamic effects of transient droop are to reduce main rotor thrust, tail rotor thrust and control power.

Cockpit visibility. By comparison with other Australian Army helicopters, cockpit visibility to the front and side is somewhat limited in the Black Hawk. This characteristic is particularly pronounced for a pilot seated on the turn direction side of the aircraft when looking forward and to the inside of the turn.

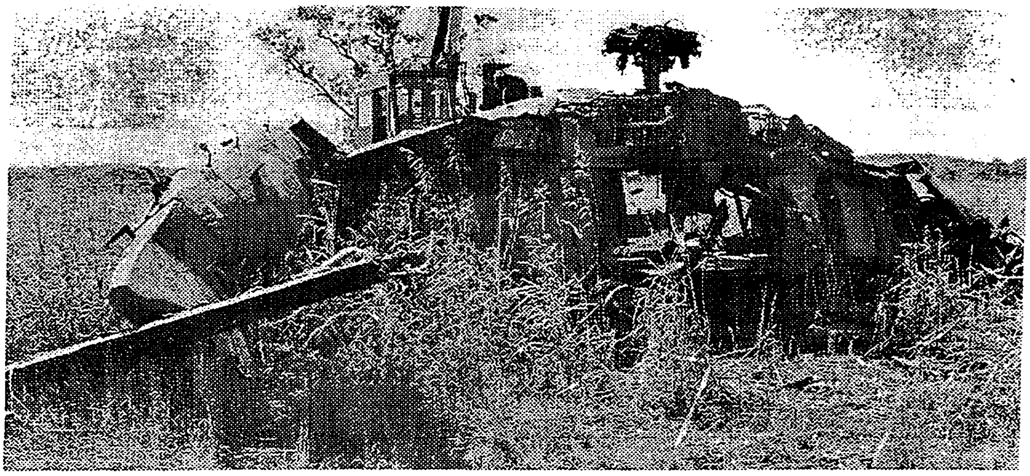
ANALYSIS

AIT analysis

The AIT firstly established the actual turn parameters, namely:

- height above ground and indicated airspeed immediately prior to turn entry;
- *angle of bank in the turn;*

Destruction of cockpit and forward cabin area of A25-217 is clearly evident.



Rear view of A25-217 depicting almost complete destruction of the airframe.

- turn entry technique and initial rotor tip height AGL; and
- indicated airspeed after 180° of turn.

The main focus of the investigation was then to determine whether:

- an aircraft system malfunction occurred which induced a rate of descent and/or reduced the effectiveness of the cyclic control; or
- the captain inadvertently flew the aircraft into the ground as a result of a piloting error or errors.

Among the areas investigated were:

1. An engine or transmission malfunction or failure – due to:

- engine flameout – the conclusion was that neither engine experienced flameout prior to impact.
- engine overspeed in flight – the conclusion was that both engines oversped and subsequently automatically shut down due to main rotor separations during the impact sequence.
- transmission failure – the conclusion was that transmission failure did not occur.

2. Tail rotor failure. The conclusion was that a failure of the tail rotor drive train or tail rotor blades did not occur. In addition, the conclusion was that a loss of tail rotor thrust for other reasons almost certainly did not occur.

3. Flight Control System (FCS) failure. The serviceability of FCS components could not be determined with certainty; however, on the weight of evidence, it was considered that it was highly probable that it was functioning correctly at the point of impact.

4. An apparent reduced cyclic control effectiveness – arising from:

- four-per-revolution vibration – the conclusion was that reduced cyclic control effectiveness arising from four-per-revolution vibration did not occur; and
- transient droop due to:
  - large collective input; or
  - flare effect.

The conclusion was that if a reduced cyclic control effectiveness actually occurred during the attempted roll-out from the turn, that reduction was probably occasioned by a transient droop condition induced by a combination of flare effect, ECU commanded fuel flow reduction and the application of a large left cyclic input.

5. Non-perception of an irrecoverable rate of descent. The conclusion was that:

- a rate of descent relative to the ground occurred and that this rate of descent was never perceived by the pilot;
- the failure of the pilot to perceive the rate of descent probably resulted, in part, from the restricted view from the cockpit towards the inside of the turn and, in the latter stages of the turn, from the effect of the sun; and
- the rate of descent developed as a result of the captain applying insufficient aft cyclic to sustain level flight, probably as a result of his consideration for his passengers.

BOI Analysis

The BOI suggested several possible mechanical failures; however, analysis of aircraft systems, inspection of the wreckage and evidence presented before it, eliminated all but the possibility of a low side failure of one of the engines. However, the Board concluded that, on the balance of probabilities, if a low side failure occurred, the rate of descent that ultimately caused A25-217 to crash, had already manifested itself and was not initiated by a low side failure.

The Board reached a different conclusion to the AIT, with respect to the mechanics of the turn. This, combined with differing and unclear accounts from survivors of the final turn, made it impossible for the Board to determine exact turn parameters.

FINDINGS

AIT Findings

The aircraft AIT found that significant factors contributing to the accident were that the aircraft captain:

- allowed the aircraft to develop a rate of descent during the execution of a break turn at low altitude; and
- failed to perceive that rate of descent, and react to it in sufficient time, before the aircraft's main rotor blades struck the ground.

Contributory to these factors were:

- the limited view from the cockpit towards the inside of tight turns in Black Hawk aircraft, particularly from the pilot seat on the inside of the turn;
- the effect of the sun on the captain's perception of aircraft attitude and altitude during the final stages of the turn; and
- a reduced roll-rate during the attempted roll-out, which may have prevented any possibility of avoiding impact with the ground, and which probably resulted from reduced control power arising from a transient droop condition induced by a cyclic input, whilst the engines were undergoing an ECU commanded reduced fuel flow.

BOI Findings

From the evidence presented to the BOI, the Board was unable to reach a firm conclusion, beyond reasonable doubt, as to what caused A25-217 to crash. Notwithstanding, the Board concluded that, on the balance of probabilities, a significant factor contributing to the accident was that the aircraft captain allowed the aircraft to descend into the ground.

The Board determined that contributory to the above was:

- the absence of a second pilot in the cockpit;
- one or more of a number of factors affecting the performance of the aircraft when recovery was attempted; and
- environmental factors which may have led the pilot to reach an irrecoverable situation before he realised it.

Finally, the Board could not rule out the possibility that the accident may have been due to an event beyond the pilot's control.

RECOMMENDATIONS

The Board determined that there was no evidence to support the need for any immediate action to prevent a recurrence of the accident. Notwithstanding, several recommendations were made, in order to address secondary issues.

Significant recommendations were that:

- flight data recorders be fitted to all Army aircraft;
- Black Hawk crewing be reviewed; and
- ARDU be tasked to further investigate the flight characteristics of Black Hawk aircraft, particularly in high performance turns. ✈

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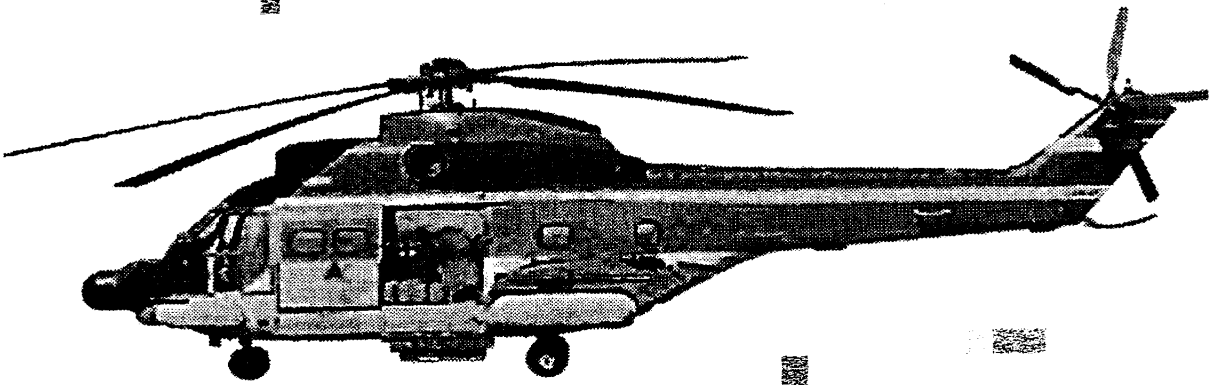
BUREAU OF AIR SAFETY INVESTIGATION REPORT

BASI Report B/915/1020



Puma SA 330J Helicopter VH-WOF
Mermaid Sound WA
12 May 1991

BASI
Bureau of Air Safety Investigation

Department of Transport

Department of Transport and Communications

Bureau of Air Safety Investigation

ACCIDENT INVESTIGATION REPORT
B/915/1020

Puma SA 330J Helicopter VH-WOF
Mermaid Sound Western Australia
12 May 1991

BASI

Released by the Director of the Bureau of Air Safety Investigation
under the provisions of Air Navigation Regulation 283

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CONTENTS

SYNOPSIS

The aircraft was tasked to carry out a marine pilot pick-up from a departing tanker. The flight was conducted by two pilots operating under night visual flight rules. Conditions were a moonless night with no defined horizon, no outside lighting other than from the ship, and a surface wind that was light and variable. The ship was steaming in a northerly direction at 12.5 kts.

The flight proceeded normally until the aircraft was established on final approach to the helideck. As the aircraft descended through 500 ft the rate of descent had increased to about 1,000 ft/min. Although the pilot in command increased main rotor pitch, the aircraft's rate of descent continued to increase until just prior to impact with the water. Both occupants were rescued approximately 1 h after they evacuated the helicopter.

The report concludes that the standard approach technique used by the pilots, coupled with the prevailing weather conditions, caused the aircraft to enter a high rate of descent shortly after the aircraft started its normal final approach to the deck. The high rate of descent was probably the result of entry to the incipient stage of 'vortex-ring state'. A lack of visual cues and inadequate management of cockpit resources prevented the crew from recognising the abnormal situation until the aircraft was well into the descent. Recovery action was commenced too late to prevent impact with the water.

1 FACTUAL INFORMATION

1.1 History of the flight

The helicopter, with two pilots on board, was engaged in a night charter flight from Karratha to a departing liquefied natural gas (LNG) tanker to collect two marine pilots. The departure and night visual flight to the final descent point were normal.

Following an approach briefing from the pilot in command, and radio advice from the ship which indicated the relative wind was from 010° at approximately 5 kts, the crew commenced the final approach from a 'gate', which is an initial approach point in level flight at 55 kts and 550 ft AMSL, approximately 0.75 NM astern of the ship. At the time, the ship was steaming in Mermaid Sound in a northerly direction at 12.5 kts, 20 km north-west of Dampier, Western Australia. As the aircraft passed through the 'gate', airspeed was reduced to below 35 kts (minimum indicator reading) and the descent was started by reducing main rotor pitch angle and selecting the correct sight picture in the windscreen. At approximately 500 ft the co-pilot, who was monitoring the instrument indications, reported the rate of descent as 1,000 ft/min. The allowable maximum rate of descent was 500 ft/min. The pilot increased the collective pitch in an attempt to reduce the rate of descent. The corrective action had little or no effect as the rate of descent continued to increase until a slight reduction occurred just prior to impact.

The accident occurred at 2133 hours Western Standard Time (Co-ordinated Universal Time + 8 h) at position 20°24' south and 116°43' east, when the aircraft impacted the water, rolled to the right and overturned. One of two liferafts stowed in the cabin area was dislodged and inflated. The flotation gear was not deployed.

The inflated liferaft provided sufficient additional buoyancy for the aircraft to remain afloat for 2 h. The crew evacuated the aircraft through the co-pilot's door and remained on the floating wreckage before transferring to a dinghy dropped by another helicopter. They were rescued by boat approximately 70 min after the accident. The aircraft sank but was subsequently recovered and transported to Karratha for inspection.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	–	–	–
Serious	1	–	–
Minor	1	–	–
Total	2	–	–

1.3 Damage to aircraft

The helicopter sustained substantial damage: the main rotor blades were destroyed, the tail boom and rotor were torn off, and the main fuselage was severely dented. In addition, the co-pilot's seat collapsed and one flotation bag was torn from its stowage. The aircraft also suffered considerable damage as a result of salt-water immersion.

1.4 Other damage

Nil

1.5 Personnel information

The pilot in command was aged 53 years. He held a current Senior Commercial Pilot Licence (Helicopters) with a valid medical certificate and was endorsed to fly Puma SA 330J helicopters. At the time of the accident he had a total flying experience of 11,100 h, 1,400 of which were on the Puma helicopter. His most recent night-flying check had occurred on 12 December 1990. The pilot in command had been a check-and-training captain on the Puma aircraft during previous employment with the operating company and had extensive experience as a helicopter instructor.

The co-pilot was aged 42 years. He held a current Senior Commercial Pilot Licence (Helicopters) with a valid medical certificate and was endorsed to fly Puma SA 330J helicopters. At the time of the accident he had a total flying experience of 7,800 h, 2,400 of which were on the Puma helicopter. His most recent night-flying check had occurred on 11 May 1991. In addition, he held an appointment as a company check-and-training captain.

Both pilots were adequately rested prior to the flight, were within their normal duty period and had no known medical abnormalities at the time of the accident.

The pilot in command had been a crew member during at least eight other approaches to an LNG tanker during the preceding five months. Most of the approaches were made during the period around sunrise.

On the night prior to the accident, the co-pilot, whilst acting both in his capacity as a check-and-training captain and as a captain under check, had supervised and conducted approaches and landings to the same ship during a flight check with another company pilot. The approaches were made towards the coast where there were additional light sources, which provided additional visual cues that helped in the judgment of the approaches.

Both pilots had extensive experience in offshore day-and-night helicopter operations and whilst they were aware of the possibility of problems caused by visual illusions, neither pilot had personal experience with them. The pilot in command had extensive experience with the 'vortex-ring state' as an instructor in light, single-engine helicopters.

1.6 Aircraft information

The aircraft, registered in Australia as VH-WOF, was an Aerospatiale Puma SA 330J, Serial Number 1508, manufactured in France in 1977. It had completed 9,836 h at the time of the accident. Valid Certificates of Airworthiness and Registration and a current Maintenance Release were in force and the aircraft was fully serviceable.

The aircraft's weight and centre of gravity were within specified limits, and there was adequate fuel on board to complete the flight.

1.7 Meteorological information

Weather conditions at the time of the accident were consistent with the forecast and included a moonless night, no defined horizon, a strong easterly wind at altitude (2,000 ft), and a light and variable wind at sea level (dying sea breeze). The wind at 500 ft AMSL was assessed by the Bureau of Meteorology as light and variable, possibly from the south-east (beginning of the land breeze). The temperature was 28°C.

1.8 Aids to navigation

Not relevant.

1.9 Communications

The only communication of relevance was the report from the ship to the helicopter crew, which indicated that they could expect a 5-kt headwind during the final approach.

1.10 Aerodrome information

The helideck was situated on the stern of the LNG tanker, behind the funnel and cabin-bridge superstructure. It met all the Civil Aviation Requirements for a helicopter landing area for the Puma aircraft.

1.11 Flight recorder

The helicopter was not fitted nor required to be fitted with a flight data recorder.

The helicopter was fitted with a Fairchild A100A four-track cockpit voice recorder (CVR). The recording medium was an endless-loop, plastic-based, magnetic tape with a recording duration of 30 min. Although salt water had penetrated the unit and caused corrosion on the tape transport assembly, the magnetic tape was intact.

The pilots' conversation was recorded clearly on channels 1 and 2. The cockpit area microphone (channel 3) recorded a high background noise, rendering it unuseable. A useable main rotor RPM trace was recorded on channel 4. The conversation channels were analysed for content, timings and stress, and the main rotor RPM channel was analysed for RPM, timings, noise and frequency.

Information from the CVR was used extensively during the analysis of the factors that led to the accident. A review of the timings indicated that the co-pilot's comment that the rate of descent was 'a bit high' started 17 s prior to impact, was completed 11 s prior to impact and was acknowledged by the pilot in command between 10 s and 8 s prior to impact. The co-pilot made a comment about the radar altimeter reading 2 s prior to impact.

1.12 Impact information and wreckage examination

The helicopter contacted the water at a high rate of descent and at zero forward speed. It was estimated that the rate of descent at impact was 2,000 ft/min. The flotation bags were not set to inflate automatically and they were not inflated manually. First contact with the water was made by the lower fuselage section that slopes up at 15° aft of the cabin floor area. The main rotor blades shattered when they struck the water and aft fuselage. The tail boom was severed in a downwards direction by the impact. The tail rotor blades were severely damaged. Immediately after the initial impact, the aircraft rolled to the right and the forward right fuselage made solid contact with the water. During this contact, the lower right windscreen panel was destroyed and the surrounding fuselage severely dented. The force of the impact caused the co-pilot's seat to collapse and one of the liferafts stowed in the cabin area was dislodged, causing it to inflate.

The recovered wreckage was examined in detail at Karratha. A number of instruments and the CVR were removed for examination. It was determined that all damage was a result of water impact and immersion and that all systems appeared capable of normal operation prior to the impact.

1.13 Medical and pathological information

A review of the pilots' medical histories indicated that neither pilot had any known pre-existing medical or psychological condition that might have contributed to the accident. There was no evidence of pilot incapacitation during the accident sequence.

The pilot in command received head injuries during the impact that caused some disorientation and led to his delay in exiting the aircraft. He also ingested a considerable amount of water. The accident injuries caused significant post-trauma medical problems for the pilot in command.

1.14 Fire

There was no fire.

1.15 Survival aspects

The crew were not expecting to make contact with the water and were unprepared when the aircraft did so. In addition, the pilot in command was dazed when he was thrown against the side of the cockpit during the impact. Both pilots were disorientated by the inverted position of the helicopter and the darkness. However, they reported that they were able to find their way out through the co-pilot's door because it was highlighted by the emergency strip lighting. The operator had fitted this emergency exit lighting to the cockpit doors following a previous accident.

The aircraft was fitted with flotation equipment. The emergency flotation system was armed and the co-pilot was monitoring the manual inflation system, as briefed, during the descent.

However, the unexpected impact prevented its activation. The aircraft was fitted with immersion switches which would cause the flotation gear to inflate if the aircraft was immersed in water, but these were not armed. The company was awaiting approval from the Civil Aviation Authority (CAA) before activating the system. The right-hand flotation bag was dislodged by the impact.

The impact dislodged one of two liferafts stowed in the cabin area. It inflated inside the cabin, providing sufficient additional buoyancy to keep the fuselage afloat for about 2 h. The crew remained on the wreckage while they awaited rescue.

A liferaft was dropped to the crew from another helicopter approximately 1 h after the accident. The crew encountered difficulty operating the inflation mechanism as they had to swim to the raft and each time they pulled on the toggle the raft followed. The raft was eventually inflated by one of the crew placing his feet on the raft as he pulled the toggle.

The tanker was unable to provide assistance as it required a considerable distance to slow and turn about. The crew was rescued by a boat from a tender vessel approximately 70 min after the accident.

The aircraft was fitted with an automatically deployable emergency locator transmitter (ADELT). Although the ADELT was armed it did not deploy because the impact sequence prevented the immersion switch entering the water before electrical power from the main battery was terminated by submersion.

1.16 Tests and research

1.16.1 Visual illusions

Many previous helicopter accidents during night approaches to landing areas over dark terrain or water have been attributed to the lack of sufficient visual information to enable the pilot to judge his position in space accurately.

UK Department of Transport Air Accidents Investigation Branch Report 5/88 concerning an accident involving a night approach to a helideck states that:

> ...a difficulty which is relevant to approaches to platforms and ships at night, is that these may be the only light source in an otherwise totally dark environment. A single light source phenomenon has long been recognised by the aviation community as one which contributes nothing to the pilot's judgement of distance. In this context, although the platforms or ships have considerably more than one light, when viewed from a distance [e.g. at the commencement of a final approach], they may be considered as a single light source. The usual effects of this phenomenon are that the pilot is deprived of the visual cues normally associated with daylight vision. These are:
>
> 1. the relationship of the object to the horizon;
> 2. the relationship to other objects and the surface texture between the aircraft and the object in view; and
> 3. the use, for ranging, of the angle subtended at the viewer's eye by the object, because:
>   (a) the absolute size of the object is uncertain, and
>   (b) the judgement of this angle when it is very small is difficult.

1.16.2 Glide path indication

Investigations of this and other accidents that have occurred during approaches to offshore landing areas (particularly at night) and comments made by both pilots and human factor specialists during this investigation about the difficulty in judging the approach path, indicate that the use of a glide path indicator located at the landing area is essential. A recommendation to this effect was made in the UK Air Accidents Investigation Branch's Report 5/88.

1.16.3 Trans-cockpit authority gradient and cockpit resource management

Studies of accidents involving crew members with comparable experience levels (especially high levels) indicate that crew interaction and supervision tend to diminish once individual members assume that other crew are fully capable of conducting safe operations and as a result the type of detailed assistance and/or supervision that they might normally provide to less experienced crew members is not required.

The outcome is a flattening of the trans-cockpit authority gradient as the pilot in command fails to establish full authority over the rest of the crew (approach brief, procedures, etc.) and the effectiveness of cross checking between individual crew members is reduced.

In this accident, the co-pilot reported that after advising the pilot of the high rate of descent and observing that action had been taken to correct it, he did not feel there was any requirement to continue to monitor the rate of descent as the pilot in command was very experienced and knew what he was doing.

1.16.4 Vortex-ring phenomenon

In his paper 'Helicopter wreckage analysis', presented at the 1979 Forum of the International Society of Air Safety Investigators, Jerry T. Dennis of the US National Transportation Safety Board stated that:

> Settling with power can best be described as settling in the aircraft's own downwash. Technically it is called the 'Vortex Ring State', where the high rate of descent exceeds the normal downwash velocity on the inner blade sections and they stall. This then causes a secondary vortex which results in turbulent flow over much of the rotor disk. It has been demonstrated that the stall starts at the hub and migrates outwards towards the tip as the rate of descent increases. Increased angle of attack (collective application) only increases the stalled area and resultant rate of descent. Descent rates exceeding 3,500 ft/min have been recorded. According to FAA [US Federal Aviation Administration] Advisory Circular 61-13B, the pilot may get into this condition by:
>
> 1. Attempting an Out of Ground Effect (OGE) hover above the hovering ceiling of the helicopter;
> 2. Attempting to hover out of ground effect without maintaining precise altitude control;
> 3. A steep, powered approach in which the airspeed is permitted to drop nearly to zero.
>
> Advisory Circular 61-13B further indicates that the following combination of conditions are likely to cause settling with power:
>
> 1. A vertical or near vertical descent of at least 300 ft/min. Actual critical rate depends on the gross weight, RPM, density altitude and other pertinent factors;
> 2. The rotor system must be using some of the available engine power (20–100%);
> 3. The horizontal velocity must be no greater then 10 mph. That velocity is not necessarily the velocity across the ground, but the transverse velocity through the rotor disc. As a result a deceleration or approach can meet all the requirements, especially if downwind.
>
> Recovery can be accomplished by increasing the forward speed and flying out or lowering the collective to reduce the stalled area.

Anecdotal evidence indicates that it is widely believed within the aviation industry that 'vortex-ring state' is always accompanied by pitching and/or yawing and rolling motions that give the pilot warning of possible loss of control. This information is usually correct if the aircraft enters a fully developed 'vortex-ring state'; however, evidence was obtained from flight tests and from four experienced Puma pilots that the Puma can begin entry to the 'vortex-ring state' with little or none of the expected sensory indications. A lack of indication is more likely if the airflow around the tail rotor is clear of the downwash as would be the case if there were a tailwind or the aircraft were moving backwards.

During the course of this investigation a series of vortex-ring demonstration flights in an aircraft identical to that involved in the accident were carried out. These flights showed that at the incipient stage of entry to vortex ring, a Puma, at a weight similar to that of the accident aircraft, displayed some mild random yawing (up to ±10°) and an increase in vibration. The pitching and rolling symptoms did not become evident until about the same time as the rate of descent indication had increased markedly (to about 2,000–2,500 ft/min).

It was also found that increasing the rotor-pitch angle by about 1–2° at the incipient stage of vortex-ring entry resulted in an increase in rate of descent from about 1,000 ft/min to 2,000–2,500 ft/min in about 5–10 s, at which point the nose tended to pitch down and random rolling occurred. Recovery was accomplished very quickly by applying forward cyclic and smoothly increasing power (rotor-pitch angle) once airspeed had registered and was increasing. Height loss from initiation of recovery averaged 200–300 ft. (It should be noted that entry altitudes for these demonstrations ranged from 8,000 ft down to 4,000 ft.)

1.16.5 Power required versus power available

The demonstration flights indicated that it was possible to enter a very high rate of descent condition, similar to that encountered during this accident, if the pilot failed to increase power sufficiently to meet the demand for increased rotor thrust required as the aircraft was flown through the entry procedures at the 'gate'. At conditions approximating the accident aircraft's weight and density altitude, it was found that if the rotor-pitch angle was left at approximately 8° (a typical power setting as the entry to the descent is established), with the airspeed indicating between 0 kts and 30 kts, the rate of descent was at or beyond 2,500 ft/min, this being the maximum on the indicator scale. In this condition heavy vibration was present, but the rate of descent reduced immediately power was increased. However, if the nose was held up such that airspeed further decreased, the helicopter entered 'vortex-ring state' accompanied by yawing, rolling and nose-down pitching with no discernible change in the rate of descent indication.

1.17 Other information

1.17.1 Crew procedures

The pilot in command indicated that he normally used a reducing airspeed technique when making an approach to an offshore landing area. He was uncomfortable with the low-speed approach technique in use at Karratha as he felt it placed the aircraft too close to the conditions required for vortex-ring entry. On this flight, as the co-pilot was a current check-and-training captain, the pilot in command reported that he used the low-speed approach technique in order to avoid any adverse criticism from the co-pilot. Although the flight was programmed as a normal ferry flight, the pilot in command still felt that it was a check flight.

The co-pilot was considered by his peers to be a careful and accurate check-and-training captain who would be expected to comment on any deviations from the standard low-speed approach technique. No deviations other than the high rate of descent and the radar altimeter reading of 100 ft were recorded on the CVR.

The company's Operations Manual requires the non-handling pilot (in this case the co-pilot) to monitor the rate of descent and collective pitch and to inform the handling pilot if the rate of descent exceeds 500 ft/min or if the pitch angle is less than 10°. The co-pilot did monitor the instruments and called the rate of descent exceedance of 1,000 ft/min. The co-pilot indicated that, as a check-and-training captain, it was his habit to monitor the approach in more detail than if he were just an ordinary co-pilot. Consequently he divided his attention between monitoring the instruments and checking the sight picture.

The pilot in command reported that he had observed a reading of 480 ft on the altimeter as he increased the collective-pitch setting from 10° to 11° following the co-pilot's warning. The co-pilot reported he observed 450+ ft and 10° of rotor-pitch angle at the time of his call.

Experience has shown that during an approach where there is a possibility of visual illusions it is imperative that one pilot constantly monitor the instruments until the visual cues become the primary source of guidance (late in the approach). Although there were indications during the initial approach that the lack of visual cues might be a problem, neither pilot recognised this and no allowance was made during the planning and briefing for the final approach.

1.17.2 Standardised approach technique

The manufacturer's flight manual for the Puma SA 330J indicates that the minimum approach speed to be used until the aircraft is 50 ft above pad height is 43 kts. The operator believed that the danger of a tail strike during the flare required to reduce airspeed from 43 kts to zero in 50 ft was too great. This danger, plus

(a) a Flight Manual requirement to maintain a high minimum engine RPM during the descent,

(b) the desire always to have the option to continue with the landing or overshoot at any stage during the approach, and

(c) an attempt to introduce a standardised approach,

led to the development of the standard approach procedure published in the operator's Operations Manual. This procedure is used by the operator in all its Puma operations worldwide.

The Normal Operating Procedures for the operator's 'steep' approach stated the following (November 1989):

> Where obstructions prevent a 'straight in' approach it may be necessary to make an approach into wind to a point above and alongside the helideck, and then to move sideways and downwards to land.
>
> During the final approach to an offshore helideck, the handling pilot should establish the approach path, with ground speed less than 50 kts, by 500 ft above the deck height. During the approach the NHP [Non Handling Pilot] is to monitor the Rate of Descent and Collective Pitch and inform the HP [Handling Pilot] whenever the R.O.D. [Rate of Descent] exceeds 500 ft/min or Collective Pitch is less than 10°. The HP is to acknowledge this.
>
> An approach decision point is to be established 150 ft above deck height. If at ADP or beyond, the R.O.D exceeds 500 ft/min or Collective Pitch is less than 10°, the handling pilot is to overshoot.
>
> The aircraft is 'committed' to land when the helideck, (or the obstructions adjacent to it), prevent an overshoot using maximum single-engine power. At the committal point the HP is to call 'committed'.

The operator indicated that these procedures were developed during the introduction of offshore operations and reviewed and adjusted slightly following a Puma accident in the mid-1980s. The procedures do not set out in detail the piloting technique to be used, nor do they indicate if there are any special requirements for night operations. Over the years the piloting technique used at Karratha was refined around these procedures. The refined approach or low-speed approach technique differed from the one used by the operator's Puma pilots in other parts of the world in that, at Karratha, a low (below 32 kts) airspeed was used during the descent from the 'gate' to the committal point instead of a reducing airspeed (500 ft/50 kts, 400 ft/40 kts, etc.). Discussion with the operator indicated that the main reason for the change appeared to be an attempt to prevent the aircraft from entering an overshoot condition caused by the normally very light wind conditions encountered in the north-west of Western Australia. The change also made airspeed control less difficult as it removed one variable from the approach. The low-speed approach technique used at Karratha required that the pilot:

(a) Establish the aircraft in level flight at the 'gate' (500 ft + deck height, 50 kts + headwind speed with the sight picture in the correct position on the windscreen).

(b) Raise the nose to reduce airspeed, at the same time lowering the collective control to prevent altitude increasing.

(c) As the airspeed approaches the 'burble', (an aerodynamic vibration where actual airspeed is unknown but is less than 32 kts which is, in turn, below the minimum gauge indication of 35 kts), commence descent by lowering the nose and selecting the correct glide path visually.

(d) Adjust attitude and rotor-pitch angle to achieve the correct glide path, with the airspeed 'in the burble', with a rate of descent of 500 ft/min and rotor-pitch angle not less than 10°.

(e) At a radar altitude of 150 ft + the deck height (bug should be set), if all parameters are satisfactory, call 'committed' and begin to reduce the rate of descent and forward speed to arrive over the Puma circle on the deck in a 15-ft wheel-height hover. If the parameters are not satisfactory the aircraft has to overshoot.

(f) Acknowledge and take corrective action when informed by the monitoring non-handling pilot that the rate of descent has exceeded 500 ft/min or that the collective pitch angle is less than 10°.

Evidence indicates that the aerodynamic 'burble' starts when the airspeed falls below 32 kts and does not vary noticeably with variations in airspeed below that figure. Although the needle on the airspeed indicator moves as speed is adjusted, the various errors caused by the rotor downwash, static and dynamic port positions make any reading unreliable as a speed indicator.

1.17.3 Company standardisation procedures

The operator maintains a comprehensive training and standardisation system involving local check-and-training captains and local and international standardisation checks. Although the low-speed approach technique was different to the technique used in the company's operations in other parts of the world, it complied with the broad procedures set out in the Operations Manual. The low-speed approach technique had been used by a number of pilots (at least 10) during both local and international standardisation checks without any comment.

1.17.4 Other pilots' techniques

Following the accident, at least two other company pilots indicated that they did not normally use the low-speed approach technique when flying without check-and-training supervision as they considered the approach uncomfortable and possibly unsafe. Their concerns were based on their overall helicopter experience rather than on any actual vortex-ring experience in the

Puma. The technique normally used by these pilots involved the use of a flatter approach with a reducing airspeed. Most if not all of the pilots contacted seemed unaware of the possible lack of what are considered to be normal indications of entry to 'vortex-ring state'.

1.17.5 Other operators' techniques

Another Puma operator which had previously used the accident flight operator's check-and-training system, discontinued the slow-speed approach because it considered the practice unsafe. Two other offshore operators of Puma aircraft indicated that they did not use the slow-speed approach and conformed to the approach specified in the approved Aircraft Flight Manual.

1.17.6 Operations in night visual meteorological conditions

The company's Operations Manual contains specific instructions on the management of cockpit resources during approaches in instrument meteorological conditions. The HP (usually the co-pilot) flies the aircraft on instruments until the NHP has visually acquired the landing area. At that point the NHP takes over and lands the aircraft.

The conditions on night approaches can be as difficult as those in instrument conditions. The operator's training system emphasised the importance of instrument monitoring during night operations in visual conditions and addressed the possibility of visual illusions. The Operations Manual does not contain any specific instructions for night approaches in visual conditions, apart from the requirement to monitor rate of descent and collective pitch setting during all offshore approaches.

1.17.7 Training in the recognition of visual illusions

Although night visual illusions in helicopter operations are recognised as a significant problem, evidence indicates that whilst companies involved in night offshore helicopter operations give general coverage to visual illusions during night flying training, they do not provide specific training to their pilots in the recognition of cues to the possibility of visual illusions. The pilots in this accident advised that they had not received any specific training.

1.17.8 Seating position and sight picture

Because of its shape and height, the Puma instrument panel interferes with the sight picture available to many pilots, who have to lean to one side to maintain visual contact with the deck. It is possible under certain wind conditions for one pilot to lose sight of the deck completely. Other factors affecting the sight picture are pilot stature and seat height. During the final approach the co-pilot was unable to see the helideck without making an exaggerated movement of his head.

1.17.9 Marine pilots' evidence

The senior marine pilot on board the ship confirmed that the aircraft had appeared to be making a normal approach when, shortly after it commenced its final approach, the aircraft entered a very high rate of descent which was reduced just before impact. The impact occurred about the same distance behind the ship as the aircraft was when the descent started. He likened the descent to a 'shooting star'. This information was supported by a second marine pilot also on board the ship. The marine pilot's job requires that he be able to judge distances from single light sources at night on the surface.

Calculations indicate that, if the approach commenced 0.5–0.75 NM behind the ship, the aircraft probably had a low, zero or negative ground speed during part of the approach. The pilots reported that this was not evident to them.

1.17.10 Environmental changes

The possibility that a sudden loss of height may have been caused by rotors or turbulence generated by the ship's superstructure, the gas efflux from the ship or low-level winds over the Burrup Peninsula was examined. Information provided by the company using the LNG carriers, the ship's manufacturer and the Bureau of Meteorology indicated that neither these nor the possibility of debilitating gases being exhausted from the ship could have been factors in the accident.

1.17.11 Other inadvertent and deliberate vortex-ring entries in Puma aircraft

One other case of inadvertent entry to an incipient 'vortex-ring state' in one of the operator's Puma aircraft at Port Hedland was disclosed during the investigation. This case was not associated with an approach to a helideck. However, the aircraft did enter a very high rate of descent very quickly and without exhibiting any noticeable yawing or rolling. The aircraft descended from 1,000 ft to 200 ft above ground level before recovery was effected. Other inadvertent entries to the 'vortex-ring state' were reported by other operators. These occurred mainly during long-line sling operations. No other cases of entry during offshore landings were disclosed. Extensive discussions were held with four experienced Puma pilots and information relating to vortex-ring entries was obtained from the manufacturer's test pilot. The consensus was that whilst it was difficult to deliberately fly the aircraft into a 'vortex-ring state', particularly at a height where ground reference was not available, the aircraft could inadvertently enter the 'state' whilst exhibiting few of the normal symptoms. Recovery was immediate when correct recovery action was taken. All except one of the reported occurrences were in aircraft not fitted with flotation equipment. The effect that this equipment might have on the entry symptoms could not be determined. The flight testing did indicate however, that the symptoms were not always significant, even in an aircraft fitted with flotation gear.

1.17.12 Descent timing

Standard (reducing airspeed) and slow (low-speed approach technique) approaches were flown by two of the operator's check-and-training pilots during demonstration flights. At least four of these approaches were timed from initiation of the descent at the 'gate' to termination at the hover over the target landing point. The approaches consistently took approximately 70 s. The CVR indicated that the accident approach lasted 27 s from the 'gate' position.

1.17.13 Windscreen reflections

The instrument panel in the Puma helicopter is designed so that it does not cast reflections on the windscreen during night operations. During the initial stages of the approach the pilot in command adjusted the cockpit lighting so that his view through the windscreen was not inhibited. Conditions at the time of the accident were dry with no visible moisture.

The pilots reported that, during the approach, their vision was not affected by either reflections on the windscreen or by refraction through moisture on the outside of the windscreen.

2. ANALYSIS

2.1 Pilot qualifications and experience

Both pilots held appropriate licences and endorsements and were very experienced in general helicopter operations. The co-pilot, who was also a check-and-training captain, had recent experience in night offshore landings. As a unit, the crew were suitably qualified for a normal night operation to the ship. However, neither pilot's general training in night visual illusions had included formal instruction in the recognition of cues.

2.2 Pilot medical factors

Neither pilot had any known pre-existing condition that might have been a factor in the accident.

2.3 Aircraft serviceability

The aircraft was fully serviceable and it was determined that all damage was a result of water impact and immersion. Equipment or system failures were not considered to be factors in the accident.

2.4 Atmospheric conditions

Atmospheric and environmental conditions probably led to the crew encountering a visual illusion and prevented them from recognising the abnormal situation during the high rate of descent. The wind conditions, with the possible onset of a south-easterly land breeze as the aircraft descended through 500 ft, probably assisted the aircraft's entry to a high rate of descent by creating conditions for a zero or negative airspeed.

2.5 Conduct of the flight

2.5.1 Pilot's perception of the type of flight

Although the accident flight was not scheduled as a check-and-training flight, the pilot in command indicated that he treated it as such and attempted to fly the approach to the ship exactly as required by the local company technique. This was at variance to his normal technique where he flew a reducing airspeed approach until he reached the committal point. He used this procedure because of his fears of entering a 'vortex-ring state' if he used the recommended technique.

2.5.2 Initial stage of the approach

The evidence indicates that the approach was completely normal until the aircraft had passed through the 'gate' during the final approach to the ship. As the aircraft settled into the descent, approximately 17 s prior to impact, neither pilot was aware of any problem other than the higher than normal rate of descent. Under the prevailing conditions it is likely that this was the only reliable cue that the aircraft was possibly about to enter an uncontrolled descent. The co-pilot drew the pilot's attention to the excessive rate of descent, as required, and the pilot responded and took corrective action by increasing the collective pitch angle from 10° to 11°. However, neither pilot continued to monitor the rate of descent and both appeared to have turned their attention to the visual sight picture. The co-pilot should have monitored the rate of descent until he was satisfied that the corrective action had the desired effect. Both pilots expected the approach to be normal from that point and were not anticipating any further formal checks until the approach decision point check of rate of descent and collective pitch, approximately 330 ft and 30–40 s later.

2.5.3 Management of cockpit resources

Available cockpit resources were not being managed effectively in the prevailing circumstances. Tasks which could be described as visual or instrument monitoring were inappropriately shared. Because the crew had not recognised that there might be problems with visual illusions, the co-pilot was alternating his scan between the instruments and outside the cockpit, rather than monitoring the instruments continuously. In the absence of any recognition that there might be a problem, the pilot in command had not briefed any alternative procedures. In general, although possible problems were covered during normal night flying training, there appeared to be a lack of recognition that night visual approaches required a different technique than day visual approaches. The company's Operations Manual did not underscore this difference.

2.5.4 Rate of descent

An excessive rate of descent was required to descend from 480 ft to sea level in less than 11 s. The aircraft probably entered the high rate of descent condition at the time the co-pilot made his report. The action taken by the pilot in command did not return the rate of descent to normal and it continued to accelerate.

2.5.5 Trans-cockpit authority gradient

The very flat trans-cockpit authority gradient (see 1.16.3) resulted in a less than optimum use of the resources available in the cockpit. The co-pilot was aware of the pilot in command's experience and when he called the high rate of descent and observed that action had been taken to correct the problem, he did not believe it was necessary to continue to monitor the rate of descent to ensure that it was reduced below 500 ft/min.

2.5.6 Intermediate stage of the approach

It was the normal practice of the co-pilot to conduct a scan that included a check of the visual picture and other instruments before coming back to the rotor-pitch angle and rate of descent indicator. The co-pilot's seating position required that he look around the instrument panel to observe the sight picture; as a result, he had to look away from the instruments. The very short time interval from the completion of the pilot in command's attempted corrective actions to impact (8 s), and possibly the distraction caused by the radar altimeter alerting light located on the instrument, prevented the co-pilot from completing his scan. By the time the co-pilot noted the radar altimeter reading it was too late to prevent the accident.

2.5.7 Final stage of the approach and partial recovery

The marine pilots reported that the aircraft appeared to commence recovery just prior to impact. The co-pilot made a comment over the intercom about the radar altimeter reading, 2 s prior to impact. It could not be determined what action the pilot took; however it is unlikely that his actions had any significant effect in the time available. The ship had reported a 5-kt northerly wind during the helicopter's approach. The pilots reported that the surface wind was very light and variable after the accident. The meteorological assessment indicated that the 5-kt wind may have been the last of a dying sea breeze, which only had an effect close to sea level. As the helicopter descended into what was a headwind, it is possible that this alleviated the cause of the uncontrolled descent and that the aircraft began recovery without pilot input.

2.6 Possible factors which can lead to premature touchdown during a night approach to a helideck

2.6.1 Possible scenarios

Research and flight testing indicates that a Puma helicopter can fly an incorrect flight path or achieve rates of descent in the order of those encountered on the accident flight in a number of ways. The most likely of these are as follows:

(a) The pilot fails to re-introduce power after the initial power reduction at the 'gate', and the crew do not recognise that the rate of descent is excessive or that the flight path is incorrect.

(b) The pilot lowers the collective and places the aircraft in autorotation, either deliberately or inadvertently, and the other crew member fails to note that this has occurred.

(c) The crew encounter a visual illusion which causes them to misjudge the correct flight path and they allow the aircraft to fly into the ground/water.

(d) The crew do not level the aircraft at the gate but continue their descent from the point where they were lined up on their final approach and a visual illusion prevents them from recognising the incorrect descent path.

(e) The aircraft begins an entry to a 'vortex-ring state' and the crew do not recognise it.

2.6.2 Low power and autorotation

Sufficient evidence is available to discount both low power and autorotation as factors. Both pilots reported a minimum pitch angle of 10° during the accident flight and the pilot in command reported that he had increased pitch angle from 10° to 11° following the co-pilot's 1,000 ft/min call. Analysis of the signature of rotor RPM recorded on the CVR confirmed that the pilot in command increased rotor-pitch angle following the co-pilot's call and there is no evidence that the aircraft entered autorotation.

2.6.3 Misjudged glide path and visual illusions during an approach

A hypothesis that was considered was that the aircraft had entered a continuous descent from the time it was lined up on final approach at 700 ft. The CVR RPM trace indicated a reduction in main rotor RPM probably as the aircraft was levelled at 550 ft prior to passing through the 'gate'. The aircraft was observed to be making a normal approach before it commenced a high rate of descent described as being like a 'shooting star'. The rate of descent at impact was estimated to be in the vicinity of 2,000 ft/min and it was reported that there had been a reduction just prior to impact. Extensive discussions with the crew and the ship's pilots, and further analysis of the CVR, indicated that a continuous descent from 700 ft, or a controlled misjudged flight path (normal result of succumbing to the effects of visual illusions) was unlikely.

2.6.4 'Vortex-ring state' and visual illusions

2.6.4.1 'Vortex-ring state'

The Operations Manual contains general instructions on how an approach to an offshore landing area is to be conducted but it does not set out the piloting techniques to be used nor does it indicate if there are any special requirements for night approaches. Although the company's Puma operations in other parts of the world use a reducing airspeed approach from the 'gate' to the committal point, a different procedure involving the use of a constant very low airspeed was in use at Karratha. The reducing airspeed approach minimised the risk of the aircraft encountering all of the conditions required for 'vortex-ring state' during the approach as the aircraft does not enter the 'burble' until it is close to the landing area and the rate of descent has been reduced to less than 500 ft/min. At that point in the approach, the crew have the added advantage of being close enough to the landing area to be able to visually assess their flight path and closure rate. The low-speed approach technique, which complied with the broad Operations Manual procedures, reduced the airspeed to the 'burble' very early in the approach and made assessment of closing rate difficult. Whilst some pilots used the reducing airspeed approach during their day-to-day flying, most used the low-speed approach technique when undergoing a check ride with a local or international check pilot. No adverse comments were made about the use of the low-speed approach technique by the check pilots and it is possible that the dangers of this approach, particularly at night, were not recognised.

The operator's insistence on the use of the low-speed approach technique for its Karratha operations meant that their aircraft were always operating in a flight envelope where the risk of inadvertent entry to 'vortex-ring state' was greater than if they had used the reducing airspeed technique.

Most of the parameters required for an aircraft to enter the 'vortex-ring state' are present during an approach using the low-speed approach technique. To achieve the final parameter of low, zero or negative airspeed, a combination of a low airspeed, light (possibly tail) winds and a failure of the crew to recognise this combination would have been required. The impact point indicated that the ground speed was probably very low, zero or negative and therefore, in the reported wind conditions, airspeed was very low during parts of the approach. The evidence clearly indicates that all of the parameters required to enter the 'vortex-ring state' were present during the approach. The witness evidence, the CVR information and the approach timings all indicate that the abnormally high rate of descent was most likely caused by inadvertent entry to 'vortex-ring state'.

It is probable that the aircraft began entry to the 'vortex-ring state' at the stage that the 1,000 ft/min descent rate was reported by the co-pilot. The pilot, in increasing the collective pitch angle, probably unknowingly triggered the rapid increase in the rate of descent, with the helicopter striking the water before the further symptoms of nose-down pitch and random rolling were felt.

Even though the pilot in command had considerable experience with 'vortex-ring state', he probably did not recognise it in this case because he was unfamiliar with the Puma's probable lack of significant indications during the incipient phase.

2.6.4.2 Night visual meteorological conditions and visual illusions

There has been considerable research into visual illusions during night helicopter approaches. Previous visual illusion accidents indicate it is very difficult for a pilot, in dark-night conditions, to visually assess closing speed, rate of descent and glide path. During a day visual approach, the pilot uses his/her experience and both visual (primary) and instrument (secondary) indications to judge when the sight picture, approach angle and closing speed are correct. However, on a dark night, visual indications will not provide suitable reference until the aircraft is close to the helideck. The pilot's seating position in relation to the Puma instrument panel may add to the problem.

Most offshore pilots are aware of the possibility of encountering visual illusions and the crew of the accident aircraft were no exception. Although the possibilities of visual illusions are discussed during training, there appears to be a deficiency in formal training in the recognition of cues to visual illusions. The CVR information and discussion with the pilots indicated that, on a number of occasions during the initial and final approach to the ship, difficulties associated with single light source approaches were observed. However, their importance in relation to the possibility of visual illusions was not recognised by the crew. The crew had difficulty finding the ship visually as it had its floodlights turned off. Having located it, they found they were too close to make a straight-in approach. The crew discussed what appeared to be additional brightness of the lights and the fact that the ship appeared to be stopped in the water. They also indicated that they had difficulty assessing closing rate on the ship during the approach.

There also appears to be a lack of appreciation that night visual approaches are different to day approaches and can be as difficult as approaches in instrument conditions. As a result, significantly different procedures may be required to conduct them in safety. The crew's approach to the task was based on the apparent visual conditions and this was probably compounded by the absence of recognisable instrument conditions such as cloud. A lack of positive direction in the Operations Manual (where the published procedures are the same for day and night), a lack of personal experience with the effect of visual illusions, familiarity with the approach and the good record of such approaches were also probable factors in the crew's failure to alter their approach technique. On the accident flight the crew accepted that the low-speed approach technique would overcome any possible problems and, as they had not appreciated that the conditions were conducive to the occurrence of visual illusions, they made no special allowances for this during the planning and conduct of the approach.

The evidence indicates that a lack of visual cues was a significant factor in the accident, as was the crew's failure to appreciate the additional procedures needed under these conditions.

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Flight Safety Foundation Publications

1. AS 350BA Strikes Glacier
2. Boost Pump Failure Starves Bell 214B Engine of Fuel
3. Unsecured Fasteners in UH-1H Tail-rotor System Lead to Loss of Control

FLIGHT SAFETY FOUNDATION
HELICOPTER SAFETY

Vol. 27 No. 6 *For Everyone Concerned With the Safety of Flight* November–December 2001

AS 350BA Strikes Glacier During Alaskan Air Tour

Pilots flying two other helicopters in the area said that they had difficulty differentiating between the overcast sky and the snow-covered terrain and that the ceiling was only a few hundred feet higher than the mountain pass.

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FSF Editorial Staff

About 1050 local time June 9, 1999, a Eurocopter AS 350BA helicopter that was being flown on a tour of glaciers north of Juneau, Alaska, U.S., struck a glacier. The helicopter was destroyed, and the pilot and all six passengers were killed.

The U.S. National Transportation Safety Board (NTSB) said in its final report that the probable cause of the accident was the pilot's "continued VFR [visual flight rules] flight into adverse weather, spatial disorientation and failure to maintain aircraft control." The report said that factors contributing to the accident were "pressure by the company to continue flights in marginal weather" and "flat" light conditions, which made the snow-covered terrain difficult to distinguish from the overcast sky. Additional factors were "the pilot's lack of instrument experience, lack of total experience, inadequate certification and approval of the operator by the FAA [U.S. Federal Aviation Administration] and the FAA's inadequate surveillance of the emergency instrument procedures in use by the company."

The morning of the accident, the skid/ski-equipped helicopter, owned and operated by Coastal Helicopters of Juneau, departed from Juneau at 1008 for what was to have been a 50-minute flight over glaciers in mountainous terrain. The helicopter was landed about 1025 at 1,000 feet on the Herbert Glacier — a routine stop on the glacier tour. Ten minutes later, the helicopter departed to continue the tour.

The pilots of two other air tour helicopters in the area of the Herbert Glacier and the nearby Mendenhall Glacier said that they heard a routine radio transmission from the pilot of the accident helicopter at 1045 in which he said, "Coastal 99S is upper Herbert for the Mendenhall, right side."

At 1055, the pilot of one of the other helicopters saw the wreckage as he flew his helicopter over the Herbert Glacier.

The report said, "Both pilots [of the other helicopters] said the snow-covered glacier was featureless [and] the overcast ceiling was difficult to discern from the snow, and [both pilots] described the lighting as 'flat.' Both pilots said the overcast layer was a few hundred feet above the elevation of the 4,100[-foot] pass between the two glaciers, but neither could discern the exact ceiling."

The helicopter was found inverted in snow at the 3,400-foot level of the Herbert Glacier, which had a 0.5-degree upward slope in the same direction as the helicopter's flight path. The fuselage and all major components were in a crater 16 feet (five meters) wide, 24 feet (seven meters) long and six feet (two meters) deep. The investigation revealed no pre-impact mechanical anomalies or fuel-system anomalies; the ruptured fuel tank contained about 10 gallons (38 liters) of a clear fluid that appeared to be jet fuel.

Eurocopter AS 350

The Eurocopter AS 350 is a light five/six-seat utility helicopter, first produced in October 1977 by Aerospatiale as the AS 350B. The AS 350B is powered by a 478-kilowatt (641-shaft-horsepower) Turbomeca Arriel 1B turboshaft engine and a rotor of three fiberglass blades that rotate clockwise as viewed from above. Directional control is effected by a two-blade tail rotor on the right side of the tail boom.

The AS 350BA, also known as the Ecureuil (Squirrel), is an upgraded version of the AS 350B. The AS 350BA is equipped with larger main-rotor blades that originally were developed for the twin-engine AS 355 and has a maximum takeoff weight that is 150 kilograms (331 pounds) higher than the AS 350B.

The Aerospatiale helicopter division and the MBB (Messerschmitt-Bolkow-Blohm) helicopter division merged in 1992 to form Eurocopter.

The AS 350B and AS 350BA have two standard bucket seats at the front of the cabin and two two-place bench seats aft.

The AS 350BA's maximum takeoff weight is 2,100 kilograms (4,630 pounds) or 2,250 kilograms (4,960 pounds) with a maximum sling load. Maximum rate of climb is 1,500 feet per minute. The AS 350BA has a maximum cruise speed at sea level of 126 knots and a service ceiling of 15,750 feet. Hovering ceiling out of ground effect is 6,500 feet. Range with maximum fuel (540 liters [142.6 gallons]) at sea level is 730 kilometers (453 statute miles).♦

Source: *Jane's All the World's Aircraft*

When the accident occurred, the pilot — a citizen of New Zealand — had about 650 flight hours in helicopters; a precise figure was not available, and the report said that when NTSB, FAA and the New Zealand Civil Aviation Authority (CAA) requested the pilot's logbook from his family, "the family responded that the pilot's logbook and all flight records were cremated with his remains."

Of the estimated 650 helicopter flight hours, 487 flight hours could be verified by employer records and flight school records compiled by FAA. The report said that the pilot probably accumulated about 125 additional hours of helicopter flight time during his first job as a flight instructor, but these records were not available.

The pilot did not have an instrument rating; he was not required by FAA to have one.

The pilot had flown microlight aircraft in New Zealand and had received 10 flight hours to 20 flight hours of helicopter training in New Zealand. He received the remainder of his training in the United States, at flight schools in Arizona and California.

"Interviews conducted by the FAA indicated the pilot had difficulty reading and writing English," the report said. "Quantum Helicopters in Chandler, Arizona, provided commercial helicopter flight training to the pilot. Quantum's chief pilot stated that the accident pilot began training for his helicopter flight instructor certificate, but the company terminated his training, citing a failure to meet the standards set forth in [U.S. Federal Aviation Regulations (FARs) Part] 61.183: 'To be eligible for a flight instructor certificate, a person must ... read, write and converse fluently in English.'"

Interviews with other flight school personnel and employers indicated no obvious language difficulties, although the report said that other people interviewed "consistently commented that upon review, none remembered the pilot performing detailed written work in person."

The pilot passed an examination for the flight instructor certificate — administered by an FAA-designated pilot examiner — on Sept. 19, 1998, and began work the next day as a flight instructor for Aero Helicopters of Scottsdale, Arizona. He left that job on Nov. 30, 1998, and from Dec. 1, 1998, until May 8, 1999, he worked as a flight instructor for Guidance Helicopters of Prescott, Arizona.

He was hired on May 8, 1999, by Coastal Helicopters as an air tour pilot and completed initial ground training on May 11, 1999. The same day, he was administered a pilot-in-command proficiency check and line check in a Bell 206B Jet Ranger. The pilot-in-command checks were administered by the president of Coastal Helicopters, who also was the company's director of operations and an FAA-authorized company check airman. The pilot completed pilot-in-command checks in the AS 350 on June 7, 1999.

When he was hired by Coastal Helicopters, the pilot said on his company resume "that he had accrued 891 hours of helicopter flight experience," the report said. "The NTSB ... and the FAA estimated the pilot actually had 612 helicopter flight hours when hired."

When he was hired, the pilot had no experience as pilot of a turbine-engine aircraft. While working at Coastal Helicopters, he accumulated 37.5 flight hours, including 5.7 hours of dual flight instruction in the Jet Ranger and 5.7 hours of dual flight instruction in the AS 350. At the time of the accident, his total time in the AS 350 was 7.9 hours, including the 5.7 hours of dual flight instruction.

When the accident occurred, Coastal Helicopters had received four favorable letters about the pilot's abilities, including one letter from a former employer, but had not received complete information from the pilot's previous employers in response to requests for employment information, as required by the Pilot Records Improvement Act of 1996. (The law allows helicopter companies involved in on-demand operations to employ a pilot for 90 days while awaiting the information.) The law requires previous employers to provide information about the pilot's training, qualifications, proficiency or professional competence but not about pilot flight time.

The report said that the accident helicopter was manufactured in 1995 and was configured to carry one pilot and six passengers. The helicopter and the engine had accumulated 1,827 hours in service. Maintenance was performed according to the manufacturer's inspection program and an approved aircraft inspection program that included inspections approximately every 100 flight hours. The most recent inspection was performed 62 hours before the accident. Maintenance records revealed no pre-existing anomalies.

The accident helicopter was one of six helicopters — two Jet Rangers and four AS 350s — operated by Coastal Helicopters at the time of the accident. The company was authorized to conduct on-demand passenger-carrying operations in day VFR and night VFR conditions. The helicopters were equipped only with "standard" flight instruments, including a gyroscopic rate-of-turn indicator, a slip-skid indicator, a gyroscopic bank-and-pitch indicator and a gyroscopic direction indicator, the report said.

Weather on the morning of the accident — as described by other helicopter pilots who were in the area and as shown in photographs taken by rescue personnel and Alaska state police — included an overcast ceiling that was difficult to distinguish from terrain. Another Coastal Helicopters' pilot characterized the appearance of the surroundings as "a milky blur."

The report said that a review of the photographs, which were taken one hour after the accident, showed "the pass between the Herbert Glacier and the Mendenhall Glacier obscured, with no discernible horizon, when looking at the pass from the accident site. The view looking down the Herbert Glacier from the accident site depicted an overcast ceiling [that] sloped up with the terrain, gradually lowering toward the upper elevations."

The nearest official weather reporting station was at Juneau International Airport, 20 nautical miles (37 kilometers) south of the accident site, where the elevation was 19 feet. The weather observation at 1053 included scattered clouds at 1,600 feet, an overcast layer at 2,100 feet and visibility of 10 statute miles (16 kilometers). The ceiling was the lowest reported at the Juneau airport for any time period during which the pilot had flown a helicopter since he began his job in Alaska. (Nevertheless, conditions above the glaciers often differ from conditions reported at the airport because of the effects of mountains, wind and temperature variations associated with the large mass of ice.)

Coastal Helicopters' records showed that the pilot had flown helicopters to and from the Herbert Glacier 31 times before the accident flight and that he had flown from the Herbert Glacier to the Mendenhall Glacier through the Upper Herbert Glacier Pass 11 times.

The company president said that the preferred tour route was to fly north over the Herbert Glacier, across the Upper Herbert Glacier Pass to the Mendenhall Glacier and south over the Mendenhall Glacier to Juneau. He said that a pilot would fly north and south over the Herbert Glacier when low ceilings closed the pass to the Mendenhall Glacier.

The report said that in the days before the accident, the pilot of the accident helicopter had made telephone calls to the owner of a helicopter company in New Zealand and a former employer in Arizona during which he said that he was unhappy with his Alaska job.

On June 2, after returning to Juneau from a tour flight, the pilot of the accident helicopter had telephoned the owner of Garden City Helicopters, the New Zealand company that had provided his initial helicopter flight training, and asked him about job opportunities in New Zealand.

The report said, "The New Zealand [company] owner told [an NTSB investigator] that the pilot was displeased with the environment and pressures to fly in marginal weather. He told the [NTSB investigator] that the pilot was uncomfortable flying a load of tourists in marginal conditions, and so his boss had taken another aircraft and told the pilot to follow him. According to the New Zealand owner, the accident pilot told him 'he had been in a clear cell following his boss in between [clouds] and surrounded by clouds, unable to land because of terrain.' The New Zealand owner told the [NTSB investigator] that the accident pilot's exact words were that 'he was living on borrowed time.'"

Coastal Helicopters' president said that he had not flown a tour flight for three days before or after the pilot's telephone call to

New Zealand but that the chief pilot sometimes flew a helicopter to "lead" a new pilot — flying a second helicopter — along an unfamiliar route. The chief pilot said that he did not remember the incident described by the New Zealand owner.

The owner of Guidance Helicopters in Prescott, Arizona, where the pilot of the accident helicopter had worked as a flight instructor for five months before beginning the Alaska job, said that the pilot called him about June 1. During the telephone call, the pilot "expressed dissatisfaction with the training he had received and also indicated he felt pressured to fly tours in marginal weather."

The report said that Coastal Helicopters' new pilot training program approved by FAA was "the minimum" outlined by FAA Order 8400.10, the *Air Transportation Operations Inspector's Handbook.*

Company training program specifications called for training in seven "special subjects," including "flight techniques in adverse weather" and "mountain flying — general and specific pass flying," but the report said that the course-training outline included "no specific mention of white-out [conditions] or flat light conditions caused by overcast clouds over glaciers, or flight techniques over large expanses of snow." How much training the pilot received in the seven special subjects could not be determined.

FAA Order 8400.10 says that pilots in VFR-only helicopter operations should demonstrate proficiency in recovery from unusual attitudes, maneuvering while using a partial instrument panel and completion of an instrument approach. Nevertheless, the report said that the FAA principal operations inspector "did not require that any instrument proficiency training or any instrument competency evaluation be included in the company training manual."

The report said that an NTSB investigator had asked the company's chief pilot "if he conducted any training for emergency use of basic flight instruments."

"He replied that he never did and emphasized the company policy was to 'go down and slow down but never go into instrument conditions,'" the report said. "When asked what he would personally do if he found himself in a white-out or [an] instrument-meteorological-conditions (IMC) situation, he indicated he was not sure because he never intended to be in that situation."

The company president said that training did not include basic instrument training or emergency instrument training.

The report said, "The company policy was that a pilot just does not fly into instrument conditions."♦

[FSF editorial note: This article, except where specifically noted, is based on U.S. National Transportation Safety Board factual report and brief-of-accident report no. ANC99FA073. The reports comprise 199 pages and include diagrams, photographs and maps.]

FLIGHT SAFETY FOUNDATION
HELICOPTER SAFETY

Vol. 28 No. 2 *For Everyone Concerned With the Safety of Flight* March–April 2002

Boost Pump Failure Starves Bell 214B Engine of Fuel

Canadian investigators said that the aircraft flight manual did not adequately describe the potential consequences of a boost pump failure and that the pilot's lack of recurrent training might have affected his ability to conduct an autorotation.

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FSF Editorial Staff

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About 0655 local time July 4, 1999, a Bell (now Bell Helicopter Textron) 214B operated by East West Helicopters descended from about 400 feet above ground level (AGL) into a shallow, rapidly flowing river 35 nautical miles (65 kilometers) northwest of Kaslo, British Columbia, Canada. The helicopter broke apart on impact and came to rest on rocks in the middle of the river. The four occupants were killed.

The Transportation Safety Board of Canada (TSB) said, in its final report on the accident, that the causes and contributing factors were the following:

- "The helicopter engine lost power in flight (engine flameout) because of fuel starvation;
- "The usable fuel in the left[-forward] cell was exhausted. Although there was fuel in the right[-forward] cell, it was not available at a usable rate because the right boost pump was inoperative and the fuel transfer was slower than engine fuel usage; [and,]
- "When the right boost pump is inoperative, the fuel-quantity gauge indicates more fuel than is actually on board. The actual amount of usable fuel would be difficult to determine in flight."

The helicopter was based at a heli-logging staging area on a forest-service road that runs through a valley. The night before the accident, maintenance was performed on the helicopter by an aircraft maintenance engineer (AME) and an apprentice AME.

"[They] had worked on the helicopter in the staging area until midnight," the report said. "It is not known what maintenance may have been performed at that time."

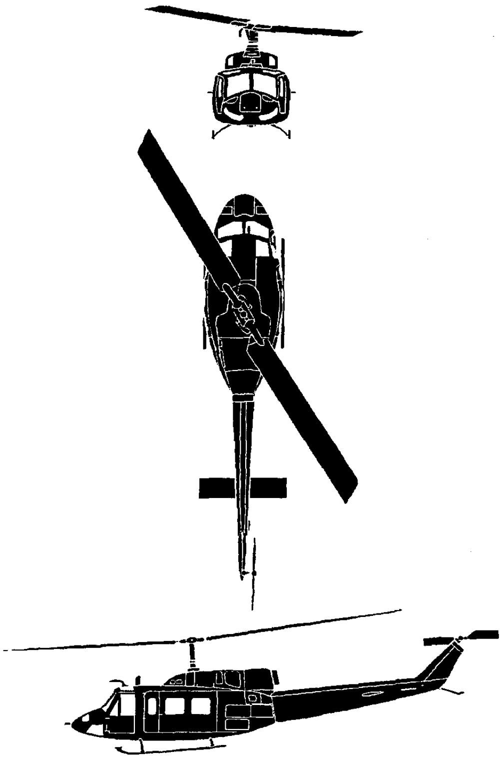
About 0600, East West Helicopters' operations manager drove the pilot, copilot, AME and apprentice AME to the helicopter. The operations manager then drove about 0.25 nautical mile (0.46 kilometer) south on the forest-service road and parked his vehicle in a log-landing area.

The pilot, 48, held a commercial helicopter pilot license and had about 14,000 flight hours, including about 2,750 flight hours in heli-logging operations and 300 flight hours in type. He was employed by East West Helicopters in June 1998 and flew Bell 214 and Bell 206 helicopters for the company.

The pilot had not received recurrent flight training in a Bell 214B after completing flight training for his type endorsement more than two years before the accident.

"Several pilot-proficiency-check (PPC) reports contained comments that the pilot's handling of emergency procedures needed improvement; however, there is nothing in the pilot's file to indicate that extra training was received," the report said. "A PPC report for a flight in January 1993 noted that the pilot needed to be briefed on autorotation procedures, both straight-in and 180-degree turns. There was no record found of the pilot having flown a PPC on the Bell 206 or Bell 214."

The report provided no information about the copilot; the copilot and the apprentice AME occupied seats in the passenger cabin. The AME occupied the right seat in the cockpit. The pilot occupied the left seat in the cockpit.



Bell Helicopter Textron 214B

The Bell Helicopter Textron 214B is a medium-sized commercial helicopter based on the Model 214 Huey and Model 214A Isfahan military utility helicopters. Called the BigLifter, the Model 214B first flew in 1974.

The helicopter can accommodate a pilot and 14 passengers or 7,000 pounds (3,175 kilograms) of cargo carried internally or externally, and can be configured for agricultural operations and for fire-fighting operations.

The 214B has one Lycoming T55-08D turboshaft engine rated at 2,930 shaft horsepower (2,185 kilowatts) and a two-blade main rotor and tail rotor. Maximum takeoff weight is 13,800 pounds (6,260 kilograms). Cruise speed with an internal load of 4,000 pounds (1,814 kilograms) is 140 knots.♦

Source: *Jane's All the World's Aircraft*

The Bell 214B is certified for single-pilot operation. The report said that the pilot is required to occupy the right seat in the cockpit during passenger flights. During heli-logging operations, however, the pilot usually occupies the left seat and concentrates on maneuvering the helicopter; the copilot occupies the right seat and monitors the engines and auxiliary systems.

"For external-load flying [e.g., heli-logging], a supplement to the aircraft's type certificate can be issued by Transport Canada (TC) for a specific aircraft," the report said. "This supplement allows a single pilot to fly that aircraft from the left seat, provided that certain modifications — including installation of dual controls, a left-door bubble window and critical instruments added to the left-door window sill — have been made to the aircraft.

"The accident aircraft had been modified to be flown from the left seat, but a supplemental type certificate had not been issued for this aircraft."

The pilot started the helicopter's engine about 0630 and operated the engine on the ground for 10 minutes to 15 minutes.

"The helicopter then took off and ascended briefly into the cloud base at about 500 feet [AGL] before descending below the cloud," the report said.

The pilot told the operations manager by radio that he was conducting a power check and that heli-logging operations could not be conducted that day because of fog obstructing the logging site. The logging site was at an elevation of about 3,660 feet — 1,000 feet higher than the staging area. There was no further radio communication between the pilot and the operations manager.

"The helicopter then flew down the valley at about 400 [feet AGL], staying closer to the northwest side of the valley, and passed nearly overhead the operations manager," the report said. "The helicopter continued down the valley, then made a 180-degree turn and flew up the southeast side of the valley [past the log-landing site]."

The operations manager then heard the helicopter returning. As the helicopter neared the log-landing site, the sound ceased. The operations manager observed white vapor trailing the helicopter as it continued flying south at about 400 feet AGL. He heard and observed slowing rotation of the main-rotor blades.

"The helicopter then made a descending 180-degree turn toward Glacier Creek, with the main rotor continuing to slow," the report said. "Immediately before the helicopter disappeared from sight behind trees, the main rotor appeared to have stopped turning."

The helicopter broke into four main pieces on impact; all the pieces were found within a few feet of each other. The fuel cells ruptured on impact, but there was no fire. The AME, copilot and apprentice AME were killed on impact. The pilot, who wore a flight helmet, survived the impact but died from injuries 45 minutes later.

"The main-[rotor blades] and tail-rotor blades exhibited very little rotational impact damage," the report said. "The fuselage exhibited indications of high-speed, near-vertical impact damage with a low-speed forward component. … The injuries to the occupants and the damage to the aircraft are consistent with high vertical-impact forces that characterize an unsurvivable accident."

The copilot was found about 10 feet (three meters) from the cabin. The apprentice AME was found beneath the wreckage. The pilot and AME were found seated in the cockpit. Both cockpit seats had four-point occupant-restraint systems, but the pilot and the AME had used only the lap belts; the shoulder straps were found stowed behind the seats.

The report said that during external-load operations, the pilot flying often must lean to the side to observe the external line and the load attached to the external line.

"Because such a body position is difficult to achieve by a pilot wearing a shoulder harness, it is a widespread practice for the pilot maneuvering the helicopter to use [only] the lap belt portion [of the occupant-restraint system]," the report said. "The shoulder straps are commonly stowed behind the seat back to prevent them from interfering with the pilot's movements."

The report said that, because of the severity of the impact forces and the high vertical component of the impact forces that occurred in the accident, it is unlikely that the pilot and AME would have survived if they had been wearing their shoulder harnesses. Nevertheless, accident investigations and research conducted by TSB have shown that use of shoulder harnesses reduces injury or prevents injury during aircraft accidents involving moderate impact forces.

Records indicated that the helicopter, which was manufactured in 1978, had accumulated 8,575 airframe hours and 8,348 engine hours, including 3,073 hours after an overhaul of the engine. The engine manufacturer recommends that the engine be overhauled every 4,000 hours.

"The maintenance records show that the accident helicopter [engine] had been 'surging' for more than a year, since the aircraft was imported from Japan," the report said. "The records, however, do not give details of any symptoms exhibited by the aircraft."

Post-accident examination of the engine, drive-train components and rotor blades revealed negligible rotational damage. Examination of the engine instruments revealed that engine rpm was 3 percent of maximum rpm and that rotor rpm was 16 percent of maximum rpm on impact.

"A more detailed inspection of the wreckage revealed that all component breakage and damage in the flight controls, drive train and main-rotor gearbox were overload in nature and were attributable to the impact forces of the accident," the report said. "Based on this information, it was determined that the helicopter had lost power before impact."

Examination of light bulbs from the annunciator panel revealed that several warning lights — including those indicating a right-boost-pump failure, low fuel and low rotor rpm — were illuminated when the helicopter struck terrain.

"An illuminated boost-pump light indicates that fuel flow from the related fuel-boost pump has dropped to the point where the flow-activated switch operates, indicating an inoperable fuel-boost pump or a lack of fuel," the report said.

The Bell 214B has five interconnected fuel cells (see Figure 1, page 4). An electrically driven fuel-boost pump in each of the two forward cells supplies fuel to the engine.

"A fuel-cell interconnect line runs between the left[-forward fuel cell] and the right-forward fuel cell, normally ensuring that the fuel level in the two forward cells remains equal," the report said. "The fuel-quantity gauge is operated by probes located in the center cell and [in] the right-forward fuel cell. If the center fuel cell does not contain any fuel, the fuel-quantity gauge is operated solely by the probes in the right-forward cell. The fuel-quantity gauge does not directly register fuel in the left-forward cell."

The report said that the fuel-quantity indication in the Bell 214B is accurate when the right-forward cell and the left-forward cell contain an equal amount of fuel.

A float switch in the left-forward fuel cell activates the low-fuel warning light.

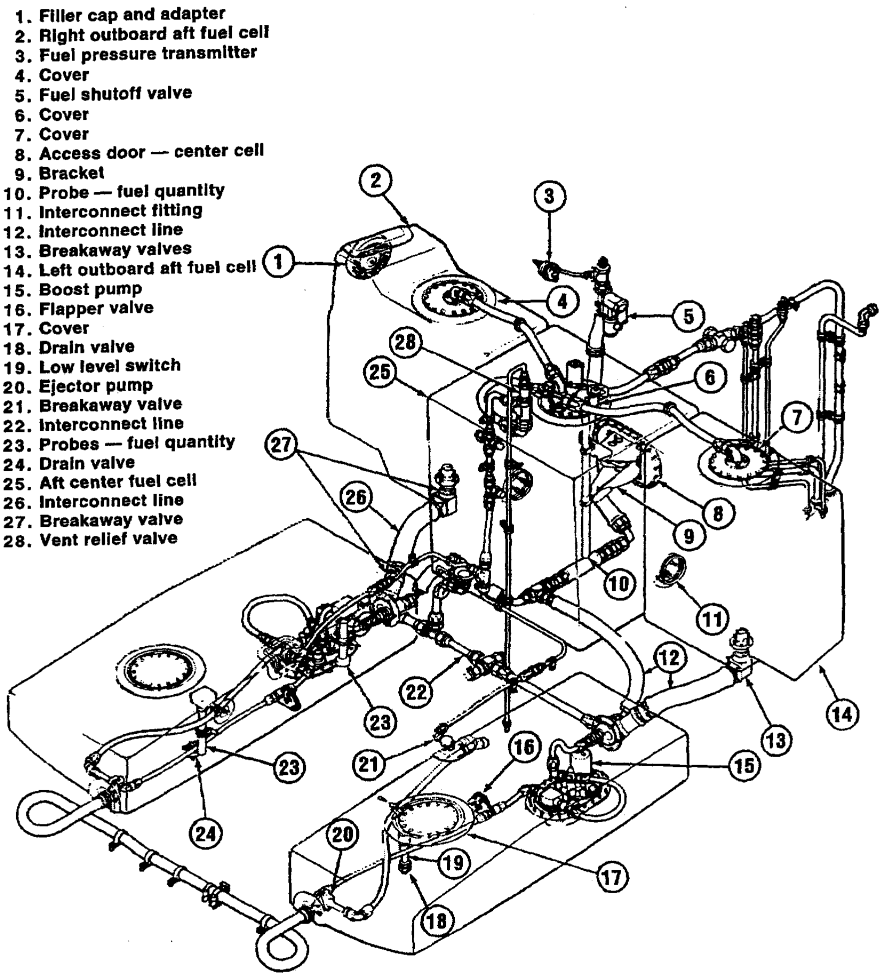
The Bell 214B flight manual said that unusable fuel during normal flight operations (e.g., with both fuel-boost pumps operating) is 23 pounds (10 kilograms). The flight manual said that unusable fuel with one boost pump inoperative is 103 pounds (47 kilograms).

"The forward-fuel-cell interconnect [line] is unable to flow fuel between the cells as rapidly as the engine can consume fuel from the cell with the operable boost pump," the report said.

Investigators estimated that when the helicopter struck terrain, the left-forward fuel cell was nearly empty, and the right-forward fuel cell contained about 250 pounds (113 kilograms) of fuel.

"The fuel-quantity gauge is designed to retain its last indicated pointer position when power is cut off," the report said. "The

Bell 214B Fuel System



1. **Filler cap and adapter**
2. **Right outboard aft fuel cell**
3. **Fuel pressure transmitter**
4. **Cover**
5. **Fuel shutoff valve**
6. **Cover**
7. **Cover**
8. **Access door — center cell**
9. **Bracket**
10. **Probe — fuel quantity**
11. **Interconnect fitting**
12. **Interconnect line**
13. **Breakaway valves**
14. **Left outboard aft fuel cell**
15. **Boost pump**
16. **Flapper valve**
17. **Cover**
18. **Drain valve**
19. **Low level switch**
20. **Ejector pump**
21. **Breakaway valve**
22. **Interconnect line**
23. **Probes — fuel quantity**
24. **Drain valve**
25. **Aft center fuel cell**
26. **Interconnect line**
27. **Breakaway valve**
28. **Vent relief valve**

Source: Transportation Safety Board of Canada

Figure 1

[accident helicopter's] fuel-quantity gauge indicated 500 pounds [227 kilograms] of fuel when it was recovered from the wreckage."

Inspection of the accident helicopter's fuel-boost pumps, which were damaged extensively on impact, showed that the brushes, impellers, bearings and other internal components were within wear limits.

"On the right boost-pump motor, one of the brushes was stuck and would not contact the commutator," the report said. "When the brush was pushed in to contact the commutator and electrical power was reapplied, the motor operated."

Investigators found no records of how long the pumps had been in service in the accident helicopter or how long the pumps had been in service since overhaul or repair.

"Globe Motors, the manufacturer of the boost pumps, contends that both … boost pumps had been repaired since new and that these repairs were not carried out by Globe Motors," the report said. "Globe Motors does not provide any facility with parts, drawings, manuals or revisions that are required for overhaul or repairs to be carried out on these pumps."

The boost pumps, which have part no. 164A213, are condition-monitored items — that is, the manufacturer's maintenance requirements are based on service data. Globe Motors said that the design service life of the pumps is 1,000 hours.

"Information gathered from several sources — including Bell 214B operators, maintenance facilities and a component-repair-and-overhaul facility — indicates that the average time between replacement or repair of Bell 214B boost pumps is 100 [hours] to 300 hours," the report said. "The component-repair-and-overhaul facility reported that if grease is added to the pump motor bearings during repair, the boost pumps are able to operate for about twice as long (600 hours) before requiring servicing."

The report said that the Bell 214B flight manual "does not adequately describe the consequences of a boost-pump failure or emphasize its seriousness."

Boost-pump failure is discussed in the "Malfunction Procedures" section of the flight manual. The manual recommends that the pilot "land as soon as practical" when a boost-pump failure occurs.

"Because the flight manual does not refer to the possibility of incorrect fuel-quantity indication following a boost pump failure, the accident pilot may not have regarded the boost-pump failure as critical," the report said.

The report said that when the engine lost power, the pilot might not have had enough altitude to conduct an autorotation, or he might not have reacted correctly to the power loss.

"The low cloud base limited the height above the ground that the helicopter was able to fly," the report said. "Thus, the helicopter may not have been high enough [for the pilot] to carry out a successful autorotation.

"Because no mechanical malfunction was found that would have contributed to an unsuccessful autorotation and because procedures following a power loss in the Bell 214B require timely and correct pilot response, it is possible that the accident pilot's lack of recent training on Bell 214B emergency procedures contributed to the unsuccessful autorotation."

TC had not conducted an audit of East West Helicopters in the three years preceding the accident. TC conducted an audit of the company 10 days after the accident. The report said, "TC found the flight-crew-training program was lacking in several areas, including the following:

- "The training program (as reflected in the company operations manual, reissued in early 1999) had not been implemented fully;

- "Flight-crew-training records were incomplete and in need of restructuring ;

- "Essential information with regard to pilot license(s), medical-validation certificate(s), type endorsement(s), competency-check status, [flight] training received, etc., was not available;

- "Pilots had not undergone the required competency checks, and one pilot was neither trained nor endorsed on type; [and,]

- "Although the company had a system to record and track pilot-flight-duty times, flight times and rest periods, the system was not being used."

TC also found that the company had inadequate operational control because of the operations manager's workload. The operations manager also served as the company's maintenance manager and was responsible for the day-to-day operation of the trucking company that owned East West Helicopters.

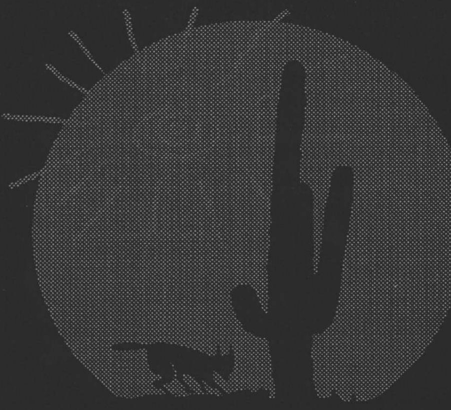
"TC staff have indicated that the company corrected all of the items noted in the audit and that the company has been put on a one-year audit cycle," the report said.

Based on the findings of the accident investigation, TSB made the following recommendation to Bell Helicopter Textron and to the Canadian Minister of Transport:

> The Bell 214B and Bell 205 flight manuals [should] be modified to provide information regarding the inaccuracy of fuel-quantity indications, thereby allowing pilots to make informed decisions in the event of a loss of fuel-boost-pump pressure. [The fuel system in the Bell 205 is similar to the fuel system in the Bell 214B.]

[TSB said that, as of March 19, 2002, no response to the recommendation was received — and no response was required by law — from Bell Helicopter Textron. TC agreed with the recommendation and on Nov. 9, 2001, requested that the U.S. Federal Aviation Administration review the fuel-system designs and require revisions of the flight manuals and the emergency procedures for the Bell 214 and Bell 205 helicopters.]♦

[FSF editorial note: This article, except where specifically noted, is based on Transportation Safety Board of Canada Aviation Investigation Report no. A99P0075, *Power Loss–Fuel Starvation, East West Helicopters Ltd. Bell 214B Helicopter C-GEWT, Kaslo, British Columbia, 35 NM NW, 4 July 1999*. The 26-page report contains illustrations and appendixes.]



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Vol. 28 No. 3 *For Everyone Concerned With the Safety of Flight* May–June 2002

Unsecured Fasteners in Tail-rotor System Faulted for Bell UH-1H Loss of Control

New Zealand investigators said that the failure to install split pins during maintenance likely caused nuts and bolts in a tail-rotor-blade pitch-control mechanism to become loose, leading to the pilot's loss of control of the ex-military helicopter during approach and landing.

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FSF Editorial Staff

About 1715 local time June 4, 2001, a Bell UH-1H Iroquois was being flown on approach to land near Taumarunui, New Zealand, when the helicopter was observed to enter a turn and then to break up while descending to the ground. The helicopter was destroyed by the impact and a postaccident fire. The three occupants were killed.

In its final report on the accident, the New Zealand Transport Accident Investigation Commission (TAIC) said, "The in-flight breakup probably started with a loss of tail-rotor control owing to the [tail-rotor-blade] pitch-control mechanism becoming loose. The tail rotor had been removed as part of a scheduled inspection of the helicopter some two months earlier. During the refitting of the tail rotor, the bolts holding part of the pitch-control mechanism in place were probably not secured by split pins [cotter pins] as required. The bolts eventually came loose, causing the loss of tail-rotor control."

The helicopter was manufactured in 1965 and was operated by the U.S. Army until late 1995. It then was modified by Western International Aviation and registered in the United States as a restricted category civil aircraft.

"In March 1996, the helicopter was imported into New Zealand, registered as ZK-HJH and issued a non-terminating airworthiness certificate in the restricted category for use in private and aerial work only," the report said. "The New Zealand Civil Aviation Authority (CAA) directed that the helicopter continue to be maintained according to the U.S. Army maintenance regime and applicable ADs [airworthiness directives]."

The helicopter, operated by Wanganui Aero Work, was used for logging, spraying and heavy-lift operations.

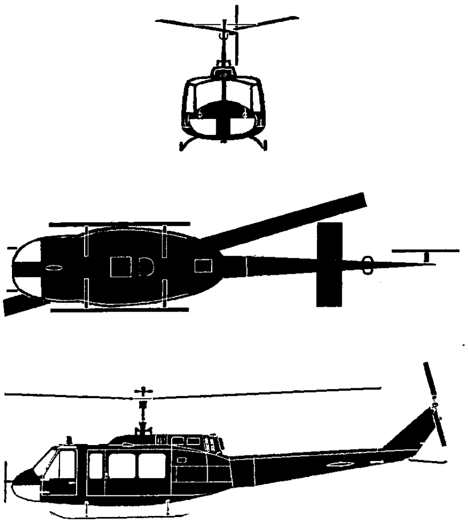
"ZK-HJH was occasionally used in the spreading of poison [bait for pest control], attracting criticism from some quarters," the report said. "While there were no reports of deliberate damage to ZK-HJH, some tooling was reported stolen from [the helicopter's storage] shed in about March 2001. The theft occurred while the shed was open and unsupervised."

The helicopter had been maintained by various licensed aircraft maintenance engineers (LAMEs) in New Zealand before October 2000; the operator then hired Air Repair Taranaki to maintain the helicopter.

"The [maintenance company] consisted of a LAME and a tradesman," the report said. "The tradesman held a pilot's license and performed maintenance under the direct supervision of the LAME, [who] was very familiar with the

UH-1H Iroquois, having worked on them for several years in New Zealand and overseas."

On March 12, 2001, the LAME and the tradesman began an annual review of airworthiness (ARA) and a 150-hour inspection of the helicopter, which had accumulated 12,000 flight hours. They were assisted by several people, including the accident pilot, at various times during the inspection.



Bell UH-1H Iroquois

Bell Aircraft (now Bell Helicopter Textron) developed the Model 204 to compete for a U.S. Army contract to build a utility helicopter suitable for evacuating casualties from front-line battle areas and for instrument flight training. The Model 204 won the contract in 1955 and was given the military designation HU-1. The U.S. Army named the helicopter the "Iroquois," but the HU-1 designation prompted the nickname "Huey." The military designation later was changed from HU-1 to UH-1, and the first production helicopters were designated UH-1A.

The UH-1A has six seats and a 770-shaft-horsepower (shp) Lycoming T53-L-1A turboshaft engine. The UH-1B, introduced in 1961, has nine seats and either a 960-shp T53-L-5 engine or a 1,100-shp T53-L-11 engine. The UH-1C, introduced in 1965, has a redesigned rotor. The UH-1D (Model 205), introduced in 1963, has longer main rotor blades and accommodates up to 14 passengers.

The UH-1H, introduced in 1967, is similar to the UH-1D but has a 1,400-shp T53-L-13 engine. Maximum takeoff/landing weight is 9,500 pounds (4,309 kilograms). Maximum rate of climb at sea level is 1,760 feet per minute. Maximum cruising speed is 120 knots. Maximum range with no fuel reserves is 284 nautical miles (526 kilometers). Hovering ceiling in ground effect is 20,000 feet. Hovering ceiling out of ground effect is 15,600 feet.♦

Source: *Jane's All the World's Aircraft*

"According to maintenance records, the tail-rotor-grip bearings and a bearing in the 90-degree gearbox on the tail rotor were replaced during the inspection," the report said. "This required removing the tail-rotor assembly, refitting the assembly and balancing the tail rotor."

Among the tail-rotor-assembly components is the crosshead (Figure 1, page 3). The two rods (pitch links) that control tail-rotor-blade pitch are attached to the arms of the crosshead and to the tail-rotor-blade horns. The crosshead is secured with two bolts and two nuts to the slider and retainer plate, which are part of an assembly — called the stack — that is fitted to the tail-rotor hub.

The LAME and the tradesman told investigators that after they reinstalled the tail-rotor assembly, they removed the crosshead again because they had forgotten to conduct a duplicate inspection of the crosshead. (New Zealand Civil Aviation Regulations require a duplicate inspection — that is, an inspection by two people — of any work performed on an aircraft control system.)

They said that after conducting the duplicate inspection, they reinstalled the crosshead and inserted split pins in the two bolts and the two nuts that attach the crosshead to the stack. [A split pin is inserted between slots in a castellated nut and through a hole in the bolt shaft; the split pin prevents the nut and the bolt from loosening.]

A post-inspection test flight was conducted on March 27, 2001, and the helicopter resumed service the next day. The helicopter was flown for 50 hours before the accident occurred.

At 1550 on the day of the accident, the helicopter departed from its base near Pukekohe [in northwestern North Island] for a positioning flight to the operator's airstrip near Taumarunui [about 200 kilometers (108 nautical miles) south of Pukekohe].

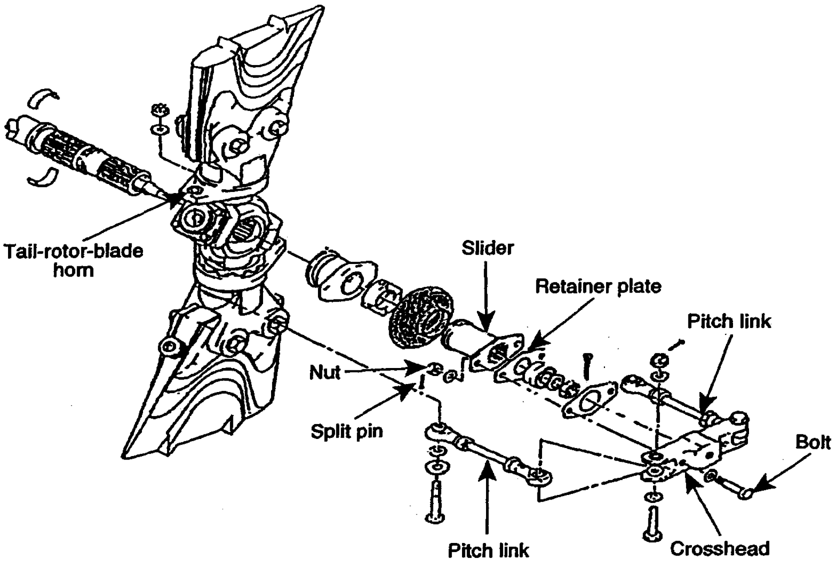
"On board [the helicopter] were the pilot, loader driver and operations coordinator," the report said. "The helicopter was to position at the operator's airstrip near Taumarunui for bait-spreading operations commencing the next day."

The pilot, 51, held a commercial helicopter pilot license and had 13,425 flight hours, including 610 flight hours in type. He had flown the accident helicopter for Wanganui Aero Work for about three years.

The pilot had flown about 54 hours in the preceding three months and about six hours in the preceding 14 days. He had been off duty more than 18 hours before reporting for the flight; he had been on duty about two hours when the accident occurred.

"The pilot was known to be cautious in his operation of ZK-HJH," the report said. "Several people had seen the pilot

Bell UH-1H Tail-rotor Assembly



Source: New Zealand Transport Accident Investigation Commission

Figure 1

complete thorough preflight inspections of the helicopter before flying. He would use a stepladder, carried on board ZK-HJH, to access difficult places — for example, when greasing the tail rotor."

Visual meteorological conditions prevailed, with clear skies and light-and-variable surface winds. The report said that the flight time and the direction from which the helicopter approached Taumarunui indicated that the helicopter likely was flown over the area where the bait-spreading operations were to be conducted the next day.

Several people on the ground at Taumarunui said that daylight was fading but visibility was unrestricted when they observed the helicopter being flown from the northeast toward the airstrip. Witnesses' estimates of the helicopter's altitude varied; the report said that the altitude was at least 1,400 feet (600 feet above ground level).

"None of the witnesses saw anything unusual as the helicopter approached, and most of the witnesses reported that the helicopter sounded normal," the report said. "The helicopter then entered a turn. While several witnesses thought the turn was to the helicopter's left, the majority believed it turned to the right."

One witness mistook the helicopter for another UH-1H operated by a former employer. The witness observed the helicopter's tail "flick" [move slightly and rapidly] left and right several times before the helicopter began to turn right.

"The witness believed that the pilot had been signaling to him that he intended to land, as the flicks were sharper and more pronounced than usual," the report said.

The tail movements likely indicated that the pilot had begun to have tail-rotor-control problems. The helicopter then turned right.

"A turn to the right is symptomatic of a loss of tail-rotor thrust for the Iroquois if a pilot does not immediately reduce power to counter the torque effect of the main rotor when the failure occurs," the report said. "However, many witnesses observed the helicopter to remain about level for the early part of the turn, indicating that the pilot did not reduce power at the onset of the emergency. This was understandable, considering the tail initially flicked both left and right, which may have confused the pilot about the type of emergency."

During the turn, the helicopter's angle of bank increased, and the helicopter began to descend.

"The helicopter quickly became uncontrollable, and it is unlikely that the pilot could have recovered control of the aircraft," the report said.

Witnesses observed pieces separate from the helicopter before it struck the ground and began to burn. Emergency-services personnel arrived at the accident site, about five kilometers (three nautical miles) east of Taumarunui, at 1725.

"Several local residents had also rushed immediately to the scene, but no assistance could be given to the three occupants, who had died instantly," the report said.

Postmortem examinations of the occupants showed that they had received extreme traumatic injuries.

"The pilot and the person sitting in the center jump seat suffered injuries that were consistent with having been struck by a main-rotor blade or parts of it," the report said. "Witness marks on the blade support this conclusion. The third occupant's injuries were probably sustained as the fuselage impacted on the ground.

"The examination did not reveal anything that would have affected the ability of the pilot to control the helicopter. There was no medical [evidence] or pathological evidence of incapacitation or impairment for any of the occupants."

Pieces of the helicopter were found 450 meters (1,477 feet) from where the main impact occurred; the wreckage trail began with several pieces of paneling from the tail fin. The tail section, including the 90-degree gearbox and part of the tail-rotor assembly, had separated from the helicopter before the helicopter struck the ground.

"The fuselage had struck the ground vertically in a steep nose-down attitude," the report said. "Two of the occupants remained in the fuselage, while the third [occupant] had been thrown clear before impact."

The report said that the helicopter damage, wreckage distribution and occupant injuries indicate that the accident sequence began with loss of tail-rotor control.

Investigators found a bolt and a washer embedded in a tail-rotor blade. The bolt was a type that is used only to attach the tail-rotor-blade pitch links to the tail-rotor-blade horns and to attach the crosshead to the slider. (The crosshead and parts of the tail-rotor-blade pitch links were not found.)

"On ZK-HJH, the two bolts attaching the pitch links to the blade horns were still in position and accounted for," the report said. "The bolt [found embedded in the tail-rotor blade] appeared straight, and the threads were intact, although exhibiting some wear.

"The hole in the bolt for the split pin was empty, and the edges of the hole did not exhibit damage other than what would be expected for normal wear. … There was no evidence that any securing split pin had broken under load or that the nut had been pulled off. Under a microscope, a small amount of debris, possibly dirt and oil or grease, was visible in the hole through the bolt where the split pin would have been positioned."

Investigators concluded that the loss of tail-rotor control probably resulted from the crosshead becoming loose.

The report said, "There are three possible explanations for the tail-rotor crosshead becoming loose and the subsequent loss of tail-rotor control. These are:

- "The failure of a tail-rotor component;
- "The split pins were removed as a deliberate act; [or,]
- "The split pins were not inserted after the reassembly of the tail rotor during the inspection completed on 27 March."

The report said that the bolt found embedded in the tail-rotor blade, the slider and the retainer plate showed no sign of a failure in the tail-rotor-pitch-control mechanism; and the bolt showed no sign of failure of the bolt, retaining nut or split pin. Therefore, failure of a tail-rotor component was not likely the cause of the loss of tail-rotor control.

The report said that although the operator had encountered opposition and had received verbal threats for spreading poisoned bait, "there was no report or evidence of any deliberate or attempted damage to ZK-HJH or the support equipment. The police, the operator and relatives of the crew were not aware of any action that would account for the deliberate removal of the split pins. … While deliberate removal of the split pins was possible, it is considered unlikely."

The report said that the presence of debris in the bolt hole indicated that a split pin had been absent for "some time" and that omission of split pins during the inspection of the helicopter was the most likely reason for the loss of tail-rotor control.

"Having just fitted the crosshead once, including most probably the split pins, to then have to repeat the procedure again [to conduct the duplicate inspection], the LAME and the tradesman may have been inclined to rush the refitting," the report said. "In the rush, when it was time to fit and check the split pins, the LAME and the tradesman may have subconsciously reverted back to the previous fitting and assumed it had been done."

The report said that distraction might have been involved in the omission of the split pins.

"The fitting of the split pins, while a crucial element in the reassembling of the tail rotor, was, nevertheless, a small and simple task to complete — a routine automatic action for an aircraft engineer, especially one familiar with the Iroquois," the report said. "Should a distraction occur during a task, it is possible that a person could believe that the required action had been completed when it had not."

The report said that during the duplicate inspection, the tradesman might have assumed that the LAME had inserted the split pins.

"Knowing that the LAME had always inserted the split pins in the past, the tradesman may have also assumed that they had been fitted and either did not consciously check, or looked and believed he saw the split pins in place."

The report said that the unsecured nuts likely did not become appreciably loose until the accident flight.

"Over the next 50 hours of flying [after the inspection], the nuts probably backed off but still retained enough pressure on the crosshead to hold it secure and give the pilot no indication of an imminent control problem," the report said. "On the last flight, the two nuts reached the point where they were able to freely run off the bolts, initiating the loss of control."

The report said that the "lost opportunity to detect the omission" of the split pins during routine checks of the helicopter was a "significant factor contributing to the accident."

The report said that maintenance documents indicated compliance with ADs issued by CAA for UH-1H helicopters but not with U.S. Federal Aviation Administration (FAA) ADs issued for civilian versions of the helicopter (i.e., the Bell 204 and Bell 205).

"To strictly conform to its type certificate, the maintainer should have reviewed the FAA ADs for the Bell 204/205 to ensure that there were no outstanding technical matters that needed to be completed," the report said. "This needed to be done annually in conjunction with the ARA."

Some documents, including the helicopter flight manual and the technical log, were destroyed in the postaccident fire. The report said that TAIC has investigated several other accidents in which aircraft flight manuals and technical logs were not recovered — in most cases because the documents were destroyed by fire.

"The aircraft technical log contained current technical information relevant to the aircraft," the report said. "Much of the information would be repeated in other documents and remain available should the technical log be lost. However, some information — for example, maintenance carried out and certified between inspections — may not be available from other sources. This information could be relevant to an investigation should an accident occur."

The report said that the accident was among three fatal accidents involving ex-military helicopters in New Zealand during the first six months of 2001. On Jan. 15, 2001, a Bell UH-1F struck terrain in Wellington. On Feb. 12, 2001, a Westland Wessex struck terrain near Motueka.

[The report provided no details about the accidents. Airclaims said that the UH-1F was departing with an external load of debris from a construction site when it was observed "wobbling." The external load was released, and the helicopter descended in a left bank to the ground. The pilot was killed.[1] Airclaims said that the Wessex picked up a relatively small log at a hillside logging site but then lowered the log back to the ground. The helicopter hovered momentarily and suddenly dived toward the valley floor, where it struck trees and terrain. The pilot was killed.[2]]

The report said that the number of ex-military aircraft used in commercial operations in New Zealand has increased significantly in recent years.

"These aircraft often provide a cost-effective alternative to using purpose-designed or equivalent civil aircraft," the report said. "However, ex-military aircraft tend to be older than other aircraft and require specialist maintenance to continue flying. Spare parts can be difficult to source, and care needs to be taken to ensure they are both suitable and serviceable.

"Ex-military aircraft are often used in operations for which the aircraft [were] never intended. For example, while the Iroquois has an underslung-load capability, it was not intended for logging operations where there are large, rapid and frequent changes in power. The control and maintenance of these aircraft, therefore, need to be strictly adhered to and reviewed from time to time to ensure the aircraft remain airworthy."

The report said that as a result of the three ex-military-helicopter accidents, the New Zealand CAA began a review of the certification, operational use and oversight of ex-military helicopters; as a result of the accident involving ZK-HJH, CAA began a review of the maintenance company that maintained the helicopter.

Based on the findings of its investigation of the ZK-HJH accident, TAIC made the following recommendations to CAA:

- "Review the operation of the aircraft technical log to ensure [that] critical information is duplicated and [is] held separately from the log, possibly with the aircraft's maintenance documents. (064/01);

- "Educate licensed aircraft engineers who are holders of an inspection authorization, particularly those maintaining ex-military aircraft, on [ADs] and the requirement for the aircraft to conform to its type certificate. (065/01); [and,]

- "Ensure the New Zealand [AD] schedule specifies applicable [ADs] called up in the ex-military type certificates data sheets. (066/01)."

The report said that TAIC received the following response from CAA: "All three recommendations are accepted as worded and will be implemented as follows:

- "064/01: The review will be completed within six months (target date 30 June 2002), but any changes to the rule requirements will depend on negotiations between the CAA and the Ministry of Transport;
- "065/01: This will be addressed in the renewal training for inspection-authorization holders that starts in 2002, with a letter to be sent to each inspection-authorization holder by 31 January 2002; [and,]
- "066/01: [CAA] will ensure that the [AD] schedule specifies the appropriate [ADs] by 28 February 2002."♦

[FSF editorial note: This article, except where specifically noted, is based on New Zealand Transport Accident Investigation Commission Aviation Occurrence Report 01-005: *Bell (Western International) UH-1H Iroquois, ZK-HJH, tail rotor failure and in-flight break-up, near Taumarunui, 4 June 2001*. The 20-page report contains illustrations.]

Notes

1. Airclaims. *World Aircraft Accident Summary*. Supplement 125 (December 2001): H01:2.
2. Airclaims. H01:4.

Further Reading From FSF Publications

FSF Editorial Staff. "Fractured Bolts Blamed for Loss of Control of Two Helicopters." *Aviation Mechanics Bulletin* Volume 49 (May–June 2001).

FSF Editorial Staff. "Helicopter Strikes Terrain During External-load Aerial Logging Operation." *Helicopter Safety* Volume 26 (November–December 2000).

FSF Editorial Staff. "Unlatched Transmission Cowl Door Separates in Flight, Strikes and Disables Tail Rotor and Gearbox." *Helicopter Safety* Volume 24 (July–August 1998).

Rosenberg, Barry. "U.K. CAA Cites Inadequately Defined Inspection Procedures for Human Errors in Aircraft Inspection." *Aviation Mechanics Bulletin* Volume 43 (November–December 1995).

Feeler, Robert A. "Human Factors in Aircraft Maintenance and Inspection." *Aviation Mechanics Bulletin* Volume 39 (July–August 1991).

Vandel, Robert H. "The Huey Retires." *Helicopter Safety* Volume 14 (September–October 1989).

Flexible Drive Shaft Failure

NTSB Report: FTW01FA115

On May 4, 2001, at 1616 central daylight time, a Bell 407 single-engine helicopter, N917AL, sustained substantial damage due to a drive shaft component failure while operating off shore in the Gulf of Mexico. The commercial pilot and his passenger were not injured.

In an interview with the NTSB investigator-in-charge (IIC), the pilot reported that while in cruise flight at 700 feet agl, a "slight vibration became noticeable." After a few minutes, the vibration became more pronounced, and was accompanied by a noise. During an attempted precautionary landing to an offshore platform, the vibration and noise level increased again, and total engine power was lost. The pilot then initiated an autorotation to the water, deployed the skid floats, and landed safely. After landing, the pilot retarded the throttles, shut off the fuel valve and placed the electrical switches to the OFF position. While the helicopter was being towed in the water, the helicopter rolled over inverted. Examination of the helicopter, after recovery by the operator, revealed that the KAflex engine-to-transmission driveshaft had fractured, and the forward section of the tail rotor driveshaft had separated.

The fractured KAflex driveshaft was last removed and reinstalled on the helicopter on April 10, 2001, at a helicopter time of 1,998 hours. The KAflex driveshaft is often removed when maintenance is performed near the transmission area, pylon mounts, engine, etc. The helicopter's KAflex driveshaft had been removed and reinstalled nine times for both scheduled and unscheduled maintenance prior to accident. The KAflex driveshaft had a total time of 2,114.2 hours and an airworthiness life limit of 5,000 hours.

According to the BHTC maintenance manual, each end of the KAflex driveshaft is comprised of four rectangular flex frames that are attached with bolts to each other and to each end of the shaft. A flange adapter is attached to each flex frame assembly with bolts. One flange adapter bolts to the transmission input adapter, and the other flange adapter bolts to the rotor disk and to the freewheel adapter. The driveshaft turns at 6,317 rpms and transmits the power from the engine to the transmission. The driveshaft is designed to flex to accommodate the misalignment between the engine and transmission that occurs during operation. According to Transport Canada (TC), three incidents involving cracked flex frames on the forward (transmission) end of the driveshaft had previously been reported.

On May 17, 2001, at the facilities of Bell Helicopter, Hurst, Texas, under the supervision of the NTSB, the KAflex driveshaft and tail rotor driveshaft were examined by Bell engineers. Bell Helicopter's materials laboratory examination of the KAflex driveshaft "revealed fatigue fractures at a bolt hole in the first flex frame at the transmission end of the shaft and fatigue fractures in the end fitting at the transmission end. The primary fracture was a fatigue crack that occurred in a bolt hole where a bolt joined the first flex frame to the center flex frame. All the other fractures were a result of overstress." The driveshaft was determined to be manufactured within engineering specifications.

Bell Helicopter's materials laboratory report also stated that "the fractured tail rotor driveshaft was a result of torsional overstress. The direction of overstress was consistent with restraint of the driveshaft from the flywheel aft while the forward portion of the shaft was driven in a clockwise direction as viewed looking forward."

Sprague Gear Assembly Failure

NTSB Report: SEA00LA129

On July 11, 2000, approximately 1230 Pacific daylight time, a Kaman K-1200 helicopter, N311KA, collided with trees about 10 miles north of Cusick, Washington, after experiencing a loss of main rotor rpm during aero-logging operations. The commercial pilot, who was the sole occupant, received serious injuries, and the aircraft, which was owned and operated by Superior Helicopters, sustained substantial damage. The 14 CFR Part 133 long-line aero-logging operation was being conducted in visual meteorological conditions. No flight plan had been filed, and there was no report of an ELT activation.

According to the pilot, who was moving approximately 5,000 pounds of logs, he recorded their total weight while in a hover over the drop site. He then lifted the helicopter straight up to a height where the logs would clear the tree line. Just as the load was clearing the trees, the helicopter "shuddered," its engine "fluctuated" three times, and the pilot heard a "loud crack." The main rotor RPM immediately started to decrease, and the pilot turned toward a clearing about 100 feet downhill from his position. Just prior to reaching the clearing, the helicopter impacted a tree and fell to the terrain below.

During the investigation it was determined that 11 of the 33 sprags in the Free-wheeling Sprag Clutch Assembly (K974110-005) had rolled beyond the "full torque" position, and 24 of the 33 sprag retainer bars had separated from the sprag retainer cage. In addition, the surface of both the sprag assembly center input shaft (K974047-005) and the sprag assembly spiral bevel input pinion (K974013-005) contained areas of severe mechanical wear, smearing, heat flowing, and distortion of the surface metal. It was also determined that the engine adapter shaft had separated in a manner consistent with a predominantly torsional overstress failure.

An FAA-monitored inspection and test run of the Lycoming T5317A-1 turboshaft engine (No. LE-81016) was conducted on July 26, 2000. During the test, the engine was operated at ground idle, flight idle, maximum continuous power, and takeoff power. In addition, the engine was made to perform "snap accelerations" from flight idle to takeoff power and from ground idle to takeoff power. During all of these tests, the engine operated satisfactorily under all conditions, and no anomalies or abnormal conditions that would have contributed to a loss of main rotor RPM were identified.

In addition, the TA-7 Fuel Regulator and the PTG-5-1 Governor were functionally tested and subjected to a teardown inspection. No functional anomalies or irregularities that would have contributed to a sudden loss of rotor RPM were noted. A partial disassembly of the fuel regulator revealed no foreign objects or contamination.

Helicopter Dynamic Rollover

by Major Dave Lobik

Irrespective of the environment, dynamic rollover can happen to any helicopter pilot. The U. S. Navy SH-60B NATOPS (Naval Air Training and Operating Procedures Standardization) manual states, "The insidious aspect of dynamic rollover is that the roll rates which precipitate it are within the range the pilot would normally allow in flight." Put another way, this statement says that a helicopter could be placed in a rollover situation well before the pilot recognizes it. The goal of this article is to provide a better understanding of the causes of dynamic rollover and how to correct for it.

Dynamic rollover typically occurs when a critical rollover angle is exceeded. This angle--often referred to as the dynamic rollover angle--is considered that angle-of-bank beyond which the pilot's control authority can't arrest the angular velocity that develops laterally about a pivot point such as a skid or tire. This angle can be as little as seven degrees and varies with a helicopter's roll rate, gross weight, and main rotor thrust. In addition, there is yet another angle that is nearly as important and provides us with some hope for recovery, it is the static rollover angle. This angle results when the helicopter's lateral center-of-gravity (c.g.) is directly over the skid or tire. In other words, if we could balance a helicopter on its side by lifting one skid or tire until the c.g. is directly over the opposite skid or tire, this would be the static rollover angle.

Let's now look at the helicopter's roll response to cyclic inputs when airborne. In level flight for example, the thrust vector that is perpendicular to the tip-path-plane of the main rotor acts about the lateral c.g. to provide roll rates as shown in Figure 1. Now, the speed at which the aircraft rolls about the pivot point is determined by the helicopter's roll acceleration or *control power* and is dependent on couple of things: the control moment which acts about the c.g. and the roll axis moment of inertia. The control moment again is a function of main rotor thrust acting about the aircraft's lateral c.g. The moment of inertia, however, is not quite as simple. It relates the mass of a component to the point about which it acts and in this case, it's the lateral c.g. Incidentally, all aircraft have specific moments of inertia about each of the helicopter's three rotating degrees of freedom – pitch, roll, and yaw.

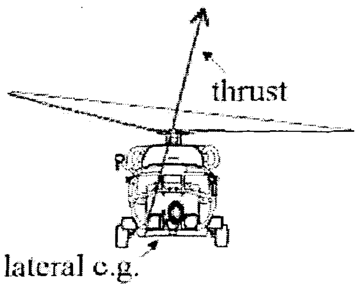


Figure 1

In flight, we are perfectly comfortable with maneuvering about the c.g. A potential problem develops, however, when the helicopter comes in contact with the ground (a lateral drift for example) and a new pivot point is established (e.g. the skid or tire). In this situation, the moment of inertia about the roll axis increases nearly five-fold due to this displaced pivot point and the control power decreases with opposite cyclic as shown in Figure 2. To make things worse, if the pilot applies opposite cyclic too late, the control moment will not act *outside* the new pivot point and will not provide the necessary control power to arrest the rolling motion.

At this point, an important question to ask is, "How do helicopters get into a dynamic rollover situation?" Well, just imagine hovering in a brownout or whiteout situation and

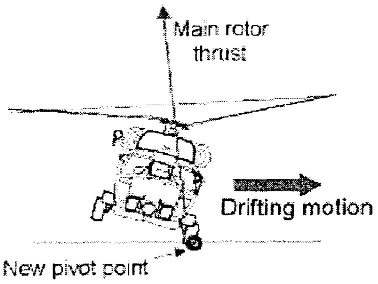


Figure 2

attempting to land. In the process, due to loss of visual cues, you establish a lateral drift and contact the ground with one wheel or skid. Unfortunately, the aircraft's c.g. now rotates about the wheel or skid causing the undesirable rolling motion and to make things worse, because the collective is not all the way down, the main rotor thrust is accelerating the motion exacerbating the situation causing the aircraft to rollover.

Identifying the hazards, taking the proper preventive measures, and ensuring that others don't get into the situation are the tenets of risk management; but what if we are unfortunate enough to get into it, how do we stop rolling over? First of all, getting rid of the control moment should be the goal of every pilot because we may not be sure if the main rotor thrust is accelerating or decelerating the roll motion – we do this by lowering the collective. Fundamentally, this action allows the weight of the aircraft to act against the rolling motion and is beneficial until the helicopter reaches the static rollover angle or the main rotor strikes the ground as shown in Figure 3.

There is yet another important question that should be asked, "What could possibly make this bad situation worse?" Well, what follows are a few points to consider. The tail rotor, for one, can provide a rolling moment about the lateral c.g. Considering only U.S. made helicopters, a rolling motion to the right (when sitting in the helicopter) will be made worse by the thrust produced by the tail rotor as it also acts about the tire or skid. Conversely, a rolling motion to the left will decrease as the tail rotor thrust acts to provide deceleration. The wind can cause the same advantage or disadvantage depending on direction as it provides a force that acts about the pivot point, as well. Additionally, the rolling motions associated with shipboard operations in high sea states can also result in a rollover situation as demonstrated recently by a U.S. Navy SH-60B. The aircraft's main rotor was turning at 100% rpm, *collective full down* and unrestrained when the ship was hit by a rogue wave resulting in 20 to 25 degrees of deck roll. The aircraft rolled to its left side and the main rotor was driven into the deck of the ship. Luckily, the aircraft remained aboard the ship and the aircrew escaped uninjured.

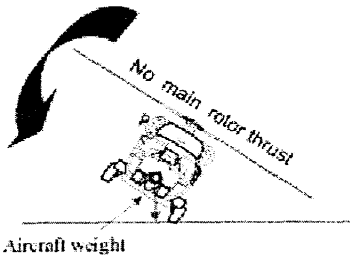


Figure 3

This same discussion on dynamic rollover has direct application to another area of helicopter flight that we are asked to perform as part of our mission – sloped landings. In the case of sloped landings, we actually *want* to pivot about the skid or tire. Normally, a sloped landing is performed by gently lowering the collective from a hover to contact the ground at a single point as shown in Figure 4. Cyclic is usually displaced upslope to provide the greatest control moment possible while preventing the aircraft from sliding. The pilot then gently lowers the collective to make full contact and rest firmly on the terrain as depicted in Figure 5. Two critical things to be aware of during this evolution are rotor clearance (personnel running into your rotor arc from the higher ground) and running out of control authority where the cyclic contacts the stops.

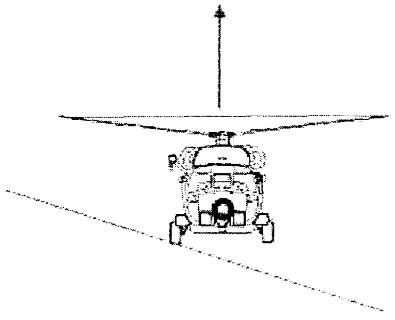


Figure 4

Quite often, a more dangerous aspect of this evolution is lifting off the slope. A common technique used when lifting into a hover from a slope is to displace the cyclic laterally toward the higher ground as up-collective is applied. This is performed delicately as the pilot searches for a level attitude before breaking contact with the ground; however, a problem can arise when the proper technique is not utilized. For example, if an arm full of collective is pulled too quickly before breaking contact with the ground, excessive momentum occur. In other words, if the aircraft is not stabilized prior to breaking contact with the ground, a "whipping" effect can occur as the pivot point quickly moves from the tire back to the c.g. This change in pivot point, thus inertia, can lead to a five-fold increase in control power rendering the aircraft uncontrollable. The end result can be catastrophic.

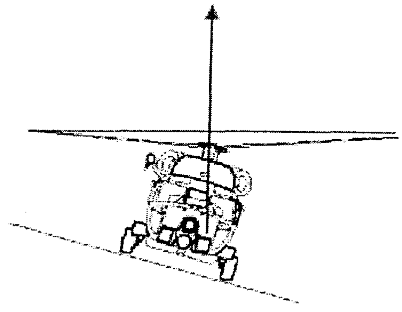


Figure 5

In summary, the brevity of this discussion on dynamic rollover should by no means reflect the importance of the topic. Over the years, several Naval helicopter pilots have experienced a dynamic rollover mishap and many more came close. The one thing that they would all likely agree on is that a firm understanding of this issue would have proved beneficial and perhaps prevented the occurrence. Don't be caught unaware, be knowledgeable and fly safely.

- Major Lobik was the Helicopter Aerodynamics instructor at the School of Aviation Safety, Naval Postgraduate School in Monterey, CA, from May 1995 - May 1998.

Updated: ***20 May 98***

Dynamic Rollover Accidents

A helicopter was substantially damaged when it rolled over during liftoff. The student pilot was not injured. The instructor had just completed 30 minutes of hover practice with the student. The student landed the helicopter and the instructor deplaned to allow the student to execute his first solo flight. As the instructor watched, the student began to liftoff and immediately rolled to the right and crashed. According to the instructor, the helicopter never left the ground. The student and instructor had lifted off about 30 minutes prior to the accident, and had flown down runway 18 to the south helicopter pad at the French Valley airport. The instructor stated that he had done many pickups and set downs with the student just prior to the accident. The instructor normally occupied the left seat of the helicopter during dual lessons. At the time of the accident, the student was occupying the right seat, and the left seat was empty. The solo flight was conducted on an asphalt helicopter landing pad designed specifically for helicopter operations. The instructor weighed 185 pounds. The student pilot weighed 233 pounds. After 30 minutes of hover practice, the helicopter had consumed 30 pounds of fuel. When the instructor deplaned, and the student attempted his first solo liftoff, the helicopter was 215 pounds lighter and the center of gravity was right of center but within limits.

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The flight instructor stated that after departure from Fort Lauderdale Executive Airport, they flew to the practice area northwest of the airport. After practicing hovering for about 35 minutes, they practiced a traffic pattern, to breakup the lesson. After performing the traffic pattern, they returned to practicing hovering. About 5 minutes later, while hovering, the student was flying the helicopter. The helicopter was drifting to the left and the student let the helicopter settle from about 5 feet. The instructor stayed light on the controls and waited for the student to correct the altitude. He told the student to raise the collective and apply some right cyclic. The student failed to correct and as the instructor began to make the corrections, the left skid skipped off the ground. This put the helicopter into a rolling motion to the left. He applied collective and full right cyclic, which was ineffective. They then experienced a dynamic rollover situation.

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The instructor stated he took his fiancé up to introduce her to helicopter operations. After completing training they climbed to altitude to overview the river valley being used as a practice area, then descended back down. They observed an airplane flying low through the valley, so the helicopter landed in the riverbed to wait for the traffic to clear. After a few minutes the instructor prepared to liftoff. As he lifted off, the right skid stayed in contact with the ground and the helicopter continued to roll over to the right.

Ground Resonance Accident

A helicopter was destroyed while performing main rotor blade tracking. Upon completing rotor engagement to track the newly installed main rotor blades, the pilot began to increase collective pitch. With approximately 2 inches of up collective, the helicopter began violent vertical vibrations. The pilot reduced collective and secured the throttle. The tail boom separated from the helicopter, the cockpit and skids were destroyed, and all three main rotor blade dampers separated from the main rotor blade trailing edges.

The main rotor blade dampers and the four shock strut oleos were removed for testing. These tests revealed that all the dampers were set 70 to 100 inch-pounds below the value specified in the maintenance manual. The red damper internal discs were assembled in an incorrect order.

The three intact strut oleos were compression tested and were all measured as very low. The qualified mechanic who performed the annual inspection stated he did not remember servicing the oleo struts. He stated the struts looked ok, and were hand checked by lifting up the tail to check for reaction. They were not checked with a pressure gauge.

The same mechanic stated that every other year during the annual inspection the dampers were disassembled, the plates cleaned using emery cloth, and reassembled with new fluid. The same parts that were removed were reinstalled into each damper, the torque was set using a dial calibration type torque wrench calibrated in inch-pounds, and the tension was checked using a scale and pulley. Lead to lag should be set from 6.5 to 7.0 inch pounds according to the maintenance manual.

The Pilot Operating Handbook for the Hughes 300 Model 269B contains an OPERATIONAL CHECK - OLEO DAMPERS section, which includes the following: "CAUTION" "Ground resonance can result if aircraft is operated when oleo damper extension, fluid type, and/or fluid-to-air proportions are incorrect."

The 269 Series – Helicopter Maintenance Instruction states: Warning: Incorrect phasing and/or torque adjustments of the dampers can lead to conditions that may result in ground resonance and destruction of the helicopter.

Chapter 15 of Helicopter Aerodynamics, by Raymond Prouty, an aeronautical engineer specializing in rotorcraft, discusses the phenomena of ground resonance. The phenomenon is associated with fully articulated rotor heads, and results when a resonant frequency is obtained between the ground, a shock strut system, and the rotor system. This resonance is initiated when the blades move on their respective lead-lag hinges, placing their combined center of gravity outside the center of rotation of the rotor disc. Damping to prevent this resonance is required in both the landing gear system and the lead-lag plane of a fully articulated rotor head."

Vortex Ring State Accident

A Bell 206B helicopter landed hard on a road approximately 200 yards short of the point of intended landing. About 100 to 150 feet above the ground, on a heading of 270 degrees the pilot flying allowed the helicopter to "slow up too much" and the airspeed went to zero and the sink rate increased rapidly. The pilot flying "made a significant collective increase drooping RPM and starting a right yaw/spin." The pilot took his hands from the controls and said to the copilot, "you've got it." The copilot took control, applied forward cyclic, down collective, and "throttle" to idle to stop the spin. He then tried to cushion the landing with up collective. The helicopter landed hard with no forward speed and no yaw on a heading of 060 degrees. A passenger, seated in the left rear seat, noticed the pilot "clutching" the controls during the second spin before impact. An examination of the helicopter provided no evidence of preimpact structural or system failure or malfunction. Weather conditions reported by the Telluride airport at the time of the accident were 6,000 foot overcast skies, a temperature of 70 degrees Fahrenheit (F), wind from 330 at 3 knots, visibility of 25 miles and an altimeter setting of 30.38 inches of mercury (Hg). Calculated density altitude was approximately 12,000 feet. This phenomenon is described in NASA publications as follows:

When entering a hover at high gross weights, and/or high altitudes under nearly calm wind conditions, vortex ring state or power settling may result. This condition occurs because vortices are built up at both the tips and along the span of the main rotor blades. A recirculation of air takes place and the helicopter settles into it's own rotor wash down flow which decreases the aerodynamic efficiency of the rotor system. The more power (higher angle of attack) selected in attempting to produce adequate lift the less efficient the rotor system becomes due to increased turbulence. An ever-increasing rate of descent is the result. In extreme power settling, the velocity of the recirculating air mass becomes so high that full power can produce a rate of descent in excess of 3,000 feet-per-minute.

Recovery from this condition is attained by increasing forward speed and rate of descent so that the rotor system "flies" out of the self-induced turbulence. When entering a hover in close proximity to the ground, sufficient altitude may not be available to recover before ground contact is made.

Mast Bumping Accident

A Fairchild-Hiller FH-1100 helicopter was destroyed during an in-flight breakup and collision with terrain. The two pilots departed on a local flight to photograph area real estate. Several witnesses said the helicopter had made abrupt maneuvers approximately 200 feet above ground level (AGL). They heard a loud "bang" and observed pieces separate from the aircraft. The witnesses said there was no fire until after ground contact. One witness said he was standing approximately 300 feet from the accident site when he first observed the helicopter. He said the helicopter was hovering around his neighborhood from "house to house" approximately 150 to 200 feet AGL. He stated: "The rotor flew off and the blade hit the cabin side. The nose pitched up, the rotor hit the cabin."

All major components were accounted for at the scene. The main rotor hub and blade assembly, with the top portion of the main rotor mast attached, was located approximately 190 feet prior to the main wreckage. The hub static stops exhibited paint and metal transfers from the rotor mast. The mast fracture was aligned with the bottom of the hub at the static stops. A metallurgist examined the fracture surfaces and said the mast exhibited overload fractures with no evidence of fatigue.

According to the Hiller Aviation Service Letter 10-10 published August 3, 1983:

"A recent fatal accident was caused by a pilot putting the helicopter into a low-G (weightless) flight condition. While he attempted to maneuver the helicopter with full cyclic inputs during the low-G condition, the rotor flapping at the teeter hinge exceeded design limits causing extreme 'mast bumping' fracturing the main rotor shaft."

"In forward flight, when a pull-up (aft cyclic) is followed by a push-over (forward cyclic, a weightless (low-G) condition will occur...[and] the rotor can exceed its flapping limits and cause structural failure of the rotor shaft. The best way to prevent mast bumping is to avoid abrupt cyclic pull-ups or push-overs during forward flight."

Loss of Tail Rotor Effectiveness Accidents

An Aerospatiale AS350BA was substantially damaged when it collided with terrain during hover taxi. The pilot said he was hover taxiing at 10 knots with a slight right quarterly tailwind over the parallel taxiway. As the pilot turned left towards the tie down area he reported that "a strong gust of wind seemed to hit the aircraft on the left side." The helicopter yawed to the left and full right pedal had no effect on arresting the counterclockwise spin. At the same time, the helicopter started spinning. Opposite anti-torque pedal input had no effect in arresting the spin. The helicopter struck the ground, and rolled over on its side. There was some thunderstorm activity west of the airport. The report noted that Eurocopter issued Service Letter 1518-67-01 in April 2001, that described three similar mishaps. The report concluded, "Pilots must ensure that the application of LEFT pedal inputs are very slight with immediate correction using right pedal. Additionally, pilots are not to apply LEFT pedal inputs while passing through 'translational lift.' This restriction is to preclude the possibility of 'tail rotor vortex ring state' which may result in a spin to the left from which recovery is not possible."

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A Hughes 269A helicopter on an aerial survey flight was substantially damaged during a hard landing following a loss of tail rotor effectiveness. The pilot stated that just prior to the accident the helicopter was flying about 100 feet above the ground on an easterly heading at an estimated airspeed of 20 knots, while making shallow turns following a dry-creek bed. The pilot reported that "suddenly the helicopter lost all of its lift and power and started descending toward the trees below." The pilot further stated that "he applied forward cyclic in an attempt to fly out of it" to no avail. He added that the "anti-torque pedals felt totally ineffective and just prior to impact the helicopter was in a flat spin to the right."

A representative of the engine manufacturer, who witnessed the engine run, reported "no pre-existing engine deficiencies were noted and the investigation did not produce any evidence that the engine was not capable of operating and producing power at the time of the accident."

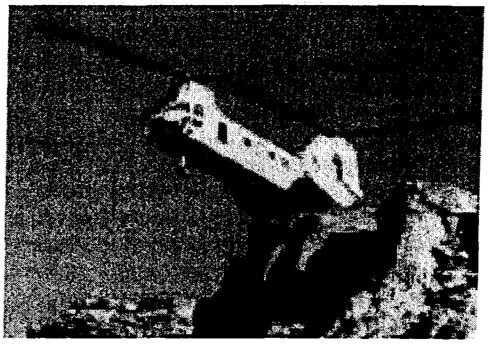
The loss of tail rotor effectiveness reported by the pilot and the resulting unanticipated right yaw (spin) also reported by the pilot are signatures consistent with an aerodynamic rotorcraft phenomena known as "tail rotor vortex ring state," for which certain relative wind velocities and azimuth (direction of the relative wind) must be present. These characteristics are present only at airspeeds below 30 knots, and with relative wind directions of 210 to 330 degrees.

The pilot reported that, at the time of the occurrence, the winds were from 340 degrees at 10 knots. Given the easterly heading of the helicopter, the relative wind direction was approximately 250 degrees.

Power Available vs Power Required,

the saga continues....

by Major David P. Lobik



The mishap investigation report read: "The helicopter was operating near max gross weight and drooped turns (main rotor revolutions per minute) at the bottom of the approach to the unfamiliar mountainous landing zone (LZ). On takeoff, the pilots realized too late that the power required to depart the LZ was more than normally available at sea level. The aircraft impacted the terrain." Sound familiar? All Navy/Marine helicopter communities have learned this lesson the hard way and though the relationship between power available and power required is recognized, it's often misunderstood.

Several Navy/Marine helicopter mishaps have occurred over the recent and not so recent past that would have been prevented with a solid understanding of the power relationship and exercising a little risk management. We in the helicopter flying business receive excellent instruction in the training command on the subject, however, knowledge and skill are both perishable and it has been proven that even the most experienced aviators suffer from a lack of understanding. Let's revisit this issue by taking a look at what comprises the power required and power available charts and of course, the main factors that affect both: gross weight and density altitude (DA).

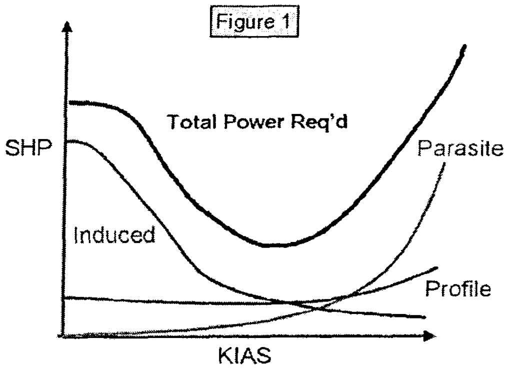
All helicopters with either a single main rotor or a tandem rotor configuration display a similar power required curve. This power required curve is made up of three power requirements - induced, profile and parasite, each demonstrating a dominance in a particular airspeed range. First, let's discuss the induced power requirement. Induced power is what people are referring to when they say helicopters "beat the air into submission." Newton's 2nd law concerning action-reaction applies in this regime where we must force air down to keep the aircraft aloft. In fact, approximately 70 - 80 % of the power required in a hover is induced power and is directly proportional to weight and DA; therefore, as aircraft gross weight or DA increases, so does the induced power required.

Secondly, we have the profile power requirement to overcome all form drag and skin friction that occurs with a rotor blade at a local zero lift condition; in other words, it's the drag of the blade at flat pitch. Look at it as the resistance that results when moving an object through the air that is producing lift such as rotor blades and vertical or horizontal stabilizers. It is proportional to forward flight speed (squared) and blade pitch, yet inversely proportional to DA.

Thirdly, parasite power is the power required to overcome the "barn door" effect. Those objects exposed to the relative wind that do not generate lift decrease our performance as airspeed increases. In a nutshell, it takes more power to move a non-aerodynamically shaped object through the air than one that is designed as a lift-generating surface. Speaking of moving barn doors through the air, designers of helicopters will work feverishly to reduce the nose-down attitude of the aircraft in high speed flight with the hopes of minimizing the area exposed to the air thus resulting in less resistance. This type of power required can be significant, especially at the upper end of our airspeed range due to its proportionality to flight speed (cubed). For example: in addition to the fuselage, the sponsons, external fuel tanks, missile launchers, and all contribute to providing unwanted resistance against the wind. Air has a difficult time negotiating sharp turns as it passes around components on our aircraft. To decrease the parasite drag doesn't necessarily mean to make it smaller, but rather, to aerodynamically shape it to move the air around the object with the least amount of turbulence. It's not by luck that external fuel tanks are not shaped like bricks!

The curves shown in Figure 1 represent the contribution of each type of power to the power required charts that we find in the back of most helicopter NATOPS manuals. These charts are normally represented as a family of curves corresponding to various aircraft gross weights, temperatures and pressure altitudes or DA and are also based on level, unaccelerated flight. From the Figure, it becomes apparent that induced power dominates the power required in the low airspeed regime to include the hover and decreases as the airflow through the rotor system increases providing for better rotor performance. Now, as the helicopter progresses through translational lift, airspeed increases and profile power kicks in. Again, the lifting surfaces such as the rotor blades fight the resistance as they slice through the air resulting in this increased power demand. As we continue to pull collective and approach cruise speeds, the parasite power requirement takes off! As seen in Figure 1, the power required to move a helicopter to velocity-not-to-exceed airspeed (V_{NE}) is quite significant and usually greater than hover power, but not always. This discussion on the power requirement curves will now help us analyze helicopter performance in the worst of fly conditions such as the high, hot and heavy environment.

Figure 1



But first, let's take a look at power available. Unlike jet engines on fixed wing aircraft, helicopter turbo-shaft engines do not show an appreciable increase in power available as a result of the inlet pressure rise associated with ram air. Therefore, helicopters demonstrate roughly the same power available in a hover as they do at V_{NE} airspeed. This is all well and good, but what happens with changes in DA and gross weight? All jet engines need to balance a proper fuel-to-air ratio to ensure maximum efficiency at all torque settings. If the air gets thinner as it will with an increase in DA, then the fuel introduced by our fuel management systems becomes less thus limiting the power available. Why? Because jet engines operate most efficiently when the fuel-to-air ratio is held constant for combustion. Therefore at high altitudes and temperatures, most engines can not provide all the horsepower the transmission can handle which means the power available line in Figure 2 will shift downward. This is occurring at the same time that the rotor system is requiring more air to produce lift; the result is a higher collective setting thus, more power required.

Figure 2

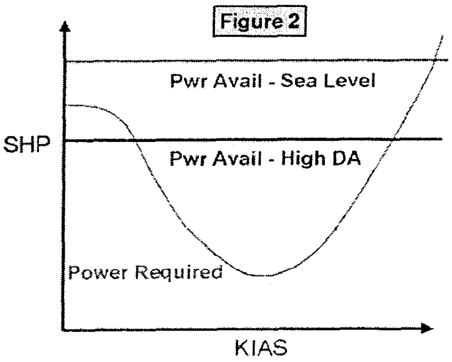
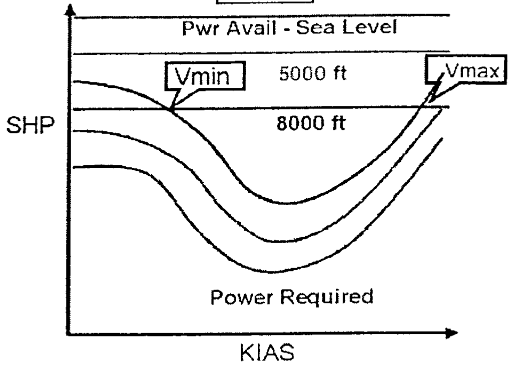


Figure 3 shows a representation of the power required curve merging with the power available, again, perhaps a high, hot and heavy situation (notice the region of deficit excess power). If the aircraft is flown at an airspeed below the left intersection (Vmin) or above the right intersection (Vmax) of the power required and power available curves, then the aircraft experiences a decrease in RPM and a descent follows--a typical result when power required exceeds power available.

Figure 3



An extreme example of a high DA and gross weight situation is the Mount Everest rescue of 1996 where a Nepalese helicopter pilot volunteered to rescue climbers after the area contract pilots refused to accept the mission due to the altitude and poor weather conditions. LtCol Maden K. C. of the Royal Nepalese Army understood very well the power requirements of his single engine AS 350. He was the officer that on May 13, 1996, rescued an American and a Taiwanese at an elevation of 20,000 ft. on the slopes of the highest peak in the world. He flew 2500 ft. above the helicopter's 20,000 ft. service ceiling to get over a ridgeline where he was successful in locating the climbers. After several landing attempts that resulted in a decrease in RPM and loss of altitude, he realized the need to shed some weight so he continued down the mountain to a lower elevation to drop off his copilot. As the afternoon sun began setting, he still knew the helicopter would have a difficult time hovering *in-ground-effect* so a no-hover landing was attempted. Concerned with the firmness of the snow, he hoped for hardpack and got it. He stayed light of the skids and took one climber at a time, staying in- ground-effect until he could push the nose of the helicopter over to pick up airspeed while following the down-sloping terrain. He successfully picked up the second climber in the early evening and is credited with performing the highest helicopter rescue in the world. Only through his familiarity with the austere flying environment and precise understanding of power available verses power required was the LtCol able to successfully achieve such a mission!

In conclusion, a change in aircraft configuration, gross weight and environment should activate a switch inside our helmet telling us to closely review the power computation sheet and understand what these changes do to helicopter performance and above all, fly the charts!

- Major Lobik was the Helicopter Aerodynamics instructor at the School of Aviation Safety, Naval Postgraduate School in Monterey, CA.

Updated: ***26 Mar 99***

Get it right on the day and do it right, because you're only..

MOMENTS FROM DISASTER

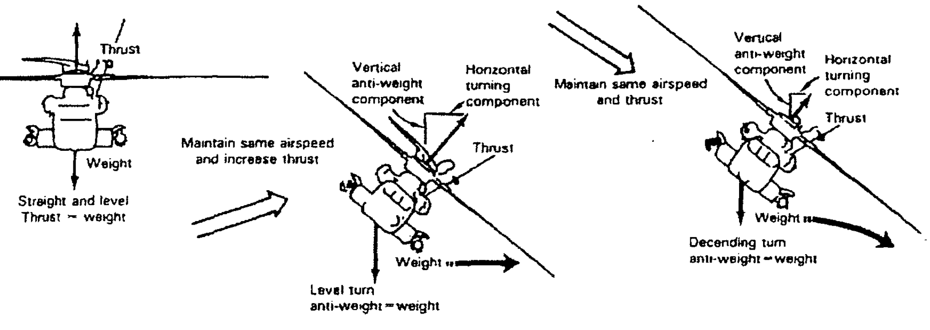
A few years ago a US Marine UH-IN was lost and one aircrewman killed on an evasive manoeuvring sortie, when the aircrew found themselves in an unarrestable rate of descent.

Following a left pop-up to gain advantage over the second Huey, the pilot found himself in a descending turn, with 70-80 per cent torque, and an airspeed of 80-90 kts. Thinking he was in a settling-with-power condition, he froze the collective and tried to fly out of the condition by lowering the aircraft nose to increase airspeed. The helo impacted the ground, with the left rear skid sustaining the initial shock and breaking free. The right skid eventually broke free as well, and the Huey slid on its belly straight ahead for 100 ft before rolling to the right. The main rotor blades struck the ground and the aircraft became airborne. It travelled 30 ft while rolling 360°, and struck the ground again on the right nose and forward cabin area. It cartwheeled back into the air, then fell back to the ground onto the left cabin roof and engine section.

The aircraft captain unstrapped and helped his copilot away from the aircraft, then returned to help the crewman in the aft cabin. The crew chief, secured only by a gunner's belt, suffered fatal injuries. An analysis of the accident revealed that the helicopter was not settling-with-power, but that the pilot had merely overbanked and failed to compensate.

We normally don't associate 'pulling Gs' with helicopters and, consequently, our lack of understanding of

Figure 1



this phenomenon has been a contributing factor in past accidents. It will be so in the future unless we educate ourselves about exactly what is happening to a helicopter manoeuvring at high angles of bank (AOB). Other accidents have involved helicopters operating at high angles of bank close to the ground. In one case the pilot on the controls was flying cross-cockpit (flying from the left seat and turning right, or vice versa), resulting in the aircraft descending and hitting the ground. This accident was not directly related to the above accident, but nevertheless reveals that many pilots don't appreciate the aerodynamics of high AOB flying, close to the ground.

Helicopter Aerodynamics

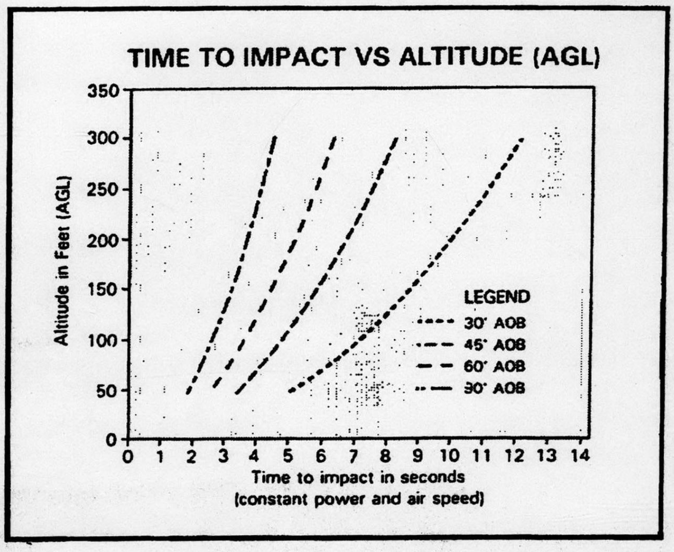
Let's look at the dynamics involved, starting from level flight (rotor thrust equals weight), and then rolling into an angle of bank while maintaining constant altitude and airspeed (Figure 1). We know from experience that to maintain this energy state requires an armful of collective. This is because of the increased thrust (manifested as collective position) required to maintain the vertical lift component when the thrust vector is tilted by entering an AOB. Our apparent weight (G-loading) increases proportionally with the AOB when we add sufficient power to maintain altitude and airspeed while banked. To determine G-loading, take the inverse of the cosine of the bank angle.

Representative bank angles and their associated G-load are tabulated in Table 1. For example, if we are in a 60° AOB (and if we increase our power sufficiently to maintain the same altitude and airspeed), then we are pulling 2G, which essentially means that we weigh twice as much as our straight-and-level gross weight.

Table 1

AOB	G-Load*
0	1
10	1.02
30	1.15
45	1.41
60	2.00
75	3.86
85	11.5
89	58.82
90	Infinity

* Apparent weight while maintaining altitude and airspeed at listed angle-of-bank (AOB).



What happens if we don't have the power available to lift twice our gross weight, or if we don't apply collective immediately upon rolling into an AOB? Figure 1 shows that we no longer have an equilibrium of vertical forces, hence we accelerate downward in the direction of the unbalanced force. For illustrative purposes, let's assume we are flying at 300 ft AGL and roll into a 60° AOB, while maintaining our airspeed but without increasing our collective power. How long will it take before we hit the ground? The above graph plots the time to impact from various entry altitudes (AGL) and bank angles, assuming no initial vertical velocity.

Actually, the plotted time to impact corresponds to when the altitude sensing port hits the ground, which obviously will be preceded by main rotor impact. This plot is independent of the type of aircraft or gross weight and is merely a function of AOB. A partial application of power or a reduction in airspeed will increase the time to impact and, conversely, power reductions or increases in airspeed will decrease the time to impact. Also, any initial rate of descent present upon entry will decrease the time to impact.

Another factor often not considered is the change in parasite power required due to a change in the area exposed to the free stream flow when we go from straight-and-level flight to an AOB. For our example, starting at 300 ft AGL and rolling into a 60° AOB without any power adjustment while maintaining our entry airspeed, the time to impact is approximately six seconds – which is about how long it took you to read this sentence!

A moment's hesitation in applying collective or distraction due to radio communication, caution panel/warning light illumination, traffic calls, visual disorientation, or whatever – coupled with a failure to immediately satisfy the power requirements when rolling into an AOB at low altitude – will result in a downward acceleration that puts you just moments from disaster. ✈

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附錄二　Training Attendees

SOUTHERN CALIFORNIA SAFETY INSTITUTE
HELICOPTER INVESTIGATION COURSE
COURSE 03-3

CLASS DATES: 8-12 September 2003 STUDENTS: 8

NAME	COMPANY	BUSINESS ADDRESS	PHONE	FAX PHONE	BUSINESS
Bruce Albert	US Army AMCOM Email: bruce.albert@rdec.redstone.army.mil	Bldg. 4488 Room C-153 Attn: AMSAM-RD-AE-I-PA Redstone Arsenal, AL 35898-5000 USA	256 705 9814	256 705 9918	Aerospace Engineer
Wen-Huan Chang	Aviation Safety Council Email: wen-huan@ASC.gov.tw	16th Floor; 99Fu-Hsing N. Rd Taipei 105, Taiwan REPUBLIC OF CHINA	886 2 2547 5200 Ext. 160	886 2 25474975	Investigator
Bill Green	US Army Email: bill.green@rdec.redstone.army.mil	Research Engineering & Development Attn: AMSAM-RD-AE-I-P-A Building 4488, Room C 135 Redstone Arsenal, AL 35898-5000 USA	256 705 9832	256 705 9918	AH-64 Systems-Drivetrain/Landing
Henry Jongeleen	Royal Netherlands Navy Email: me.mvkk@mindef.nl	Maintenance Department, Engineering Naval Air Station de Kooy Rijksweg 20 Den Helder, 1780 CA THE NETHERLANDS	31 223 658552	31 223 658752	Senior Maintenance Engineer
Ed Malinowski	NTSB Email: malinoe@chi.ntsb.gov	31 W. 775 North Avenue West Chicago, IL 60185 USA	630 377 8177	630 377 8172	Air Safety Investigator
Ken Muzzo	US Army Email: kenneth.muzzo@rdec.redstone.army.mil	Attn: AMSAM-RD-AE-I-P-A Building 4488, Room C 135 Redstone Arsenal, AL 35898-5000 USA	256 705 9846	256 705 9918	

NAME	COMPANY	BUSINESS ADDRESS	PHONE	FAX PHONE	BUSINESS
David Ross	Transportation Safety Board of Canada Email: david.ross@tsb.gc.ca	335-550 Century Street Winnipeg, MB R3H 0Y1 CANADA	204 983 8843	204 983 8026	Operations Investigator
Thormodur Thormodsson	AAIB Iceland Email: thormodur@rnf.is	Hus FBSR,Flugvallarvegi 101 Reykjavik ICELAND	354 511 1666	354 511 1667	Chief Inspector of Accidents