行政院及所屬各機關出國報告
（出國類別：實習）

參加美國 FAA 運輸安全學院
旋翼機安全及失事調查訓練報告

服務機關：交通部民用航空局
出國人職稱：約聘人員
姓　　名：薛迪寬

出國地區：美國 德州 達拉斯
出國期間：民國九十二年三月九日至三月二十三日
報告日期：民國九十二年六月十六日

系統識別號:C09202003

公 務 出 國 報 告 提 要

頁數: 16　含附件: 否

報告名稱:

參加美國FAA運輸安全學院旋翼機安全失事調查訓練報告

主辦機關:

交通部民用航空局

聯絡人／電話:

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出國人員:

薛迪寬　交通部民用航空局　飛航標準組　約聘人員

出國類別: 實習

出國地區: 美國

出國期間: 民國92年03月09日 -民國92年03月23日

報告日期: 民國92年06月16日

分類號/目: H2／航空　H2／航空

關鍵詞:　FAA,TSI,NTSB,IIC,ASC,失事調查

內容摘要: 美國FAA運輸安全學院（Transportation Safety Institute）主要扮演安全訓練及技術協助的角色，提供高品質的訓練及輔導予私人公司乃至於地方、各州、及聯邦機關等各層次之多樣化客戶。其所屬航空安全部門（Aviation Safety Division）之訓練課程，由在該教學領域執教多年經驗之專業教師執教。範圍涵蓋了普通航空業及運輸業程序以及所有的民航及公務航空失事調查方面之教育訓練。每年針對飛機、旋翼機失事調查、航空器客艙安全調查、私人製造航空器、渦輪引擎等失事調查及人爲因素調查等主題，各開辦多批訓練課程。本次參訓之「直昇機安全及失事調查」課程，訓練目的在使受訓者能在旋翼機失事或意外事件發生後，對蒐集調查相關資料，各種因素對事件影響之分辨，失事原因分析，能建立概念，並提出飛安改善建議。並能經由各種案例，對飛安提供鑑往知來之防範未然之效。

本文電子檔已上傳至出國報告資訊網

參加美國FAA運輸安全學院
旋翼機安全及失事調查訓練報告目錄

附件四、民用航空旋翼機風險

附件五、安全投資效益與風險之評估

附件六、單引擎與雙引擎直昇機風險之評估

壹、目的：

民用航空局檢派航安檢查員，參與美國聯邦航空局（FAA）運輸安全學院（TSI）委請貝爾直昇機公司主辦之旋翼機飛安及失事調查訓練課程，目的係為使本局航安檢查員經由此一訓練課程，能更深入瞭解直昇機之各種失事原因，進而透過對國內業者作飛安輔導檢查機會，將相關經驗對業者作機會教育。另如有失事發生時，可協助調查真相，祈使對直昇機飛航安全及失事預防能有所助益。

貳、過程紀要

一、 行程說明

本次出國行程自民國九十二年三月九日至三月二十三日為期十五日，詳細行程如下表所示：

月	日	起　訖　地　點	行　程　紀　要
3	9	台北－洛杉磯	搭乘中華航空班機前往美國洛杉磯
3	10	洛杉磯－德州達拉斯	搭乘美國航空班機轉往德州達拉斯
3	11-20	德州達拉斯	受訓
3	21	德州達拉斯－洛杉磯	搭乘美國航空班機往洛杉磯
4	22-23	洛杉磯－台北	搭乘中華航空班機返回台北

二、 受訓課程表：

三月十一日(星期二)

08:00-10:00　課程及環境介紹
　　教官:Dave Dosker
10:00-12:00　美國運輸安全委員會中南區工作介紹
　　教官:Aaron M Sauer
13:00–16:30　直昇機系統介紹
　　教官: Dave Dosker

三月十二日(星期三)

08:00–12:00　直昇機空氣動力學
　　教官:Bill Love
13:00–16:30　直昇機系統介紹
　　教官: Dave Dosker（續）

三月十三日(星期四)

08:00–12:00　危險評估、
　　教官: :Roy Fox
13:00–15:00　墜機生還調查
　　教官: :Roy Fox
15:00–16:30　旋翼機人為因素
　　教官:Roy Fox

三月十四日(星期五)

08:00–12:00　未認證料件
　　教官:Bob Trainor
13:00–16:30　BELL 事件研討
　　教官:Jim Wildey

三月十七日(星期一)

08:00-12:00　Robinson 事件研討
　　　　　　　教官:Butch Brelser
13:00-15:00　旋翼機合金材料
　　　　　　　教官:Robert Figuero
15:00-16:30　複合材料
　　　　　　　教官:Phil Woody

三月十八日(星期二)

08:00-12:00　Boeing 事件研討
　　　　　　　教官:Adrian Booth
13:00-16:30　Lycoming 事件研討
　　　　　　　教官:Greg Erikson

三月十九日(星期三)

08:00-12:00　Rolls-Royce Allison 事件研討
　　　　　　　教官:Jeff Edwards
13:00-16:30　Eurocopter 事件研討
　　　　　　　教官:Joe Syslo

三月二十日(星期四)

08:00-10;00　Sikorsky 事件研討
　　　　　　　教官:Chris Lowenste
10:30-12:00　失事調查實習
　　　　　　　教官: Dave Dosker
13:00-16:00　失事調查實習飛機失事調查
　　　　　　　教官: Dave Dosker
16:00-16:30　課程檢討,
　　　　　　　教官: Dave Dosker

參、受訓心得：

本課程係由美國聯邦航空局（FAA）運輸安全學院（TSI），在教學領域具多年經驗且非常專業的教師執教。訓練地點在德州貝爾直升機公司實施，除了課堂上之講授研討之外，亦包括了至貝爾實習工廠，實際參觀該公司各型直昇機實體拆解訓練現場教學，另亦利用失事直昇機殘骸實際的作分組調查演練。

此一課程之目標為增進瞭解直昇機失事調查管理及現場調查技巧及程序。授課教師有來自國家運輸安全委員會（NTSB）調查員、貝爾直昇機公司、羅賓森直昇機公司、來康明引擎公司、勞司來司引擎公司及歐洲直昇機公司之飛安部門專業人員。

此次參加上課之學員計有 26 員，除本人 1 員外籍學員，其餘均為來自美國聯邦航空總署各州之 PART135 航務、機務、航電檢查員，另亦有航管人員參訓。訓練單位規定課堂上不得錄音、錄影或照相，本人所佩帶之識別證亦加註需受監督，不得單獨行動文字，此點雖未嚴格執行，但影響心理感受卻不佳。

◆ **美國 FAA 檢查員失事調查扮演之角色及職掌：**

➢ 檢查員之陳述：承辦檢查員（IIC）宜將有價值之資訊紀錄下來，以便分享其他檢查人員，且陳述必須保持真實性，最好簡明扼要，不要有推測或添加自己之意見，只需陳述自己發現的事項，而不要認定事件是如何發生的，且初報不需長篇大論。

- 經費：失事調查之經費非常有限，不要隱藏任何發現之事情，包括保安、飛機拆解或實驗室測試，所有的開銷均需有主任調查員或區域指導員核准。
- 航管報告：失事事件牽涉到航管單位時，方需要求航管單位作報告；或者國家運輸安全委員會主任調查員要求時。完成以後作成兩份報告交美國聯邦航空局（FAA）及國家運輸安全委員會（NTSB）各乙份。
- 資料遺失：為避免資料在傳遞中遺失，儘量以可追蹤之方式郵寄（掛號）。
- 時限：國家運輸安全委員會(NTSB)在失事發生 180 天之內要完成失事調查，美國聯邦航空局（FAA）接獲駕駛人或使用人之報告表（6120.1/2），印製副本後，將正本儘速送交 NTSB 之 IIC，避免將正式失事報告之內容電傳傳真。
- 照片：照片會說話因此只需相關之照片來支持失事肇因及因素記住避免將人攝入照片中。
- 藥物報告：如接獲任何酒精或違禁藥物檢驗報告，即刻將原始資料通知 NTSB。
- FAA 作業中心：運用 FAA 區域作業中心（ROC）做初始失事通報，如可行的話，在出發至現場前與 NTSB 聯繫。區域作業中心在失事調查工作中扮演很重要的角色，他們的專業及創見非常受歡迎。
- 與媒體協商：在場外失事，將所有之媒體問題知會 NTSB 之 IIC，如非場外失事，針對媒體問題只給予事實及簡明之回答。請不要推測或加入自己之意

見。告訴他們調查正在進行中及向其詢問進一步之資料。

- 溝通：如果你對失事調查有任何問題或疑問，請電話 NTSB 之 IIC；失事調查程序中之飛安會議，你扮演了一個極重要的角色。在很多方面，你是失事現場飛安會的耳目。
- 善用 NTSB 的調查官：在中南區有一位調查官被指定擔任 FAA 調查員處理非關失事之各類行政事務。
- 我們珍惜你的回應：當你收到 NTSB 初始報告或續報副本，如果你有更改增加或刪除建議，電知 IIC。
- 電話：為了減少 NTSB 行政人員工作負荷請在任何時間以 IIC 的直撥電話打給 NTSB 區域辦公室。
- 避免親自攜帶飛機零配件或文件：儘可能複印你所需要的任何文件，並將原始本留給所有人或殘骸上，不要帶走任何零件、文件、資料牌或個人財物，除非你給所有人或其代表一份收據。
- 殘骸釋回：儘快的將殘骸釋回給所有人或使用人，最佳方式是以文書釋回殘骸，較可行之方法是使用 NTSB 之 6120.15 表格。
- 不要拆移或損壞資料牌：飛機資料牌屬於所有人，NTSB 或 FAA 均無權移除，或切割開。
- 殘骸移動：在某些時候有需要移動殘骸（如阻擋使用中之跑道、阻擋高速公路、校園等）如因時間關係，你是唯一有權移動殘骸者，在授權移動前，確

定失事現場用錄影機或照相完整紀錄，另外要求殘骸以油漆或其他半永久之方式作標示，取得受委託作殘骸紀錄者的名字。

- 目擊證人：可靠的目擊證人通常是最佳之工具，獲得其姓名、電話號碼及地址（所有的證人）；如可能的話，在現場請他們對證詞簽名。
- 駕駛人/使用人報告：在外出前往失事現場時，請攜帶至少兩份NTSB6120.1/2 表格之影本（駕駛人/使用人航空器失事報告表），如可能的話，在離開現場前，請駕駛人/使用人完成你所提供之報告表格。
- 損害評估：一旦你評估完成航空器之損壞等級後，請適時的告知 NTSB 檢查員。在大多數的案件中，航空器所遭受損壞的程度將決定其為失事或是意外事件，如果損害評估為失事，被指定的 NTSB IIC 應可提供檢查員與指定之失事件號等所需資料。

◆ **調查現場作業概述：**

- ✓ 協調地方憲警協助管制現場時，請其比照犯罪現場管制，較易溝通。
- ✓ 繪製現場簡圖：磁羅盤、捲尺、筆、時鐘、記事本、方格目紙等；記錄基準點、飛行方向、散落物件/殘骸位置及間距/撞擊點/受撞擊物件。
- ✓ 照相或攝影記錄：殘骸及散落物件移動前/不同方位角/空中/進場方向/週遭環境/撞擊物/撞擊點。
- ✓ 污染液體之記錄：適當之容器。
- ✓ 飛機各系統之檢查記錄。

✓ 目擊證人訪談及記錄：航空知識之有無宜予註記。

◆ **飛機各系統之檢查：**

- 機體：外觀之凹痕判斷撞擊方向/撞擊物之性質/照相時利用陰影表達。
- 駕駛艙：儀表面板受人員撞擊之痕跡/撞擊方向

  座椅受擠壓程度/方向

  各類開關/油門桿之位置

  儀表指針顯現碰撞壓痕/停止之時鐘

  迴旋桿/集體桿之狀況/插銷位置
- 滑橇：彎折之形狀判斷落地方向/輕重/地面質地/地面障礙物之關係。
- 尾桁：彎曲/折損/撞擊砍傷之狀況、方向
- 旋翼系：主旋翼頭組件之狀況

  旋翼片之材質/彎曲/受損/斷裂之狀況（不同材質斷裂程度有異）

  彎曲變形之模式（高/低轉速、有無動力呈現不同）

  尾旋翼受損傷模式
- 傳動系：尾傳動軸彎曲變形之方向/耦器狀況
- 發動機：外觀/破損/滲漏燃油滑油/管線排列/互搭狀況

  燃油系/滑油系/進氣系分類

  管路接頭手動檢查鬆緊狀況/有動狀況復原後標記並記錄

管路上紅色標記/保險是否在定位

確認壓縮器一級/發電機/N2/傳動軸間之互動狀況

壓縮/注油檢查

真空檢查

- **直昇機風險評估：**

- 歷年各類型直昇機失事分析
- 直昇機與其他大型航空器應有不同失事率計算基準及方式
- 失事預防
  - 在人員死亡、傷害預防
  - 失事安全因素
  - 失事反應計劃
  - 求生訓練
- 單引擎與雙引擎飛機安全之迷思
  - 各有不同之使用時機及環境
  - 大多數時間除經濟差異外，並無安全差異。
  - 任務前詳加計劃
- 失事率與引擎數量無絕對關係/造成之人員傷亡亦無關聯
- 良好之維護訓練及飛行訓練管理可降低失事率

- **可疑未經核准料配件：**
  - ✖ 所有料件均要有文件顯示出處
  - ✖ 送修料件之原始掛單必須檢查
  - ✖ 缺少或可疑之文件、偽造之印章、戳記
  - ✖ 掛籤簽證人員之筆跡太過一致，可疑之複製簽名
  - ✖ 失效、過期之料件
  - ✖ 退件頻率過於頻繁
  - ✖ 翻修之壽限料件、壽限料件之效期更改加長
  - ✖ 可疑、變造之資料牌或資料牌遺失
  - ✖ Data plate 之變更需有非常明確的文件資料及原廠查證
  - ✖ 無包裝或不當的包裝、可疑之包裝
  - ✖ 價錢之差異
  - ✖ 外觀異於常態
  - ✖ 料件上之件號資料號碼之清晰度及排序
  - ✖有照翻修人員，至世界各地蒐集*失事飛機*引擎料件整修，再分送第二家、第三家廠商大修，以獲取各家之認證後再使用。
  - ✖ 已遭取消資格之維修廠翻修件仍然在通路販售
  - ✖空中解體/機體經火燒/機體撞擊扭曲變形/有鹽分之水域或海水淹沒 24 小時以上

◆ **失事案例概述：**

航空器失事事件沒有新花樣，大多數如同歷史般不斷的重演！瞭解失事案例原因，作前車之鑑，鑑往知來，提醒自己防範未然。

- ✧ BK-117 型機主旋翼頭扭張力帶因腐蝕斷裂造成失事。
- ✧ BK-117 型機發動機蓋板鎖扣斷裂，蓋板飛脫撞擊主旋翼及尾旋翼，造成失事。
- ✧ AS-250-B2 型機集體變距桿控制及液壓開關不經意關斷造成失事。
- ✧ BELL-47 型機郵輪甲板起飛，繫留鏈條未解脫及油箱蓋未蓋妥造成失事及失火。
- ✧ UH-1H 型機直尾翅天線座螺桿四缺三，震動致使斷裂造成尾旋翼打擊天線，軸承及尾齒輪箱飛脫，飛機失控失事。
- ✧ BELL-206 型機短軸偶合器無潤滑，過熱導致齒條融化，喪失轉速失事。
- ✧ BELL-206 型機長時間擔任吊掛（大馬力滯空），尾桁受高溫排氣下洗氣流長時間烘烤，受應力側之部份鉚釘斷裂，尾桁斷裂造成失事。
- ✧ 主旋翼（鋁合金材質）鏽蝕，造成葉片斷裂失事。
- ✧ 主旋翼片砂眼或外物損傷之傷口，未發現或處理，造成金屬疲勞而斷裂失事。
- ✧ 主旋翼片不可修補部位，未按規定逕行修補，造成斷裂失事。

- ✧ 主旋翼翼根與翼片接合處，外表細裂痕未發覺，深入旋翼片內部造成斷裂失事。
- ✧ 主旋翼頭快拆接頭插銷未完全插至定位，造成旋翼片脫離失事。
- ✧ 尾旋翼鐵氟龍材質叉型軸承，未按規定擅自噴用 WD-40 除鏽劑，軸承損壞脫落造成失事。
- ✧ 尾旋翼齒輪箱支座上漆，齒輪箱裝上後，接合處因油漆歷經熱脹冷縮，致使原加之螺桿扭力改變，尾齒輪箱鬆脫失事。
- ✧ 尾桁內留置修護工具，導致尾傳動軸磨損斷裂失事。
- ✧ 尾旋亦傳動軸結合處螺桿鬆脫，導致尾傳動軸磨損斷裂失事。
- ✧ 滑油箱油封更換後，螺桿未上扭力，運轉後滑油壓力肇使油封斷裂，漏滑洩漏失事。
- ✧ BELL-206 型機隨機乘員手持紀錄夾，伸出機外飛脫，卡在尾旋翼上造成失事。
- ✧ 新手直昇機駕駛員，無夜航經驗進入夜航造成失事。
- ✧ 休斯 500D 型機，迴旋桿配平馬達磨損，碎屑造成系統短路，而使配平行程單向伸展，造成失事。
- ✧ S-76 型機 EMS 特種目視起飛後，空中申請儀器飛航，航管批答頒布前撞山失事。

✧ BK-117 型機 EMS 起飛赴任務區，因躲避雷雨區繞道，未注意油料用罄失事。

◆ **課外座談會**：（參加人員全體學員、NTSB 西南區代表、FAA 代表、飛機製造商）

⊕ 美國直昇機 EMS 任務失事率與日增高。

⊕EMS 業者試圖沿襲軍方使用夜視鏡飛航，FAA 法規無明文規定，需否修法。

⊕ 直昇機模擬機無法完全模擬目視及 50 呎以下之動作，雙發動機直昇機製造廠商稱無此需求，製造商意見兩極。

⊕學員詢問 NTSB 為何專注於 PART121 之調查，忽略 PART135 及其他之業別，NTSB 代表稱因 PART121 之失事較引媒體及社會大眾注意，另其自身人力亦有限。

⊕檢查員懷疑八天之訓練如何至失事現場當專家參與調查，贋品料配件請製造商提供正確辨識方法。

⊕ 加拿大對不確實填報失事者並不處罰，而以其他方式規勸主動報告。

肆、建議事項：

一、　本課程內容確能提升一般無經驗者對直昇機之瞭解，對有直昇機經驗之人員，更能融會貫通其精義，最適合檢派普通航空業航務、適航部門檢查員參訓，以增進對直昇機飛安觀念之輔佐生根。

二、　課程內容對直昇機風險評估及失事分析亦有所著墨及特殊之觀點，業管失事分析人員，亦應列為爾後撿派受訓對象，以利吸取國外對直昇機失事分析之創新觀念。

伍、附件：

附件一、參訓學員名冊

附件二、緊急醫療服務（HEMS）直昇機失事率分析（1991-2003）

附件三、美籍直昇機失事率分析（1991-1998）

附件四、民用航空旋翼機風險

附件五、安全投資效益與風險之評估

附件六、單引擎與雙引擎直昇機風險之評估

附件一

U.S. DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SAFETY INSTITUTE
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附件二

Helicopter Emergency Medical Services (HEMS)

During the period of 1991 to 1997 there has been a relatively low amount of EMS accidents, averaging approximately 2 per year. Since 1998 there has been a significant increase in these numbers. The accidents that occurred between 1998 and 2003 (to date) make up 75% of all EMS accidents in the 1991-2003 time period. Despite this increase, however the percentage of fatal accidents is declining. EMS accident data from several sources, the National Transportation and Safety Board (NTSB), Helicopters Association International (HAI), and Air Medical Pilots Association (AMPA) have been reviewed and displayed in the following tables. Accidents that occurred during maintenance flights, check rides ferry flights, etc. were not included in the study. Chart 1 shows the increase in accidents since 1991. Table 1 below shows the number of accidents, fatal accidents and fatalities.

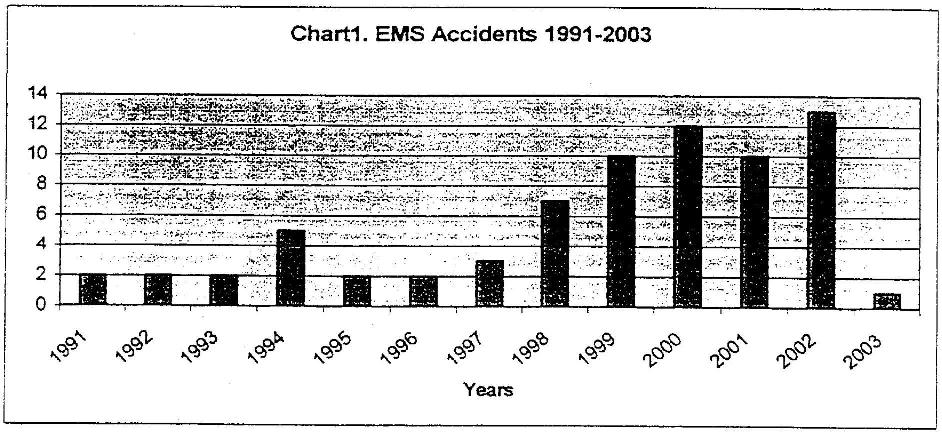


Table 1. Number of EMS Related Accidents, Fatal Accidents and Fatalities

Year	Accidents	Fatal Accidents	Fatalities
1991	2	2	7
1992	2	1	2
1993	2	2	5
1994	5	3	9
1995	2	0	0
1996	2	1	3
1997	3	2	5
1998	7	4	14
1999	10	3	10
2000	12	4	11
2001	10	2	2
2002	13	5	13
2003	1	1	2
Total	71	30	83

Tables 2, 3 and 4 describe the number of accidents by time of day, weather condition and leg of flight respectively. Approximately 14% more accidents occurred during the night than day. Accidents that took place at dusk were also placed in the night category. Only 15% of the accidents were in adverse or instrument meteorological conditions (IMC), while 53% occurred on the leg going to the accident.

Table 2. Number of EMS Related Accidents By Day/Night

Year	Day	Night
1998	2	5
1999	5	5
2000	4	8
2001	5	5
2002	7	6
2003	0	1
Total	**23**	**30**

Table 3. Number of EMS Related Accidents By Weather Conditions

Year	VMC	IMC/Adverse
1998	5	2
1999	7	3
2000	11	1
2001	10	0
2002	12	1
2003	0	1
Total	**45**	**8**

Table 4. Number of EMS Related Accidents By Leg

Year	Going To Accident	Transferring Patient	Returning to Base
1998	4	3	0
1999	5	2	3
2000	3	3	6
2001	6	2	2
2002	9	4	0
2003	1	0	0
Total	28	14	11

Three times as many accidents were caused by pilot error or technique, 64%, compared to mechanical and weather related which accounted for 21% and 15% respectively. Approximately one-third of the pilot errors were weather related. The largest number of accidents occurred in the Western Pacific region, 22%. Pilot information; average age, total flight hours and total flight hours in type are indicated in Table 7.

Table 5. Number of EMS Related Accidents by Cause Factor

Year	Pilot Error/Technique	Mechanical	Weather
1998	2	3	2
1999	6	1	3
2000	9	2	1
2001	7	3	0
2002	10	2	1
2003	0	0	1
Total	34	11	8

Table 6. Number of EMS Related Accidents By Region

Regions	Accidents
AWP	12
ASW	11
ASO	9
ANM	9
AGL	8
ACE	3
AEA	1

Table 7. Average Pilot Age, Total Hours and Hours in Type

Age	Total Flight Hours	Total Flight Hours in Type
45	5134	673

附件二

FLIGHT SAFETY FOUNDATION
HELICOPTER SAFETY

Vol. 27 No. 1 *For Everyone Concerned With the Safety of Flight* January–February 2001

Data Show Downward Trends in U.S.-registered Helicopter Accidents in 1991–98

An analysis of information gathered by government agencies and a helicopter trade organization shows an average accident rate of 8.74 accidents per 100,000 flight hours during the period and declining trends in the number of accidents and fatal injuries.

—

Joel S. Harris

FLIGHT SAFETY FOUNDATION SINCE 1947

U.S.-registered helicopters were involved in 1,482 accidents from 1991 through 1998.[1] Of those accidents, 277 resulted in fatal injuries. This report presents a statistical review of the accidents, using data from the Helicopter Association International (HAI), the U.S. National Transportation Safety Board (NTSB) and the U.S. Federal Aviation Administration (FAA).

FAA data show that the number of U.S.-registered helicopters decreased from 1991 to 1993, then increased each year through 1997, the last year for which estimates were available.[2] From 1994 through 1997, the number of piston-powered helicopters increased more than 39 percent, and the number of turbine-powered helicopters increased more than 46 percent (Figure 1, page 2).

Figure 2 (page 2) shows the FAA-estimated number of multi-engine turbine-powered helicopters and single-engine turbine-powered helicopters from 1993 through 1997.

Accident trends were mixed during the period. HAI data on helicopter accidents during the period 1991 through 1998 show the following trends:

- An average of 185 helicopters were involved in accidents each year. Although more helicopters were involved in accidents in 1998 than in the three previous years, the linear trend line (the graphical representation of the trend of the data) shows a slight decline during the eight-year period (Figure 3, page 3);
- An average of 35 helicopters were involved in accidents that resulted in fatal injuries each year. The data show a declining trend during the eight years, although the 1998 figure of 34 fatal helicopter accidents was the highest number recorded since 1994 (Figure 4, page 3);
- The average accident rate for the eight-year period was 8.74 accidents per 100,000 flight hours. Annual accident rates ranged from a low of 6.79 accidents per 100,000 flight hours in 1991 to a high of 12.27 accidents per 100,000 flight hours in 1994. The trend during the eight-year period was statistically level (Figure 5, page 4); and,

continued on page 4

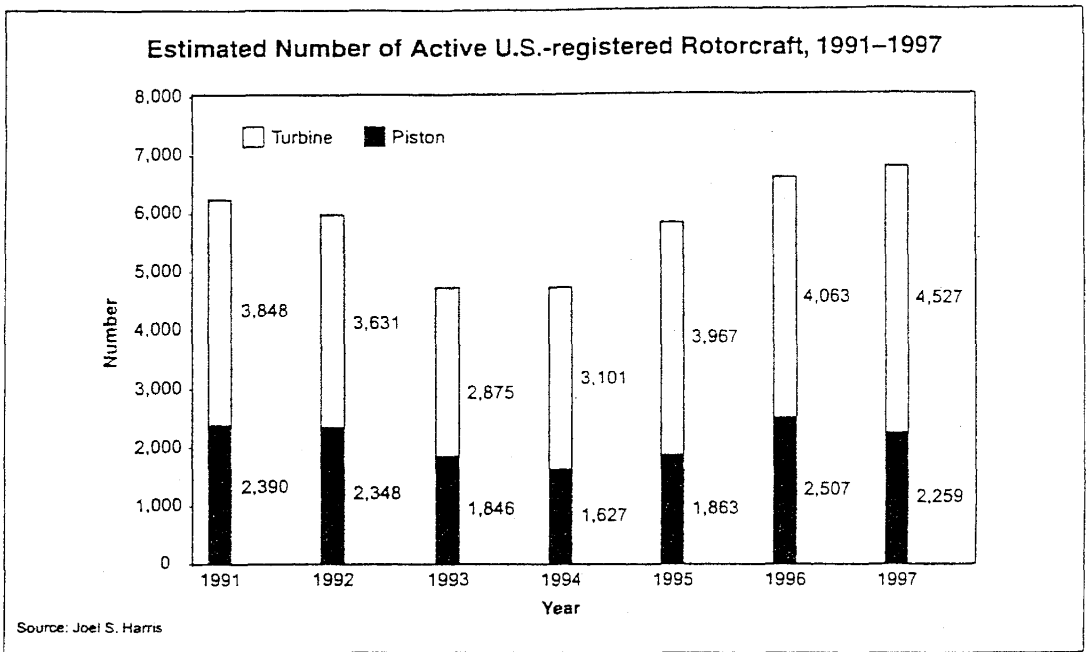


Figure 1

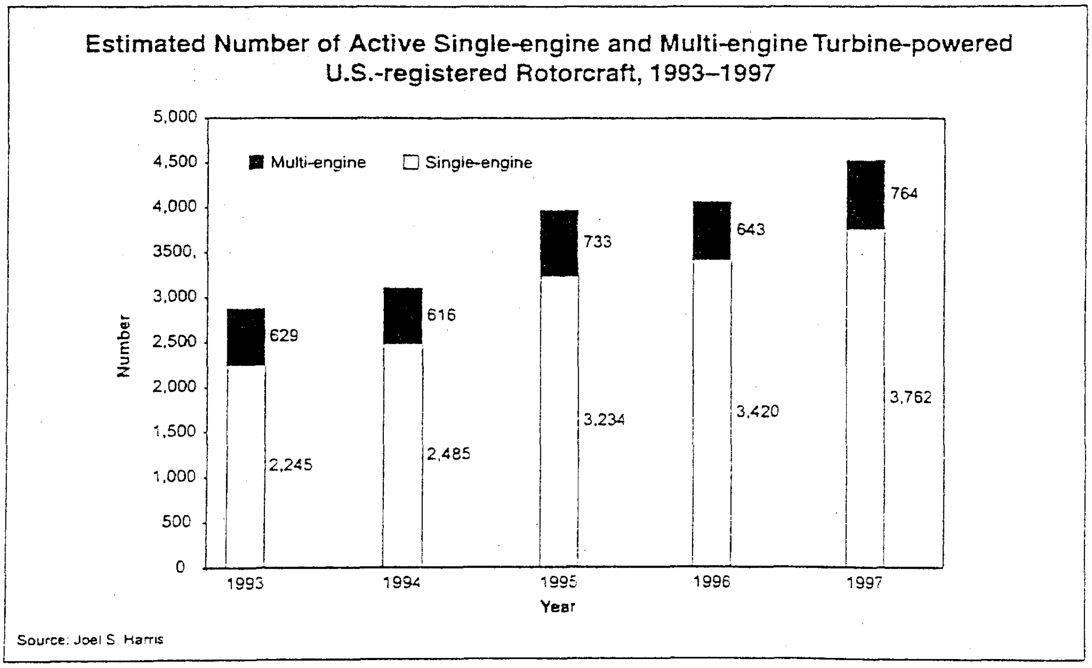


Figure 2

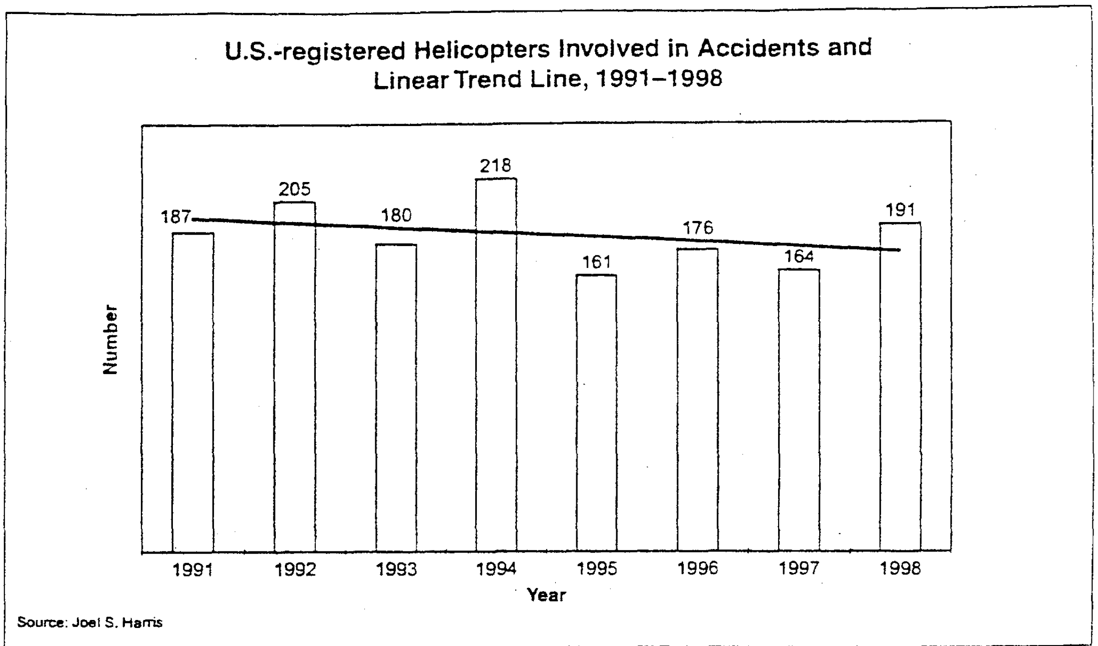


Figure 3

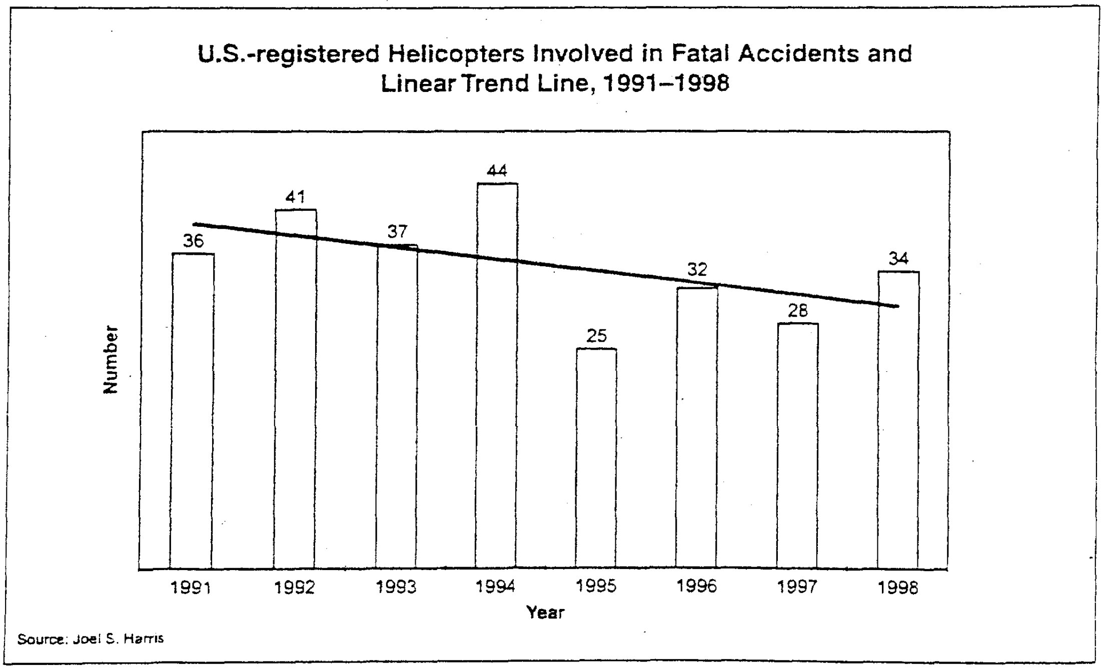
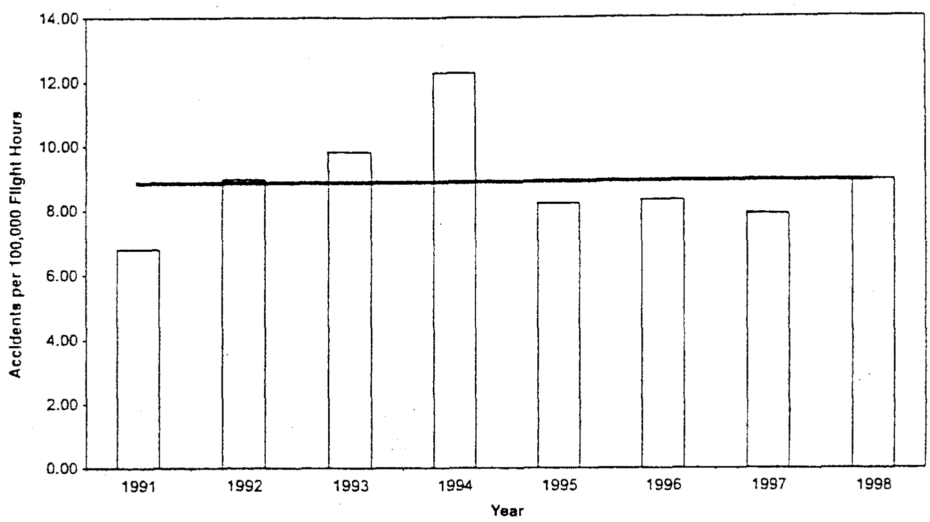


Figure 4

Accident Rate of U.S.-registered Helicopters and Linear Trend Line, 1991–1998



Source: Joel S. Harris

Figure 5

The average fatal accident rate was 1.63 accidents per 100,000 flight hours. Data show a downward trend in the fatal accident rate, even though the 1998 rate of 1.59 fatal accidents per 100,000 flight hours was the highest since 1994 (Figure 6, page 5).

Three types of aircraft were represented in the data: piston-powered helicopters, single-engine turbine-powered helicopters and multi-engine turbine-powered helicopters. Figure 7 (page 5) shows the accident rates and fatal accident rates for each type.

Helicopters with a single piston engine were involved in about 55 percent of the accidents during the period 1991–1998. Data show 810 accidents during the period and a rate of 24.11 accidents per 100.000 hours flown in this type of helicopter. Single-engine piston helicopters were involved in 106 fatal accidents with 149 fatalities, and the fatal accident rate was 3.15 per 100,000 flight hours.

Helicopters with a single turbine engine were involved in approximately 39 percent of the accidents. There were 587 accidents, including 137 fatal accidents with 284 fatalities: the accident rate was 6.03 per 100.000 flight hours, and the fatal accident rate was 1.41 per 100,000 hours flown.

Multi-engine turbine helicopters were involved in 6 percent of accidents. Data show a total of 85 accidents and 34 fatal accidents with 74 fatalities; the accident rate was 2.20 per 100,000 flight hours, and the fatal accident rate was 0.88 per 100.000 hours flown in this helicopter type.

The NTSB accident/incident database[3] for 1991–1998 includes final reports for 1.336 U.S.-registered helicopter accidents. In 1,259 of these reports (94 percent), basic weather conditions at the time of the accident are described as visual meteorological conditions (VMC). Sixty-nine reports (5 percent) described weather conditions as instrument meteorological conditions (IMC). The accidents that occurred in IMC typically were more serious than accidents that occurred in VMC. NTSB data show that 53 percent of accidents in IMC resulted in fatalities, compared with 17 percent of accidents in VMC. Eight final reports did not describe weather conditions. Nevertheless, NTSB reports indicate that the percentage of accidents occurring each year in IMC is decreasing (Figure 8, page 6).

NTSB final accident reports indicated light conditions for 1.328 accidents. Of that number, 1,179 accidents occurred in daylight conditions, 98 accidents occurred in darkness, 18 accidents occurred at dawn and 33 accidents occurred at dusk (Figure 9, page 6).

NTSB accident reports typically cite multiple causes and contributing factors to accidents. Therefore, the probable cause determination often identifies the combined influence of more than one factor in an accident. An analysis of 74

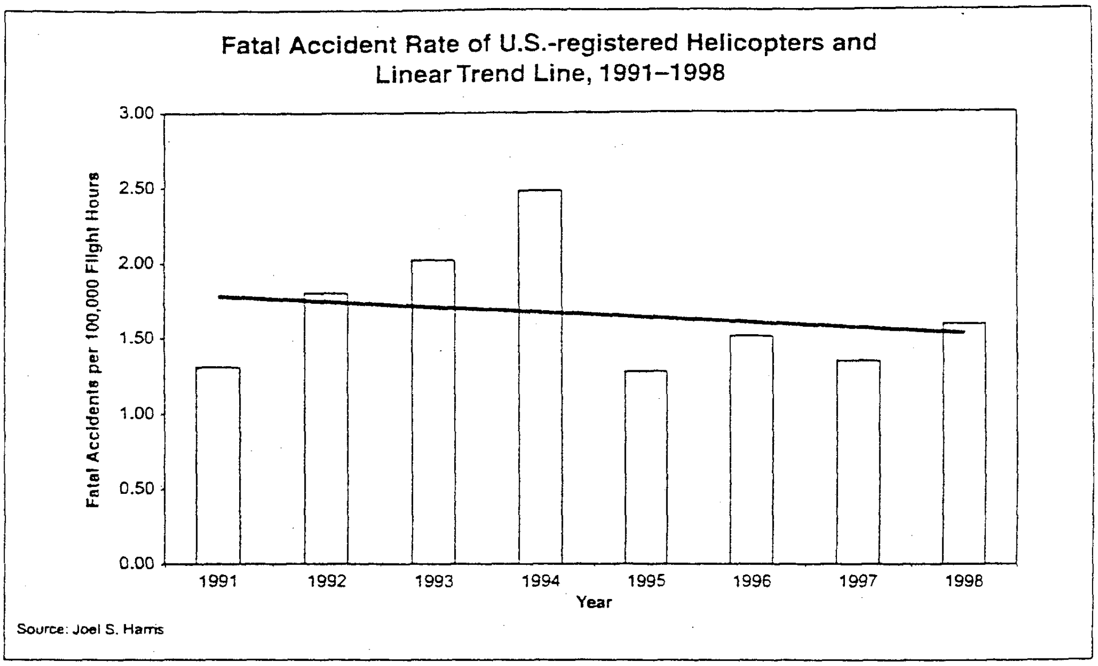


Figure 6

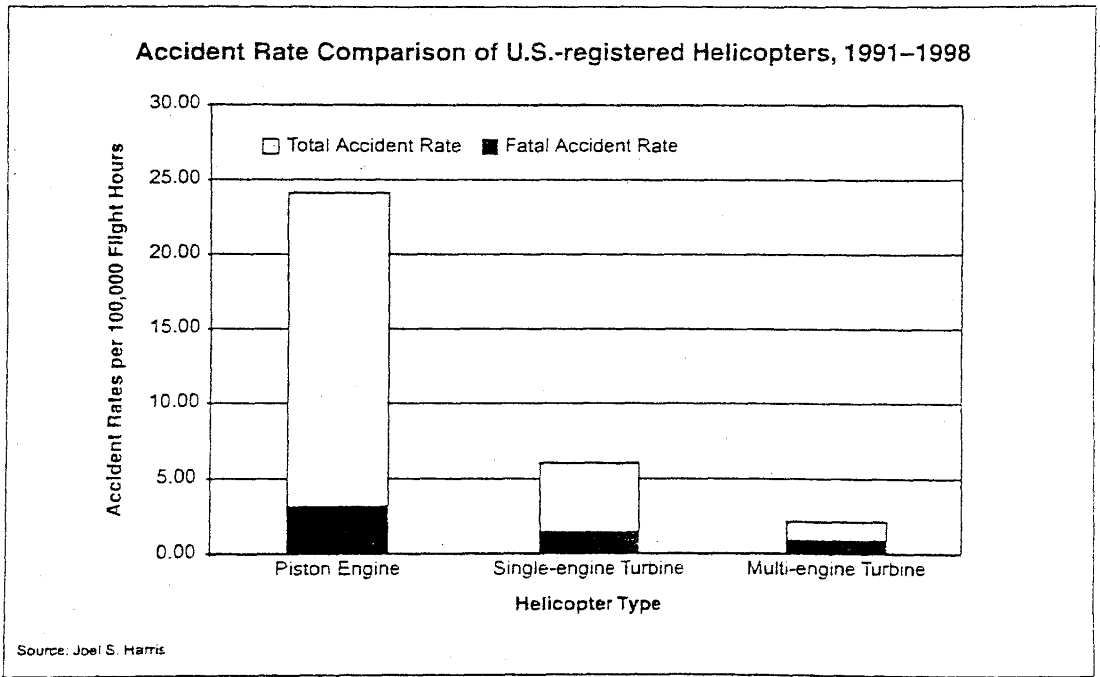


Figure 7

U.S.-registered Helicopter Accidents in Instrument Meteorological Conditions and Linear Trend Line, 1991–1998

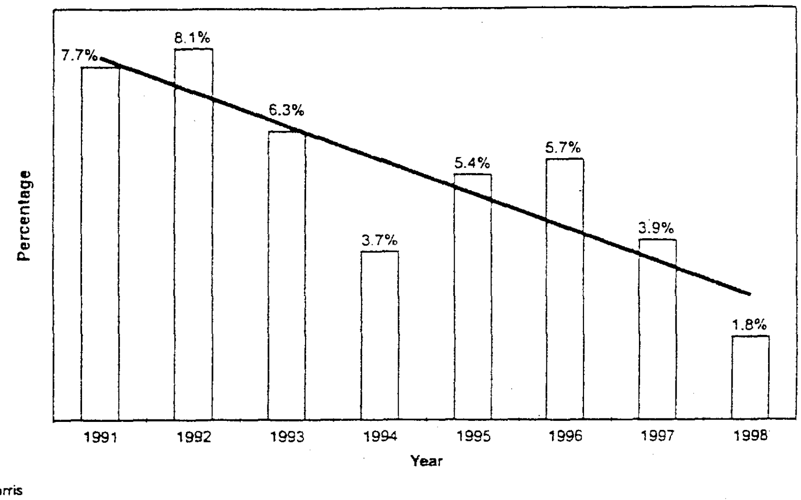


Figure 8

Visual Conditions During Fatal Accidents Involving U.S.-registered Helicopters, 1991–1998

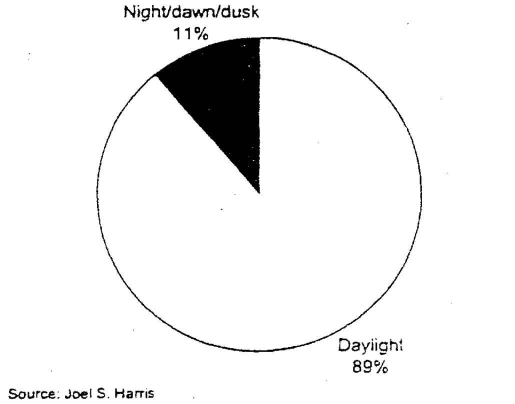


Figure 9

NTSB final reports (5.6 percent) on fatal helicopter accidents and nonfatal helicopter accidents from 1991 to 1998 shows that pilot error was either a cause or a contributing factor in 78 percent of all accidents and 88 percent of fatal accidents.[4]

Table 1 (page 7) shows NTSB data for accident rates[5] for all general aviation and air taxi aircraft, as well as HAI data for accident rates among U.S.-registered helicopters during the period 1991 through 1998.

HAI data show that 2,908 people were involved in the 1,482 helicopter accidents that occurred from 1991 through 1998. Of these, 1,496 people received no injuries, 566 people received minor injuries, 362 people were injured seriously and 484 people were injured fatally (Figure 10, page 7).

NTSB final helicopter accident reports show that between 1991 and 1998, 378 helicopters were destroyed, 947 helicopters were damaged substantially and 11 helicopters received minor damage or no damage (Figure 11, page 7).[6]♦

Notes and References

1. Data is available from the Helicopter Association International, 1635 Prince St., Alexandria, VA 22314-2818 U.S.

2. U.S. Federal Aviation Administration (FAA) estimates of the number of active aircraft are on the Internet: www.api.faa.gov/ga97/TAB_1-2.DOC.

3. The U.S. National Transportation Safety Board (NTSB) accident/incident database is on the Internet: www.asy.faa.gov/asp/asy_ntsb.asp.

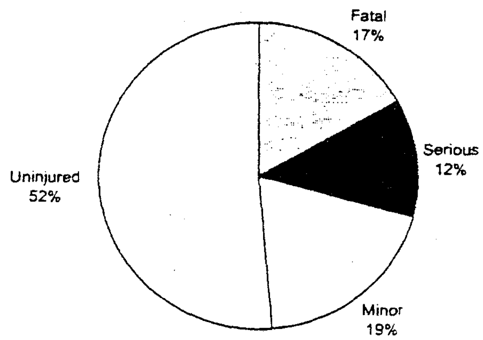
Table 1
Accident Rates and Fatal Accident Rates for U.S.-registered General Aviation and Air Taxi Aircraft, 1991–1998

	General Aviation*		Air Taxi*		All Helicopters		Piston Turbine Helicopters		Single-engine Turbine Helicopters		Multi-engine Turbine Helicopters	
Year	Total	Fatal	Total	Fatal	Total	Fatal	Total	Fatal	Total	Fatal	Total	Fatal
1991	7.85	1.56	3.93	1.25	6.79	1.31	20.00	2.22	3.70	1.19	1.91	0.70
1992	8.36	1.80	3.86	1.22	8.98	1.80	29.33	4.33	5.32	1.53	2.02	0.40
1993	8.94	1.74	4.16	1.15	9.82	2.02	26.76	4.59	6.71	1.49	2.31	1.03
1994	8.97	1.81	4.59	1.40	12.27	2.48	29.54	4.34	8.96	1.91	4.18	2.23
1995	8.24	1.66	4.39	1.41	8.21	1.27	26.41	2.08	5.41	1.33	2.21	0.60
1996	7.67	1.45	4.43	1.43	8.30	1.51	13.87	2.20	7.81	1.22	2.35	1.28
1997	7.28	1.39	3.64	0.67	7.87	1.34	25.00	2.33	5.79	1.34	1.50	0.56
1998	7.12	1.36	3.03	0.71	8.93	1.59	30.46	4.02	6.04	1.29	1.82	0.73

* General aviation and air taxi categories include fixed-wing aircraft and rotary-wing aircraft.

Source: Joel S. Harris

Injuries in Accidents Involving U.S.-registered Helicopters, 1991–1998



Source: Joel S. Harris

Figure 10

Aircraft Damage in Accidents Involving U.S.-registered Helicopters, 1991–1998

Source: Joel S. Harris

Figure 11

4. The author randomly selected for analysis 74 (5.6 percent) of 1,328 final helicopter accident reports in the NTSB online database. Sixteen of the accidents that were selected involved fatal injuries.

5. FAA. *Statistical Handbook of Aviation*. 1999.

6. U.S. Federal Aviation Regulations Part 830 defines "substantial" damage as "damage or failure which adversely affects the structural strength, performance, or flight characteristics of the aircraft, and which would normally require major repair or replacement of the affected component." Ted Lopatkiewicz of the U.S. National Transportation Safety Board public affairs office said that "minor" damage typically is considered to be any damage that is less than substantial.

About the Author

Joel S. Harris holds an airline transport pilot certificate and a flight instructor certificate with ratings in both helicopters and airplanes. He is a U.S. Federal Aviation Administration-designated pilot-proficiency examiner, a Federal Aviation Regulations Part 135 check airman and safety counselor. Harris is assistant director of standards for quality assurance at FlightSafety International. He has administered more than 10,000 hours of flight, simulator and ground-school training to professional pilots.

AN-WP/6898
2/6/94

INTERNATIONAL CIVIL AVIATION ORGANIZATION

AIR NAVIGATION COMMISSION

ANC Task No. OPS-9102: **Review of helicopter safety statistics**

(Presented by the Director of the Air Navigation Bureau)

SUMMARY

This paper presents a summary of the replies received from selected States to a letter requesting information related to statistics on helicopter safety experience, and findings of the Secretariat's analysis of this information.

CO-ORDINATION

AIG

REFERENCES

AN-WP/6556	* C-Min. 131/19
AN-WP/6361	Annex 6, Part III
* AN-Min. 127-4	HELIOPS/1, 2, 3 and 4 reports (yellow cover)
C-WP/9213	
C-WP/9034	

* Principal references

1. INTRODUCTION

The Air Navigation Commission (127-4) requested the Secretariat to develop questionnaire to obtain statistical information on helicopter safety experience. The questionnaire was se to twenty-four selected States and four international organizations under cover of letter AN 11/32 date 26 July 1991.

2. BACKGROUND

2.1 The ICAO Helicopter Operations (HELIOPS) Panel was tasked to produce Part III t Annex 6 to address international helicopter operations in a manner similar to that for aeroplane (Annex 6, Part I). The objective of Annex 6, Part III was to provide a level of safety equivalent t

(12 pages)
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aeroplane operations, particularly in Section II, "International Commercial Air Transport." It is useful to note that Annex 6 Standards are written for International Commercial Air Transport, that is, aircraft operations involving the international transport of passengers, cargo or mail for remuneration or hire. As such, these Standards and Recommended Practices (SARPs) are not applicable to helicopters engaged in aerial work which is defined as "an aircraft operation in which an aircraft is used for specialized services such as agriculture, construction, photography, surveying, observation and patrol, search and rescue, aerial advertisement, etc." It is worth noting also that Assembly Resolution A29-3 "Global Rule Harmonization" urges, in particular, States to take positive action to promote global harmonization of national rules for the application of ICAO Standards.

2.2 Amendment 1 to Annex 6, Part III, was developed by the HELIOPS Panel over a period of five years, from 1983 to 1988. Amendment 1 imposes restrictions on the operation of Performance Class 3 helicopters, equivalent, generally, to single-engine helicopters, as follows:

a) no operations from elevated heliports and helidecks in congested areas (Annex 6, Part III, 3.1.4 and 3.1.5 refer);

b) no operations at night and/or IMC (Annex 6, Part III, 3.1.2 refers).

2.3 The Standards in both a) and b) of 2.2 above apply to international civil air transport operations only, not to international general aviation.

2.4 Amendment No. 1 included, in addition to helicopter operations and performance operating limitations, fuelling practices for helicopters while passengers remain on board, certification for ditching and recording of operational information in helicopters with electronic flight displays.

2.5 Following consultation with States on the panel's final proposals, the Air Navigation Commission (122-6, 7 and 8) conducted its final reviews on the basis of AN-WP/6369 and Addenda Nos. 1 and 2 and AN-WP/6361 and Addendum No. 1. The Council took this into consideration when considering C-WP/9034 in the process of adopting Amendment 1 to Annex 6, Part III on 21 March 1990 (129/12). Consistent with ICAO practices, States were given the opportunity to register disapprovals prior to the amendment becoming effective.

2.6 On 12 December 1990, the Council (131/19) considered a request from several Representatives that the applicability date of 15 November 1990, which had been established for Amendment 1 to Annex 6, Part III, *International Operations – Helicopters* and for Annex 14, Volume II, *Heliports*, be delayed pending further study of some of the requirements set out in those documents. The Council was concerned about the restrictions placed on single-engine helicopter operations and, in particular, restrictions placed on turbine single-engine helicopters. Amendment 1 to Annex 6, Part III did not distinguish between turbine and piston-powered aircraft. Although the Council did not agree to the requested delay in the applicability date, it referred the matter to the Air Navigation Commission for study and report back to Council.

2.7 At the fourth meeting of its 127th Session, the Commission considered AN-WP/6556 which presented the Council referral, as well as the request of one State to obtain current statistical information on safety experience with Performance Class 2 and 3 helicopters. During its discussion of the issue, the Commission was informed that such information was not available in the ADREP system, as there was no ICAO requirement to obtain accident data on aircraft in that weight class. It was observed that the present world helicopter fleet was predominantly single-engine and mostly in the weight class of less than 2 250 kg.

2.8 The Commission agreed to obtain statistical data on helicopter-safety performance from selected States and international organizations and, accordingly, requested the Secretariat to develop an appropriate questionnaire. The Secretariat developed a questionnaire related to helicopter activity levels, including night operations and operations from off-shore helidecks and elevated structures. Information was requested with respect to piston single-engine, turbine single-engine and turbine multi-engine helicopters to support subsequent analysis of the safety performance of those three types of aircraft. The questionnaire was dispatched to the following States and international organizations:

> Australia, Brazil, Canada, China, Colombia, France, Germany, India, Indonesia, Italy, Japan, Mexico, New Zealand, Norway, Papua New Guinea, Philippines, Poland, Spain, Sweden, Switzerland, Union of Soviet Socialist Republics, United Kingdom, United States, Venezuela, European Helicopter Organization, Helicopter Association International, IATA and IFALPA.

3. DISCUSSION

3.1 While responses were received from sixteen States, few completed the questionnaire, and only two States provided information of adequate specificity to distinguish between the observed performance characteristics of piston single-engine, turbine single-engine and turbine multi-engine helicopters. These two States, however, represent about 64% of the known world-wide distribution of civil helicopters.

3.2 After further clarification of the information reported from the two States, the Secretariat compared accident rates per 100 000 flight hours for piston single-engine, turbine single-engine and turbine multi-engine helicopters for the period 1983 through 1989 (Table A-1 and Figure A-1).

3.3 One State reported night accident rates for the period 1983 through 1988 (Table A-2 and Figure A-2) as well as accidents per 100 000 helideck operations and accidents per 100 000 on-shore elevated structure operations, which are presented in Table A-3 and Figure A-3 in the Appendix to this paper. The State of the report accounts for approximately 58% of the known distribution of civil helicopters.

4. FINDINGS

4.1 ICAO received less information from States than had been requested. Moreover, not all of the information which was received usefully supported this analysis. With the benefit of hindsight, the ICAO questionnaire could have been better designed. Additionally, however, it appears that not all States possess readily available information necessary to support a comparative safety analysis of single-engine piston, single-engine turbine and multi-engine helicopter operations.

4.2 Notwithstanding the above, the statistics presented in this report represent a large segment of the helicopter population. The Secretariat views the information as representative of the industry generally.

4.3 An analysis of helicopter safety statistics derived from more than three million hours of flight time accumulated over seven years indicates that single-engine piston helicopters are more accident prone than single-engine turbine helicopters. Indeed, on the basis of accidents per 100 000 flight hours of operation, the single-engine turbine helicopter performance is closer to that of the twin turbine than to the single-engine piston. This is not reflected in Annex 6, Part III, where identical operating limitations are specified for single-engine piston and single-engine turbine helicopters.

4.4 The night-time accident rate for the single-engine turbine helicopter was actually better (less) than that of the twin turbine. As no obvious explanation for this finding can be derived from the data available, it may be concluded that the performance variance is nil. Single-engine piston helicopter night accident rates are considerably higher than either single- or twin-engine turbines.

4.5 Accident rates for helideck and on-shore elevated structure operations also suggest that turbine helicopters are safer than piston helicopters. The smaller number of flight hours and accidents reported for these operations, however, may contribute to the relative differences in helicopter performance characteristics both for helidecks as well as elevated structure operations.

5. ACTION BY THE AIR NAVIGATION COMMISSION

The Air Navigation Commission is invited to:

a) note the information presented in this report;

b) review the findings reported in paragraph 4;

c) decide on appropriate follow-up action; and

d) instruct the Secretariat regarding preparation of a report to Council on the issue.

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TABLE A-1

COMPARATIVE ACCIDENT RATES PER 100 000 FLIGHT HOURS

	1983	1984	1985	1986	1987	1988	1989	Avg. 83-89
SINGLE PISTON								
US ACCIDENTS	131	121	106	111	104	108	111	113.1
US FLT HRS (000)	560	560	531	794	558	495	746	606.3
US ACCIDENTS PER 100,000 HR	23.4	21.6	20.0	14.0	18.6	21.8	14.9	18.7
CAN ACCIDENTS	13	11	12	10	11	13	10	11.4
CAN FLT HRS (000)	41.8	33.9	22.9	21.1	23.6	25.0	25.0	27.6
CAN ACCIDENTS PER 100,000 HR	31.1	32.4	52.4	47.4	46.6	52.0	40.0	41.4
WEIGHTED AVG BY FLT HOURS	23.9	22.2	21.3	14.8	19.8	23.3	16.7	19.7
SINGLE TURBINE								
US ACCIDENTS	108	124	104	92	65	87	71	90.1
US FLT HRS (000)	1199	1534	1277	1374	1258	1899	1458	1366.6
US ACCIDENTS PER 100,000 HR	9.0	8.1	8.1	6.7	5.2	4.2	4.9	6.6
CAN ACCIDENTS	38	27	37	37	41	45	46	38.7
CAN FLT HRS (000)	370.0	332.8	327.0	319.2	355.7	366.0	370.0	348.6
CAN ACCIDENTS PER 100,000 HR	10.3	8.1	11.3	11.6	11.5	12.3	12.4	11.1
WEIGHTED AVG BY FLT HOURS	9.3	8.1	8.8	7.6	6.6	5.7	6.4	7.4
TWIN TURBINE								
US ACCIDENTS	12	18	12	17	10	12	18	14.1
US FLT HRS (000)	25	283	211	327	313	307	489	279.3
US ACCIDENTS PER 100,000 HR	48.0	6.4	5.7	5.2	3.2	3.9	3.7	5.1
CAN ACCIDENTS	2	0	3	0	3	1	3	1.7
CAN FLT HRS (000)	20.1	25.6	40.7	38.8	41.6	43.0	45.0	36.4
CAN ACCIDENTS PER 100,000 HR	10.0	0.0	7.4	0.0	7.2	2.3	6.7	4.7
WEIGHTED AVG BY FLT HOURS	31.0	5.8	6.0	4.6	3.7	3.7	3.9	5.0

FIGURE A-1

COMPARATIVE ACCIDENT RATES
(Canadian and U.S. Accident Data, 1983 – 1989)

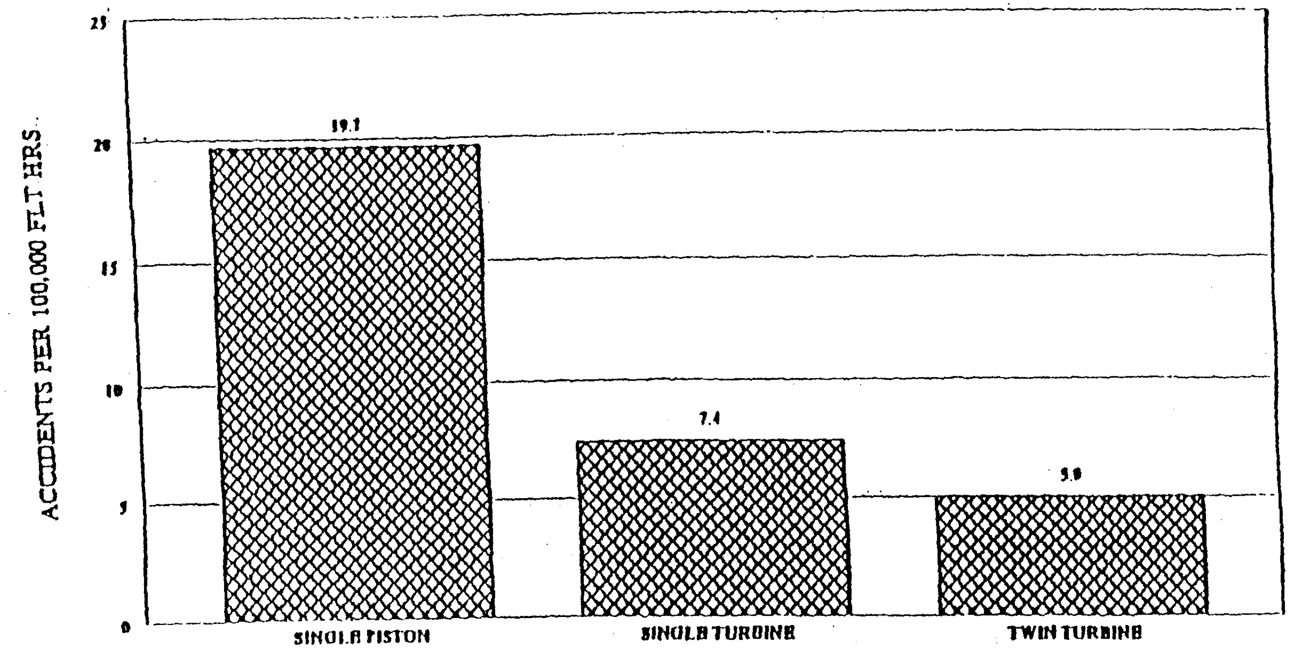

TABLE A-2

COMPARATIVE NIGHT ACCIDENT RATES
(based upon U.S. data)

	1983	1984	1985	1986	1987	1988	AVG. 1983–1988
SINGLE PISTON							
Night accidents	0	4	4	6	2	4	3.33
Night flight hours (000)	26.32	15.68	14.34	23.82	19.53	18.81	19.75
Accidents per 100 000 hours	0.0	25.5	27.9	25.2	10.2	21.3	16.9
SINGLE TURBINE							
Night accidents	7	9	7	13	2	6	7.33
Night flight hours (000)	44.36	67.50	75.34	100.30	89.32	105.53	80.39
Accidents per 100 000 hours	15.8	13.3	9.3	13.0	2.2	5.7	9.1
TWIN TURBINE							
Night accidents	3	3	4	3	1	1	2.50
Night flight hours (000)	0.60	8.21	6.96	19.62	25.04	23.64	14.01
Accidents per 100 000 hours	500.0	36.6	57.4	15.3	4.0	4.2	17.8

FIGURE A-2

COMPARATIVE NIGHT ACCIDENT RATES
(Average 1983 – 1988)

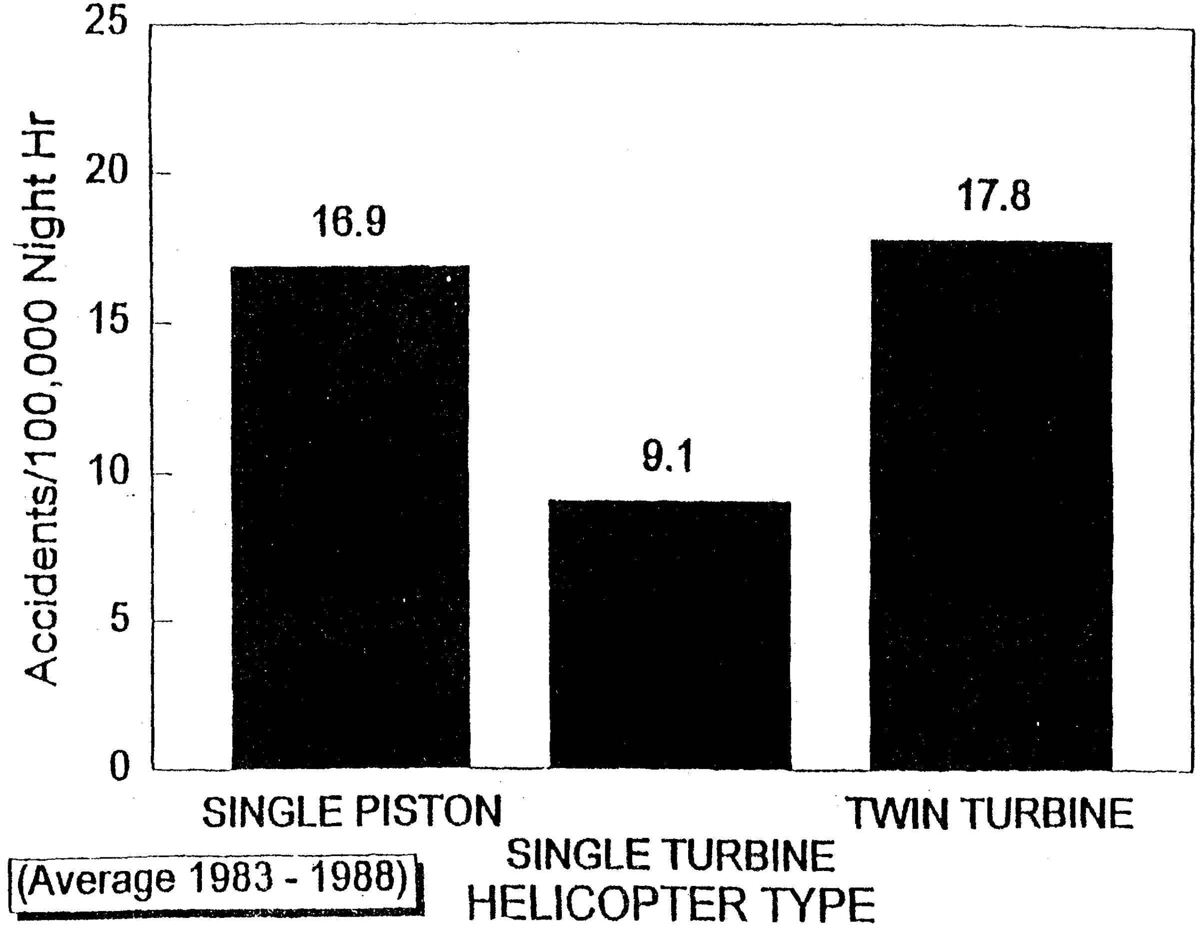

TABLE A-3

COMPARATIVE HELIDECK ACCIDENT RATE
(based upon U.S. data)

	1983	1984	1985	1986	1987	1988	AVG. 83-88
SINGLE PISTON							
ACCIDENTS	0	1	0	1	0	1	0.50
HELIDECK OPERATIONS (000)	0.83	1.00	1.33	1.66	2.33	2.83	1.66
ACCIDENTS PER 100,000 OPS	0.00	100.00	0.00	60.24	0.00	35.34	30.05
SINGLE TURBINE							
ACCIDENTS	5	2	3	6	4	2	3.67
HELIDECK OPERATIONS (000)	3816	3681	3547	2768	2851	3108	3258.17
ACCIDENTS PER 100,000 OPS	0.14	0.05	0.08	0.22	0.14	0.06	0.11
TWIN TURBINE							
ACCIDENTS	2	3	2	2	2	3	2.33
HELIDECK OPERATIONS (000)	537	572	612	450	446	571	531.33
ACCIDENTS PER 100,000 OPS	0.37	0.52	0.33	0.44	0.45	0.53	0.44

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FIGURE A-3

U.S. HELIDECK ACCIDENT RATES
(Average 1983 – 1988)

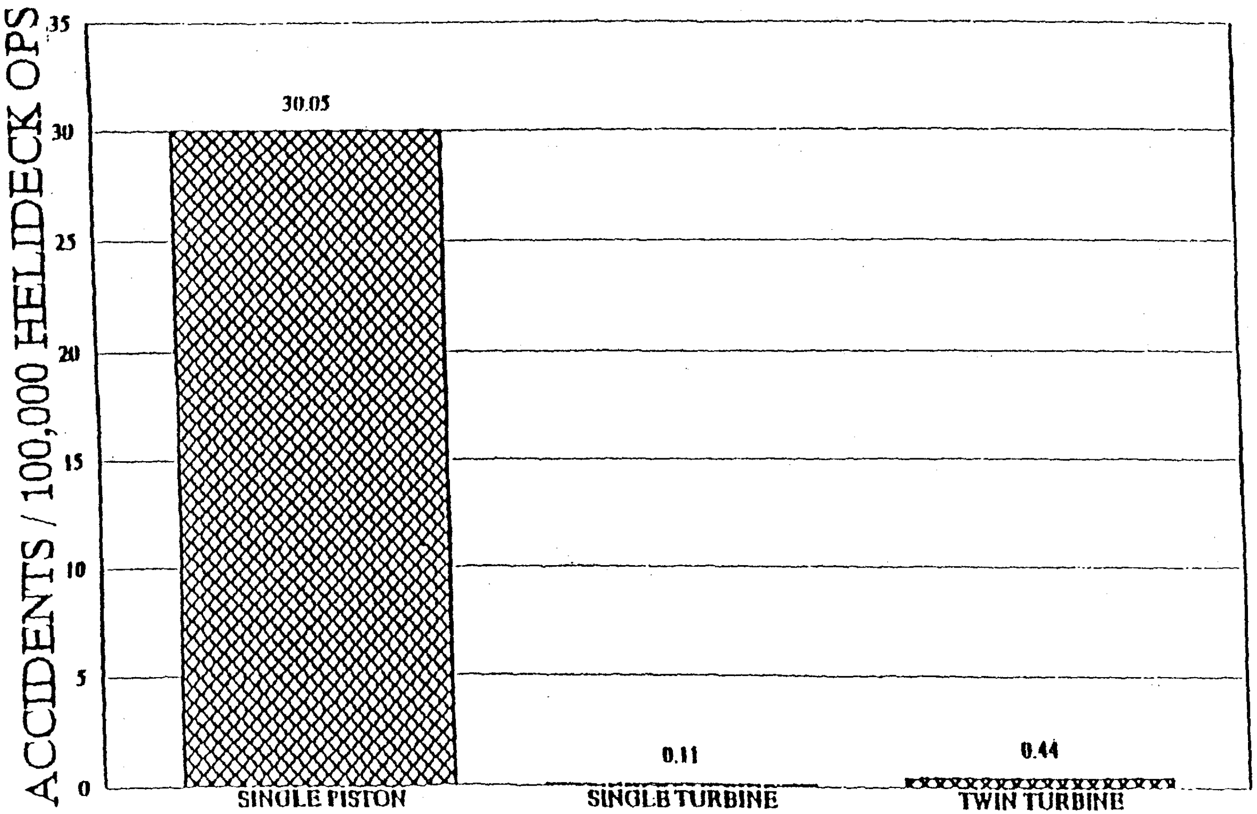

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TABLE A-4

COMPARATIVE ELEVATED STRUCTURE ACCIDENT RATES
(based upon U.S. data)

	1983	1984	1985	1986	1987	1988	AVG. 83-88
SINGLE TURBINE							
ACCIDENTS	1	1	1	0	1	1	0.83
OPERATIONS (000)	331	348	424	369	423	357	375.33
ACCIDENTS PER 100,000 OPS	0.30	0.29	0.24	0.00	0.24	0.28	0.22
TWIN TURBINE							
ACCIDENTS	0	0	0	2	0	1	0.50
OPERATIONS (000)	7	16	21	52	100	103	49.83
ACCIDENTS PER 100,000 OPS	0.00	0.00	0.00	3.85	0.00	0.97	1.00

FIGURE A-4

COMPARATIVE ELEVATED STRUCTURE ACCIDENT RATES
(Average 1983 - 1988)

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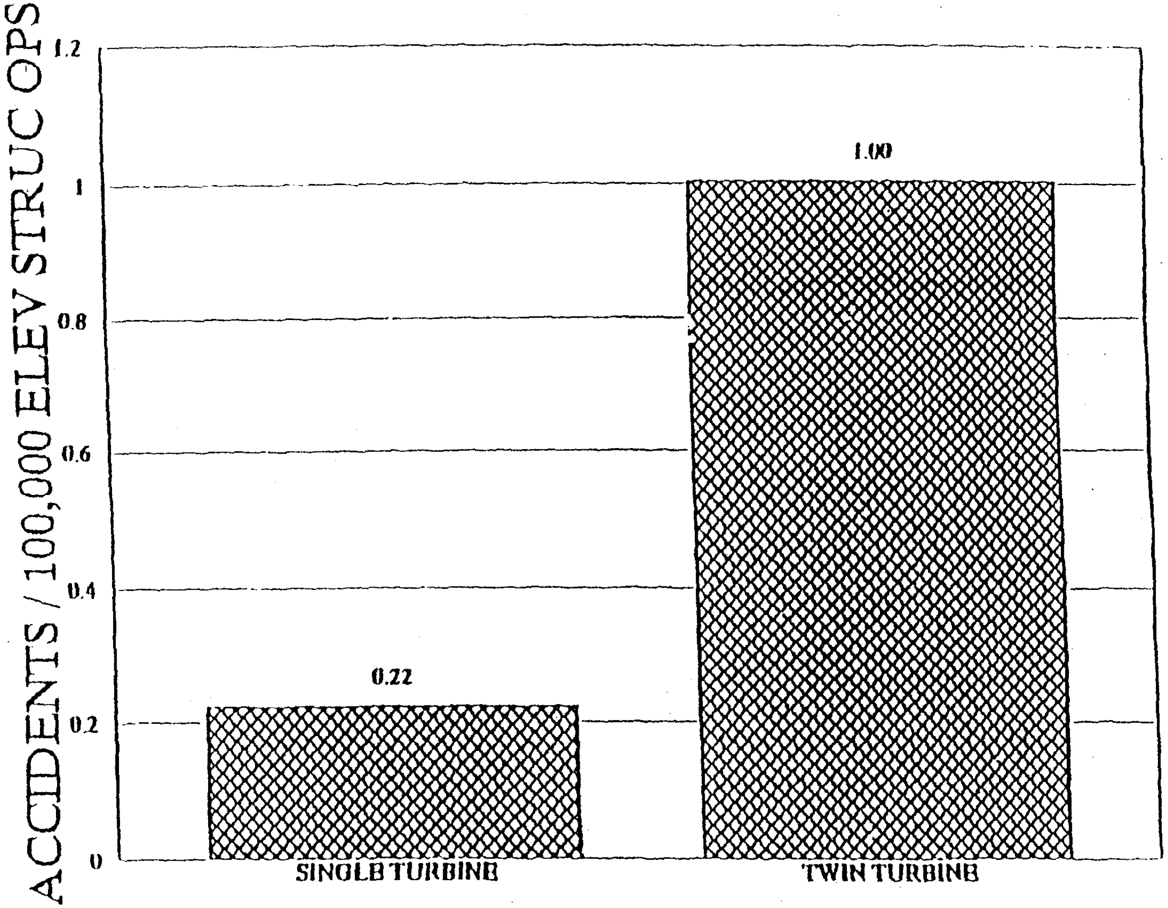

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附件四

CIVIL ROTORCRAFT RISKS

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Presented at the2002 China International Helicopter Forum,
Chengdu, Sichuan, People's Republic of China,
27–28 August 2002

CIVIL ROTORCRAFT RISKS

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INTRODUCTION

Safety has always been a factor in the growth or lack-of-growth of the helicopter industry. The perception of the lack of safety has caused fleet groundings and the prohibition of helicopter operations. There are many facets of safety, but the bottom line is that occupant safety is achieved by the management of risk. If you can reduce the risk, safety has improved.

CIVIL HELICOPTER HISTORY

The civil helicopter history started with the first civil certificated helicopter in 1946, the Bell Model 47, registry of NC1H (Fig.1.). The civil helicopter industry, like the military helicopter industry, has since grown and spread throughout the world. The Model 47 series included about 4,600 civil and military models until all Model 47 production was stopped in 1974. The safety history of the Bell Model 47 series, which was the most popular helicopter in those early days, is typical of the early aviation. The 47 accident rate was very high at the start of civil helicopter aviation, as the operators were finding new ways to use the helicopter. The designers were fixing those problems due to the aircraft as they became evident from accident investigations. The annual accident rate decreased over time with the maturing of the 47 fleet, but it stabilized to a fairly constant rate (Fig. 2). The large fluctuations in annual accident rates in the later years are due to inaccuracies of the FAA's estimates of Model 47 flight hours. Basically, the Model 47 accident rate has been the fairly constant for the last 40 years.

WHAT IS AN ACCIDENT?

When an unusual occurrence happens in or around an operating aircraft, the severity of the damage or possible injuries can vary widely. Thus there is a threshold beyond which the government must be notified of a serious occurrence. Events severe enough to be called accidents are required to be reported to the government and some type of investigation is warranted. Events less than this threshold level, such as maintenance or very minor events, are generally not reported to government. Therefore the location of this dividing line between required reportable and non-reportable events becomes quite important and must be defined. Each government has an agency tasked to investigate such serious occurrences with the goal of reducing that type of problem in the future for the flying public. In the United States of America (USA), that government agency is the National Transportation Safety Board (NTSB). Each of the Military Services has a similar segment of the service that is tasked to do accident investigations. Countries that are signatories of the International Civil Aviation Organization (ICAO) have agreed to standardization of accident investigation (as much

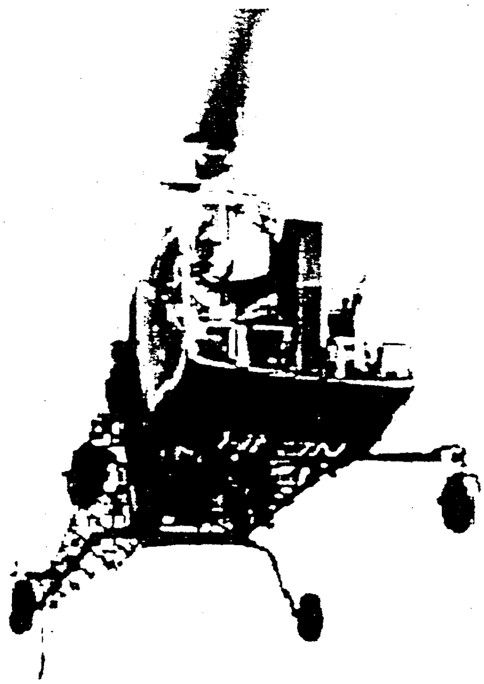


Fig. 1. NC1H, the first civil certificated helicopter.

Prepared for the 2002 China International Helicopter Forum, Chengdu, Sichuan, China, 27–28 August 2002.

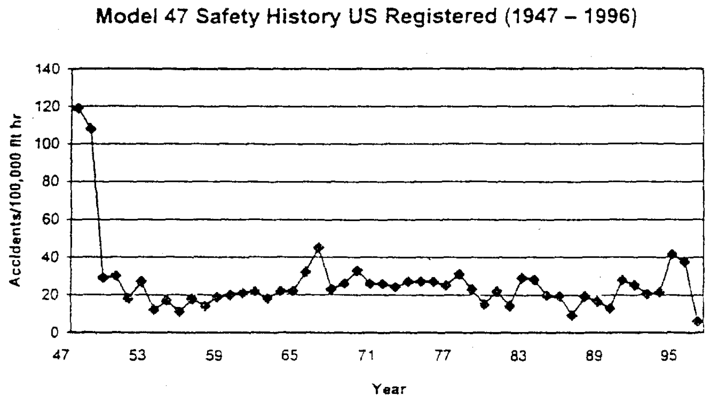


Fig. 2. Model 47 annual accident rates for 50 years.

as possible) based on ICAO Annex 13. Each country then bases its definition of a reportable event on the definition in Annex 13. NTSB's definition is defined in 14 CFR Part 830.2, which states:

> "Aircraft accident" means an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage.

Substantial damage requires further definition, as the range of damage may be quite wide. Therefore 14CFR Part 830.2 continues and states:

> "Substantial damage" means damage or failure which adversely affects the structural strength, performance, or flight characteristics of the aircraft, and which would normally require major repair or replacement of the affected component. Engine failure or damage limited to an engine if only one engine fails or is damaged, bent fairings or cowling, dented skin, small puncture holes in the skin fabric, ground damage to rotor or propeller blades, and damage to landing gear, wheels, tires, flaps, engine accessories, brakes, or wingtips are not considered "substantial damage" for the purpose of this part.

Examples of this wide range of what is considered an accident with substantial damage range from a minimal accident of a wrinkled tail boom requiring maintenance with no injuries during a poor landing (Fig. 3.) to a very serious accident where the aircraft is destroyed by fire and all occupants were fatally injured (Fig. 4). As a side note, the aircraft data plate from this foreign accident shown in Fig. 4, was sold for $1.00, and another aircraft was counterfeited using that plate and a military surplus UH–1 fuselage. That counterfeited aircraft later crashed in the USA due to a military surplus part failure.

Accident rate comparisons should always use a common definition of what constitutes an accident. Otherwise, one data set will be including only extremely severe events whereas the other data set will be considering minimal damage events as well as severe fatal events. With civil aviation around the world, the definition of an accident is quite commonly based on the ICAO Annex 13, and does not change over the years. The U.S. Military Services under Department of Defense (DOD) use a different classification system. Both the civil NTSB and the U.S. Military Services include a serious or fatal injury as part of the accident definition threshold, but differ in the aircraft damage. The DOD definition for aircraft damage is based on the cost to repair. This level of aircraft damage cost for a Class A mishap has changed over the years from:

- $100,000 or more, then changed to
- $200,000 or more, then changed to
- $500,000 or more, then changed to
- $1,000,000 or more (present level)

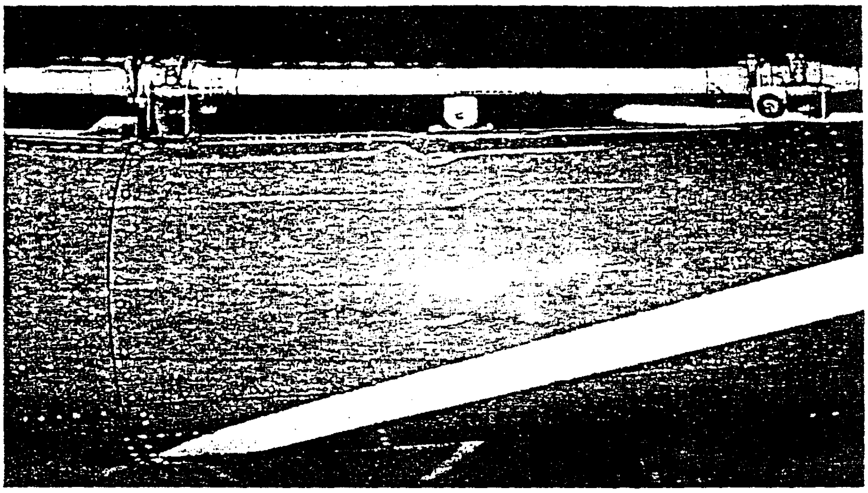


Fig. 3. Wrinkled tail boom accident.

Fig. 4. Aircraft destroyed by fire with fatal injuries.

Thus one should not attempt safety comparisons between civil helicopter safety and military helicopter safety, due to the lack of a common event being measured. Safety comparisons should stay within common guidelines of events and types of exposure to be meaningful.

PERIOD OF EXPOSURE TIME

Measuring risk can only be done by knowing the amount of exposure to risk. Some people express risk in terms of accidents per departure or takeoff, which is quite misleading. You are at risk at all phases of flight, not just during the departure/takeoff. In flying, you are exposed from the time you leave the ground until you return to the ground; that period is referred to as the flight time, measured in hours. Thus the flight hours of an aircraft type must be known in order to develop the different types of risks relative to that aircraft type. The only official U.S. Government source of flight hours is the FAA General Aviation Avionics and Activities Survey (now called General Aviation and Air Taxi

Activity Survey), which is conducted on an annual basis. The FAA sends out a questionnaire to a sampling of operators of U.S. Registered aircraft base on models and the state of the owners. The FAA then develops annual flight hours based on the questionnaire responses. Unfortunately, the FAA has stopped providing flight hours by model series, beginning in 1997. Thus the latest year for developing meaningful risk measurements is 1996.

The helicopter accidents used to determine frequency of occurrence must be applicable to the flight hours available for that model. The amount of flight hour exposure was determined for this study by helicopter model for the last 10-year period of 1987 through 1996 from the FAA data. Helicopter models deleted to improve accuracy were those models with less than 50,000 flight hours for the 10-year period, homebuilt/kit helicopters, and those with non-U.S. registry numbers. Also, if a model had an accident in a year in which there were no FAA flight hours estimated, that accident was deleted. This resulted in the elimination of 181 accidents. The remaining 1534 accidents and their respective flight hours were separated into five groups for analysis.

The "Military Surplus UH–1" group was separated out. This is a rapidly growing segment due to the U.S. Department of Defense (DOD) services (Army, Navy, Marine Corp, and Air Force) release of military aircraft as surplus aircraft into the civil fleet. These single turbine-powered helicopters were designed and produced by Bell to military requirements and not to civil certification requirements. These aircraft include UH-1A/B/C/D/E/F/H/K/L/M/P/V military models. The military services have modified their aircraft design over the years before their release into the civil world. Some of the UH–1s are being used well beyond what they were designed to do, which has caused a growing number of accidents. The military surplus UH–1 aircraft are in many severe uses, such as repeated heavy lift and logging. The FAA flight hour estimate is a mixture of these military surplus UH–1s and the Bell civil certificated 204B and 205A1. The 204B and 205A1 flight hours in some years were separate; in other years, the flight hours were combined into the military surplus UH–1. The 1996 U.S. registry showed that 93.2% of this group of 616 aircraft (UH–1, 204B, 205A1) were actually military UH–1 aircraft. Therefore this single turbine-powered helicopter group is predominately military surplus UH–1s and is treated as such. Since more UH–1 aircraft are scheduled to be surplussed in the future, they will continue to be major growing segment of civil aviation.

The "206" series is a group of its own, since it flew 40.9 % of all helicopter flying during this 10-year study period. The single-turbine-powered 206 helicopter continues to be the most prevalent helicopter in the USA and the world. The "Other Single Turbine" group consists of the remaining single turbine-powered helicopter models with FAA flight hours, which are the 369/500/600, AS350, and SA316/319 models.

The "Single Piston"-powered group consisted of the following series: R22, 47/H13, 269/300/TH55, F28/280, and UH12/H23. The term "piston" is commonly used to describe a reciprocating engine that has pistons. Those accidents of aircraft where the original piston-engine certificated configuration was modified to a single turbine configuration were also deleted.

The "Twin Turbine" group consisted of the following series: BO105, BK117, 412, 212, AS355, 222/230, A109, S76, S61, and S58T. The flights hours of exposure and the number of accidents for these five groups are Table 1.

The helicopter models within this study of Table 1 accounted for 9,841 U.S. registered helicopters as of the end of 1996. The percentage of each group's fleet is Fig. 5.

RISK TO THE AIRCRAFT

When the amount of damage or injury exceeds the definition of an accident discussed earlier, that event is an accident and must be reported to the government authorities. The frequency of those reported accidents also determines the financial risk of operating fleet of those aircraft. The proper metric is the common accident rate calculated as the number of accidents of a time period divided by the flight hours flown during that time period. This rate determines the likelihood of having a reportable accident for all causes, but that

Table 1. Helicopter groups with 10-year accidents and exposure

Helicopter Group	Accidents (1987 – 1996)	Flight Hours (1987 – 1996)	Percentage of Flight Hours
Single piston (reciprocating engine)	864	4,974,421	23.3
206 Single Turbine	306	8,739,554	40.9
Other Single Turbine	226	3,734,015	17.5
H–1 Military Surplus Single Turbine	55	496,204	2.3
Twin Turbines	83	3,406,927	16.0
Totals	1,534	21,351,121	100.0

is not the same as the likelihood of the occupant being injured or killed. Different types of aircraft have different accident rates. Further, the types of operations (missions) being flown by these aircraft are likewise very different. Some types of operations are extremely safe and others are extremely hazardous. So the same helicopter model can have significantly different accident rates, depending on how it is being used. As a starting point, the risk to the aircraft of a government reportable accident is shown in Fig. 6. The five helicopter groups of this study are noted in red color. "R/W" indicated rotary-wing aircraft (helicopter), whereas "F/W" indicates fixed-wing (airplane). Fixed-wing airplane segments of U.S. Aviation are noted in blue color. Scheduled 121 Air Carriers and Scheduled 135 Air Carrier (Commuter) operations are the typical airlines used by the flying public. The Non-Scheduled 135s group is made up of commercial operations called Air Taxi, which are predominately fixed-wing airplanes.

The "HSAC Gulf of Mexico" is a select group of helicopters (single-turbine and twin-turbine) that operate offshore in the Gulf of Mexico to and from oil/gas rigs. Note that the HSAC aircraft risk of a reportable accident is significantly lower than the other three turbine helicopter fleets of this study that include all types of operations, even though their over-water operations can be quite hazardous. HSAC (Helicopter Safety Advisory Conference) is a group of oil companies and helicopter operators who have banded together as an organization to improve safety for all that operate in the Gulf of Mexico. Their accident rate is about the same as General Aviation turbojet airplanes and the Commuter Airlines.

Accident rates are risk of a reportable accident occurring, which is not the same as the risk of injury to an aircraft occupant.

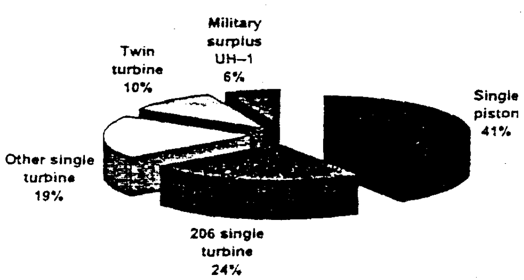


Fig. 5. US Registered Helicopter Fleet in 1996.

RISK OF ACCIDENT DUE TO INITIATING CAUSE

The overall accident rate just shown in Fig. 6 is the total of all of the accident causes that required the reporting of an accident to the government agency (NTSB). Accident causes are separated into two major categories. One category consists of those accident causes that were due to the aircraft (called airworthiness causes, as they directly relate to the certification of airworthiness). The other category consists of the non-airworthiness causes of pilot error, weather, maintenance error, other persons, and unknowns. The accident rates from all causes and airworthiness-only causes are shown in Fig. 7. The Twin Turbine helicopters had the lowest accident rate (risk to the aircraft) for all causes and the Single Piston helicopters had the highest accident rate. Considering only the accidents that are due to the aircraft (e.g., airworthiness failures), the lowest accident rate is shared by the Twin Turbine and the 206 (a single turbine) at a rate of 0.7/100,000 hours. The highest accident rate due to the aircraft airworthiness failures was the Military Surplus UH–1s at 5.4/100,000 flight hours. This is an indicator of the severe use (and sometimes abuse) of using an aircraft to do missions for which it was not designed.

Again all of these aircraft are used in many different types of operations (Table 2).

ARE YOU SAFER WITH A TWIN ENGINE OR A SINGLE ENGINE?

This question has been around for years and the myth has unfortunately continued into the turbine helicopter fleets. The two-engine safety myth is based upon early 1900s aviation, when airplanes were equipped with extremely unreliable reciprocating engines that failed quite often. This historic multi-engine airplane thinking has mistakenly been applied to helicopters. In commercial airline operations, we started with two-engined airplanes, then went to three-engined airplanes, and then went to four-engined airplanes. The commercial airlines then switched from reciprocating engines to the new and reliable turbine engines. In the last decade or so, commercial airlines have gone from four-turbine engines, to three-turbine engines, and to the present two-turbine engine aircraft. The reliability of the present-day turbine engine in airplanes and helicopters is extremely high. Even on the latest large transport airplanes (Boeing 767, etc.) used by the airlines, ETOPS regulations allows the two-turbine engine airplane in commercial service, after an engine failure or is shutdown, to fly up to 3 hours on the remaining engine (now it is a single engine aircraft) before it is required to land. Even with the major engine reliability improvements is aviation over the years, some people still mistakenly believe the myths of Table 3.

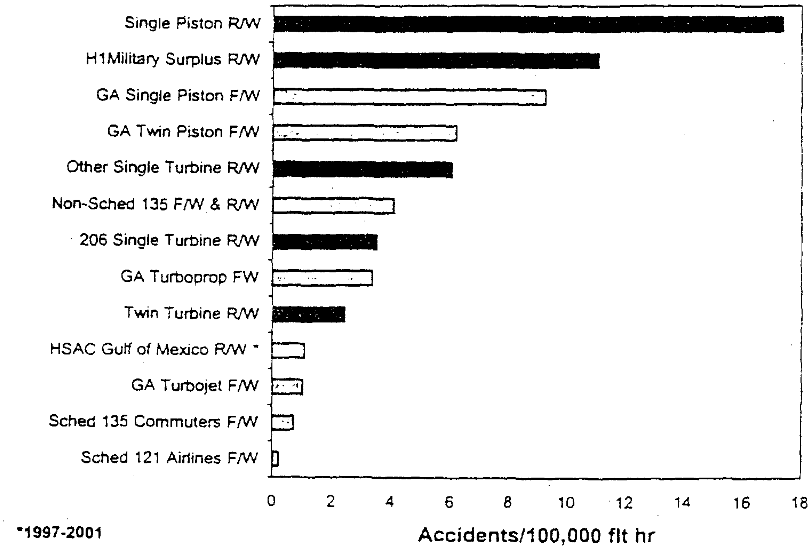
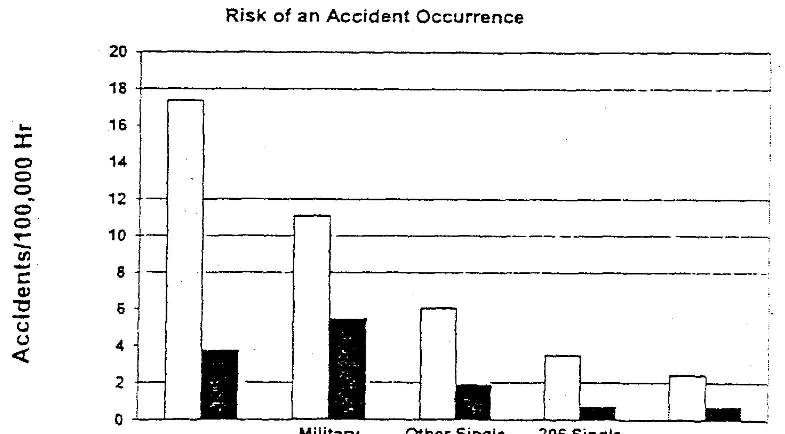


Fig. 6. Risk of Reportable Accident of US Registered Aircraft (1987-1996).



	Single Piston	Military Surplus UH1	Other Single Turbine	206 Single Turbine	Twin Turbine
□ All Causes	17.4	11.1	6.1	3.5	2.4
■ Airworthiness	3.7	5.4	1.9	0.7	0.7

Fig. 7. Risk of a reportable accident.

Table 2. Helicopter civil types of operations.

FAR	TYPE OF CIVIL OPERATIONS
137	Aerial Application
133	External Loads (Logging)
133	External Loads (Others)
135	Air Taxi (Air Medical Service)
135	Air Taxi (Commercial Air Tour)
135	Air Taxi (Commercial Passenger – Other)
135	Air Taxi (Cargo)
91	Aerial Observation/Patrol
91	Air Medical Service
91	Business
91	Commercial Air Tour
91	Corporate/Executive
91	Electronic News Gathering
91	Instructional (Part 61/145)/Training
91	Maintenance/Test Flight
91	Personal/Private
91	Positioning/Ferry
91	Sightseeing
91	Utility Patrol & Construction
91	Other Aerial Work
N/A	Public Use/Government Use (FARs not applicable)

All of the beliefs in Table 3 are FALSE. They are only myths that are not supported by actual facts.
The single-turbine 206 and twin turbines from Fig. 7 had the same airworthiness accident rate of 0.7/100,000 flight hours. Airworthiness includes failures of all components of the aircraft such as the engine(s), airframe structure, rotors, drive systems, hydraulics, electrical, controls, etc. Comparing just the engine failure portion to the rest of the aircraft failure causes shows a different distribution of where the airworthiness failures are being initiated (Fig. 8). On the 206, 80% of the airworthiness accidents were due to the engine, and the Twin Turbines had 12% of their airworthiness accidents still caused by engine failure. So the second engine in a twin did not eliminate all accidents due to power loss and thus dispels one of the myths. The non-engine airworthiness (the rest of the aircraft) causes accounted for 20% for the 206s and 88% for the Twin Turbine's airworthiness accidents. It is obvious that the "remainder-of-the-aircraft-stays-the-same" belief is not true, and is only a myth.

There are many factors at work. One should not count number of engines, as that is misleading from a safety point of view.

Sometimes a single turbine is best choice for safety; sometime a twin turbine is the best choice for safety. Most of the time, it doesn't matter for safety reasons, and the choice should be based on payload and economic issues. The specific type of operation being planned, where it is to be done, and how you will do that operation are far more important than an engine count. The above is only related to the chance of a reportable accident occurring and does not consider the myths related to the actual risk of an occupant being hurt, which will be discussed later.

Table 3. Twin-Engine Safety Myths

1.	You are automatically safer with two engines than with one engine, since you have one engine left when the other one fails such that you can always fly away.
2.	That the effects of the remainder of the aircraft failing is the same with one or two engines installed.
3.	That the increase of pilot errors from the additional pilot workload, decisions, and mistakes in normal and emergency procedures is the same with one or two engines installed.
4.	That safety regulation should be based on One Engine Inoperative (OEI) performance and the failures of the rest of the aircraft can be ignored
5.	That the injury risk resulting from an engine failure is eliminated by having a second engine.
6.	That the injury risk is the same in all types of helicopters.
7.	That the injury risk is the same regardless of what caused the accident.
8.	Regardless of being in a helicopter or in an airplane, if you lose all engine power, you will likely die.

WHAT CAUSES HELICOPTER ACCIDENTS?

The causes of the accidents of the five separate helicopter groups are Fig. 9. The Engine Airworthiness (Eng AW) and Non-Engine Airworthiness (Non-Eng AW) were those accidents where the failure was confirmed (i.e. fatigue, broken, etc.). There was another group in which the pilot "claimed" that he had a power loss and that was the reason he crashed. However, during the accident investigation, the engine subsequently ran fine and no failures in the engine or related systems such as fuel, could be determined. The dilemma for the investigator then becomes what/who to believe. The hard facts (nothing found wrong with the engine or related systems) or the pilot's statement? This is a difficult situation that will not likely improve in the future until there is some type of recording device onboard, such as a Flight Data Recorder (FDR) or Cockpit Audio Visual Recorder (CAVR). Until the investigator can prove one way or the other, this group of accident causes (Suspected Eng AW) will continue.

During this 10-year study, the Suspected Engine AW accidents were considered as actual Engine AW accidents, with the exception of Fig. 9. This Fig. 9 is in descending order of all Airworthiness failures (Engine, Suspected Engine, and Non-Engine AW). Pilot Error is the most common cause of helicopter accidents. The segment labeled "Maint-Other" is accidents due to gross maintenance errors and other persons (other than the pilot or mechanic) that caused the accident. This could include interfering with flight controls or a non-pilot attempting to fly. The remainder was Unknown causes. Although most accidents have several causes, the initiating cause was used in this study.

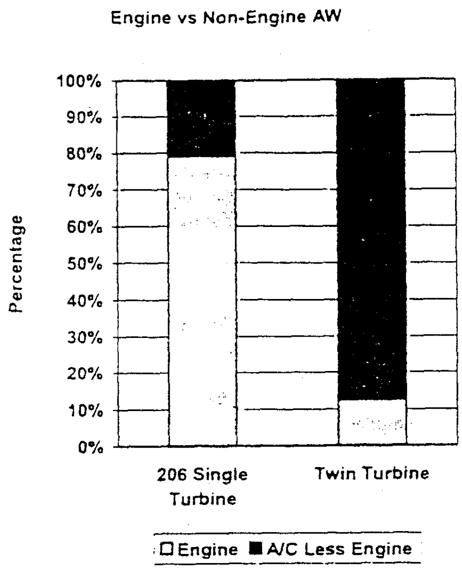


Fig. 8. Airworthiness failure causes of accidents.

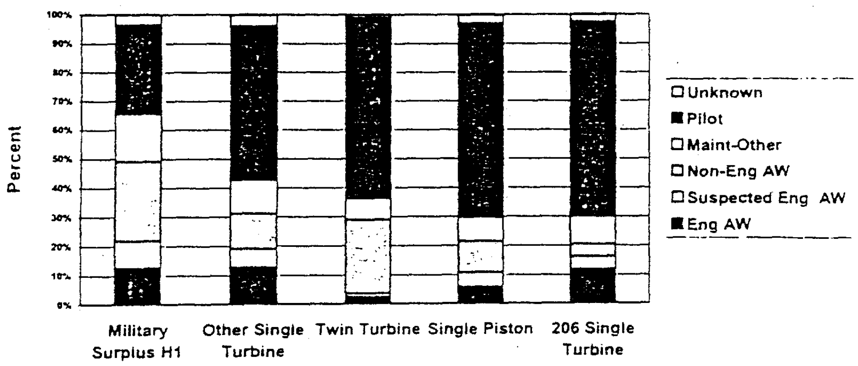


Fig. 9. Accident causes.

SURVIVAL IN HELICOPTER ACCIDENTS

Is the risk of an occupant injury determined by the aircraft accident rate? No. Most of the occupants in accidents are not seriously hurt. Survival depends on many factors, such as

- Aircraft attitude at impact,
- The amount of impact load and direction,
- The type of restraint worn,
- Occupant impact load tolerance,
- Impact surface,
- Aircraft,
- Type of seat,
- Post-crash fire protection,
- Emergency egress

Fig. 10 shows the percentage of occupants that received a fatal injury or survived in Airworthiness caused accidents and the remaining accidents (Non-AW causes) for each of the five groups. Fig. 10 is ordered by descending percentage of fatalities. About 5% of the occupants received fatal injuries in accidents from airworthiness failures (includes engines and non-engine airworthiness failures). Overall, 90% of the occupants survived in helicopter accidents. It is interesting to note that the Twin Turbine had the highest percentage of fatalities for all airworthiness failure of the five study groups. Again, it is apparent that the number of engines is not the controlling factor in occupant survival and the remaining myths are dispelled. Although these values are percentages, they are consistent with the injury rates that are discussed in a later section.

SAFETY IS THE LACK OF INJURY RISK

Webster's Dictionary defines "safety" as "the condition of freedom from harm, loss, or injury." There is no absolute safety in aviation. If you minimize the risk to the occupants, you have improved their safety. Safety is the management of risk. The key is to remember that safety is primarily an outcome related to the occupant, whereas an accident is an event primarily related to reporting aircraft damage.

Some people incorrectly use fatal accident rates as a measure of safety. A fatal accident in any accident in which at least one person receives a fatal injury. The fatal accident rate then is the number of fatal accidents divided by the hours of exposure. As an example, consider a Model A aircraft had an accident in which one of the two occupants received a fatal injury and that fleet had flown 100,000 hours. The Model A fatal accident rate is 1/100,000 hr. Model B also flew 100,000 hours, and one aircraft crashed and 235 occupants of the 300 occupants onboard received fatal injuries. The Model B fatal accident rate was 1/100,000 hr, which was the same fatal accident rate of Model A. Therefore Model A and B have the same safety? No, there is a vastly different societal loss. Fatal accident rates are misleading and should not be used.

RISK OF FATAL INJURY

Safety is measured by an individual's risk of being seriously injured. Risk of fatal injury (RFI) is the method to calculate that individual's risk as the likelihood of an accident

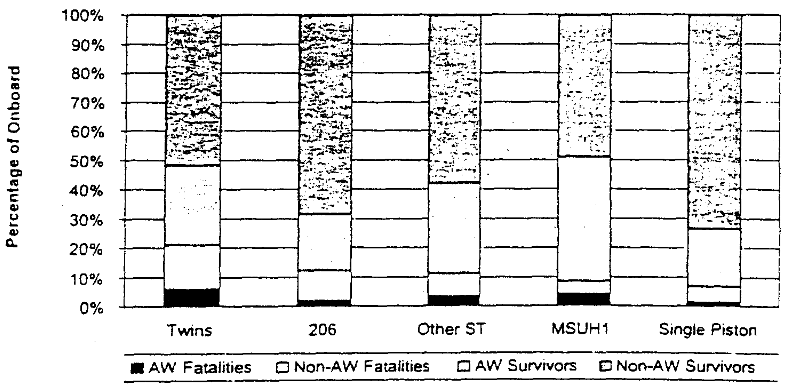


Fig. 10. Survival percentage in helicopter accidents.

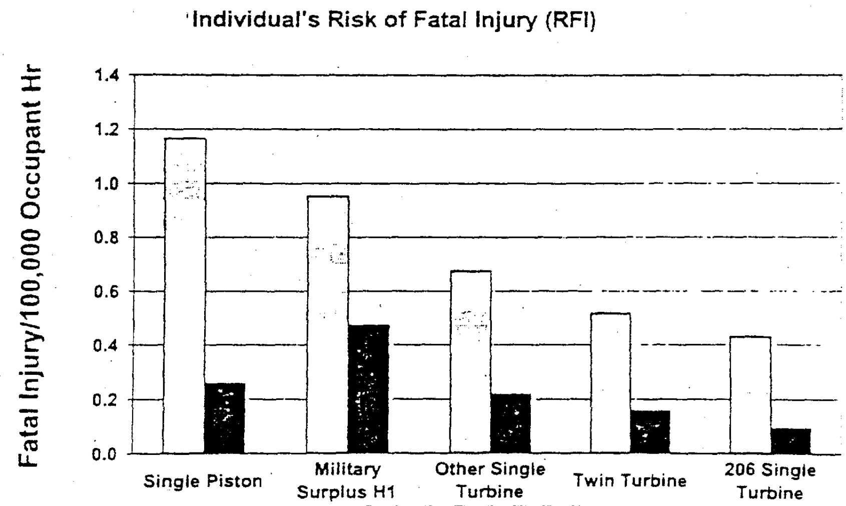
occurring, times the likelihood of receiving a fatal injury. Thus RFI can be expressed as follows:

$$RFI = \frac{\text{Number of accidents}}{\text{Flight hours flown}} \times \frac{\text{Number of people with fatal injuries}}{\text{Total number of people on board in accidents}}$$

RFI is your individual risk of receiving a fatal injury per 100,000 occupant hours to which you are personally exposed (flying) in that aircraft. The RFI for the five groups was determined for all accidents (all causes) and for just those caused by airworthiness failures (Fig. 11).

First, consider what your individual risk is, due to the aircraft itself. The lowest individual's RFI was 0.09/100,000 occupant hours for all airworthiness-caused accidents (including suspected airworthiness causes) was the single engine 206. This occupant risk in a 206 was a 43.8% lower risk than for an occupant in the Twin Turbine group. This indicates that the number of engines on a helicopter is certainly not the predictor of an individual's risk of a fatal injury—and more myths are dispelled. Likewise, the 206 occupant RFI for airworthiness-caused accidents was 59.1%, 65.4%, and 80.9% lower than the Other Single Turbine group, Single Piston group, and Military Surplus UH-1 group, respectively. This points out that the individual aircraft design and how the aircraft is used, and the type of operation being conducted, are extremely important. The detrimental effect of the Military Surplus UH-1 being used in operations for which it was not designed is quite evident. The laws of physics always apply, regardless of civil aviation regulations and aviation myths.

The reality is that you will not die from just airworthiness failures. Your true risk in flying must include accidents due to all causes. The lowest individual's RFI for all causes was 0.43/100,000 occupant hours in the single-engine 206; that was a 17.3 % lower risk than for an occupant in the Twin Turbine group. Again, this points out that the number of engines installed is not the determinator of your safety. The 206 occupant RFI for all causes was 35.8%, 54.7% and 64.2% lower than the Other Single Turbine group, the Military Surplus UH-1 group, and the Single Piston group, respectively. Again, there are many facets of safety that affect your likelihood of a fatal injury to include the design of the aircraft, its design simplicity and forgiveness in an emergency, crash survival features such as the use of a shoulder harness, the type of operation being conducted, abusive use, maintenance, and pilot skills and judgment. Once again, the actual facts regarding occupant risk prove that the "twins are always safer" beliefs are all myths.



	Single Piston	Military Surplus H1	Other Single Turbine	Twin Turbine	206 Single Turbine
□ All Causes	1.17	0.95	0.67	0.52	0.43
■ Airworthiness	0.26	0.47	0.22	0.16	0.09

Fig. 11. Individual's risk of fatal injury.

LIFE SPAN IN FLIGHT

An individual RFI is an extremely small number and comparisons of such small numbers are difficult for the flying public to comprehend. A more understandable interpretation of the RFI would be the answer to "On the average, how many hours can I fly before I would die in a helicopter accident?" The Flight Life Span is the inverse of RFI or 1/RFI, which answers that question. Another way to express this is, using the average hours of occupant flight exposure that are expected to occur between fatal injuries. Since each of us is only allocated one fatal injury, it becomes our life span average in the flight environment. Your Flight Life Span when flying in the five study groups for accidents due to Airworthiness and All Causes is Fig. 12.

If one could only die from just an Airworthiness failure, the individual's Flight Life Spans would range from 384,475 to 1,071,300 occupant hours. The Flight Life Spans for All Causes (what each of us are truly concerned about) ranges from 85,684 to 232, 265 occupant hours. That is a long, long time.

As a general comparison, how does your Flight Life Span compare to when you are flying in the highly standardized and consistent environment of the Part 121 Air Carriers (Scheduled and Unscheduled) and the Commuter Air Carriers (Part 135)? That comparison, plus the inclusion of Unscheduled Air Taxi (consisting of mostly airplanes) under Part 135, is shown in Fig. 13. This shows that your individual risk in turbine-powered helicopters falls between the typical Unscheduled Air Taxi operation under Part 135 and the Air Carriers. The excellent history of the Large Transport Airplanes operating under Part 121 gives us, the helicopter industry, a safety direction for the future. Unfortunately, that airline safety level is an unrealistic and non-achievable goal, even as a safety target, for helicopters due to unique missions that are the only reasons that helicopters even exist. Regulators should not expect helicopters to match airline safety. The helicopter can do unique tasks that no airplane can. These helicopter tasks are always riskier that the highly structured (and expensive) tasks of going from Airport A to Airport B in controlled airspace and returning. We in the helicopter industry must use a multi-faceted and continuing approach to reduce risk of an accident occurring as well as to reduce the risk of an injury when the accident does occur. There is no single solution. Safety is the continuous process of improvement by the management of risks.

Since no one individual flies 24 hours a day, every day of the year, a conservative estimate of your flight career longevity in helicopters can be made. Assume you fly 8 hours a day on each day of the year. The number of years of your Flight Life Span is shown in Fig. 14.

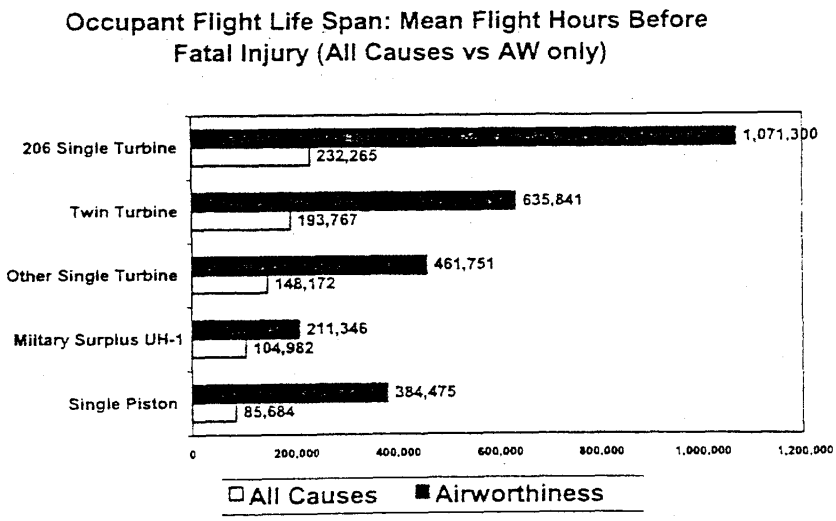


Fig. 12. Occupant flight life span.

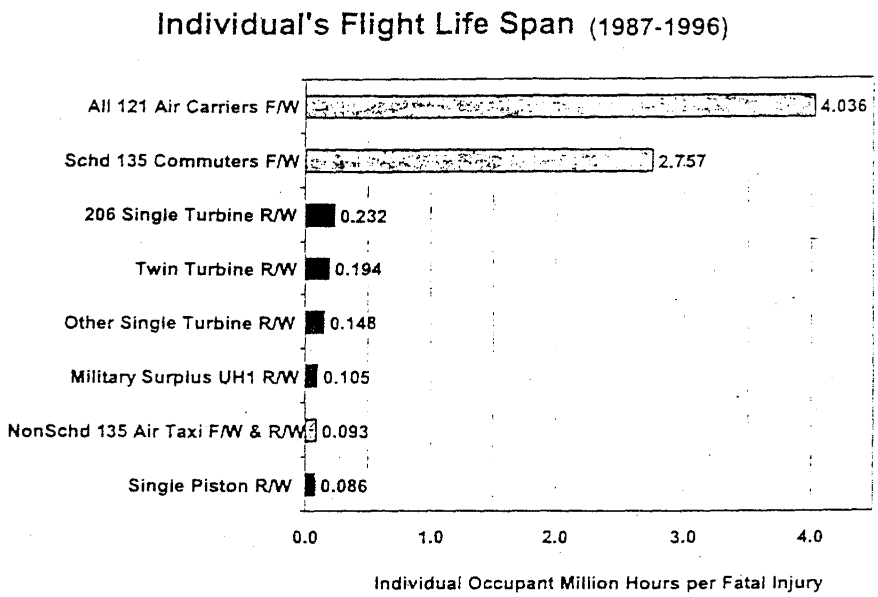


Fig. 13. Individual flight life span in helicopters and airplanes.

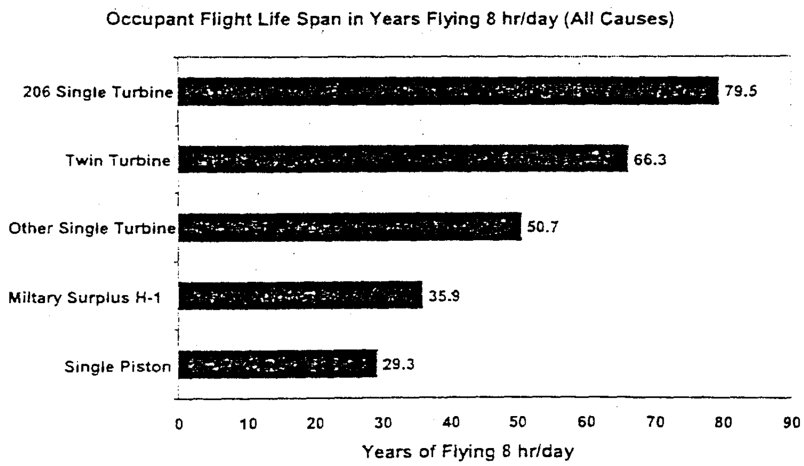


Fig. 14. Occupant flight life span in years.

Thus a helicopter occupant could expect a Flight Life Span period of 29.3 to 79.5 years of flying 8 hours/day (e.g. 2,292 hours/year). In reality, there are very few people who are in the air 2,292 hours each year, so this is quite conservative. This does show that an individual is safe when flying in all helicopters.

SUMMARY

A study of 1,534 U.S. registered helicopters in five groups for the last 10-year period of 1987 through 1996 found that

- For all helicopter accident causes, your individual Risk of Fatal Injury ranged from once in 85,684 to 232,265 occupant hours of exposure, based on today's fleets and different types of operations.
- For only airworthiness causes, your individual Risk of Fatal Injury ranged from once in 384,485 to 1,071,300 hours of occupant exposure.
- Accident rates are more related to airframe damage, and are poor indicators of occupant safety. Individual Risk of Fatal Injury is a better indicator of occupant safety.

Further, the myths related to "twin-engines are always safer than one engine" was dispelled by actual helicopter safety history. An occupant in the single-engine 206 has a risk of a fatal injury due to all airworthiness failures (engine and the rest of the aircraft) that was 43.8% lower than an occupant in a Twin Turbine helicopter. Likewise, an occupant in the single-engine 206 has a risk of a fatal injury due to all causes that was 17.3% lower than an occupant in a Twin Turbine helicopter. Overall, it was shown that there are many more factors to be considered rather than the counting of engines. In some cases, a single turbine helicopter is safer; in some cases, a twin turbine helicopter is safer. However, in the majority of cases, the number of engines does not make any difference, and other issues such as payload, type operation, pilot issues, and economic factors should determine what type of helicopter should be used.

All helicopters are safe with some more than others, but we must improve much further for wider public acceptance. The key to moving to a new safety plateau level will require recording devices to document what is actually occurring in the cockpit during the accident sequence. Only then with understanding those actions and sequences, can we correct those elusive human errors.

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MEASURING SAFETY INVESTMENT EFFECTIVENESS RELATIVE TO RISKS

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Presented at the American Helicopter Society
54th Annual Forum, Washington, DC,
May 20 – 22, 1998

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ABSTRACT

In aviation, safety is the management of risk. This paper addresses several methods of measuring safety to determine risks to helicopters and the risk of injury to occupants. Variable factors are discussed that cause accident rates to be dramatically different on the same type of helicopter. Groupings of accident causes related to potential safety investment areas are presented to indicate areas needed for future improvements and potential frequency of use. Risk frequencies related to the more significant safety investment areas are determined and compared to the present safety level and the National Aviation Safety Goal. This comparison provides an assessment of the likelihood of meeting the National Aviation Safety Goal.

BACKGROUND

A White House Commission on Aviation Safety Study (Ref. 1) investigated commercial airline safety. Study Recommendation 1.1 stated: "Government and industry should establish a national goal to reduce the aviation fatal accident rate by a factor of five within ten years and conduct safety research to support that goal." President Clinton then announced that National Aviation Safety Goal and tasked NASA to determine and realign research in those areas that could assist in meeting the National Aviation Safety Goal. The NASA Aviation Safety Investment Strategy Team (ASIST) program brought together NASA, FAA, DOD, other government agencies, and the aviation industry to work together as part of NASA's Aviation Safety Program. The Helicopter Accident Analysis Team (HAAT), formed to support the NASA effort, analyzed 34 selective fatal helicopter accidents to determine basic research areas with potential for safety intervention (Ref. 2). Due to the urgency and the nature of accident report selection process, the HAAT effort was primarily to brainstorm problems and solutions. The HAAT selective accident data could not be used to determine valid frequencies of potential Safety Investment Areas (SIA). The study presented herein was structured to sufficiently determine frequencies of major SIAs to be able to predict whether it is possible to actually meet the National Aviation Safety Goal.

Presented at the American Helicopter Society 54th Annual Forum, Washington, DC, May 20–22, 1998.

APPROACH

The overall approach used in this study was to analyze the National Transportation Safety Board (NTSB) accident data on helicopters for potential SIAs to assist NASA in determining effective research priorities. Combined with flight-hour exposure from Federal Aviation Administration (FAA) documents, this analysis allowed the relative frequency of SIA occurrence to be determined for the baseline period of 1990 through 1994. The National Goal was then determined to be an 80% reduction (e.g., a five-fold reduction) in fatal accident rates from this baseline. The effectiveness of the various SIAs in reducing their respective frequencies of occurrence was then forecast against the NASA National Aviation Safety Goal, which provided a metric of the likelihood of meeting the National Aviation Safety Goal for various SIAs. Such a metric can be useful in establishing what SIA combinations are most beneficial and which should be developed and implemented to achieve National Aviation Safety Goal.

ANALYSIS ISSUES

There were several challenges in performing such an analysis. The major ones were as follows:

- The average helicopter did not represent the helicopter fleet. There was a very large range in helicopter costs, maintenance, uses, and likelihood of accepting any improvements. The helicopters ranged from rebuilt from crash damaged parts, military surplus, to twin-turbine powered passenger transport helicopters.
- Sporadic quality and completeness of accident data from the NTSB ranged from excellent for many of NTSB field accident investigations to minimal information for NTSB limited investigations. The NTSB limited investigations are accidents where some limited, basic information (hence the name "limited investigation") was obtained by investigators from their NTSB office-the investigators did not actually go to the accident site and see the wreckage. Inadequate staffing due to funding constraints precluded the NTSB from conducting field investigations of all aircraft accidents. The majority of helicopter accidents were only limited investigations.
- Helicopter configurations varied significantly due to the many major modified models, such as conversions from

piston engines (reciprocating) to turbine engines. Many of these helicopters were used in agriculture missions. Flight-hours exposure data from the FAA were severely lacking on these modified configurations.

- Flight hours estimated and published by the FAA was lacking or non-existent on many helicopter models that experienced accidents. Meaningless accident rates result when the number of accidents is divided by zero flight hours.

These issues required the following ground rules and assumptions in the analysis.

Helicopter Grouping

In studies of worldwide Bell helicopter accidents, there are many factors that have caused the accident/injury frequencies of the same helicopter model to vary significantly. These variability factors are grouped as shown in Table 1 from "Riskier" to "Safer" within each column. These representative factors are furnished to provide the reader with an understanding of the wide spectrum of factors rather than to establish any mathematical relationships between factors. For example, readers can get a general idea of the risks of their operations by identifying where their situations fall within each column.

This variability is manifested in the accident rates as noted in Fig. 1. There are significant differences in the accident rates of different families of helicopters and other types of aircraft in civil use in the United States. For example, the Helicopter Safety Advisory Conference (HSAC) is a group of oil companies and their helicopter operators that came together for the common goal of improving safety in offshore helicopter safety over the Gulf of Mexico. For the period of 1989 through 1994, their average fleet of 611 turbine helicopters moved 20.5 million passengers in 2.7 million hours and made 10.1 million takeoffs and landings. In 1994, they averaged 4,909 flights each day of the year. Even with this much aviation activity over the Gulf of Mexico, the accident rate of these helicopters was 63.4 percent lower than the total civil turbine helicopter fleet accident rate of 4.1 accidents/100,000 hours. The difference was not due to the type of aircraft used; rather, it was due to the human side of professionalism in operational aspects.

For the study herein, the original design certification status was used for three helicopter groups:

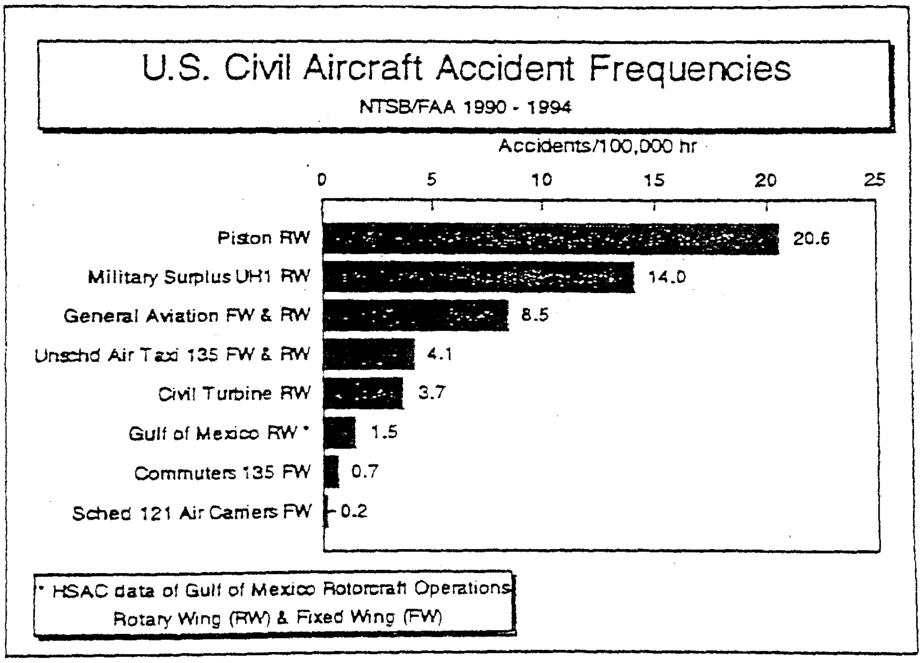

Fig. 1. U.S. civil aviation safety.

Table 1. Helicopter safety variability factors.

Pilot	Machine	Environment	Mission	Crash survival
RISKIER	*RISKIER*	*RISKIER*	*RISKIER*	*RISKIER*
Private license, minimal control and experience	Aircraft misused and abused beyond design limits	Harsh landing surfaces (water, etc.) First time to land at remote spot in unknown conditions (on a mountain ridge)	Logging/external loads in remote sites, operating near gross weight, severe use.	Lap belt only use
Qualified, commercial FAA license	Unauthorized (bogus) parts, salvaged, & multiple rebuilds	Low level flying, hitting obstacles, little emergency reaction time	Personal, instructional, agricultural spraying	Rugged cockpit and cabin, life vests, good emergency egress
Professional, self-induced standards	Strictly observe operating and maintenance procedures	FAA-approved sites, sporadic use, VFR flights	Business, on-demand air taxi, corporate / executive	Shoulder harness for each occupant (increase spinal tolerance by 6x)
Highly structured professionalism, CRM/ADM, simulators used	Onboard monitor systems to identify problems prior to failure, allows timely scheduled maintenance	Regimented IFR, scheduled use, same landing sites (airports/heliports) are used.	Scheduled air carriers	Energy attenuating seats, where feasible, to reduce spinal injury. Crash resistant fuel system to reduce thermal injuries.
SAFER	*SAFER*	*SAFER*	*SAFER*	*SAFER*

- Civil turbine-powered
- Civil piston-powered
- Military Surplus UH-1

The accident rates for these three helicopter groups in Fig. 1 vary over a large range. The modified piston-powered helicopters such as Models 47, H-23, and UH-12 that were modified with a turbine-engine or a new fuselage configuration were deleted from this study. The decision to implement any safety intervention approaches or not is a function of the cost to the operator. For example, the likelihood of getting a safety device costing $50,000 into a fleet of aircraft that cost $5 million each is quite good, whereas it is quite unlikely that the same $50,000 safety device will be forced on a fleet of aircraft that are only worth $80,000 per aircraft. Thus aircraft value is a major factor in the type of safety intervention that will be acceptable to the helicopter operators. The typical price ranges of the three used-helicopter types selected are shown in Table 2.

The anticipated composition of the helicopter fleet in ten years is basically the same as that of the fleet that exists today. This is due to three factors. First, very few newly manufactured aircraft are introduced into the fleet each year compared to the existing fleet. These new aircraft are of the same basic designs as the aircraft flying today. Totally new aircraft designs are rare and their limited numbers do not affect the makeup of the fleet. Second, the existing fleet does not reduce significantly in size due to accidents. Most aircraft are repaired if the accident damage is substantial. It is appropriate to repair substantially damaged aircraft, but it is not appropriate, or legal, to rebuild an entire aircraft from an aircraft identification data plate from a destroyed aircraft (i.e., counterfeit or bogus aircraft), a practice that also prevents older aircraft from leaving the civil fleet. Third, the U.S. Army has been surplusing and continues to surplus several thousand military-qualified helicopters. These military surplus helicopters are going into many uses in the civil sectors. For these reasons, it is estimated that over 90% of the existing helicopters will still be in the fleet in 10 years. Thus safety intervention concepts on new helicopter

Table 2. Typical price ranges of used helicopter types

Helicopter type	Lower price limit	Upper price limit
Civil piston-powered	$22,000	$170,000
Military surplus UH-1	$50,000	$150,000
Civil turbine-powered	$120,000	$4,800,000

designs—such as a glass cockpit—will have little to no significant effect on the future fleet accident rates. Safety interventions need to be applicable to the existing fleet to be able to achieve a significant accident rate reduction.

Exposure Data Limitations

Frequency of a safety problem is measured as a rate of the problem per hour of exposure. The exposure of flight hours estimated by the FAA is the official flight hours, regardless of their accuracy. If an accident occurred to a helicopter model in a specific year and there were no FAA flight hours for that model for that specific year, that accident was deleted from the study. Models with annual flight hours for only one or two years out of the five-year period were also deleted from the study.

Study Period

The baseline or starting point to be used to forecast an 80% reduction was determined. The five-year period of 1990 through 1994 of U.S. registered helicopters was used as the latest period where NTSB computerized accident data and FAA flight hours were available.

SAFETY INVESTMENT AREAS

This study used the major intervention concepts of the NASA Helicopter Accident Analysis Team effort described in Ref. 2. Poor pilot judgment where various forms of aeronautical decision making (ADM) improvements can make a difference was separated into various segments in the HAAT effort. However, due to the large number of accidents in the study herein, the detailed investigation needed to identify specific judgment factors could not be performed within the time allotted. From a previous study of the root causes of human-error-caused (e.g., pilot) accidents in Bell Helicopter accidents around the world (Ref. 3), poor judgment was found prevalent in all of these human-error-caused accidents. Thus the relative nature, frequency, and effectiveness of the many forms of judgment improvement were not characterized in the study herein.

The SIAs used in this study are found in Table 3. There is some overlap between SIAs to allow visibility for a more specific approach as compared to a very general approach. Most accidents had more than one SIA and some accidents had no SIA—for example, accidents where the person at the controls was not a helicopter pilot but had stolen the helicopter and crashed. There is no SIA that could help with that accident mode. These latter accidents had factors that are expected to continue to occur in the future, regardless of government/industry attempts to improve safety. Also included in Table 3 is a first-attempt at a potential solution to better explain the intervention concept for a SIA. The solution noted is one, but not the only, approach that can achieve an improvement in related accidents. Onboard and self-contained solutions in the aircraft are more likely to be successful due to the remote locations in which the helicopter is used.

SAFETY METRICS

How does one measure safety? Actually, we do not measure safety; rather, we measure risk, which is the lack of safety. A means of transportation with a low accident rate (e.g., a low risk of hitting the ground) is considered to have a high level of safety. The identification of risks that are to be measured is critical to the outcome and usefulness of a safety analysis. The core response to measuring risk is to include the specific factor of concern. Many ways are used to measure safety (Ref. 4) depending on the item of primary concern. If the primary concern is the risk of not completing the mission, the number of accidents (e.g., the number of occasions of not completing a mission or a flight) per 100,000 departures would be appropriate. This study was not concerned with the risk to mission completion.

If the specific factor of concern is to determine the risk to the aircraft (e.g., how often is the aircraft damaged beyond the accident definition threshold), the appropriate metric is accidents/100,000 hours. This was one of the safety metrics in this study, as it is commonly used throughout the world.

In this particular study, we are responding to a NASA Aviation Safety Goal of reducing the fatal accident rate by 80%. Thus, the specific factor of concern is how often there is an accident in which there is at least one fatality. This is a misleading metric. For example, compare two different aircraft: Aircraft A, a two-place aircraft, flies 100,000 hours with one accident in which one of the two occupants receives fatal injuries; Aircraft B is a 400-seat aircraft that also flies 100,000 flight hours and has one accident in which 235 people received fatal injuries. Both Aircraft A and Aircraft B had a fatal accident rate of one per 100,000 flight hours and thus were of equal risk. Obviously, this is a false safety metric as the societal loss was vastly different between these two aircraft. A fatal accident is defined as the number of accidents in which there is at least one fatality divided by the flight hours flown for that period. A fatal accident rate totally disregards the number of fatalities by only counting accidents in which there was at least one fatality. Nevertheless, this study included this misleading metric, fatal accidents per 100,000 flight hours, in order to directly respond to the National Aviation Safety Goal.

Table 3. Safety investment areas (SIA).

SIA No.	SIA Description	Potential SIA Solutions
1.	OBSTACLE STRIKE. Strikes to wires, towers, trees, poles, or other structures. Not as descending into a forest. Includes main and tail rotor strikes and fuselage striking something.	Wire detection/protection systems, object detection systems, aircraft installed systems, and synthetic detection systems such as GPS compared to moving map database.
2.	LOSS OF AIRCRAFT SITUATIONAL AWARENESS (SA). SA external to the aircraft in real time. Being aware of the relative location of the aircraft to items in its proximity. Examples are trees, terrain, water and CFIT. Obstacle strikes are a special subset for individual items such as a wire while traveling horizontally or climbing. The overall SA loss also includes strikes while descending which can have additional solutions.	Obstacle proximity detection systems, enhanced radar altimeter and ground proximity, weather in the immediate proximity, moving maps/GPS with real time satellite updates. Systems must be real time with trending to be able to forecast in time to allow adequate pilot notification and intervention.
3.	REAL TIME AIRCRAFT PERFORMANCE EXCEEDED. Changing conditions, pilot actions, or the situation is demanding more aircraft performance than is available or puts the aircraft beyond its envelope limits.	Real time performance indication such as an onboard system that tells the pilot how close he is to exceeding any aircraft limits in real time. An onboard system that calculates/displays the actual aircraft performances of what is required to fly (i.e., what is physically needed in this instance) versus what the aircraft can provide at this same location and time with present control settings. The difference is the safety margin. Trends calculated onboard will allow the forecasting of reaching or exceeding envelope limits. Typical problem is attempting to hover out-of-ground-effect (HOGE) beyond aircraft's ability. By seeing the reduction in safety margins, the pilot can abort or modify his flight to stay within limits and not lose control.
4.	LOSS OF SITUATION AWARENESS OF AIRCRAFT INTERNALLY. Pilot apparently did not understand what is happening within the aircraft during normal and emergency operations (including approaching the limits), what can be done, or what should be done. SA is internal to the aircraft and its systems.	Pilot Aiding Solutions: Onboard systems that identify the problem and lead the pilot through the appropriate emergency procedure such as during an autorotation, dynamic rollover, or ground resonance. Systems that check other characteristics to verify the problem & then advise pilot. Systems that forecast the time remaining until limits are reached/exceeded. Advance systems could modify/take partial control near envelope extremes. Examples could include soft-stops on controls so you know you are near the limits, fuel usage vs available to predict when fuel exhaustion is going to occur.
5.	LOST OF VISIBILITY. Inability to see, such as in fog, whiteouts, brownouts, and inadvertent entry into IMC. Pilot vertigo or a late breakout to VFR conditions are likely.	Visibility Aids. Synthetic vision or other short term recovery systems that allow pilot to keep A/C upright until visibility is restored.

Table 3. Safety investment areas (SIA) (concluded).

SIA No.	SIA Description	Potential SIA Solutions
6.	INABILITY TO RESPOND IN SHORT DURATION EMERGENCY. Pilot did not recognize the emergency, did not know the corrective action, or performed the emergency procedure poorly or too late. Short time available for the initiating and complete the emergency response is the key.	Automatic recovery systems are short-time quick-acting systems that take over for the pilot in an emergency and gets aircraft back in a stable recovered state. Examples include mini auto-pilot that can be activated in a panic and the aircraft would return to and remain in an upright position and not descend for a few minutes, auto landing systems to level aircraft and slowly lower to ground, automatic system to recover from dynamic rollover initiation or ground resonance.
7.	AIRCRAFT COMPONENT FAILURE. An aircraft component fails while the aircraft is in operation.	Health and Usage Monitoring System (HUMS) is a monitoring system that can record failure parameters, exceedences, and usage. Some HUMS can identify an impending part failure that can be removed in maintenance prior to the catastrophic part failure. Present HUMS monitor the drive train, rotors, and engine by means of vibration sensors. Rotor out of track is also monitored. HUMS today is only a maintenance aid but the future HUMS should be alerting the pilot of impending failure and other degradations of the aircraft health. . Aircraft Health is a new concept that goes beyond present HUMS.
8.	MAINTENANCE ERROR. Maintenance errors where the mal-maintenance is obvious. Examples are not putting oil in the gearboxes, not replacing parts as required by the manual, and not installing all of the aircraft parts prior to flight.	Electronic maintenance manual, aids, and checklists. Maintenance errors could be reduced with simplified electronic maintenance procedures/checklists. Checklist alerting to the pilot as to aircraft status prior to flight.
9.	COCKPIT ACTIONS UNKNOWN. What really happened or did not happened is rarely known unless the investigation determines it was due to a material failure. This is because there are no Cockpit Voice Recorder (CVR) or Flight Data Recorder (FDR) in the vast majority of helicopter accidents. CVRs and FDRs are only required on very large helicopters involved in commercial work. Except for part failures found, much of the evidence is circumstantial. Pilot's statements in some cases don't match with physical laws. Example is a reported powerloss in a marginal performance situation and yet the engine runs fine after the accident. Since the actual root causes of most pilot error accidents are not now known, it is not possible to determine the appropriate SIAs until there is documented data.	Cockpit Activities Recording. A Cockpit Audio Visual Recorder (CAVR) that records photo sequence of all instruments/lights and pilots control stick motions with time. An area microphone records noises within the cockpit. Playback will show what the pilot did or did not do, when it was done, and the aircraft response. It could also show instruments or lights change that the pilot reacted to, or sounds heard. If the proper procedure was followed and he crashed, the procedures need to be corrected. Proactively, CAVR can be used as training aid with a student to correct actions/habits to preclude accidents. If a CAVR is fielded a few years before the year 2008, many of the accident causes would have been identified and corrective action initiated. Thus the benefits of a CAVR can be counted as eliminating that corresponding accident within the study group.
10.	BAD JUDGEMENT. Extremely obvious examples of pilot bad judgement or aircraft operation. Examples are taking off with skid tied down, water in the fuel, flying longer than fuel available, flying drunk, and flying into volcano fumes.	Aeronautical Decision Making (ADM) training and training aids can help in most poor judgment accidents. Electronic training aids that teach judgments are possible. The total number of potential ADM improved accidents is much higher than indicated here. These accidents are only the more obvious ones without full investigation into the details of the individual accident.

However, if the risk of an individual receiving a fatal injury is the primary concern, then the appropriate metric is the risk of fatal injury per 100,000 occupant exposure hours (RFI). Basically, the RFI is the individual risk of a fatal injury per hour of exposure spent in that type of vehicle. RFI is included as the true safety metric. An occupant's RFI in a type of aircraft is calculated as

$$RFI = \frac{\begin{array}{c}\text{Number of}\\ \text{all accidents}\end{array}}{\begin{array}{c}\text{Flight-hours}\\ \text{flown}\end{array}} \times \frac{\begin{array}{c}\text{Number of}\\ \text{fatalities}\end{array}}{\begin{array}{c}\text{Number onboard}\\ \text{in all accidents}\end{array}}$$

Therefore, this study used three safety metrics of

- Fatal accidents per 100,000 hours (required response).
- Accidents per 100,000 hours (risk to the aircraft).
- RFI per 100,000 occupant hours (risk to an individual of a fatal injury).

The amount of flying for these three helicopter types and the number of accidents involved in this study are shown in Table 4.

ANALYSIS

The present risks for the period of 1990 through 1994 are shown in Table 5. Also shown is the 80% reduction goals for ten years hence, assumed for this study to be the year 2008.

Potential Effects of Safety Investment Areas (SIAs)

The frequency of SIAs in Table 3 were determined for the three helicopter types on an individual basis as if that specific SIA were the only one selected to be used. Most accidents had multiple SIAs that could reduce that particular type of accident in the future. The present individual SIA rates of accidents per 100,000 hours are shown in Table 6.

The present fatal accidents per 100,000 hours for each individual SIA is Table 7.

Table 4. Helicopter accidents and exposure.

	Flight Hours	Accidents	Fatal Accidents
Piston	2,361,526	486	66
Turbine	7,990,747	294	77
Military surplus UH-1	171,049	24	4
Combined	10,523,322	804	147

Table 5. Rotorcraft safety measures of present and future

	Civil piston	Civil turbine	Military surplus UH-1
PRESENT RISKS (1990s)			
Accidents / 100,000 hours	20.58	3.68	14.03
Fatal accidents / 100,000 hours	2.79	0.96	2.34
Risk of fatal injury / 100,000 occupant hours	2.43	0.76	2.08
FUTURE RISKS GOALS (2008)			
Accidents / 100,000 hours	4.12	0.74	2.81
Fatal accidents / 100,000 hours	0.56	0.19	0.47
Risk of fatal injury / 100,000 occupant hours	0.49	0.15	0.42

Table 6. SIA accidents per 100,000 hours.

		Civil piston	Civil turbine	Military surplus UH-1
1.	Obstacle strike	2.46	0.44	0.58
2.	Loss of aircraft situational awareness	7.54	1.00	2.34
3.	Real time aircraft performance exceeded	4.28	0.68	5.26
4.	Loss of situational awareness within the aircraft (internal)	4.53	0.53	0.54
5.	Loss of visibility	0.42	0.58	0.48
6.	Inability to respond in short duration emergency	0.97	0.21	0.00
7.	Aircraft component failure	4.36	1.08	9.35
8.	Maintenance error	2.20	0.31	1.75
9.	Cockpit actions unknown	16.47	2.63	9.94
10.	Bad judgment	1.14	0.48	1.17

The present individual occupant risk of fatal injury per 100,000 occupant hours of exposure for each individual SIA are in Table 8.

The previous tables show the differences in risks among the type of helicopters in this study. The three helicopter types were combined into a common helicopter fleet based on flight hours. Table 9 shows the accident rate, fatal accident rate, and risk of fatal injury rate for each of the individual SIAs. The two most frequent SIA rates are SIA 9 (Cockpit Actions Unknown) and SIA 2 (Loss of Aircraft Situational Awareness). This indicated that there was a lack of information in the accident report as to what actually was going on in the cockpit prior to the crash, followed by a pilot's lack of awareness of where his aircraft was relative to obstacles and terrain.

Effectiveness

The SIA rates use the assumption of 100% effectiveness in eliminating that accident cause. This is appropriate for the study herein, which was to determine the potential change from various SIAs. In future studies, the effectiveness of a specific intervention can be estimates as a percentage of the SIA rates presented herein. Factors to consider in an effectiveness analysis should include the following specific

Table 7. SIA fatal accidents per 100,000 hours.

	Civil piston	Civil turbine	Military surplus UH-1
1. Obstacle strike	0.80	0.18	0.00
2. Loss of aircraft situational awareness	1.10	0.44	0.01
3. Real time aircraft performance exceeded	0.17	0.09	0.04
4. Loss of situational awareness within the aircraft (internal)	0.30	0.11	0.00
5. Loss of visibility	0.04	0.29	0.01
6. Inability to respond in short duration emergency	0.04	0.04	0.00
7. Aircraft component failure	0.51	0.23	0.23
8. Maintenance error	0.30	0.05	0.00
9. Cockpit actions unknown	2.29	0.74	0.05
10. Bad judgment	0.25	0.18	0.01

Table 8. Present SIA risk of fatal injury per 100,000 occupant hours.

	Civil piston	Civil turbine	Military surplus UH-1
1. Obstacle strike	0.83	0.13	0.00
2. Loss of aircraft situational awareness	0.96	0.37	0.47
3. Real time aircraft performance exceeded	0.10	0.05	1.58
4. Loss of situational awareness within the aircraft (internal)	0.20	0.07	0.00
5. Loss of visibility	0.06	0.27	0.58
6. Inability to respond in short duration emergency	0.02	0.02	0.00
7. Aircraft component failure	0.45	0.16	1.04
8. Maintenance error	0.27	0.02	0.00
9. Cockpit actions unknown	2.01	0.64	1.81
10. Bad judgment	0.29	0.13	0.58

Table 9. Combined fleet risks.

	Accidents / 100,000 hr	Fatal accidents / 100,000 hr	Risk of fatal injury / 100,000 occupant hr
1. Obstacle strike	0.89	0.31	0.28
2. Loss of aircraft situational awareness	2.49	0.59	0.57
3. Real time aircraft performance exceeded	1.56	0.13	0.08
4. Loss of situational awareness within the aircraft (internal)	1.43	0.15	0.11
5. Loss of visibility	0.47	0.24	0.24
6. Inability to respond in short duration emergency	0.38	0.04	0.02
7. Aircraft component failure	1.95	0.30	0.25
8. Maintenance error	0.76	0.10	0.07
9. Cockpit actions unknown	5.85	1.11	1.04
10. Bad judgment	0.64	0.20	0.17

intervention values multiplied against the overall potential rate for SIA (as presented herein). In formula form, this is

$$E = SIA_{BR} \times SIA_{MODES} \times I_{EFF} \times I_{USAGE}$$

where E = effective SIA rate
SIA_{BR} = SIA base rate
SIA_{MODES} = percentage of all modes within the SIA that are addressed by the specific intervention method
I_{EFF} = percentage of specific intervention effectiveness, if used
I_{USAGE} = percentage of specific intervention usage expected

The last factor, likelihood of specific intervention being used, will require a cost-benefit analysis. It is expected that cost acceptability will be the driving factor; thus an effective intervention method for a high-priced aircraft will not be effective for an inexpensive aircraft. The key to the success of safety intervention is going to be the acceptability of cost to implement changes.

GROUPING OF SIAs

The study focus then became what area or areas should be the primary focus with limited funding? There is no simple answer. If only one SIA were allowed, it would be SIA 9 Cockpit Action Unknown. This SIA is the most significant for all three helicopter types and for all three risk metrics. Since we do not know what actually happened inside the cockpit, many of the safety interventions (fixes) may not be effective.

Most of the accidents had multiple SIAs that could have been effective. For example, the totals of the risk rates within the columns of Tables 6, 7, 8, and 9 will actually exceed the total risk rates due to multiple SIAs in each accident. To preclude multiple counting of the same accident in determining effectiveness, an accident was counted only once. Subsequent SIAs could not take credit for that accident.

The major SIA that is common to each risk area is SIA 9 of Cockpit Actions Unknown. This is a key area that must be improved to be able to understand the accident sequence, what was indicated in the cockpit, what was the pilot's response, whether the response was appropriate and timely, and whether the emergency procedures were adequate. Once this knowledge is obtained, the other SIAs areas would increase in effectiveness. The apportionments between the SIAs are unknown. Thus, the sequence of applying SIAs was to use those better-defined approaches before applying the more encompassing SIA 9 area of unknown cockpit procedures. Use of a cockpit audio-visual recorder (CAVR) would also prevent accidents if used as a student pilot training aid. SIA 10 (Poor Judgment) is quite understated in frequency herein due to lack of detailed accident data. Using information gained by the CAVR, an understanding of the many different human errors can finally be obtained in the future, which will allow the development of training, devices, and procedures.

The most effective mix of SIAs is shown in Table 10 with the sequence priority rationale as follows. SIA 2 (Loss of Aircraft Situational Awareness) and SIA 1 (Object Strike) were selected as the first related group. Their full elimination in the future would reduce the risk rates from the present levels to that noted in Table 10. For example, the overall accident rate would be reduced from 7.64 to 5.07 per 100,000 hours, which is far short of the National Aviation Safety Goal of 1.53 per 100,000 hours.

SIA 7 (Aircraft Component Failure), then SIA 3 (Real Time Aircraft Performance Exceeded), and then SIA 4 (Loss of Situational Awareness Within the Aircraft) were combined into the second group. These SIAs share common information related to the health of the aircraft. The addition of t second group drops the accident rate from 5.07 to 2.14/100,000 hours, which is still short of the 1.53/100,000 hours goal.

The last group to be added was SIA 9 (Cockpit Actions Unknown), consisting of accidents not previously eliminated by prior SIAs. Cockpit monitoring by the use of a CAVR is expected to drop the accident rate of 2.14 to 0.36 per 100,000, which is below the goal rate of 1.53 per 100,000 hours.

Injury Mitigation

The study dealt with the potential risk reductions using the accident prevention approach. Although the injury prevention/reduction approach was ignored in this study, injury reduction can reduce risk even if the accident rates never change. For example, the risks related to helicopter accidents involved in a post crash fire (PCF) are shown in Table 11. Injury mitigation approaches such as a crash resistant fuel system (CRFS) can reduce occupant risks, but the weight and cost penalties of retrofitting a CRFS into existing helicopters is high. Thus the benefit of a CRFS may not be realized due to non-acceptance by the operators.

CONCLUSIONS

1. Accidents involving turbine-powered, piston-powered, and military surplus UH-1 helicopters being operated in U.S.

Table 10. Combined fleet potential of meeting goals.

SIA No.	Risks	Accidents/ 100,000 hours	Fatal accidents/ 100,000 hours	Fatal injuries/ 100,000 occupant hours (RFI)
	Present risks: Implement SIAs solutions in order yields the following residual risks (assuming 100% acceptance & implementation in the field)	7.64	1.40	1.23
2, 1	Proximity detection systems.	5.07	0.76	0.65
2,1, 7,3,4	Add HUMS, aircraft health, real time performance, and pilot aids	2.14	0.39	0.37
2, 1, 7, 3,4, 9	Add cockpit monitoring (CAVR)	0.36	0.06	0.10
	Residual risk after SIAs combined potential	0.36	0.06	0.10
	Year 2008 targets/goals:	1.53	0.28	0.25

civil aviation were analyzed to determine risks, potential areas for safety intervention, and their respective frequencies. These risks formed the baseline from which to estimate the likelihood of achieving potential improvements ten years in the future.

2. Presently, the actual risk to a helicopter occupant of a fatal injury is 1.23 fatalities per 100,000 occupant hour of exposure. This is the true measure of occupant risk.

3. The present risk to a helicopter of being involved in an accident is 7.64 per 100,000 hours.

4. The risk of being involved in an accident involving one or more fatal injuries (e.g., fatal accident rate) was determined to be 1.40 per 100,000 hours. This fatal accident rate is misleading but needs to be included, as it was part of the National Aviation Safety Goal.

5. It appears possible from this study that the National Aviation Safety Goal of reducing the fatal accident rate by 80% in ten years is achievable for the entire fielded fleet. This assumes 100% acceptance and implementation prior to the year 2008 of the SIAs of Table 10. These combined SIAs include systems that could (1) detect objects (wires, trees, etc.) and terrain in close proximity of the helicopter, (2) provide alerting systems, (3) provide aircraft situational awareness relative to its surroundings, (4) advance HUMs and other aircraft health monitoring devices, (5) use real-time performance indications with forecast capabilities, (6) use pilot aiding systems, and (7) use a CAVR.

Table 11. Risks of combined fleet involved in PCF.

Risk	Frequency of occurrence
Post crash fires per 100,000 hours	0.76
Post crash fires in fatal accidents per 100,000 hours	0.54
RFI in post crash fire accidents per 100,000 occupant hours	0.35

6. Projected *potential* percent risk reductions of accident rates, fatal accident rates, and fatal injury (RFI) rates were 95.3%, 95.7%, and 91.9%, respectively. The key is that these are the maximum *potential* improvements that exist, assuming 100% acceptance and implementation. However, in the writer's opinion, it is unlikely that the National Aviation Safety Goal will be met by the year 2008.

7. Better means of recording and compiling helicopter flight hours by the FAA are needed now and will become critical in the future when attempting to measuring the progress and trends toward meeting this National Aviation Safety Goal. A new flight hour gathering method is needed so that accurate rotorcraft flight hours will be available annually starting in the year 2000. This new approach could be electronic and include flight hour data that can be available the year after the last year measured. This would allow tracking of progress and realignments of assets and priorities as needed to achieve the National Aviation Safety Goals in 2008.

8. The key to the success of safety intervention in existing helicopter fleets is the operators acceptance due to cost of implementation. This is especially critical on the lower cost aircraft, which have the largest contributions to accidents.

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LIGHT TWIN TURBINE HELICOPTERS AND 206 SINGLE TURBINE in USA

Data Sources: Accidents from National Transpotation Safety Board (NTSB)
Flight hours from Federal Aviation Administration (FAA)

Light twin-turbine helicopters closest in size to single-turbine 206 helicopter are grouped together

- A109
- AS355
- BO105
- BK117

Light twins flew 400,418 hours for latest period of 1991 through 1994.

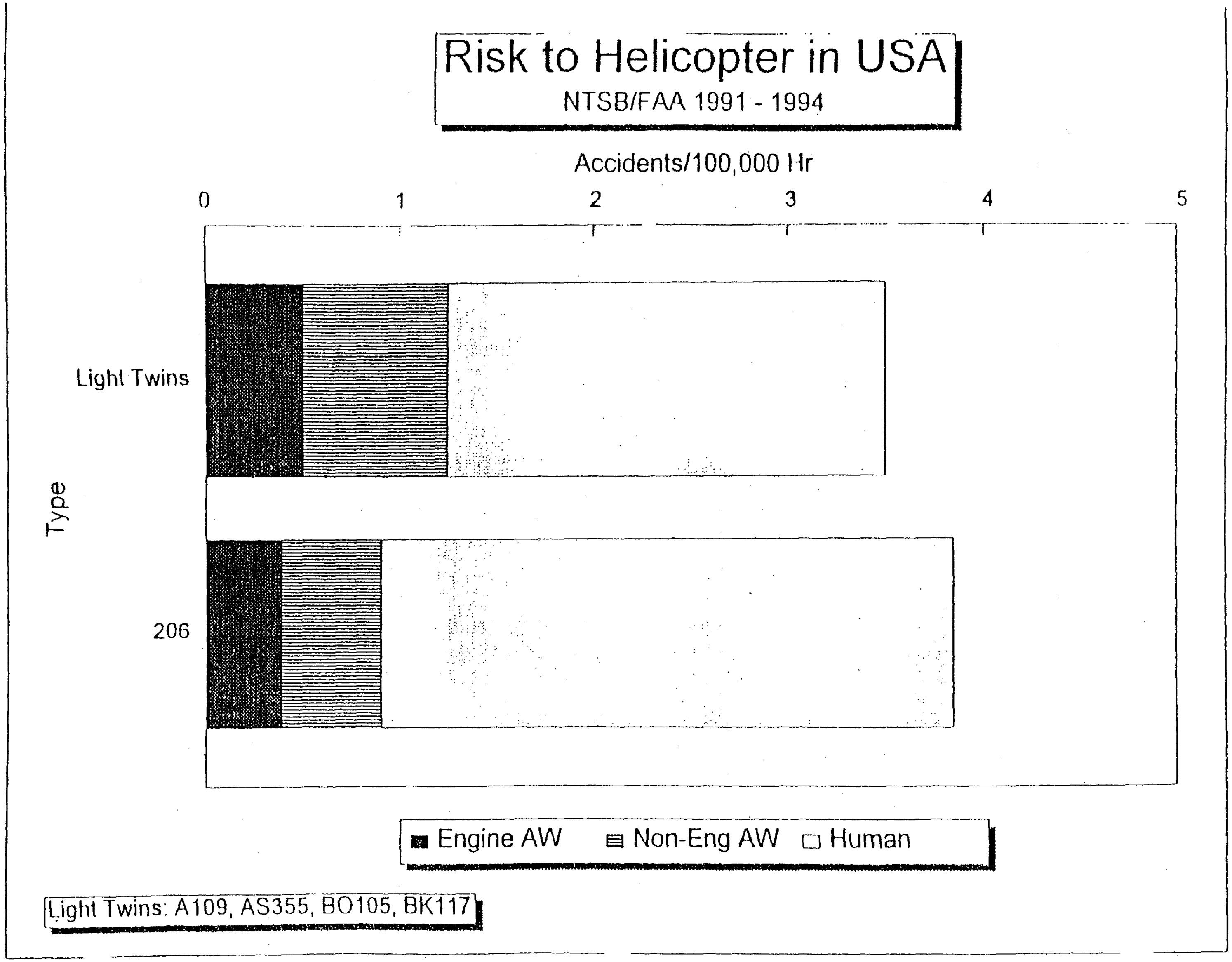
206 flew 2,308,990 hours for the same period of 1991 through 1994.

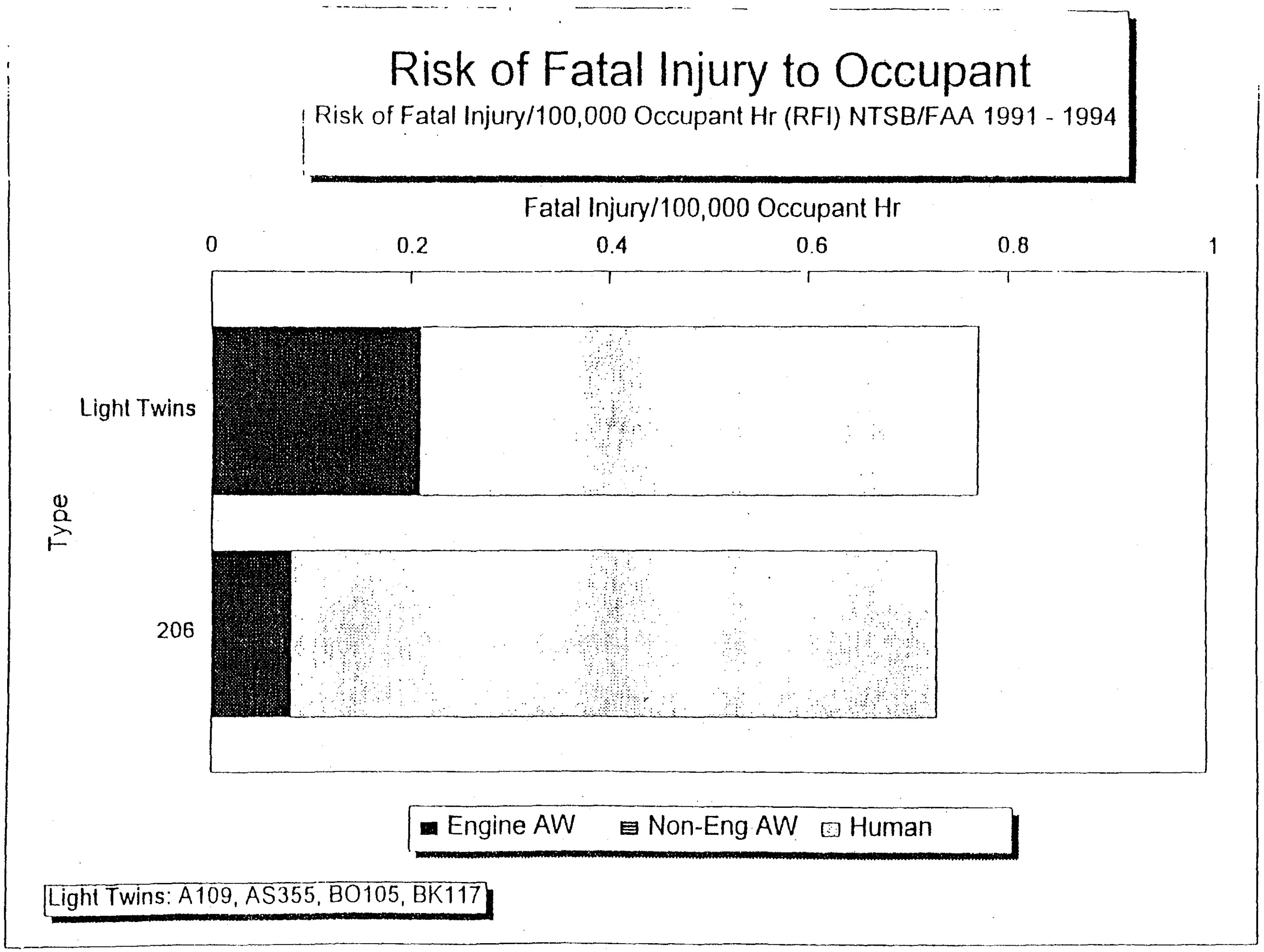
Both Single- and Twin- Turbine Helicopters ARE SAFE.

THE NUMBER OF ENGINES DOES NOT DETERMINE OVERALL SAFETY, RATHER IT IS THE HUMAN/OPERATIONAL ISSUES THAT DETERMINE YOUR RISK.

[R. Fox NTSBFOX.WK4]

Presented 21 February 1997 in AeroExpo 97 In Acapulco, Mexico

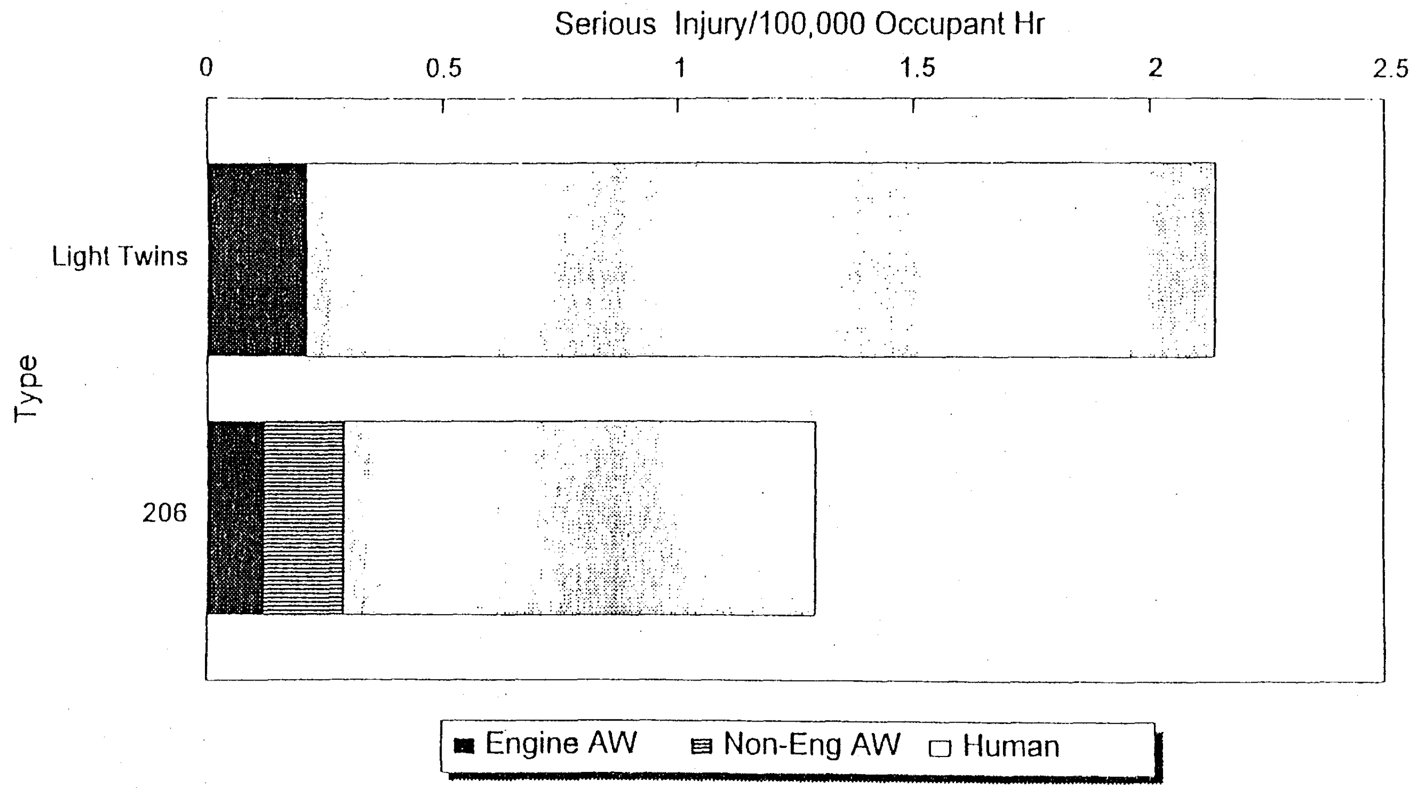

Risk to Helicopter in USA
NTSB/FAA 1991 - 1994
Accidents/100,000 Hr
0
1
2
3
4
5
Type
Light Twins
206
Engine AW
Non-Eng AW
Human
Light Twins: A109, AS355, BO105, BK117



Risk of Fatal Injury to Occupant
Risk of Fatal Injury/100,000 Occupant Hr (RFI) NTSB/FAA 1991 - 1994
Fatal Injury/100,000 Occupant Hr
0
0.2
0.4
0.6
0.8
1
Type
Light Twins
206
Engine AW
Non-Eng AW
Human
Light Twins: A109, AS355, BO105, BK117

Risk of Serious Injury to Occupant

Risk of Serious (Major or Fatal) Injury/100,000 Occupant Hr (RSI) NTSB/FAA 1991 - 1994



Light Twins: A109, AS355, BO105, BK117

Worldwide 206 Powerloss Study

21 October, 1996

Roy Fox representing: Bell Helicopter Textron, Inc. (BHTI)
and Aerospace Industry Associations (AIA)
and Helicopter Association International (HAI)

In support of the Performance Working Group (PWG), there have been several analyses of engine failure frequencies of the engine in the Model 206. There are data from different countries and different aircraft uses. The single-turbine powered Model 206 was used since it (1) has the largest number of a single model civil helicopter used in the world and (2) there are accident/incident/powerloss data available. Other single-turbine powered model helicopters would be expected to have similar results if data were available. This latest study is the summary of the previous pertinent analysis results and additional information.

1. Performance Classes

There is very limited mishap data on helicopters that are separated into Performance Class 1, 2, or 3. Most twin turbine helicopters are Performance Class 2 aircraft that can be operated as a Performance Class 1 under specific payload, altitude, temperature, and operating procedures. Each model has it's own limitations. Each manufacturer has developed specialized procedures (like using a 50 foot drop down) to optimize the helicopter performance so a direct comparison is not possible. Disregarding the additional performance gained by these special procedures, it is possible to estimate the reduced payload effect required to operate as Performance Class 1 by comparing the maximum aircraft weight allowed for a OEI HOGE (One Engine Inoperative and Hover Out of Ground Effect) at sea level on standard day from published data, to the aircraft maximum gross weight. The weight penalty to operate as Performance Class 1 is shown in Table 1. More severe conditions like higher altitude or temperature would increase the payload reduction required.

Table 1. Weight Penalty to Operate as Performance Class 1

MODEL	MAXIMUM TAKEOFF WEIGHT IN POUNDS (kg)	OEI HOGE WEIGHT IN POUNDS (kg)	PAYLOAD TO BE REMOVED TO OPERATE PERFORMANCE CLASS 1 IN POUNDS (kg)
212	11,200 (5,080)	8,700 (3,946)	2,500 (1,134)
S-76B	11,700 (5,307)	8,500 (3,856)	3,200 (1,451)
S-76C	11,700 (5,307)	6,700 (3,039)	5,000 (2,268)
412	11,900 (5,398)	8,230 (3,733)	3,670 (1,665)
Puma Mk 1	19,000 (8,618)	15,300 (6,940)	3,700 (1,678)
S-61N	20,000 (9,072)	16,000 (7,527)	6,400 (2,903)
Puma Mk 2	21,000 (9,525)	16,000 (7,527)	5,000 (2,268)

Due to the severe weight penalty and the increased cost of operation, most twin turbine helicopters in the world are operated as Performance Class 2. This severely affects the mishap data and precludes documenting exposure time by performance class. Therefore, the study cannot compare mishap histories of

Performance Class 1 versus 2 helicopters. However, we can look at Performance Class 3 single turbine helicopters as a baseline. Performance Class 2 should be better than that baseline in the area of engine powerlosses.

2. Approach

There were several approaches used to look at historical helicopter data to understand the powerloss history of single turbine helicopters. The initial approach was to look at accident frequencies per 100,000 flight hours for accidents initiated by an engine failure. This included helicopters operated in commercial and aerial work.

Shepard's "1995/1996 Civil Helicopter Handbook" provided a good estimate of civil helicopters on a worldwide basis excluding the helicopters of the former Soviet Union. There were a total of 21,596 helicopters with a breakdown of (1) Single Piston 37.4%, (2) Single Turbine 44.5%, and (3) Twin Turbine 18.1%. The single most common helicopter is the single-turbine powered Model 206 with a fleet of 4,768 aircraft which accounted for 35% of all turbine-powered helicopters and 49.6% of all single-turbine powered helicopters. Thus the Model 206 mishap history is the most representative of the single-turbine powered fleet and is the basis of these studies.

3. 206 Worldwide Safety History

The worldwide safety history of the 206 is shown in Table 2. These data include commercial and aerial work operations. Accident frequency are actually the risk of having a reportable accident of the aircraft. This is really the risk to the aircraft, not the risk to it's occupants. In the vast majority of helicopter accidents, no one is injured. Your individual risk of a fatal injury for a given exposure time (e.g. time in the air exposed to the potential of an accident) due to an engine failure can be calculated as:

Risk of Fatal Injury (RFI) =

$$\frac{\text{Number of Engine Failure Accidents}}{\text{Number of Aircraft Hours Flown}} \times \frac{\text{Number of Fatalities in Engine Failure Accidents}}{\text{Number of People Onboard Engine Failure Accidents}}$$

This RFI takes into account the number of people onboard as each one is being exposed at the same time. The resulting RFI is the risk of a fatal injury to an individual occupant per occupant hour of exposure. The RFI due to engine failure is also shown in Table 2.

From this table it is apparent that the engine-related safety in the last five years is better than in previous years. It is also apparent that the likelihood of a fatal injury is not the same as the likelihood of an engine caused accident. The occupant's RFI due to an engine failure is less than 1/10th of the risk of an engine failure caused accident. It is not correct to assume a fatality occurs if an engine fails.

4. U.S. Aviation Safety

An example of the different use of the same turbine helicopters is evident in the accident rates for all causes in Figure 1. The types with the lowest four accident rates are commercial operations with the safest being commercial air transport airplanes (Part 121). The turbine fleet (single and twin) in general use (commercial and aerial work) have an accident rate of 4.2/100,000 hr whereas the commercial operators in the Gulf of Mexico with the same turbine fleet (singles and twins) has an accident rate of 1.6/100,000 hr which is 62 percent lower. This shows the dramatic effect that commercial operators with special efforts can have on safety.

Table 2. 206 Worldwide Safety History

	10 years (1985 - 1994)	5 years (1991 - 1994)
Flight hours flown	19,335,741	7,925,894
Engine Airworthiness failure caused accidents/ 100,000 flight hours	0.86	0.49
Non-Engine Airworthiness failure caused accidents/100,000 flight hours	0.21	0.28
Total Airworthiness caused accidents/ 100,000 flight hours	1.07	0.77
RFI: Risk of Fatal Injury due to Engine Failure / 100,000 Occupant Hour of Exposure	0.08	0.05

5. Accident Rates Vary

There are many variables that cause the accident rate of the exact same model helicopter to be vastly different. Operational use of commercial versus aerial work is one major factor. A trend of variable factors have been noted in accident investigations. In each factor (column) of Table 3. there is a distribution ranging from the riskier to the safer end. The worldwide accident data presented thus far have been a combination of commercial and aerial work. The PWG is tasked to determine the risk of only commercial helicopters, not for the aerial work helicopters.

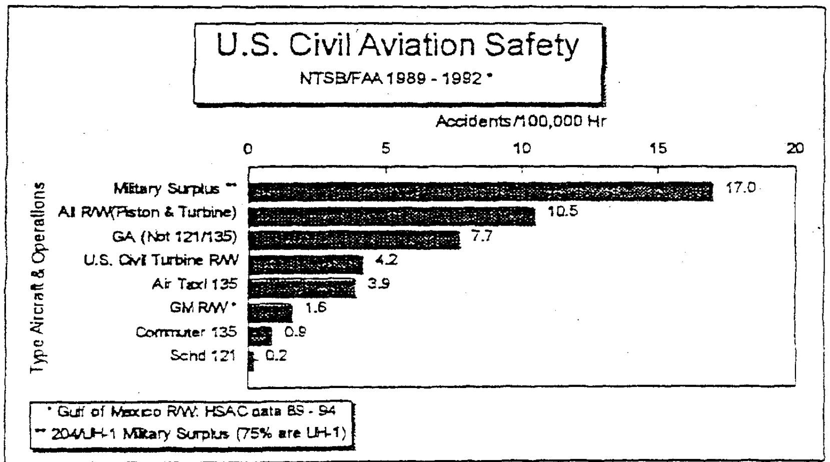


Figure 1. U.S. Aviation Safety versus Commercial Gulf of Mexico Helicopters

Table 3. Trends of Variability Affecting Safety

PILOT	MACHINE	ENVIRONMENT	MISSION	CRASH SURVIVAL
RISKIER	*RISKIER*	*RISKIER*	*RISKIER*	*RISKIER*
Private license, minimal control and experience	Aircraft misused and abused beyond design limits	Harsh landing surfaces (water, etc.) First time to land at remote spot in unknown conditions (on a mountain ridge)	Logging/external loads in remote sites, operating near gross weight, severe use.	Lap belt only use
Qualified, commercial FAA license	Unauthorized (Bogus) parts, salvaged, & multiple rebuilds	Low level flying, hitting obstacles, little emergency reaction time	Personal, Instructional, Agricultural spraying	Rugged cockpit & cabin, life vests, good emergency egress
Professional, self-induced standards	Strictly observe operating & maintenance procedures	FAA approved sites, sporadic use, VFR flights	Business, On - Demand Air Taxi, Corp/Exec.	Shoulder harness for each occupant (increase spinal tolerance by 6X)
Highly structured professionalism, CRM/ADM, simulators used	On-board monitoring systems to identify problems prior to failure, allows scheduled maintenance	Regimented IFR, scheduled use, same landing sites (airports/heliports) are used.	Scheduled Air Carriers	Energy attenuating seats where feasible to reduce spinal injury. Crash Resistant Fuel System to reduce thermal injuries.
SAFER	*SAFER*	*SAFER*	*SAFER*	*SAFER*

6. Model 206 Powerloss Histories

Accident/incident data on the Model 206 from several countries represented on the PWG were obtained and compared in Table 4. In addition, data was obtained from the two largest commercial 206 operators in the Gulf of Mexico. Their combined commercial 206 fleet included 237 aircraft flying 3.5 million hours offshore and making 25.6 million takeoffs and landings in the last 15 years. The question of what time period of powerloss data should be used was discussed in the PWG. The time periods were separated to allow a look at the latest time period which are more representative of future rates that the older rates. The question of were the newer rates statistically significantly different from the older rates. Table 4 also includes the statistical significant check that was done by using the "Student T" method. The question being answered was: Is the annual rates of the last period statistically different (e.g. lower) from the annual rates of the prior period? A significance level resulted, such as 95%, which means that you have determined that the rates of the two periods are statistically different 95 times out of a hundred. There is a significant difference in those rates. From Table 4, the later period rates are significantly different, except in the UK, and thus the later time period was used for further analyses.

There was concern among the PWG that we should consider even those engine powerlosses that did not result in an accident, the occurrence of abrupt engine powerlosses, and any powerloss for any reason (not necessarily an engine failure). This last condition is equivalent to powerloss modes that are used to allow extended time of operation to reach a suitable landing site with one engine inoperative (ETOPS) for two-engine commercial airplanes operating over water or other hostile terrain. JAR Information Leaflet No. 20 provides temporary guidance material on ETOPS. ETOPS modes include engine failure, fuel system failure, fuel contamination, flying beyond your fuel capacity, and engine shutdowns (desired and inadvertent). Basically, anything that causes a powerloss is counted as a ETOPS event. This also includes events while on the ground. The ETOPS frequency was determined in each of the sets of mishap data and is shown in Table 4.

7. ETOPS Powerloss For Short Time Exposures

From the previous analyses and sets of data, there is only one that is representative of commercial helicopter operations which is the 206 Gulf of Mexico operators. All of the other data, worldwide, included aerial work. Thus, the ETOPS powerloss frequency of 1.20/100,000 hours of the commercial 206 Gulf of Mexico operations can be used to determine the risk of a powerloss for shorter time periods. This is calculated in minutes of exposure as:

$$\text{Risk in (T) exposure minutes} = (1.20/100,000) \text{ X } (T/60).$$

The risk of a powerloss for any reason (engine, fuel system, maintenance, pilot, etc.) is shown in Figure 2 for different amounts of exposure. For general comparison, the commercial two-engine airplane ETOPS acceptable risk of 6/100,000 hr (e.g. 3 hours X .02/1000) in which a two-engine airplane can fly 3 hours on one engine to reach a safe landing site is added to the figure. This indicates that the risk of a powerloss for any reason in a commercially operated 206 offshore in the Gulf of Mexico for 30 minutes is equivalent to flying three hours on a commercial two-engine airplane flying on one engine to reach a safe landing site. Likewise, the 206 powerloss risk for 10 minutes is equivalent to 1 hour one-engine-inoperative flight in a commercial two-engine airplane. JAR OPS 3.480(a)(8) allows up to 10 minutes of operation over water which is consistent with a powerloss risk of 2/1,000,000 hours. In most locations in the world, it takes less than 30 minutes of helicopter flight to find a suitable and safe landing spot. Thus it is concluded that the risk of a powerloss for any reason in a commercial single turbine helicopter for short exposure times over hostile areas is acceptable for exposure times up to 30 minutes.

8. Risk Events

During the 1991 to 1995 time period, the commercial 206s in the Gulf of Mexico made 7,205,753 takeoffs and landings. This accounted for 3,602,876 flights. With one fatal accident due to a powerloss during that period, the probability of a fatal accident due to powerloss per flight is $2.8 \text{ X } 10^{-7}$. The exposure time of risk is considered to be the takeoff and landing times. There were an average of 3.6 takeoffs and 3.6 landings for each flight hour flown. If we consider both the takeoff and the landing as a Risk Event, there were 7.2 Risk Events per flight hour. The risks of the various levels of powerlosses can be expressed in Risk Events as shown in Table 5. The last two entries are interesting. During a million takeoffs, you could expect 1.7 powerlosses for all reasons.

Table 4. Powerloss Rates and Significance

Type of rate/100,000 hr	Early Period Average	Latest Period Average	Significant Difference? (Yes or No)	Significance Level (How sure that it is significantly different)
Gulf of Mexico 206 Commercial Operators (3,561,717 hours and 25.6 million takeoffs and landings)	81 - 90	91 - 95		
Accidents only	0.74	0.30	Yes	99%
Engine powerlosses	3.12	1.50	Yes	99%
Abrupt engine powerlosses	2.93	0.90	Yes	99%
ETOPS powerloss related	3.40	1.20	Yes	99%
U.S. 206 Commercial and Aerial Work Operators (11,587,947 hours)	82 - 89	90 - 93		
Engine powerlosses	1.06	0.25	Yes	99%
Abrupt engine powerlosses	0.94	0.25	Yes	99%
ETOPS powerloss related	1.53	0.59	Yes	98%
Allison Single 250 Series, (206 & All Other Models) Commercial and Aerial Work Operators (Worldwide 51,370,185 hours)	81 - 90	91 - 95		
Inherent to engine	0.68	0.18	Yes	95%
ETOPS powerloss related	1.39	0.63	Yes	95%
U.K. 206 (Bell & Agusta) Commercial and Aerial Work Operators (385,875 hours)	80 - 89	90 - 94		
Engine powerlosses	7.02	13.44	No	
Abrupt engine powerlosses	4.68	11.37	No.	
France 206 (Bell & Agusta) Commercial and Aerial Work Operators (111,221 hours)	82 - 95			
Engine powerlosses	9.0			
Abrupt engine powerlosses	6.3			

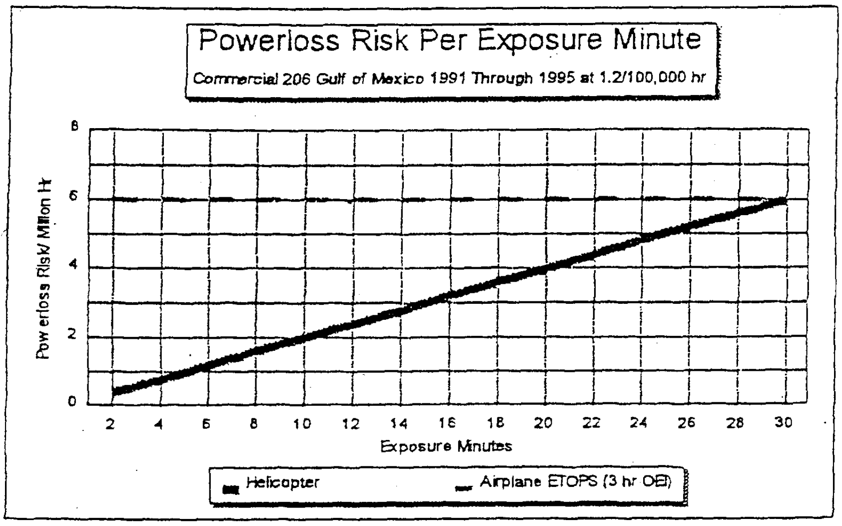


Figure 2. Commercial Helicopter Powerloss Risk Per Exposure Minute

9. Survivable Envelope

The PWG requested information to justify a "survivable" envelope following a powerloss when an autorotation may not be successful. Historically, engine failures are in everyone's mind but they are not the major initiator of accident injuries. A study of U.S. civil single- and twin-turbine powered helicopter accidents looked at initiating cause of accidents in which there were serious injuries (major and fatal) as shown in Table 7. The time period was 1982 to 1986 and includes commercial and aerial work operations. It is noteworthy that twin helicopters have fewer engine airworthiness caused injuries and much higher non-engine airworthiness caused injuries.

Frequency rates are more meaningful than raw percentages. A worldwide analysis was done on the 206 and Bell medium twin helicopter fleets for the last five years (1991 through 1995) to get an estimate of the powerloss effects on survivability. The 206 fleet flew 4,627,539 hours and the medium twins fleet (212/412/222/230/214ST) flew 1,878,748 hours. Figure 3 shows the occupant's Risk of Fatal Injury for each of the major cause factors. The RFI per 100,000 occupant hours for Engine Airworthness was 0.05 for 206 occupants and 0.00 for the twin occupants. However, the RFI per 100,000 occupant hours for Non-Engine Airworthness was 0.02 for 206 occupants and 0.07 for the twin occupants. The real threat to the occupants is not the airworthiness portion, but the non-airworthiness portion made of pilot, maintenance, operator management, passengers, etc. An occupant's RFI is lower in the single-engine 206 than he is in a twin-turbine helicopter. It must be remembered that both of these fleets are a mixture of commercial and aerial work. Specifically, the RFI in a 206 due to engine failure is 5×10^{-7} occupant hour which is a quite low.

Table 5. Powerlosses per Risk Events.

Exposure Time	ETOPS Powerloss Risk in Exposure Time	BCAR Probability	BCAR Severity of Effects
5 sec	1.67×10^{-8}	Extremely Remote	Hazardous
10 sec	3.33×10^{-8}	Extremely Remote	Hazardous
15 sec	5.00×10^{-8}	Extremely Remote	Hazardous
20 sec	6.67×10^{-8}	Extremely Remote	Hazardous
25 sec	8.33×10^{-8}	Extremely Remote	Hazardous
30 sec	1.00×10^{-7}	Very Remote	Major
35 sec	1.17×10^{-7}	Very Remote	Major
40 sec	1.33×10^{-7}	Very Remote	Major
45 sec	1.50×10^{-7}	Very Remote	Major
50 sec	1.67×10^{-7}	Very Remote	Major
55 sec	1.83×10^{-7}	Very Remote	Major
1 minute	2.00×10^{-7}	Very Remote	Major
2 minutes	4.00×10^{-7}	Very Remote	Major
4 minutes	8.00×10^{-7}	Very Remote	Major
5 minutes	1.00×10^{-6}	Very Remote	Major
6 minutes	1.20×10^{-6}	Remote	Major
8 minutes	1.60×10^{-6}	Remote	Major
10 minutes	2.00×10^{-6}	Remote	Major
12 minutes	2.40×10^{-6}	Remote	Major
14 minutes	2.80×10^{-6}	Remote	Major
16 minutes	3.20×10^{-6}	Remote	Major
18 minutes	3.60×10^{-6}	Remote	Major
20 minutes	4.00×10^{-6}	Remote	Major
22 minutes	4.40×10^{-6}	Remote	Major
24 minutes	4.80×10^{-6}	Remote	Major
26 minutes	5.20×10^{-6}	Remote	Major
28 minutes	5.60×10^{-6}	Remote	Major
30 minutes	6.00×10^{-6}	Remote	Major

Table 6. Powerlosses per Risk Events.

Type of Powerloss	Probability of powerloss per Risk Events
Powerloss Accidents	0.4 X 10^{-6}
Engine Powerloss Incidents	2.1 X 10^{-6}
Abrupt Powerloss Incidents	1.2 X 10^{-6}
ETOPS Powerloss Incidents	1.7 X 10^{-6}
ETOPS Powerloss Accident with a Fatality	0.14 X 10^{-6}

Table 7. Serious Injuries by Accident Initiator Factor

Known Accident Cause that Initiated the Accident	Percent of All Serious Injured Occupants in Single Turbine Helicopters due to Specific Accident Cause Factor	Percent of All Serious Injured Occupants in Twin Turbine Helicopters due to Specific Accident Cause Factor
Engine Airworthiness Failures	14.8 %	3.4 %
Non-Engine Airworthiness Failures (e.g. rest of the aircraft)	11.0 %	31.0 %
Pilot	61.0 %	62.2 %
Other Non Airworthiness Failures (Maintenance, passenger, heliport, etc.)	13.2 %	3.4 %

Of the total number of people onboard in 206 engine caused accidents, 92.9 % survived (fatal to only 7.1%). None of these accidents were successful autorotations to adequate landing sites as they would not have been reported as accidents. Of the total number of people onboard in all 206 accidents, only 1.3 % of them received fatal injuries due to an engine failure.

Figure 4 shows the vertical velocity component at impact of survivable U.S. civil helicopters. This study was done to understand the crash scenarios and to develop realistic crash survival regulatory requirements. The result of this study was the incorporation into in CFRs 27 and 29, the requirements for the dynamic seats tests the Crash Resistant Fuel System, and the installation and use of a shoulder harness at all seat locations. There are many variables that will determine the level at which the impact is so severe that it will likely be fatal If the aircraft attitude is level at impact, the landing gears will deform and absorb some energy. The minimum per the FAR is that the landing gear can take up to 10 ft/sec drop and the gear will be damaged but the rest of the aircraft will not. Depending on the model landing gear and the gross weight at the time, the crash loads experienced on the occupant are likely to be less than 3 Gs which are not injurious. This is without fuselage contact. On Figure 4, this equates to about 70 % of all survivable accidents. Once the fuselage contacts the terrain, predicting loads and survivability are more difficult. If the terrain allows some deceleration motion during impact (like soft plowed field, swamp, snow, and some local fuselage deformation occurs, it is estimated that the non-injury limit could go up to approximated 14 ft/sec which would equate to about 80 percent of survivable accidents. At impacts with higher vertical velocities, there will be serious injuries but not necessarily fatal.

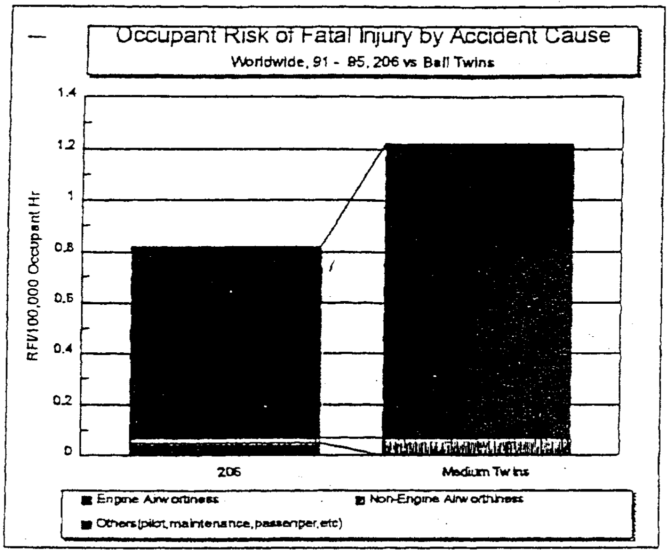


Figure 3. Occupant Risk of Fatal Injury

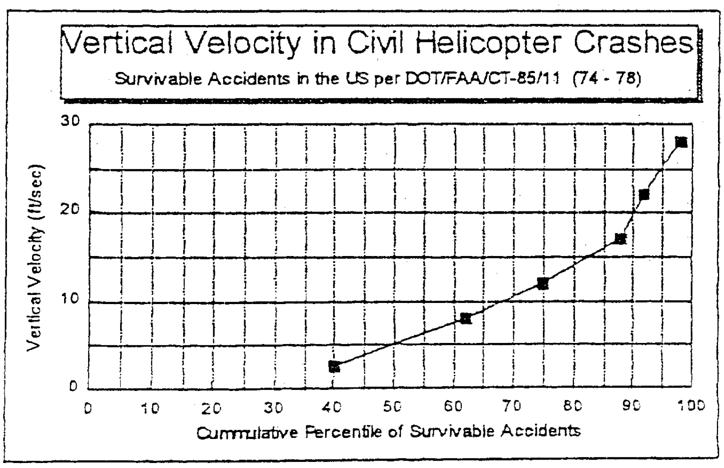


Figure 4. Vertical Velocity at Impact versus Percentage of Survivable Accidents

A misconception exist about the Height - Velocity (HV) Curve that in the pilot's manual. There is a fear that any operation inside the shaded "Avoid" zone means you may get a fatal injury. This is not true. The

HV curve is a set of autorotation initiation test conditions determined by the manufacturer's test pilots in which they could autorotate and land the helicopter. This means that the engine can be restarted or throttle rolled back up and takeoff for another flight. An unsuccessful autorotation could be limited to landing gear damage which is not a reportable accident. More damage will get it into an accident category and only then does the potential for injury arise. If the situation is positive on your side with items like a headwind, low temperature, at sea level, low aircraft weight, a quick response, and a few others, it could be possible for a successful autorotation without damage some places inside the "Avoid" zone. The key word is "Avoid" not "Flight is Prohibited". It should be remembered that the HV curve is to provide information that under certain situations, a pilot may not be able to get the aircraft down without doing damage to it. It serves it's purpose but it should not be part of a regulatory prohibition. Some lifesaving tasks will require that the helicopter be in the "Avoid" region for a short period of time.

10. Summary

1. There is wide variations in accident and incident rates aroumd the world. Most of the helicopter data are mixtures of commercial and aerial work. There are many variables at work which make the analysis of specific commercial operation safety very difficult. The commercial operation by the two largest 206 operators in the Gulf of Mexico (3.5 million hours and 25.6 million takeoffs and landings in 15 years) provide the best estimate of single-turbine powerloss potential when operated in a commercial environment similar to JARS OPS 3. The rate of the last five years of these Gulf of Mexico operations (1.2/100,000 hr) was used to determine powerloss risk for short exposure times.

2. The ETOPS concept of JAR Information Leaflet No. 20 was used to use the equivalent powerloss causes (i.e. anything or anyone that causes a powerloss even on the ground). The ETOPs powerloss frequency was determined for the Gulf of Mexico commercial operation and used to determine risk at short exposure times. This was then compared to commercial two-engine airplane ETOPS allowances (with appropriate procedures and monitoring equipment) to fly for three hours on a single engine to reach a safe landing site.

3. The risk of a powerloss for any reason in a commercial single-turbine helicopter (based on the 206 in the Gulf of Mexico) for 30 minutes is Remote (6.0×10^{-6}) which is equivalent to the acceptable risk of a commercial two-engine airplane while flying three hours with one-engine-inoperative to reach a suitable landing site.

4. Survivable envelopes were investigated. Considering all occupants onboard the 206 accidents of all causes, worldwide in 7.9 million hours, only 1.3 % received fatal injuries due to an engine failure. Civil helicopter crash impact study of vertical velocity at impact suggest that in over 70 % accidents, serious injury were not anticipated at the lower impact speeds.

5. The commercial 206 operations in the Gulf of Mexico had a probability of a fatal accident due to powerloss of 2.8×10^{-7} on a per flight basis. On a per takeoff basis, you could expect 1.7 powerlosses for all reasons during a million takeoffs.

6. Thus it is concluded that the risk of a powerloss for any reason in a commercial single turbine helicopter for short exposure times over hostile areas is acceptable for exposure times up to 30 minutes.

附件六

MEASURING RISK IN SINGLE- AND TWIN-ENGINE HELICOPTERS

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Reprint of article presented at the 2nd Asian Vertiflite Seminar, sponsored by the American Helicopter Society, Singapore, February 24, 1992

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附件六

MEASURING RISK IN SINGLE - AND TWIN - ENGINE HELICOPTERS

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ABSTRACT

Safety is the management of risk. Many decisions are made by businesses, government agencies and individuals using their perceptions of an aircraft's safety. Public perception of safety can deny the introduction or expansion of aviation in specific areas. Decisions to buy, use, repair, install improvements, insure, sell, and replace aircraft are all related to perceived safety. Likewise, governmental restrictions and rule-making are based on the perceived deterioration of safety, as in the proposed single-engine helicopter restrictions of ICAO Annex 6. Accurate aircraft safety measurements are thus essential to bring perceived and actual safety together. Such accuracy also provides realistic corrective actions for safety problems and evaluation of desirable and undesirable aspects of different aircraft configurations, as well as allowing individuals to determine their risk in flying in specific types of aircraft. Existing safety measuring methods are discussed, along with the advantages, disadvantages, and correctness of each method. Recent safety training and its effects are discussed, related to improved pilot judgment and significant reductions in accident rates--without any regulatory changes.

INTRODUCTION

Safety has always been a paramount concern in aviation. Safety is not an absolute; rather, it is a relative measure of the risk involved when flying in an aircraft. Several methods are used by publications that attempt to measure safety. Some of these methods are misleading and inaccurate, and create the perception of a low level of safety in helicopters. Misconceptions about helicopter safety can cause overly restrictive regulations and prohibit the use of safe aircraft. Thus, accurate measuring of helicopter safety is crucial to the helicopter operators and the flying public.

Presented at the 2nd Asian Vertiflite Seminar, sponsored by the American Helicopter Society, Singapore, 24 February 1992.

There is a continuing question of whether an occupant is safer in a single-engine helicopter or a twin-engine helicopter. Some proponents say that two engines must be better than one. Others say, "We have two engines in commercial fixed-wing airplanes; therefore, helicopters also need two engines." However, facts do not support application of "fixed-wing thinking" to helicopters. Helicopters have unique uses and designs and are operated in difficult environments. Thus, helicopters are different from fixed-wing airplanes. One must look at all causes of accidents and injuries, not just at components like engines or tail rotor blades. This paper addresses the safety issues for both single-engine and twin-engine helicopters.

Accident data from the United States of America (USA), the United Kingdom (UK), and Canada were analyzed to determine the risk to occupants of single- and twin-engine powered helicopters. These three nations (States) account for about 82% of all known (non-Soviet bloc) civil helicopters. Although the subject of this paper is rotary wing aircraft, the methodology is equally applicable to fixed-wing airplanes.

WHY MEASURE SAFETY?

Many important decisions made by businesses, government agencies, and individuals are based on the perceived safety of an aircraft. Decisions to buy, use, fix, improve, insure, and sell or replace an aircraft are related to perceived safety. Likewise, government operational prohibitions are based on the perceived deterioration of safety. For example, the recent Amendment 1 to International Civil Aviation Organization (ICAO) Annex 6, Part III (Ref. 1) establishes three categories of helicopter performance and recommends certain operational limitations. The categories are

Performance Class 1. Includes multiengine helicopters that are capable of continuing normal operations with one engine inoperative, regardless of when the engine fails.

Performance Class 2. Includes multiengine helicopters that are capable of continuing flight after one engine fails, except that a forced landing would be required following an engine failure between takeoff and a specific point and between a specific point and landing.

Performance Class 3. Refers to single-engine helicopter operations; a forced landing would be required after an engine failure.

Amendment 1 to ICAO Annex 6, Part III recommends prohibition of the use of Performance Class 3 single-engine helicopters for instrument flight rule (IFR) flights, night flying, flights out of sight of the earth's surface, flights with cloud ceilings of less than 600 feet or visibility less than 1,500 meters, and flights to elevated structures (heliport). ICAO itself does not regulate world standards; however, it recommends that individual member states adopt its criteria into their own regulations. The United States and many other countries have not adopted the recent recommendations of ICAO Amendment 1 to Annex 6, Part III.

Since single-engine helicopters account for three out of four helicopters in the world, adoption of this amendment would have a drastic effect on the helicopter community and on the public benefit derived from helicopter use. Some single-engine helicopter operations will no longer be performed, due to the higher costs involved, if twin-engine helicopters are mandated. Most multiengine helicopter operations are conducted in Performance Class 2. Since the accident data do not discriminate between performance classes, the safety comparisons of Performance Classes 2 and 3 from the available data is accomplished in this paper by looking at the differences between single-engine (Performance Class 3) and multiengine (Performance Class 2) operations. The performance class restrictions on helicopter operations in accordance with the ICAO Amendment 1 change includes the prohibition of single-engine helicopter operations involving transport of passengers, cargo, or mail for remuneration or hire, and general aviation uses. This prohibition is based on a perceived belief that twin-engine helicopters are always safer than single-engine helicopters in all environments. Thus, accurate helicopter safety measurements are critical to ensure that perceived safety and actual safety may be similar. Such accuracy also allows prioritized correction of safety problems and the evaluation of desirable and undesirable aspects of different aircraft configurations. This is of personal importance to an individual, allowing a person to determine his risk when flying in a specific type of aircraft.

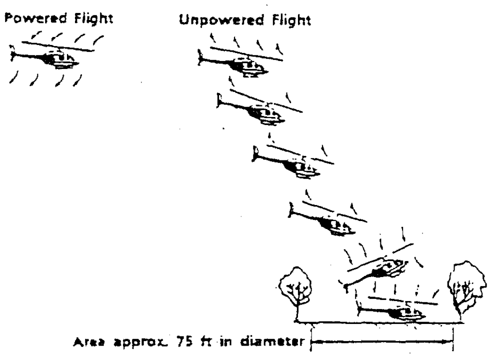
Why Worry about Safety?

Why do people worry about safety in the first place? The primary reason is that no one wants to get hurt or die. Since none of us wants to think about our own death or injury, we tend to tell ourselves "I am never going to be in an accident, therefore I won't have to worry about being injured or killed." The next step in this internal stress coping action is to assume that all that is needed to accomplish the goal is to prevent all accidents. This internal protection mechanism helps each of us go through all of the stresses of each day. Aviation accident prevention is based on this concept: "If I can prevent the emergency, I won't have to worry about my pain and my death." This human coping mechanism works well for the average individual; but management (aviation and regulatory) must go beyond to first determine the actual risk and subsequently manage the risk to an acceptable level. *Safety is the management of risk.*

HELICOPTERS AND AIRPLANES RESPOND DIFFERENTLY TO POWER LOSS

If a power loss occurs, the resulting emergency landings are significantly different for airplanes than for helicopters. To maintain control of an airplane, its airspeed must stay above wing stall speeds until ground contact. This means the airplane airspeed at ground contact will be typically 60 to 100 knots. This high speed requires a shallow approach angle and a long cleared landing site. Any obstructions (e.g., trees, buildings, fences, or ground irregularities) will be impacted with significant crash forces and resulting injuries.

Conversely, all helicopters have a safety feature capability to make an unpowered, controlled landing, called "autorotation." Figure 1 shows the airflow during this emergency procedure. The pilot controls the pitch of the main rotor blades at all times. In normal flight under power, the air is pulled through the main rotor disc and thrust downward, providing lift to hold the helicopter in the air and controlling the aircraft. In unpowered flight or an emergency descent, the pilot enters autorotation and changes the pitch on the main rotor blades to allow the air to come upward through the main rotor disc as the helicopter is descending. This airflow turns the main rotor blades like the wind turns a windmill. The pilot prevents overspeeding of the main rotor by converting some of this energy being gained to lift. Thus, the spinning main rotor acts like a parachute and a near-constant descent rate is maintained. The main rotor blade structure/weights store this rotational energy in a manner similar to a giant flywheel. Since the helicopter is fully under control, the aircraft can be maneuvered to the best landing site, allowing a steep approach into a confined area. Upon approaching the selected landing site, the pilot flares (aircraft nose is pitched up) to reduce the airspeed for a slow touchdown. The pilot then converts the stored rotational energy in the spinning main rotor back to lift and gently lands the helicopter. The typical autorotation rate of descent at touchdown is lower than a normal landing of a scheduled airline landing on the runway. The helicopter forward airspeed at touchdown will typically vary from 0 to 5 knots, so emergency landings can and have been achieved in very small spaces.



1-N109

Fig. 1. Helicopter autorotation.

Helicopters Have Different Missions and Uses

Using National Transportation Safety Board (NTSB) accident data for 1982 through 1985 for USA-registered helicopters, the type of mission underway at the time of accident was determined (Ref. 2). As shown in Table 1, single-piston, single-turbine, and twin-turbine helicopters are used in the same missions but in varying degrees. Single-piston helicopters have a concentration in relatively high risk areas of flight training, personal use, and agricultural work, where relative low cost is a driving factor. These types of usage are major contributors to the safety record for single-piston helicopters. If twin-turbine helicopters performed similar missions and were operated like the single-piston helicopters, the twin-turbine helicopter accident rate would rise significantly.

Table 1. Helicopter missions at accident NTSB data 1982 - 1985 (% of accidents)

Type of Operations	Single Piston	Single Turbine	Twin Turbine	All Helicopters
Personal	26.2	24.4	16.0	24.9
Business	9.4	23.6	32.0	14.9
Instruction	21.3	2.0	8.0	14.4
Executive/ corporate	0	5.6	16.0	2.4
Agricultural	29.8	8.8	4.0	21.9
Observation/ survey	5.1	5.2	0	5.0
Public use	1.1	4.0	8.0	2.3
Ferry/ Positioning	2.3	4.8	16.0	3.6
Other work	4.8	21.6	0	10.6

Helicopter Fleet Is a Mixed Fleet

The U. S. FAA Civil Aircraft Registry for August 1990 shows the following distribution of helicopters (Table 2). The 34 military surplus twin-piston helicopters on the Registry were not included. However, the numbers of aircraft on the Registry can be misleading, because it includes many aircraft that are wrecked, being salvaged for parts, under repair, stored, or used as static (nonflying) aircraft. Thus flight hours are a better indicator of actual aircraft usage. Flight hours by model series were extracted from the U. S. Federal Aviation Administration (FAA) General Aviation Activities and Avionic Survey annual reports for the same time period. If the FAA estimated flight hours for a model for two or more years of the 5-year period, those flight hours were used. The accidents of that model series were used if flight hours occurred in the year of the accident. If no hours or one year of flight hours were estimated by the FAA reports, the accidents and flights hours for those affected models were deleted from the study. The author considers this data to be the best available and therefore has used it in this

Table 2. USA-registered helicopters by engine type (FAA data)

Type of Engine	Number of Helicopters (11-31-90 Registry)	Flight-hours flown 1984 – 1988	Flight-hours (%)
Single piston	5,371	2,961,252	25.9
Single turbine	3,642	7,035,846	61.5
Twin turbine	1,108	1,442,116	12.6
Total helicopters	10,121	11,439,214	100
Aircraft with most flight-hours: 206 single turbine only	2,092	5,215,001	45.6

paper. The usable models with flight hours were then arranged in groups: single-piston, single-turbine, and twin-turbine helicopters, and the most common helicopter, the Model 206. The Model 206 flew 45% of all helicopter flight hours during the 1984 through 1988 time period. The Model 206 is the most prominent model and is used as a standard by which other helicopters are typically compared. The single-turbine engine Model 206 will be shown by itself as well as being in the generic single-turbine fleet throughout this paper.

The Canadian, UK, and USA helicopter fleet flight-hours shown in Table 3 indicate that these helicopter fleets are also varied. The Canadian accident and flight hour data from the Transportation Safety Board of Canada and Canadian Aviation Statistics Centre were for the period 1982 through 1987. The United Kingdom accident data and flight hours from the Civil Aviation Agency were for the period 1980 through 1987. The mixture of the UK fleet flying is significantly different from that in Canada and the USA. This helps to explain why attitudes and helicopter usages vary among ICAO States. The most common helicopter flying in the UK was the S-61 twin turbine, which accounted for 28.2% of the UK flight-hours whereas the Model 206 made up 12.3%.

Disregarding home-built and experimental helicopters, it is estimated that of approximately 15,200 rotorcraft in the world (excluding the Soviet bloc states) that 12,511, or 82%, of these rotorcraft are in the USA, the UK, and Canada. Thus the conclusions from these data should be applicable to the remaining helicopters in the non-Soviet-bloc world. The helicopter data are presented by configuration groups of single piston (SP), single turbine (ST), and twin turbine (TT).

MEASURING SAFETY

Now that we have some indication of the helicopter activities, the next step is to measure safety or determine relative risk. There are various methods used; some are useful and others are misleading. Using the total number of accidents that have

Table 3. USA, UK, and Canada civil helicopters by engine type (flight-hours flown)

Engine Type	USA (84 - 88)	UK (80 - 87)	Canada (82 - 87)	USA /UK / Canada Combined	%
Single piston	2,961,252	91,737	190,894	3,243,883	21.3
Single turbine	7,035,846	239,548	2,078,376	9,353,770	61.5
Twin turbine	1,442,116	932,474	242,696	2,617,286	17.2
Total helicopters	11,439,214	1,263,759	2,511,966	15,214,939	100
Most common aircraft: 206 single turbine	5,215,001	155,648	1,471,675	6,842,324	45.0

occurred for a model is probably the most misleading method. This primitive method does not account for fleet size and subsequent usage/exposure over the years and should be avoided. Accident-per-amount-of-exposure methods are more appropriate.

Accidents per Fleet Ratio

One attempt to address the effects of fleet size is to determine the ratio of accidents to the size of fleet in existence at the time of comparison. This approach is only slightly better than counting accidents. The ratio is determined by counting the number of accidents that have occurred on a specific model in the USA since its introduction. The total accident history number is then divided by the latest "estimated" number of active helicopters of that model in the USA. The ratio technique is inaccurate and misleading because it (1) disregards the changing fleet size over the years, by only using the latest year's "active" fleet, (2) looks at models in different periods of their service life, and (3) disregards the different amount of flying done by various models. Also, the number of accidents will increase as a model fleet continues in use. In Figure 2, the Model 47, which is the oldest civil helicopter model, suggests what may happen to all other models as they mature in the future. The number of accidents from 1958 through 1963 were estimated from accident trends before and after that period. Since the number of "active" helicopters are seldom known, the actual numbers of civil aircraft delivered with a U.S. Registry number were used. Note that the last Model 47 was delivered in 1973 in the USA. The total number of accidents grows each year and far exceeds the number of aircraft delivered. Obviously, the ratio of total accidents to an existing fleet is going to be different depending on when that ratio is calculated. If the

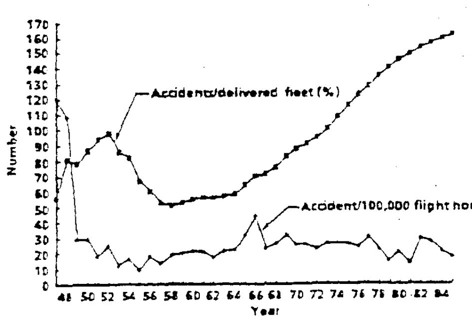


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Fig. 2. Model 47 accident/fleet ratio.

ratio is determined within two years of model introduction, the ratio will probably be low. Five, ten, fifteen years later, the ratio continues to increase regardless of the true model safety. Also shown in Figure 2 is the annual accident rate per 100,000 flight hours. Note that the accident ratio continues to climb to about 160% as of 1985 even though the accident rate is basically decreasing over the last three years. This disparity will be present for all other models and is dependent on when in the model's life cycle the ratio is computed.

Accidents per Departure

When comparing vastly different types of aircraft, it was apparent that some types spent the majority of their flight time in the more hazardous flight phases of takeoffs and landings. Thus the accident rate per departure (or mission) was used. This approach answers the question "Is the likelihood of this mission failing greater or lesser for Means A vs. Means B?" but is not concerned with how long Means A or Means B takes to accomplish the mission. For example, if the mission is to get a person from Point X to Point Y, the following means of travel can qualify for the task:

- -Rocket
- -Jet airplane
- -Helicopter
- -Train
- -Automobile
- -Boat
- -Balloon
- -Walking.

The number of accidents that occurred from the time of departing Point X and arriving at Point Y would then be determined for each means of travel. When divided by the number of missions attempted, this becomes the accident rate per departure.

Helicopters can perform some missions which no other transportation means can achieve. These unique missions, involving hovering or very slow flight, cause very short flight times, and result in a large number of takeoffs and landings. Since large airplanes spend the vast majority of their flight time in cruise rather than in takeoff/landings, comparisons with helicopters are somewhat biased. A study in 1981 included a look at Part 135 unscheduled air-taxi helicopter safety related to airplane air carriers (Ref. 3). The helicopter operators surveyed flew 603 single- and twin-turbine helicopters during the subject period (1977 through 1979). The percentage of singles vs. twins is no longer available; however, the percentage of single turbines vs. twin turbines is available for 1983, which is the nearest period. The 1983 U.S. Registry indicates a mix of 83% single turbines and 17% twin turbines. The mix in the helicopter survey group should have been similar. The accident rate per flight hour for the combined turbine helicopter fleet compared to the air carriers is shown in Figure 3A. This shows that the helicopter accident rate per flight hour was slightly better than that of commuter (regional) air carriers. To account for time spent in the more hazardous phases of flight (i.e., takeoff and approach/landing), the accident frequency is based on number of departures (i.e., takeoffs). The helicopter accident rate per 100,000 departures was 73% lower than commuter air carriers, as shown in Figure 3B. The helicopter rate was much closer to the rate for the large certificated air carriers. Figure 3C, fatal accident

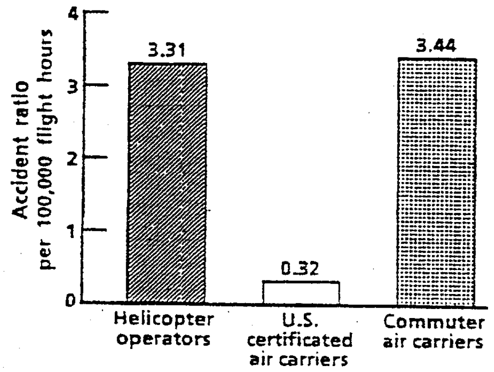

Fig 3A. Accident rate per flight hour (all causes).

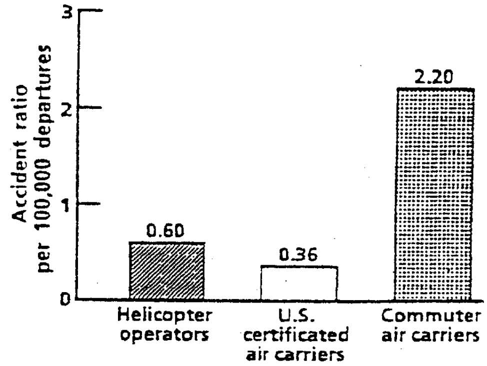

Fig 3B. Accident rate per departure (all causes).

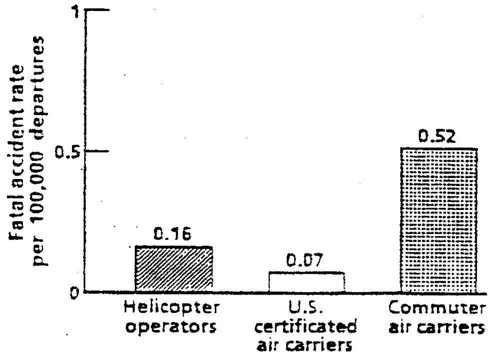

Fig 3C. Fatal accident rate per departure (all causes).

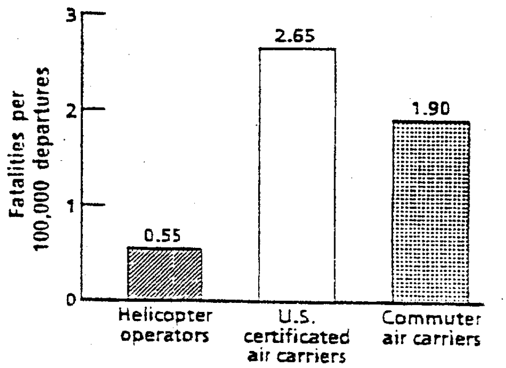

Fig 3D. Number of fatalities per departure (all causes).

* Part 135 helicopter operators survey.

** National Transportation Safety Board, Special Study, *Commuter Airline Safety* (Reference 4).

1-N11)

Fig. 3. Accident and fatality rate comparison (1977 - 1979).

rate per departure, shows that the helicopter rate was 69% lower than the commuter air carriers. Figure 3D shows comparable data for fatalities per departure. In this case, the helicopter rate is 71% lower than commuter air carriers and 79% lower than certificated air carriers. The helicopter industry in general is safer than perceived by those outside of this industry, considering the amount of time spent in hazardous phases of flight. This also indicates the variability of potential safety perceptions, depending on the method of measurement.

The offshore oil industry in the Gulf of Mexico gives a good indication of the safe operation of turbine helicopters (Table 4). In 1990, there were 1,855,345 takeoffs and landings. About 1,500,000 of these takeoffs and landings were at offshore platforms. There were 3,958,525 passengers moved by helicopter. Of the 619 helicopters in the Gulf of Mexico, 138 (22%) are IFR equipped. Single-turbine helicopters account for 349 (56%) of the total helicopter fleet. This significant usage of single-turbine helicopters indicates that single turbines are being operated safely from elevated platforms and over water.

This method based on departure exposure is accurate for determining the risk to mission accomplishment, but is not accurate for determining safety. Safety is related to "freedom from harm, injury, or loss and should be counted in terms of time of individual occupant exposure.

Accidents per Patient Transport

This recent safety measurement variation is used by the emergency medical services (EMS) community. This accident rate is the number of EMS aircraft accidents that occur divided by the number of patients transported during the same time period. This unique approach uses the EMS primary function of "moving patients" as the basis for comparison with the safety of other modes of "moving patients." This approach is appropriate for only that medical transport mission comparison of mission completion, not safety of the crew and patient. Figure 4 (from Ref. 5) shows the annual EMS helicopter accident rates per 100,000 patients transported. It cannot be used to compare with "non-patient-carrying" aircraft. Since many of the EMS helicopter accidents occurred without a patient onboard (e.g., en route to pickup, returning after transport, or repositioning), this is a mission-oriented measurement (similar to "per departure"), rather than "per human" exposure.

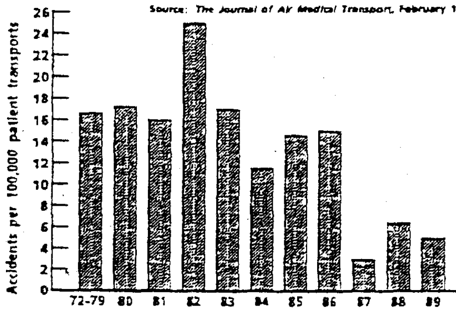

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Fig. 4. EMS accidents per patient transport operation.

Accidents per Passenger Mile

Accidents per passenger mile is another "per mission" measurement, with an adjustment for the distance traveled. Fixed-wing scheduled air carriers and fixed- and rotary-wing air taxi operators have

Table 4. Gulf of Mexico helicopter safety data

Year	Fleet Size	No. of Accidents	Flight-hours	Departures	Accidents per 100,000 Departures	Accidents per 100,000 Flight-hours
1987	708	17	691,655	2,101,850	0.80	2.46
1988	599	10	455,330	1,384,000	0.65	2.20
1989	608	9	515,770	1,885,571	0.48	1.74
1990	619	9	533,761	1,855,345	0.49	1.69

passenger-carried information from revenue flights; but General Aviation and helicopters, in general, do not. Thus comparisons are seldom made in this area. Limitations of "per mission" measurement are easily noted by comparing the safety of an 80-knot aircraft with a 400-knot aircraft, both having the same number of passengers and accidents per passenger mile. Some people try to interpret this as the same level of occupant safety. However, the slower machine is in the air five times as long as the faster aircraft for the same distance. Therefore, the slower aircraft must have only one fifth of the accident rate per flight hour of the faster aircraft. This dichotomy is due to the primary concern being "per mission" and not related to "per human"or occupant safety. Accident per passenger mile is only meaningful if your primary concern is mission completion of moving a passenger a given distance, not the safety of the occupants.

Accidents per Flight-hours

The most common method presently used is "accident rate per 100,000 flight hours." This accident rate per hour is the number of accidents of a model for a specific period of time divided by the hours flown by those aircraft over the same time period. This accident rate per 100,000 flight hours is an good method to determine the aircraft damage cost expected in a model fleet or the likelihood of aircraft damage. Table 5 shows the accident rates per 100,000 flight hours for USA General Aviation fixed-wing and rotary-wing aircraft in descending order.

Helicopter accident rates for the 1980s from the USA, the UK, and Canada for the time periods of Table 3 are shown in Table 6.

AIRWORTHINESS VS. OPERATIONAL ISSUES

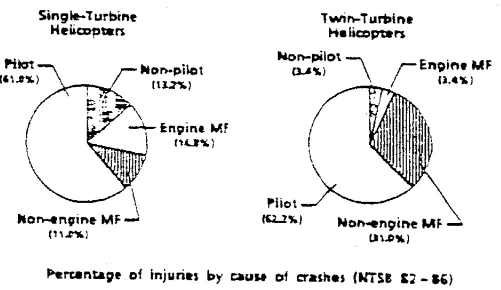
The causes of accidents resulting in serious (major/fatal) occupant injury were determined (Ref. 6) using NTSB data from 1982 through 1986 for single-turbine and twin-turbine civil helicopters, as shown in Figure 5. Engine material failure (MF) initiated the crashes that caused 14.8% of the serious injuries to occupants of single-turbine helicopters, as compared to only 3.4% for the serious injuries to occupants of twin-turbine helicopter accidents. If you stop here with only this one piece of information, the obvious conclusion is that two is better than one. However, consider only material failures other-

Table 5. USA-registered general aviation accident rates (NTSB/FAA data 1984 - 1988)

Type of Aircraft	Accidents per 100,000 flight-hours
Single-piston helicopter	17.83
Single-piston airplane	8.55
Single-turbine helicopter (all)	5.49
Twin-piston airplane	5.12
Twin-turbine helicopter	4.37
Bell Model 206 single-turbine helicopter	4.28

Table 6. 1980s USA, UK, and Canadian accident rates (all causes) (accidents per 100,000 flight-hours)

Type of helicopter	Canada (82 - 87)	United Kingdom (80 - 87)	United States of America (84 - 88)
Single piston	33.53	73.79	17.83
Single turbine (all)	9.86	17.12	5.49
Twin turbine	4.67	4.83	4.37
Model 206 single turbine	8.70	14.07	4.28



1-N113
Fig. 5. Seriously injured occupants by accident cause.

than-engine or non-engine MF. Only 11.0% of the seriously injured occupants were in single-turbine helicopter crashes initiated by non-engine material failures as compared with 31.0% in twin-turbine helicopter crashes. This is an indicator of the detrimental effects of complexity and more parts. If you were to consider only this last piece of information, the obvious approach should be to ban all twin-turbine helicopters and only use single-turbine helicopters. Actually, the total material failures, engine and non-engine, should be considered together, which yields percentages of seriously injured occupants due to all types of MF-caused accidents of 25.8% for occupants in single turbines and 34.4% for occupants in twins. This is consistent with the greater number of parts and increased complexity present in twins. Since deaths or injuries do not only occur as a result of engine-related factors, it is essential that all other factors be considered as well, both material failure and nonmaterial failure (i.e., human error). The accident rates for the combined U.S. helicopter fleet (all helicopters) and the individual types are shown in Table 7.

Engine material failures are just one of the material failures (also called airworthiness failures) that cause accidents; the remaining non-engine material failures that caused accidents are also shown in Table 7. The single-piston accident rate per 100,000 flight-hours for non-engine material failure accidents is the highest rate, followed by twin turbines, all single turbines, and (with the lowest rate) the Model 206 single turbine. Table 7 shows the combined engine and non-engine material failures (e.g., all airworthiness failures), and indicates that the accident rate for all airworthiness failures in twin turbines is significantly lower than for single pistons, and slightly lower than for all single turbines, but still 51.4% higher than the single-turbine 206 rate. From an overall airworthiness standpoint, there is no justification to require twin-turbine engines on *ALL* helicopters for *ALL* mission applications.

Statistical Significance

Individual yearly airworthiness failure accident rates will vary from year to year due to the random natures of rare events like accidents, as shown for turbine helicopters in Table 8. The statistical significance of the single- and twin-turbine helicopter accident rates was used to determine if the rates for all their accidents due to airworthiness failures were significantly different or not. The statistical method used for this determination, "Student T," utilized a level of significance of 0.05. This technique can determine the likelihood that the two sets of data (i.e., accident rates of singles vs. twins) will be from the same group (i.e., not of significant difference), with the observed rate varying only due to chance. A level of significance of 0.05 indicates that

Table 7. USA-registered helicopter accident rates (Sources: NTSB/FAA for 1984 through 1988) (Accidents per 100,000 flight-hours)

Type of Helicopter	Engine-only Airworthiness	Non-engine Airworthiness	All Airworthiness	All Causes
All helicopters	1.22	1.08	2.30	8.54
Single piston	1.99	2.09	4.09	17.83
Twin turbine	0.35	1.25	1.59	4.37
Single turbine (all)	1.08	0.61	1.69	5.49
206 single turbine	0.88	0.17	1.05	4.28

Table 8. USA turbine helicopter fleet airworthiness-failure annual accident rates (NTSB/FAA data for 1984–88) (Accidents per 100,000 flight-hours)

Type of Helicopter	1984	1985	1986	1987	1988	Average (84 – 88)
Single-turbine helicopter (all)	1.65	1.95	2.04	1.59	1.30	1.69
Twin-turbine helicopter	1.76	0.95	2.14	1.92	0.98	1.59
Bell Model206 single-turbine helicopter	0.95	1.46	1.21	0.79	0.92	1.05

the statement being made will be wrong no more than 5 times out of 100. In other words, the statement being made will be correct 95 times out of 100. *The airworthiness-failure accident rates of singles and twins are not significantly different 95 times out of 100.*

Comparing the all-airworthiness-failure accident rates of the three ICAO States (the USA., the UK, and Canada) are Table 9 and Figure 6, which show the variability that is a function of the mix of aircraft models within a type and how they are used in the different ICAO States. The rates of twin turbines and Model 206s appear to be quite consistent. It is interesting to note that the single-turbine Model 206 has the lowest airworthiness accident rate in two of the three ICAO States and second lowest in the remaining State. *These data do not justify the ICAO Annex 6, Amendment 1 prohibition of single-engine helicopters.*

Table 9. 1980s USA, UK, and Canadian airworthiness-failure accident rates (Accidents per 100,000 flight-hours)

Type	Canada (82 - 87)	United Kingdom (80 - 87)	United States of America (84 - 88)
Single piston	8.91	18.45	4.09
Single turbine (all)	2.12	4.17	1.69
Twin turbine	1.27	1.93	1.59
Bell 206 single turbine	1.43	1.17	1.05

Time-Exposed Comparisons

Accidents are quite rare events. A trip around the world at the equator would take about 192.3 hours for a turbine helicopter flown at an average cruise speed of 130 miles per hour (113 kn) Thus, a comparison of the mean-time-between-accidents (MTBA) can be expressed in an exposure-time equivalent of around-the-world trips. The MTBA is the number of hours flown by an aircraft type divided by the number of accidents (e.g., the inverse of the accident rate).

The around-the-world trip equivalent for the Model 206 and twin-turbine helicopters shows the

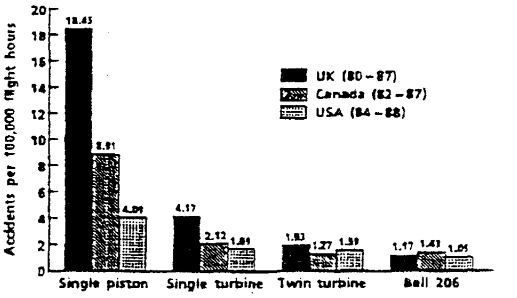


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Fig. 6. Airworthiness failure accident rates for UK, USA, and Canada in the 1980's.

remoteness of accidents from all airworthiness failures (both engine and non-engine). Using the data from Table 7, the MTBA for the Model 206 and a twin-turbine helicopter can be derived as 95,283 hours and 62,893 hours, respectively. Thus, on the average, the expectancy of an accident due to airworthiness failure was equivalent to 495 trips and 327 trips for the Model 206 and for twin-turbine aircraft, respectively. Likewise, the number of years for one aircraft to fly those around-the-world trips, without landing (i.e., continuous 24-hr/day flying) would be about 10.9 years and 7.2 years for the Model 206 and a twin-turbine helicopter, respectively. The chance of an accident, for both types, is extremely remote. *There is no safety justification for prohibiting single-engine or twin-engine helicopters from flying over congested areas or hostile-earth surfaces.*

Accident Site Surface

A failure of the engine does not automatically mean that an accident will occur. The type of terrain can influence whether the results of autorotation will be merely a forced landing or an accident with damage. If the engine fails over terrain hospitable to an emergency landing, such as prepared hard surfaces, unprepared ground, soil, fields, open terrain, or helipads, then autorotation is possible without further damage, and no accident occurs. If the helicopter is equipped with an aircraft flotation system, an emergency landing can be made on water. Such a water landing is not considered an accident unless significant aircraft damage or an injury occurs; with significant damage or injury, it is considered an accident. If the terrain is inhospitable (e.g., covered with trees, swamps, or walls), the emergency landing may result in an accident.

The known impact surfaces for all U.S. civil helicopter-accidents from 1984 through 1988 are shown in Table 10. Accidents from all causes are included. Unknown site surfaces, inflight breakups, midair collisions, and unknown types of ground surfaces, accounting for about 28% of the accidents, were deleted as nonusable. The surface category "Trees/swamp/wall" includes terrain where a successful emergency landing without damage is not likely after a power loss or any other immediately required emergency landing. This was the surface for 10.5%, 10.7%, and 8.8% of the impacts for twin turbines, single turbines, and the Model 206, respectively. Thus, the accident history for impacts into trees (inhospitable sites) has not been different for twin-turbine than for single-turbine helicopters. Care should be taken in reading Table 10, as the exposure over these surfaces has not been the same for each type of aircraft. The value of many helicopter jobs over inhospitable terrain cannot justify the use of an expensive helicopter, and therefore a small, less expensive helicopter is often used. The table is indicative of how aircraft are being used, rather than pointing out relative danger of impact sites. For example, the twin-turbine helicopter had 33.3% of its known-site accidents in the "Prepared surface/pad" category, which is the least dangerous impact site. Overall, the table shows that basically all types of impact sites have occurred with all types of helicopters.

Table 10. Known accident impact sites

Type of Impact Surface	Model 206 Single Turbine (%)	All Single Turbines (%)	Twin Turbines (%)
Clearing/ brush/burm	6.4	5.4	0
Rough ground/ rocks	11.1	10.7	0
Ground/soil/ unprepared	23.4	31.9	12.3
Prepared surface/pad	19.3	17.1	33.3
Trees/swamp/ wall	8.8	10.7	10.5
Buildings	1.2	1.0	3.5
Auto/boat/ railroad	0.6	0.6	3.5
Snow/ice	2.9	3.7	1.8
Water	24.0	17.4	29.8
Rig	2.3	1.3	5.3

Fatal Accidents per Flight-hours

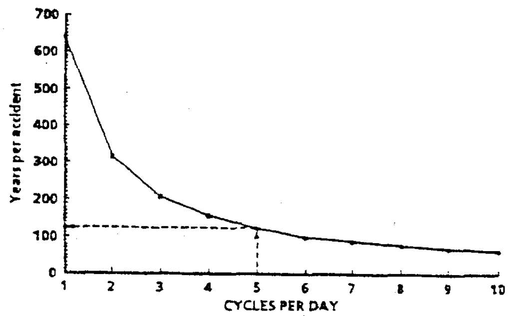
Safety is typically defined as a condition of freedom from harm, injury, or loss. Thus, measurement of those accidents involving fatal injuries is relevant to the relationship of safety to human suffering. A fatal accident is an accident in which at least one person is fatally injured. A fatal accident rate is the number of fatal accidents per 100,000 flight hours. Table 11 shows the fatal accident rate for the three types of helicopters in the USA. These aircraft types have about the same fatal accident rate. This method is still inaccurate, as it does not account for the number of people onboard that had the chance of being fatally injured. For example, for a twenty-place helicopter with ten people onboard, there is five times the chance of someone being killed as for a five-place helicopter with two people onboard. This is due to the difference in ten people impacting the ground in one airframe vs. two people in the other airframe. Obviously, the number of helicopter seats is not important; but the number of people onboard is important. Thus, fatal accident rates are misleading when they are related to aircraft airframe accidents, not to the occupants. Fatal accident rates should not be used to measure safety.

Table 11. USA helicopter fatal accident rates (NTSB/FAA 1984 - 1988)

Type of Helicopter	Fatal accidents per 100,000 flight-hours
Single piston	1.89
Twin turbine	1.10
Single turbine	1.08

Risk around Heliports

Some neighbors around heliports have voiced concern about safety of helicopters approaching or leaving a heliport. These concerns are unfounded. The actual risk to the neighborhood from helicopters was analyzed (Ref. 7) to determine the likelihood of a helicopter accident in a 0.8-km (1/2-mile) radius of the heliport/airport using NTSB/FAA data for the period of 1975 through 1978. This analysis was based on the Model 206 accident rate of 4.33/100,000 flight-hours. A 3-minute time period spent over the 0.8-km (1/2-mile) radius for an approach or landing was used to be conservative. One can then calculate the likelihood of an accident within the 0.8-km (1/2-mile) radius which becomes a function of how many takeoffs and landings are made. The term "cycle" is used for the combination of a takeoff and landing (e.g., 6 minutes over the 0.8-km [1/2-mile] zone). Using the average number of cycles per day for a year, the average number of years between accidents can be determined using Figure 7. For example, for a busy heliport conducting 5 cycles per day (182.6 hours per year over the 0.8-km [1/2-mile] zone), the expected average of years between accidents should be 128 years. One accident in 128 years is an extremely remote possibility.



1-N115

Fig. 7. Helicopter accidents within 0.8 km (1/2 mile).

Likewise, the likelihood of a helicopter striking a residence or building within a 0.8-km (1/2-mile) radius of a heliport can be estimated using Figure 8. The accident frequency used was for all helicopter accidents (i.e., single piston, single turbine, and twin turbine) involved in striking a residence or building. For the 5-cycle-per-day case, a helicopter striking a building/residence is estimated, on average, once every 4,000 years. This is extremely remote. Figure 9 shows the likelihood of an on-the-ground person (i.e., not a crewman or passenger) being injured within this 0.8-km (1/2-mile) radius. For the 5-cycle-per-day case, this shows that the average number of years between injuries to be about 5,000 years. This is likewise extremely remote.

The heliport operating at 5 cycles per day over a one-year period is an extremely busy heliport. For a

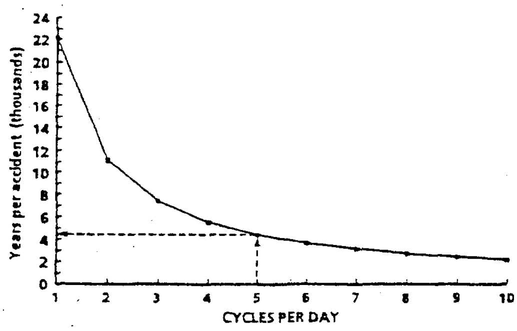


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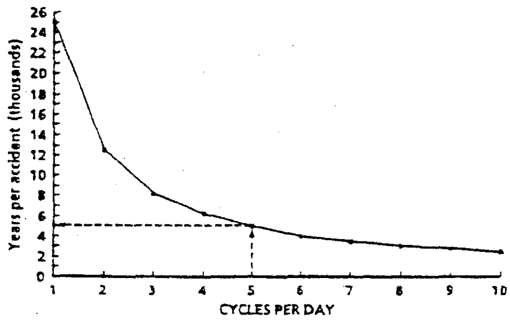
Fig. 8. Helicopter strikes residence or building (within 0.8-km radius).



1-N117

Fig. 9. On-the-ground personal injury (within 0.8-km radius).

private heliport or limited use that averages less than 1 cycle per day over each year period, the risk is significantly lower. Using 1 cycle per day average, the likelihood of an accident in the 0.8-km (1/2-mile) area, the likelihood of striking a residence/building, and the likelihood of an on-the-ground person being injured are once in 635 years, 22,400 years, and 25,000 years, respectively. These average year values in themselves are not important but their magnitudes indicate the extremely remote threat due to helicopters operating over a congested area.

If only airworthiness-failures-caused accidents are considered using the Model 206 and twin-turbine helicopter rates of Table 7, a comparison of the likelihood of an airworthiness-caused accident over the neighborhood can be made. For a constant usage of 5 cycles per day, the expected accident frequency within the 0.8-km (1/2-mile) radius of the heliport is an accident once in 34.4 and 52.2 years for a twin-turbine helicopter and Model 206 single-turbine helicopter, respectively. Thus one should expect the Model 206 accident significantly less often than the twin-turbine helicopter accident. The likelihood for both helicopter types is extremely remote. *There is no more justification to prohibit twin-turbine helicopters than there is to prohibit a Model 206 from flying over congested (e.g., populated) areas.*

Causes of Accidents Resulting in Fatalities

A study of Bell civil and military turbine-powered helicopter accidents around the world was conducted to determine the accident causes that resulted in fatalities. The period of time was January 1970 through March 1987. The size of the Bell turbine fleet delivered at the time was approximately 19,700 single-turbine aircraft and 1,800 twin-turbine aircraft. An engine failure was the initiating cause that resulted in 6% of all fatalities in single-turbine helicopter accidents and 3% of all fatalities in twin-turbine helicopter accidents as shown in Figure 10. However, the percentage of fatalities due to remaining airworthiness failures (non-engine material failures) was 12% and 22% for single-turbine and twin-turbine helicopters, respectively. Thus the total percentage of fatalities for all airworthiness failures was 18% for single-turbine helicopters and 25% for twin-turbine helicopters. It is apparent that more complex twin-turbine helicopters will have a higher total number of material failures (engine and non-engine) with a corresponding higher total number of fatal injuries than a simpler single-turbine helicopter.

OCCUPANT RISK

Relative Risk of Serious Injury

Accident rates compare the frequency of aircraft being damaged to such an extent that it must be reported as an accident. In the majority of accidents, there is no serious injury, so the accident reporting is basically an aircraft damage mishap frequency. This information is useful in forecasting the number of aircraft expected to be damaged, repaired, replaced, or other activities based on aircraft damage. It does not address the safety of the occupant. A person's safety is a personal issue, applied on an individual basis, not an aircraft basis. Risk must be limited to an individual occupant to be meaningful. Occupant safety must be determined for each individual occupant based on his individual exposure.

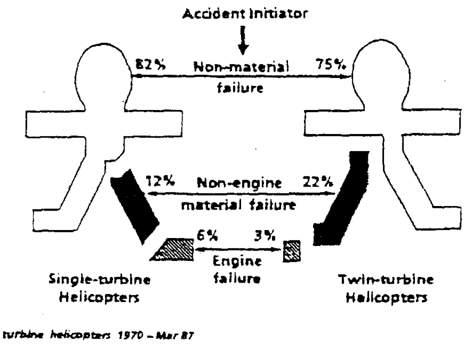


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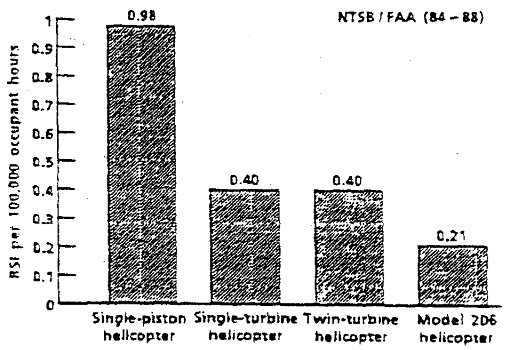
Fig. 10. Percentage of fatalities by accident initiator.

This is done with Relative Risk of Serious Injury (RSI). RSI is the probability of an accident occurring times the probability of serious (e.g., major or fatal) injury. The RSI is calculated by

$$RSI = \frac{\text{Number of accidents}}{\text{Flight-hours flown}} \times \frac{\text{Number of people with major or fatal injury}}{\text{Total number of people on board in accidents}}$$

The RSI or an individual occupant risk of serious injury for every 100,000 occupant-hours of exposure is shown in Figure 11 for all airworthiness-failure causes. This is the true measure of occupant safety related to the aircraft design.



1-N119

Fig. 11. RSI from airworthiness failures.

Thus an occupant's risk of a serious injury due to accidents caused by all airworthiness failures is the same in the generic single-turbine and the twin-turbine helicopters. An occupant's risk in a Model

206 single-turbine helicopter is nearly half that of being in a twin-turbine helicopter. *Based on the risk to helicopter occupants, there is no justification to prohibit the use of single-turbine helicopters.* The reasons that risks are generally higher in twins than singles are

1. More parts and increased complexity yield more non-engine material failures, causing accidents.
2. There are more freestanding passenger seats and resulting seat failures in twins.
3. There are more passenger seats without shoulder harnesses.
4. More fuel cells leads to increased likelihood of post-crash fires.

The introduction of passenger shoulder harnesses, energy-attenuating seats for all occupants, and the Crash Resistant Fuel Systems may lower the RSI. FAA Amendments* will require shoulder harness and dynamically tested energy-attenuating seats for all occupants in future helicopter designs. A shoulder harness is required for all seat locations in all helicopters manufactured in the USA or for use in the USA after September 16, 1992.** FAA Notice of Proposed Rule Making (NPRM) 90-24 in progress is addressing a requirement to include a Crash Resistant Fuel System in large and small helicopters to minimize thermal injuries due to post crash fires. Thus occupants of future helicopter designs may have even lower risk of serious injury, regardless of what causes the accidents.

A study (Ref. 8) of U.S. Army helicopter accidents and injuries found similar results to the risk in civil helicopters. Table 12 shows the RSI for the four Army helicopters in the study. The UH-60 is the twin-turbine helicopter and the remainder are single-turbine powered. The risk of injury was lower in the single-turbine helicopters than in the twin turbine. There are several reasons for this; two of these are the greater complexity of the UH-60 and its higher impact speeds. Again, one must be careful to evaluate all aspects of an aviation system since improvements in one area can have detrimental effects in another area. One of safety's goals is to strive for the best mix to get the lowest risk.

*FAA Amendments 27-25 and 29-29 of November 13, 1989.
**FAA Amendments 21-69, 27-28, 29-32, and 91-223.

Table 12. Relative risk of serious injury (RSI) in Army helicopters (Class A & B)

Type of Helicopter	RSI / 100,000 occupant hours
UH-60	5.11
AH-1	4.13
OH-58	2.91
UH-1	1.36

Safety Is Risk Management

To manage your risk, you must first understand your total risk. Prudent risk management will reduce both probabilities in the RSI formula (probability of an accident times probability of a serious injury) and achieve the lowest possible risk. Accident prevention programs attempt to reduce the probability of an accident. Training, standardization, equipment, maintenance, and positive management attitude toward safety are key factors in reducing the probability of an accident occurring. This important effort must continue. Pre-accident planning, flight following, aircraft/occupant survival gear and training, and aircraft crashworthiness features address the reduction of the probability of serious injury. This important effort must also continue. To believe that you can prevent all accidents is analogous to a baseball team made up of only a pitcher and a catcher. The other baseball team members will not be needed, because the pitcher will always strike out the batter. Totally effective accident prevention is a worthwhile goal, but realistically, it is doubtful that it will ever happen. The aviation community must work to reduce both probabilities.

UNIQUE SAFETY ENVIRONMENTS

Australian CAA Study of Single vs. Twin Helicopter Transfer of Marine Pilots

The Australian Civil Aviation Authority (CAA) conducted a study (Ref. 9) in September 1989 to respond to a recommendation to mandate twin-engine helicopters be used rather than single-engine helicopters for marine pilot transfers. A marine pilot is a special ship pilot that boards the ship and brings that ship into a harbor. He likewise will pilot a ship out of a harbor to open sea after which he is returned to land. A single-engine helicopter is used for this transfer to and from the ship. A recommendation had been made to mandate the use of only twin-turbine helicopters. The study looked at accident data from around the world. Applicable paragraphs from the study findings and conclusions are quoted below:

> "The CAA believes that greater weight should be given to actual accident performance figures (where these are available) than to theoretical assumptions about fatal accident rates derived from, say, engine shutdown. For example, it would fail to account for the trade-off between the extra reliability from having a second engine and the lower reliability of the more complex helicopter system. . . ."
>
> "Informal advice from the industry suggest that it would approximately double the cost of transferring marine pilots by helicopter if twin-engine helicopters were made compulsory. . . .
>
> "This report does not pursue costing further because of the lack of conclusive evidence of twin-engined helicopters leading to lower fatal accident rates. . . .
>
> "Marine Authorities have indicated that in some cases the higher cost of twin-engined helicopters could lead to them reverting to launches to transfer pilots, which these authorities have stated is less safe than transfer by helicopter. . . .
>
> "CONCLUSION
>
> "The CAA believes the proposal to regulate to make it compulsory to use twin-engined helicopters for the transfer of marine pilots to and from ships should be shelved at this time. The CAA concludes that the proposal should be shelved because the present very low engine-failure accident rate is acceptable, and because there is no conclusive evidence that using twins would result in a lower fatal accident rate."

This Australian study is a good example of the importance of analyzing accident data for factual information considering all aspects.

Helicopter Accidents at Elevated Structures

The accident histories of turbine-powered helicopters at elevated structural platforms were compared to determine if the ICAO Annex 6 prohibition of single-engine helicopter operation from elevated structures was justified. The USA accidents from NTSB for 1984 through 1988 were used. There were no distinctions made between type of operations being conducted such as air transport vs. aerial work. Since the vast majority of helicopter uses are for hire or remuneration in some aspect, it is not possible to use the ICAO definitions. Many helicopter operations in the USA are not clearly within the ICAO definitions and also can change categories of work several times in a day. For example, a helicopter used for emergency medical services (EMS) can fall in the operational categories of business, unscheduled air taxi, and other work. If the owner is a government/ municipality entity or the civil operators contract with a government agency for helicopter services, the same helicopter can also be considered to be in the category of "public use." The accident data should be considered in its entirety to be consistent with flight hours.

Each NTSB helicopter accident narrative for the latest available data (1984 through 1988) was used to determine all accidents that occurred on an elevated landing site or approaching/departing the elevated structure. A key word search was used for the following words in the NTSB accident narratives. These key words were

Elevated	Helipad	Net
Structure	Helideck	Rail
Platform	Heliport	Pad
Rig	Hospital	Raised
Roof	Building	Deck

The resulting accidents were then separated into movable landing structures or stationary landing structures. Accidents at movable landing structures of landing dollies, trailers, trucks, boats, barges, and portable landing structures were eliminated as not being applicable to the safety history of helicopters operating on an elevated structure. The stationary elevated structure accidents are those that were at rooftops or offshore platforms. There were no single-piston helicopter accidents related to stationary elevated platform structures, but some were on movable landing structures.

There were fifteen single-turbine helicopter accidents—at stationary elevated platform structures. Twelve were at offshore platforms and three at a rooftop. Of the fifteen accidents, there were four power losses reported. There were no material failures found during the investigation of two of these power losses. The remaining eleven clearly resulted from human causes as follows:

- Takeoff with aircraft tied down
- Landing gear caught on safety net
- Landing gear caught on deck obstruction
- Main rotor blade strike
- Blown off platform during engine start by wind
- Elevator cover not removed prior to flight

There were thirteen twin-turbine helicopter accidents at elevated platform structures. Nine were at offshore platforms and four were at rooftops. Of the nine offshore platform accidents, two were due to material failures of tail rotor drive shafts and one pylon mounting failure allowing ground resonance. The remaining seven offshore platform accidents were human caused as follows:

- Tail or tail rotor strike
- Main rotor strike
- Flight controls restricted (maintenance error)
- Takeoff with wheel in safety net
- Flight control loss

Of the four rooftop accidents, two were power losses due to fuel exhaustion. A tail rotor strike and a flight controls restricted (loose object in cockpit) made up the two remaining accident causes. Two of these twin-turbine helicopter accidents on stationary elevated structures were deleted prior to the accident rate calculation as no FAA flight-hours were available for the year of the accidents. These accidents were two twin-turbine SA-330J helicopters which were included above to show the types of accidents (i.e., 13 accidents) but are deleted in Table 13 when accident rates are used (i.e., 11 accidents). All single-turbine accidents (which were Model 206s) on stationary elevated structures were usable accidents.

Table 13 shows the USA elevated structure helicopter accident history for 1984 through 1988. This table also identifies the stationary elevated structure accidents that were related to power losses. For all accidents at elevated structures, the accident rates for the single-turbine and twin-turbine helicopters were 0.21 and 0.76 per 100,000 flight-hours, respectively. Thus the single-turbine rate was 72.4% lower than the rate for twin-turbine helicopters. Considering only those related to power losses, the single-turbine and twin-turbine helicopter accident rates were 0.071 and 0.139 per 100,000 flight-hours, respectively. The single-turbine rate for power loss accidents was 48.9% lower than the twin-turbine

Table 13. USA elevated structure turbine helicopter accident history (1984-1988)

Type of Aircraft	Fleet Flight-hours	All Accidents	All Causes Rate*	Power-Loss Accidents	Power-Loss Accident Rate*
Single	7,035,846	15	0.21	5	0.071
Twin	1,442,116	11	0.76	2	0.139
Using hours of aircraft models involved in accidents:					
Single					
206	5,215,001	15	0.29	5	0.096
Twin					
222 AS355 B0105 S58T S76	932,438	11	1.18	2	0.214

*Accidents per 100,000 flight-hours

rate. The second part of Table 10 is similar, except the fleet flight-hours used were for only the models that were involved in elevated structure accidents. In this analysis, the single-turbine and twin-turbine accident rates for all causes were 0.29 and 1.18 per 100,000 flight-hours, respectively. The single-turbine rate was 75.4% lower than the twin-turbine rate. Considering the power loss accidents, the single-turbine and twin-turbine accident rates are 0.096 and 0.214 per 100,000 flight hours, respectively. The single-turbine rate for power-loss accidents was 55.1% lower than the twin-turbine rate. Thus, the actual helicopter accident experience related to helicopter operations at a stationary elevated structure does not justify the prohibition of single-engine helicopters.

Offshore Helicopter Operator Experience

Petroleum Helicopters, Incorporated (PHI) is the largest commercial helicopter operator in the world. Most of their flying is offshore oil support and as such provides an excellent example of safe helicopter operations in a difficult environment. The latest PHI-furnished flight-hour information and NTSB accident data on PHI helicopters from 1984 through 1988 indicate that single-turbine helicopters can be and are operated safely over water and onto elevated platforms. PHI flight hours in Table 14 show that 66.1% of their flying was in single-turbine helicopters. Table 15 compares the PHI accident rates for all causes with the U.S. civil helicopter fleet rates for all causes. PHI accident rate for single-turbine helicopters was 65.8% and 62.2% lower than the general U.S. single-turbine and twin-turbine helicopter rates, respectively. This shows that a safe operation can be and is being conducted using single-turbine helicopters without severe operational regulations like the recent ICAO Annex 6, Amendment 1 change.

Table 14. Petroleum Helicopter, Inc (PHI) flight-hours (1984 through 1988)

Type of Aircraft	Flight-hours	Percentage of Total
Single turbine	1,064,439	66.1%
Twin turbine	545,670	33.9%
Total	1,610,117	100%
206 only	982,611	61.0%

Table 15. PHI vs. USA helicopter accident rates (Accidents from NTSB, Hours from FAA and PHI, 84 - 88)

Type of Aircraft	US (NTSB/FAA)	PHI (NTSB/PHI)
Single turbine	5.49	1.88
Twin turbine	4.37	1.65
206 only	4.28	1.73

*Accidents per 100,000 flight-hours

Time of Accident, Day vs. Night

Since the actual flight hours flown at different times of the 24-hour day are not know, it is difficult to determine relative safety of night flight vs. daylight flight. However, it is possible to approximate the distribution of flying at night by considering the random nature of material failures. For the period of 1982 through 1988, the USA distribution of accidents (all causes) by the time of day from NTSB data is shown in Figure 12. The breakpoints between light and dark were assumed to be 0600 and 1959 hours. This distribution of accidents should be conservative, as most flying is done during the summer months when the length of daylight is highest. This indicates that 91.8% and 82.8% of all single-turbine and twin-turbine helicopter accidents, respectively, occurred during daylight hours. Figure 13 shows the time of accident distribution of airworthiness-failure accidents (all material failures including the engine). For all airworthiness-failure accidents, 98.2% and 94.1% of single-turbine and twin-turbine helicopter accidents, respectively, are occurring in daylight hours. The two figures have similar distribution; thus accidents due to material failures do not appear to be adversely affected by lighting, and

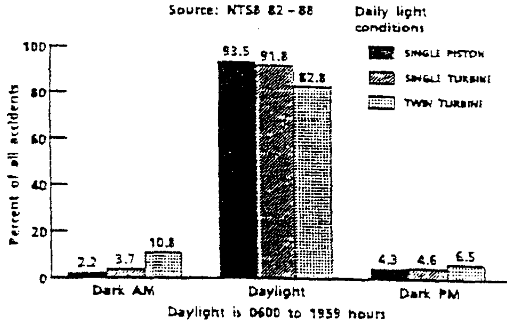


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Fig. 12. Time of accidents due to all causes.

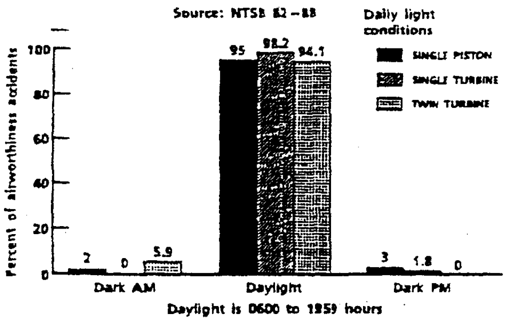

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Fig. 13. Time of accidents due to airworthiness failures.

therefore, there is no rationale to prohibit single-engine helicopters from flying at night.

The big difference in helicopter and fixed-wing aircraft emergency landings is that the fixed-wing aircraft requirement for a long cleared landing site increases the likelihood of injury during the final phase of the emergency. Conversely, a helicopter (regardless of the number of engines) can use a landing site that is quite small in comparison to the fixed-wing aircraft needs. Likewise, visibility at night is not as critical in a helicopter as in a fixed-wing airplane due to the helicopter's lower speed and greater maneuverability during autorotation.

Likelihood of Material Failure Accident at Night

Assuming a Model 206 and a twin-turbine helicopter flew 10 hours of darkness every night throughout one full year, each helicopter would fly 3,652.5 hours each year. Using the NTSB/FAA accident data for 1984 through 1988 (Table 7), the likelihood of an accident due to a material failure (which includes engine) for the twin-turbine helicopter is estimated at once in 17.2 years whereas the 206 likelihood is estimated at once in 26.1 years. Both of these likelihoods are extremely remote. Thus the likelihood of any material-failure-caused accident is 51.4% higher in a twin-turbine helicopter than in the single-turbine Model 206. Again, there is no rationale that supports the prohibition of night flights of single-engine helicopters.

BELL'S SAFETY TRAINING APPROACH

Accident data analyses can be used to determine if safety programs or other factors are making a change in the accident frequencies. Two out of three accidents are not caused by airworthiness failure but are basically due to human error. This is not a "pilot" problem, but a human problem (i.e., the problem is not merely related to the process of piloting, but to the larger problem of human limitations). Accidents caused by human error (generally called pilot error) are an extremely complex problem with a large number of root causes and an even larger number of potential solutions. Engineers and regulatory agencies are comfortable working on physical parts as their performance and failure modes are fairly predictable. Thus aviation safety efforts in the past have made significant gains in minimizing airworthiness failures. More attention is now being made toward understanding and eventual reduction of human error accidents. An engineering study in 1985 and 1986 into worldwide human error accidents of Bell civil helicopter models found that poor judgment was the common factor in all of these accidents (Ref. 2). Two directions of concentrated effort at Bell were launched in 1987 to aggressively attack the complex human error problem, with the emphasis on Judgment Training.

Individual Judgment Training Aid

Human Factors Engineering's approach was to develop an artificial-intelligence based software which would allow a pilot to use a personal computer (PC) as a judgment (decision-making) simulator. This is roughly a decision-making simulator equivalent of the present-day six-axis motion simulators that allow the pilot to test his motor skills without endangering his aircraft or his life. This program, called Cockpit Emergency Procedures Expert Trainer (CEPET), also includes emergency procedures training. A CEPET was developed for the Bell JetRanger (206BIII) and LongRanger (206L-3), with one for the 212/412 completed late in 1990. The CEPET is a long-term effort where an individual pilot can use the CEPET software and a PC to improve his safe decision-making skills. A CEPET package is provided with each new aircraft delivery starting in 1991. Pilots can also purchase a separate CEPET package.

Group Safety Training

The other direction was concentrated safety education. System Safety Engineering developed a 3-hour safety briefing for immediate use with groups of pilots/managers. This safety briefing presented by the Chief Safety Engineer includes how to measure one's risk, what happens in a crash, how one can improve his chances of survival, causes of accidents, root causes of human error, and Judgment Training. Judgment Training emphasizes the use of all resources available to the pilot and is something of a single-pilot version of the Cockpit Resource Management (CRM) used in crew-served airplanes. Judgment Training emphasis is on situational awareness and internal pilot monitoring rather than crew interactions of CRM. Judgment Training is also called Pilot Decision Making (PDM) and Aeronautical Decision Making (ADM). Portions of the FAA study, DOT/FAA/PM-86/45, Aeronautical Decision Making for Helicopter Pilots (Ref. 10) are used in this safety briefing and the FAA report is given to the student for further self study. This safety brief is given at operator's and regional safety seminars and is included in Bell's weekly 206 pilot's ground school as part of the Helicopter Professional Pilots Safety (HELIPROPS) program.

Bell's Chief Training Pilot also conducts customer HELIPROPS safety briefings on safety awareness, professionalism, and management's role in safety. These safety briefings are held at Bell, customer sites, and regional safety seminars. In 1988, Bell's Customer Support and Service Department (CSSD) initiated the HELIPROPS program to add continuity and coordination of these safety education efforts. A HELIPROPS Administrator was assigned full time for coordination and to also conduct customer site and regional safety seminars. The HELIPROPS effort was spread to the other helicopter manufacturers with three companies trained in the techniques that were working for Bell. These companies then started their own safety training version of HELIPROPS.

The worldwide effects of this 4-year safety education effort on the human error accident rate since the Model 206 effort was fielded in 1987 is shown in Table 16. There have been over 5,000 Model 206 series helicopters produced or 70% of Bell's entire civil turbine helicopter model fleet. Bell also conducts pilot flight training in Model 206s. Based on these two factors, the concentrated safety education effort has been directed at Model 206 pilots. For comparison, the same worldwide data for Bell's medium civil helicopters models (i.e., 204B, 205A1, 214B, 212, 214ST, 222, and 412) are also shown in Table 16. These medium helicopter data indicate some reductions in human error causes but were offset with non-human-error causes; thus the accident rate for all causes was basically the same over the two 4-year periods. Conversely, accident rates due to human error in a 206 for the 4-year period before the initiation of this safety effort (1983-1986) and the four-year period since (1987-1990), show a 36.2% reduction. This is a significant safety improvement since we have covered only a portion of all Model 206 pilots in the world thus far. The overall (all causes) Model 206 accident rate is now reduced by 26.3%. Since many pilots fly helicopters in addition to the Bell Model 206, we can expect some spillover of the

Table 16. Worldwide Bell turbine accident rates (Rates per 100,000 flight-hours)

		Causes of Accidents		
Aircraft and Period	Flight-hours	Human Error	Non-Human and Unknown	All Causes
Model 206				
1983 - 1986	7,903,072	3.90	2.05	5.95
1987 - 1990	9,341,573	2.49	1.89	4.38
Percent change		−36.2%	−7.8%	−26.3%
Bell Mediums				
1983 - 1986	2,438,515	2.62	2.01	4.63
1987 - 1990	2,472,091	2.31	2.39	4.69
Percent change		−11.8%	+18.9%	+1.3%

Table 17. USA human error accidents involving weather

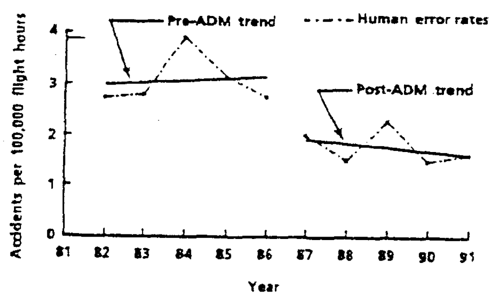
	Single Piston	Single Turbine	Twin Turbine	206 Single Turbine
Flight-hours				
84 - 86	1,899,081	4,167,156	821,679	2,997,911
87 - 88	1,062,171	2,868,690	620,437	2,217,090
HE WX Accidents				
84 - 86	26	40	7	25
87 - 88	8	8	2	5
HE WX Accidents per 100,000 flight-hours				
84 - 86	1:37	0.96	0.85	0.83
87 - 88	0.75	0.28	0.32	0.23
HE WX Rate Reduction	−45.3%	−70.8%	−62.4%	−72.3%

beneficial effects of Judgment Training (ADM), which should affect the overall helicopter-industry accident rate. Further, since the Model 206 flies most of the helicopter fleet hours, the industry accident rates will be lower.

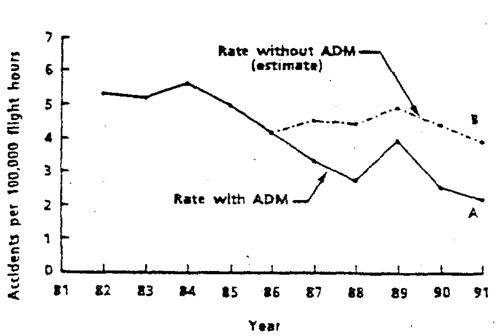
Analysis of human error accidents involving weather shows a changing trend in the USA. NTSB accident data and FAA flight hours for 1984 through 1988 were divided, with an early period of 1984 through 1986 compared to the later period of 1987 and 1988. The results are Table 17. The year 1987 was the beginning of Bell's concentrated safety training programs to reduce human error accidents as discussed above. Thus the range of human error accident rate reductions due to poor weather decisions in the most recent time period has been significantly reduced between 45% and 72%. This reduction is due to safety training, not mandatory regulations.

The annual human error accident rates in the Model 206 were determined for the period of 1982 to mid-1991 to check the statistical significance at even longer periods. The FAA flight-hours for 1982 through 1989 were used. The flight-hours for 1990 and 1991 (through June 30) were forecast, using the trend of the previous 8 years of FAA data. The accidents used were from NTSB data (1982 through 1988, the latest available). The accidents occurring from 1989 through June 30, 1991 were estimated from Bell information. Figure 14 shows the Model 206 accident rates due to human error for the accident data period 1982 through 1987 (i.e., prior to the introduction of safety training) and the period 1987 through June 30, 1991 (with concentrated Model 206 safety training, including ADM). *The human error accident rate for the ADM safety training period (since 1987) is significantly different from the previous period 95 times out of 100. This reduction in accident rate has occurred with no changes to regulatory restrictions.* As a further check, the accident rate of the Model 206 for all causes was determined with and without the ADM safety training, as shown in Fig. 15. Curve A is the actual accident rate for the Model 206, with the ADM training effects since 1987. Curve B is the estimated accident rate for the Model 206 with a continuation of the consistent human error accident rate trend of 1982 through 1986 extended throughout the remaining years. The trend of the accident rates without ADM is consistent with historical accident rates. *The actual accident rates with ADM safety training (Curve A) are significantly different from that normally expected without ADM training (Curve B) to a significance level of 0.05.* In other words, 95 times out of 100, the two curves are significantly different.

The Canadian government is starting to integrate PDM into their pilot training requirements as of 1991. PHI, the largest U.S. helicopter operator, introduced Judgment Training as an integral part of their internal training which has subsequently cut their accident rates in half. Bell looks for further accident rate reductions as we continue this worthwhile effort. *Judgment Training (e.g., PDM or*



1-N122
Fig. 14. Model 206 human error accident rates (USA, 1982 to mid-1991)



1-n123
Fig. 15. Model 206 accident rate with and without ADM (USA, 1982 to mid-1991).

ADM) has more safety improvement potential that the total elimination of all airworthiness failure causes (a primary goal since the start of aviation).

Consideration of the safety education effects of several manufacturers efforts on the human error accident rates of the types of helicopters in the USA is found in Table 18. This shows a significant reduction in human error accident rates in the turbine helicopter fleet. More work is needed in the single-piston fleet. Since safety education is an ongoing effort, it will take several years to reach all helicopter pilots.

CONCLUSIONS

Helicopters are not fixed-wing aircraft and therefore behave differently when undergoing any engine failure. The helicopter's ability to autorotate allows a low speed emergency landing from an engine failure and the selection of suitable landing sites. One should not make safety decisions on any one

Table 18. Safety education effects on human error accident rates NTSB/FAA (USA-registered)

Type of Helicopter	Rate* Before (84 - 86)	Rate* Since (87 & 88)	Percent Changes
Single piston	11.16	10.92	−2.2%
Non-206 single turbine	4.11	3.07	−25.3%
Twin turbine	2.56	1.61	−37.1%
206 single turbine**	3.40	1.76	−48.2%

*Human error accidents per 100,000 hours
**Concentrated HELIPROPS safety education

helicopter part without considering the safety aspects of all other parts and the human causes. Considering all airworthiness failures (all material failures including the engine), the twin-turbine helicopter accident rate is 1.5 times higher than in the single-turbine 206. Considering all accident causes, the twin-turbine helicopter accident rate is close to, but still higher than, the Model 206 rate. *Mandating twin engines does not reduce the likelihood of a material-failure-caused accident, but merely changes the types of failures that cause accidents.* Single-turbine accident experience related to elevated structures is better than for twin turbines. The risk to the neighborhood around a heliport from an airworthiness-failure-caused accident is lower for the single-turbine Model 206 than for twin-turbine helicopters. Mandatory use of twin-engine helicopters around the world does not make sense from a safety point of view. In some specific harsh environments such as the North Sea, the twin-turbine helicopter is, and should be, used. However, there are many environments and uses where the twin-turbine helicopter is not the best choice.

Based on the preceding analyses, there are no statistically significant differences between Performance Class 2 (twin-turbine engine) and Performance Class 3 (single-turbine engine) accident rates, and therefore the restrictions placed on Performance Class 3 operations are unwarranted from a safety standpoint. Additionally, these restrictions can impose severe humanitarian and economic hardships by denying the less costly services that could be provided by a simpler and less restrictive Performance Class 3 single-engine helicopter.

The safety measurement method that should be used is strictly determined by the subject of primary concern. The denominator of the frequency rate will include this primary concern. If aircraft damage frequency is your primary concern, then an accident per aircraft flight-hour method is appropriate. If the mission is the primary concern, then the accidents per mission (e.g., launch, departure, takeoff, flight, trip, passenger mile or patient transport) method is appropriate. If the primary concern is the risk of an accident in a neighborhood without regard to the aircraft occupants, then years-between-accidents measurement for that specific neighborhood exposure is appropriate. With the safety of the aircraft occupant as the primary concern, measuring relative risk of serious injury per occupant flight-hour is the best method.

The recent concentrated Judgment Training/ADM/PDM efforts of manufacturers, operators, and regulatory agencies have made a significant reduction in human error accidents. This major reduction has occurred without any regulatory changes or limitations. Major improvements in helicopter safety for the future require the continuation and refinement of these safety efforts. Occupant risk in a helicopter is low now but the aviation community can, and must, reduce it further.

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