行政院及所屬各機關出國報告
（出國類別：進修）

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# 美國南加州飛安學院失事調查訓練報告

服務機關：行政院飛航安全委員會
出國人職　稱：工程師
姓　名：王士嘉、劉震苑
出國地區：美國
出國期間：民國九十年八月二十日至九月十四日
報告日期：民國九十年十月十五日

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聯絡人：鄧嵐嵐　　　　　　電　話：(02) 2547-5200 分機 175

出國人員姓名：王士嘉、劉震苑
服務機關：行政院飛航安全委員會
職稱：工程師　　　電話：(02) 2547-5200

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分類號/目

關鍵詞：美國、新墨西哥州、南加州飛安學院、失事調查訓練

內容摘要：

南加州飛安學院（South California Safety Institute）位於新墨西哥州阿柏克基市，其教學特色在於運用區內空軍基地的失事殘骸實驗室提供學員實習之用，該實驗室，有許多飛機失事殘骸在此做現場重建，且是目前世界上最大的飛機殘骸實驗室，該學院之授課教師大多具有豐富的調查經驗與專業知識，但以軍方背景的人員佔多數；參訓學員則是來自各個不同的國家、地區，藉由課程議提之討論促進專業之交流並達成合作關係的延伸。

本次訓練共計四週，參與三項課程訓練：**1.**航空器失事調查 **2.**失事調查的人為因素 **3** 失事調查管理。參訓學員除我國外，尚有來自美國、加拿大、德國、比利時、土耳其、肯亞、新加坡、韓國、阿拉伯聯合大公國等多國家，隨著課程的不同學生人數也有所變動。四週的訓練課程相當緊湊，有時星期六亦需至實驗室實習。此次三項課程中第一堂航空器失事調查(為期兩週)算是失事調查全貌簡介，其中包括失事/重大意外事件之定義、調查人員之裝備、調查技術、報告撰寫等，能提供失事調查一整體概念，應為新進調查人員之入門課程，至於其它課成如人為因素、調查管理、發動機等則應視調查人員之專長、背景及擔任之工作而選擇適當之課程作深入之研究。

本文電子檔已上傳至出國報告資訊網

## 行政院及所屬各機關出國報告審核表

出國報告名稱: 美國南加州飛安學院失事調查訓練報告
出國計畫主辦機關名稱: 行政院飛航安全委員會

出國人姓名：王士嘉、劉震苑
職稱：工程師
服務單位:行政院飛航安全委員會

出國計畫主辦機關審核意見:

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

層轉機關審核意見:

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

# 目　　錄

1. 失事調查課程簡介
2. 航空器失事調查
3. 失事調查的人為因素
4. 失事調查管理
5. 結　語

# 第一章 訓練課程簡介

南加州飛安學院的英文全名是 South California Safety Institute (SCSI)，是專司航空器飛航安全管理與失事調查訓練方面的機構。

其講師大都具備軍方及民航等之經驗，基於上述背景與經驗基礎，SCSI 更網羅了學術界、航空領域專家從事理論教學與失事現場調查等訓練工作。同時，該學院在新墨西哥州阿柏克基市郊的空軍基地內，有與空軍共同使用的失事殘骸實驗室(Crash Site)，提供學習之用。

本次本會派出工程師王士嘉、劉震苑等二人參與南加州飛安學院的三項課程，課程名稱-如下述：

1. 航空器失事調查(Aircraft Accident Investigation)。
2. 失事調查的人為因素(Human Factors for Accident Investigators)。
3. 失事調查的管理( Investigation Management)。

上課地點在南加州飛安學院。學生除我國外，尚有來自美國、加拿大、德國、韓國、土耳其、新加坡、肯亞、阿拉伯聯合大公國、荷蘭、比利時等不同國家，依課程的不同選修的學生也有所不同。

訓練課程由年 8 月 20 日至同年 9 月 14 日結訓。

# 第二章 航空器失事調查

本課程是由航空器失事調查、技術、攝影、航太醫學及人為因素與失事調查等五項議題所組成，分別由專業講師教授，並至空軍基地飛機殘骸實室實地實習。

## 一、航空器失事調查

授課教師：

Mr. Gary R. Morphew：

Mr. Morphew 是 SCSI 的專案經理，曾為美國空軍飛行軍官，建置、發展多項安全計畫方案，以及督導失事調查。Gary 是一位很有經驗的失事調查官及「人為因素」顧問；同時他教授失事調查、人為疏失與失事之肇因、組織行為、環境保護、CRM 以及基礎電腦等訓練課程，而且也參與許多國際間相關組織之活動。

課程內容簡述：

1.失事調查的目的：是為預防止失事事件之發生。

芝加哥國際民用航空公約之第十三號附約的論點：

失事及重大意外事件調查之目的在於「預防失事及重大意外事件之再發生」。

2.失事調查原則：

I+A+C+R=P
I Investigation 失事調查
A +Analysis 分析
C +Conclusions 結論
R +Recommendations 建議
P Prevention 預防

3.失事調查及預防之步驟：

(1)事前準備(2)現場調查(3)分析(4)結論(5)失事終結報告(6)改善建議之執行情況與評估。

4.失事調查應由何處著手(開始)：

(1)失事殘骸中什麼東西不見了。

(2)失事殘骸中多了些什麼額外的東西。

(3)以及該航空器最後一次性能維修資料。

5.失事理論(Mishap Theory)：The Critical Interface

又稱為 6M 理論是由以下六項因素所組成：

其中前五項因子相互關連產生影響介面，而最後一項也就是錢、預算決定計劃之成敗。

(1)任務(Mission)

(2)人(Man)

(3)媒介(Medium)

(4)機器(Machine)

(5)管理(Management)

(6)錢(Money)

6.失事調查的準備：

(1)調查小組成員之選定

a.界定專業範圍：識別此失事事件牽涉之專業領域為何(如人為因素、機械故障、天氣等)。

b.訓練：調查小組成員共識之建立。

c.現場部署：失事現場人員之工作分配。

d.完成調查：工作的圓滿達成是所有小組成員及各支援系統合作而成。

(2)Go Kit 的準備

a.調查員依失事狀況準備個人及調查所需之裝備(如帽子、手套、相機、手電筒、定位器、電腦等)。

b.事先了解調查現場是否有危險：如失火、爆炸、放射性物質或毒品等充斥現場。

c.調查人員自身安全保護之認知：如危險品之控制及個人防護裝備之齊全。

d.失事航空器相關資料之收集：如飛機結構、製造廠商及各相關手冊等。

e.調查員的心理準備：面對罹難者遺體、家屬、生還者等之心理建設。

7.失事調查：

(1)失事搶救：

a.消防

b.生還者搶救

c.醫療照顧

d.罹難者遺體停放服務

e.災難控制

f.地方政府支援

(2)失事現場控制：當生還者及消防搶救過後，現場必須控制並保持殘骸不被移動，以利調查。

(3)失事現場安保及調查小組人員之安全：如警戒區域、爆裂物棄置地區及危險區等之安全設施。

(4)失事現場評估：如地形特徵、地面痕跡、撞擊的角度/速度、零件的分佈、屬於航空器的零件及不屬於的零件、航空器外形、著火及發動機等資訊之瞭解與評估。

(5)建立蒐證優先順序(易腐爛的證據優先搜集)：如罹難者遺體、飛機殘骸、地面撞擊痕跡、飛航記錄器、維修記錄等。

(6)調查小組的行動：

a.調查行動之組織(建立共識)。

b.小組成員工作分配。

c.擬定失事調查計劃。

d.建立支援系統：提供調查工作所需之設備或交通工具等。

(7)調查小組會議：

a.至少每日一次小組會議。

b.檢視及修訂調查計劃。

c.調查人員分享調查發現及印象深刻之事。

(8)識別飛機主要組件：

a.利用航空器之圖解協助辨識。

b.核算主要及次要飛行控制界面之數目。

c.識別所有發動機及推進器之位置。

d.運用飛機組件之序號。

(9)失事現場深入調查：如飛機組件之分析、殘骸分佈位置、標記、殘骸清單等。

(10)支援系統之協助：

a.合格之維修人員。

b.技術協助。

c.技術文件提供調查人員參考。

d.工具、設備等之提供。

e.攝影師提供專業攝影服務。

(11)失事現場殘骸調查：

a.調查人員應先走一遍失事現場之全範圍(殘骸分佈位置)

b.製作殘骸清單。

c.建構初步殘骸分佈圖。

d.界定失事現場並以樁柱標示範圍。

e.製作正式殘骸分佈圖。

(12)目擊者之訪談：

a.可能之目擊者：參與此次事件之飛行組員、旅客、管制員，或間接參與事件之維修人員、督導人員以及地面目擊者。

b.影響訪談可信度之因素：關於目擊者之學識、訪談當時之情緒、是否過度宣染事實、時間對記憶產生之影響、遺忘、受傷之影響等。

c.目擊者本身之問題：害怕(生理、情緒等)、偏見、觀念等問題。

8.失事調查資料彙整及報告撰寫：

(1).事實資料(Factual Information)：包括飛航經過、人員傷亡情形、航空器損害情形、組員及航空器資料、天氣、助導航設施、無線電通信、航空站、飛航記錄器、飛機殘骸、醫學資料、消防搶救、飛機組件測試等。

(2)分析：

a.此階段是為了找出造成失事之原因。

b.試著運用片段之資訊找出事件之主要問題。

c.運用事實資料進行分析。

d.藉由資料之分析不斷的嘗試證明假設。

e.結論及發生原因作連結。

(3)結論：(發現 findings)

a.所獲得之結論必須支持分析階段之證據。

b.找出影響事件產生之重要因素。

(4)可能原因：

a.以上之 findings 是直接造成失事之主因。

b.以上之 findings 或若被事先預防或移除就能避免失事事件之發生，所以調查人員應很清楚的識別這些因子。

(5)飛安建議：

a.預防失事事件再發生之必要行動。

b.就失事原因進行改善行動。

## 二、材料與結構方面之調查技術

授課教師：Mr. Charlie Hausenfleck

Mr. Hausenfleck退休自美國空軍，擁有超過4000小時及不同機種經驗之飛行員，並具單引擎及多引擎之飛航經歷，曾擔任教師機師、試飛官與特種任務指揮官。其在航空生涯中涉獵之領域很廣；有航務運作、機務維修及研究發展等方面，並在培養軍方、民航人才等方面不遺餘力，是相當具有貢獻與成就的。

課程內容簡述：

從航空器結構材料的性能，並由設計的觀點來分析、研究造成失事的原因，並應用非破壞性檢驗來檢驗殘骸及找出真正損壞的原因。

1.航空器設計依據：

(1)軍用機設計之標準及規格要求是依據軍方標準1530航空器完整結構方案(ASIP)。

(2)商用航空器之設計標準是依據FAR Part 25。

2.航空器設計之負荷考量：

(1)空氣壓力負荷。

(2)靜態壓力之分佈。

(3)空氣動力。

(4)航空器變動作之負荷。

(5)陣風之負荷。

(6)降落之負荷。

3.航空器之金屬疲勞：

(1)定義：飛機局部結構逐漸損害，它的發生是由於材料受到重覆強力緊拉但壓力小於其力量之極限。

(2)結構的疲勞現象，可分成三階段直到破裂：

a.初步破裂：因為局部塑化應力造成，其張力會使結構呈現局部45度的裂紋。

b.裂紋成長：因承受週期性應力會致使裂紋沿初始成長的45度方向伸展。

c.最終損壞階段：因承受應力大於Ultimate Stress，所以最後結構會損壞龜裂。

4.航空器之金屬腐蝕：

(1)定義：金屬受到化學或電化學之損害稱之。

(2)腐蝕之一般型態：

a.化學物質之直接侵蝕。

b.高溫之氧化作用。

c.電化學腐蝕。

5.非破壞性檢驗：

(1)檢驗主要規範項目包括：

a.構受力、結構疲勞與損壞容忍度(damage tolerance)。

b.顫震(flutter)、發散與不穩定氣動彈性(aeroelastic instability)。

c.震動(vibration)。

d.材料特性。

對於顫震與震動的產生，係由於結構本身的共震頻率與氣動力激發(aerodynamic excitation)的震動頻率相近，進而產生 lock-in 線，以致結構受力逐漸增加，最後造成結構破裂。所謂使用壽命的規範可用總操作時數、總飛行架次及總起降架次來定義。結構材料的性能在設計階段需考量航空器在設計極限的承受力(design limit loads)與溫度效應下不會

變形的要求。課程中亦複習了一些專有名詞，諸如：static load 、load factor 、limit load 、ultimate load 、rigidity 等。

航空器的結構可分為主要結構、次要結構與其它結構三種。其中主要結構包括：機翼結構、機身結構、起落架結構、發動機及發動機支撐結構。

分布在航空器上的受力可以受力特性區分為靜態受力、動態受力與週期性受力等三種。

(2)非破壞性檢測技術包括：

a.液滴染料滲透法。

b.磁性粒子檢驗法。

c.X 光攝影術。

d.X 光照相術與螢光染劑。

e.超音波檢驗法。

f.渦電流檢驗法。

6.結構損壞的種類：

(1)即時損壞(Instantaneous Failure)。

(2)瞬間外形改變(Plastic Deformation / Distortion)。

(3)永久外形改變。

(4)破裂。

(5)漸進式損壞(Progressive Failure)，包括疲勞破裂、腐蝕、磨損及潛變等。

金屬材料的特性包括：強度、彈性、可朔性、延展性、易脆性等。

## 三、攝影於航空器失事調查中之角色

授課教師：Mr. Frank H. Snapp

Mr. Snapp 早期曾參與美國空軍擔任飛行安全軍官，並擁有12 年失事調查及失事預防管理等經驗。他認為失事現場或殘骸照片之拍攝對資料收集深具影響，故應予重視並深入探討此一課題。

課程內容簡述：

攝影是失事調查中現場記錄不可或缺的方法，好的照片可讓人容易瞭解複雜的失事現場及微妙的證物。

使用有條理順序的方式，以照相記錄整個失事現場。圍繞失事現場從八個方位角拍下航空器的殘骸分布情形，若是分布太廣無法以此方式拍照，則依殘骸軌跡順序拍下去，並每次重疊約三分之一。

有關照片的說明應包括其編號、主題及標示。說明文字一律放在

照片的下方；若須在照片上做標示時，先用透明膠片覆蓋後再做標示，不要直接畫在照片上。

1.失事事件需要攝影之原因：失事現場照相的優先順序原則，是從容易消失的優先，不易消失的次之。

(1)保存易腐壞之證物。

(2)於調查報告中呈現證據資料。

(3)於調查人員之結論中以圖解說明。

2.攝影設備之選擇：

(1)設備之選擇應視下列情形而定：

a.失事地點。

b.失事地點之距離。

c.失事現場之環境：如熱帶地區、沙漠、寒帶、海洋等。

d.失事現場與文明地區之距離。

(2)照相機應具備：

a.堅固。

b.輕巧。

c.使用簡便。

d.多功能。

e.耐用及可靠。

(3)照相機的其它配備：

a.鏡片：如廣角、望遠鏡、長距離、近距離、濾光鏡等鏡片。

b.閃光燈

c.照相機支持附件：如三腳架、夾子等。

3.調查員攝影裝備之建議：數位照相機：包括自由焦距鏡頭、長距離攝影能力、內設或外加閃光燈、小型尺等。

拍照時若需知道其概略的尺寸，則必須使用參考尺，建議準備一把 20 公分不會反光的直尺備用；同時，附著掛簽的照片不僅容易識別，而且對尺寸大小是既方便又清楚的參考。

4.專業攝影師裝備之建議：

(1)2-35mm 單眼照相機。

(2)由焦距鏡頭含蓋 28-135mm 焦距長度。

(3)長距離鏡頭。

(4)外加強力閃光燈。

(5)照相機支持附件：如三腳架、夾子等。

(6)偏光濾鏡、灰卡、色階卡等。

5.失事現場之攝影：

(1)由較容易腐壞之證物優先攝影存證：

a.航空器於地面滑行之痕跡。

b.消防搶救等工作之進行：墜毀、失火、救援行動儘可能使用彩色相片；燃燒中的顏色對於失事調查是非常重要的，可以從火焰的顏色來判斷是何種燃油。

c.醫學之證據：醫學證物的照相包括死者、傷者個人的效應以及在殘骸上的組織血液，都必須使用彩色相片。但絕對不可以將死者照片用於正式報告之中。

(2)私人財產之損傷。

(3)收集較不易腐壞之證據：

a.失事現場全景

b.失事現場綜觀：失事現場的空中照相是必須的，若可能，最好能取得失事前該地的照片。

空中拍攝的要領：

(a)使用可開門的直昇機，儘可能以垂直的方式向下拍。

(b)由順光面拍攝，並且由背光面再拍一次。

(c)拍攝時必需包含一個參考物。例如：車子、房子或特殊或易於辨明的物體。

(d)必需記錄每一張照片拍攝時的高度。

c.製作航空器殘骸清單圖識：照相時，必需記錄每一張照片的精確時間及地點，並簡單描述當時情景。

d.殘骸各步驟之存證：任何殘骸的變動，包括：移動、打開、拆解、切割等都必須照相存證，已備後續調查之可能需要。

(4)其它重要之證據：

a.殘骸斷裂部分。

b.遺失/多出來之部分。

c.開關之位置。

d.航空器結構變色。

f.地面之痕跡。

g.樹或葉片之損傷狀況。

h.由目擊者觀點看失事現場：對於主要證據必需照相記錄並加特寫；若需要則用照相來表現目擊者所看到的景像；若有關文件無法影印亦可用照片來取代；有時可用照片來表現未受損的組件情形，以為比較。

i.任何不正常之狀況。

## 四、醫學、人為因素及飛航安全

授課教師：Dr. Harry L. Gibbons, M.D., M.P.H

Dr. Harry 是一位具有航太醫學背景之執業醫師，同時也參與航空事業關於醫療方面之顧問工作，並從事生物醫學與飛航安全方面之研究包括失事調查並參與 FAA 及 NTSB 調查員有關人為因素之訓練工作。

課程內容簡述：

1.NTSB 航空器失事罹難者遺體解剖法律依據：根據 CFR49 831.10 主任調查官代表委員會，為調查所需有權要求做罹難者遺體解剖或其它之測試。

2.空間迷向：

(1)空間迷向之發生與否是受人體三項不同之組織結構影響：

a.人體肌肉及骨骼：人體是由神經貫穿全身，它們能辨識壓力及重力。若沒有視覺之參考駕駛員極易迷失。

b.內耳：

(a)半規管只是在飛機轉彎加速時作反應。

(b)半規管有一臨界值，若是轉彎時之加速在臨界值之下，則不會有任何感覺。

(c)半規管內充滿液體，當飛機轉彎時液體也跟著流動，但

飛機停止動作時液體仍繼續移動一段時間而末稍神經反映在相對的方向。

c.眼睛：眼睛應是最可靠之參考工具，但仍有其限制；如氣候及黑暗等之限制。

(2)空間迷向之類型：

a.Type I：駕駛員未能察覺狀況，此期較常出現視覺上之幻覺。

b.Type II：駕駛員已覺知空間迷向(此期與內耳有關連)。

c.Type III：無法抗拒及無法挽救之狀況(此期與內耳有關連)。

3.航空醫學在失事調查上之功能：

(1)駕駛員使用藥物之原因及藥物對造成失事與否之鑑定。

(2)罹難者之識別：可用之鑑識方法為

a.解剖

b.牙科記錄

c.其它參考資訊

d.DNA 比對

4.疲勞對飛航組員之影響：

(1)增加反應之時間：如延長緊急應變之時間。

(2)降低注意力。

(3)記憶力衰退。

(4)情緒低落。

## 五、人為因素在航空器失事調查之角色

授課教師：Mr. Richard M. Anglemyer

Mr. Anglemyer 是美國空軍退役的飛行軍官，飛過多種不同的機種；如 C-130、T-38 及 C-12 等，也曾擔任美國東方航空公司 B-727 及 DC-9 駕駛員，並擁有 26 年經驗在訓練發展、設計及航務管理等領域上，過去七年來其除致力於人為因素之訓練，尚參予「品質保證」、「座艙資源管理」、「人為因素」等國內外航空人員專業訓練，且在多所大學校擔任上述課程的講師。

課程內容簡述：

1.CRM 組員資源管理：什麼是對的而非是誰對。

(1)定義：有效運用所有能獲得的人、物等資源以達成飛航安全與經濟運作的目的。

(2)CRM 在失事調查中之角色：調查員應能夠了解 CRM 是造成失事事件之其一因素。

(3)FAA 對 CRM 之內涵議題：

a.溝通：

(a)有關溝通方式的統計分析：

--9%在寫。

--16%在讀。

--30%在講。

--45%在聽。

因此，75%的溝通是使用語言，但語言溝通這部份的重要性常被忽略。

(b)溝通的類別：

--溝通不良：聽而不聞、聽而不解、聞而不行。

--溝通良好：瞭解意思但未應或未行。

--有效溝通：瞭解意思、應且行，模式良好。

(c)溝通上的障礙：

--盲從長官、盲信老經驗。

--禮貌上遵從老前輩。

--自滿、以致過於自信。

--怕惹人厭。

--怕報復。

--急於完成任務。

--忙不過來或太閒散。

(d)建議提出溝通的方式：

--禮貌性的稱呼以引起對方的注意，果斷而有禮。

--表達你的關切。如：我覺得不妥。

--指出問題所在及可能的結果。

--提供建議。如：我覺得應該---。

b.行為分析：包括個人之文化背景、價值觀、信仰、對規範之了解等。

c.壓力管理

d.狀況覺知

e.領導方法

f.衝突管理

g.下決定

2.失事肇因模型 Reason Model(Swiss Chess Model)

如附件參考料。

# 第三章 失事調查的人為因素

本課程是由失事調查的人為因素及人為因素在失事分析及預防之研究等兩項議題所組成。

## 一、失事調查的人為因素

授課教師：Dr. Gary Mucho

Dr. Gary 曾是美國空軍飛行員，退休自美國國家運輸安全委員會(NTSB)，為一資深且經驗豐富之調查官，目前擔任失事調查顧問及專業講師等工作。

課程內容簡述：

1.人為因素之定義：有關人在其工作環境之研究。

人為因素定位：主要是解決真實世界所存在之現實問題。

2.人為因素訓練項目：

(1)工程學

(2)心理學

(3)醫學

(4)生理學

(5)生物學

(6)社會學或人類工程學

3.失事調查員的 5 W：

(1) who：從事調查工作需具備之知識

a.專業技術

b.好奇的個性

c.犧牲奉獻的精神

d.勤勉

e.有耐心的

f.謙卑

g.正直

h.有邏輯概念

(2) What：相關的資訊

a.Shell Model

b.NTSB Checklist

c.決定需搜集多少資料方才足夠

(3) When：何時開始搜集資料

a.易腐壞之資料

--失事前 72 小時之歷史資料

--毒物檢體分析

--塔台雷達/無線電磁帶

--目擊者

b.不易腐壞之資料

--硬體設備

--文件

--軟體資料

(4)Why：

a.分析原因之流程：理論依據、假設等。

b.運用推理對所知或是疑點進行解釋。

c.運用基本方式去發展整體調查工作。

d.失事原因之解釋必須依據所獲得證據之價值。

3.資料之分析：資料若缺乏有效性是無法放入結論中。

4.方法：

(1)推論法(實際的)：

a.容易呈現：如發動機失效。

b.較能提出具說服力之結論：如金屬疲勞。

c.較能提出直接原因及影響：如不適當之檢查。

(2)歸納法(無實體的)：

a.不容易呈現：如聽覺、視覺、心肌梗塞、毒品等。

b.較推論法不精準。

c.較像事件行為之解釋。

d.最後之結論無法被檢測。

e.需依據一合理之理論為基礎。

最後，在決定資料搜集的深度及詳細度其目的是為調查人為因素，這項任務是在解釋事件發生之因果關係及為什麼沒有在發生不幸前去阻斷這些因子，而不是在作責任之歸咎。

二、人為因素在失事分析及預防之研究

此課程由兩位教師聯合授課

授課教師：Scott A. Shappell, Ph.D.

Dr. Shappell 為現職美國 FAA 人為因素研究部門之經理，並於大學教授相關課程。

授課教師：Douglas A. Wiegmann, Ph.D.

Dr. Wiegmann 目前任教於伊利諾大學-香檳城校區，擔任航空研究實驗室助理教授一職。

課程內容簡述：

根據美國 NTSB 之評估在美國搭機之旅客存活機會超過 99.99%，所以航空器仍是最安全之交通工具。

1.人為因素包含：

(1)駕駛員疏失

(2)人類工程學

(3)航空醫學議題

(4)組員資源管理

(5)組織因素

2.人為因素指導原則

(1)原則 1：航空是界於自然與複雜操作系統之間。

(2)原則 2：在某些範圍如一個系統下，人為疏失常是無可避免的。

(3)原則 3：歸責駕駛員的疏失就像是歸責航空器機械失效一般。

(4)原則 4：一次失事事件無論是多麼輕微，它也是一個系統之失效。

(5)原則 5：失事調查與疏失預防是一起的。

3.人為因素提供：

(1)提供一個架構去瞭解整個大畫面。

(2)強調人為因素重要之安全議題及其互動關係。

(3)提供所需之具體介入策略。

4.運用 Chess Model 建立 Checklist：共分四層

(1)第一層組織影響：

a.資源管理

b.組織氣氛

c.組織程序

(2)第二層不安全之督導：

a.不適當之督導

b.不適當之計劃及操作

c.未能有效修正問題

d.違規(法)之督導

(3)第三層先決條件造成不安全之行動：

a.非標準狀態之操作

--不正常的心理狀態

--不正常的生理狀態

--生/心理之限制

b.非標準規範之操作

--組員資源管理：如不適當之任務前提示、組員協調不良。

--個人的意願

(4)第四層不安全之行動(最底層)：

a.疏失

--錯誤的決定

--基本技術錯誤：如不適當的飛航控制、遺漏檢查表之項目。

--知覺的錯誤

b.違規(法)：如違反命令、法規及SOP等

--經常性的

--例外的

5.人為因素之概念及作法能運用之領域：

(1)駕駛艙

(2)機務維修

(3)醫學

(4)航管

# 第四章 失事調查管理

此課程是以討論方式進行，由三位講師組成 panel 並就其專業作經驗分享及問題解答。

授課教師：Dr. Gary Mucho

Dr. Gary 曾是美國空軍飛行員，退休自美國國家運輸安全委員會(NTSB)，為一資深且經驗豐富之調查官，目前擔任失事調查顧問及專業講師等工作。

授課教師：Mr. Ron Schleede

Mr. Ron Schleede 曾任美國國家運輸安全委員會(NTSB)失事調查部門主管，並具備豐富之失事調查經驗，目前擔任失事調查顧問及專業講師等工作。

授課教師：Mr. John W. Purvis

Mr. John W. Purvis 曾服務於波音飛機製造公司技術部門，為一資深之工程師，並多協助失事調查工作，目前服務於國際飛航安全服務組織(Safety Services International)。

課程內容簡述：

1.失事調查程序：

(1)失事事件發生：時間由零起算

(2)初步工作階段：需時約 1 至 2 天。

其工作內容：

a.相關單位之通知。

b.組織各單位。

c.成立指揮中心及建立後勤支援。

d.調查小組抵達失事現場。

(3)失事現場工作階段：需時約 1 至 2 週。

a.召開組織會議。

b.失事調查各小組形成：典型的調查工作小組分為：

＊航務組(Operations)

＊生存因素組(Survival Factors)

＊維修紀錄組(Maintenance Records)

＊發動機組(Powerplant)

＊航空器性能(Aircraft Performance)

＊人為因素組(Human Performance)

＊天氣(Weather)

＊航管組(ATC)

＊航空器結構組(Structures)

＊系統組(System)

＊目擊者組(Witnesses)

＊記錄組(Records)

c.每晚召開進度會議。

(4)後續工作階段：需時約 3 至 6 週。

a.搜集更多之證據。

b.檢查及測試工作之進行。

c.資料分析。

d.事件模擬。

(5)長程工作階段：需時約 2 個月至 2 年或更長。

a.額外之測試及模擬。

b.準備技術報告。

c.閱讀政府失事報告。

2.一個失事調查主要之組成要件：

(1)調查前之準備工作：

a.法規、政策及程序等之準備：如 ICAO annex 13。

b.主任調查官、經理人及調查員之資格及訓練：如基礎及

複訓、在職訓練等。

c.調查員及經理人之權限：其權責應述諸於法規中。

d.與政府、製造廠及媒體建立良好之關係。

e.連續性之計劃。

f.會議練習。

(2)失事/意外事件之通知：

a.溝通(內部及外部)：

--建立24小時連絡電話。

--建立語言輔助系統：如翻譯。

b.國際間之協議：如annex 13

c.計劃：

--事件發生時通知國家及人員名單。

--定期修正及更新需接觸之人員資料。

--住家、公司、車上皆放置檢查表。

d.與緊急應變小組協調：

--建立主要連絡人員名單。

--建立危險物品資料。

e.是否有犯罪議題：

若是失事事件同時含有飛安及犯罪之因素，則失事調查單

位及檢警雙方皆需參與調查工作，此時需決定由誰擔任領導。

(3)調查員/調查小組之派遣：

a.需有行政支援

b.建立失事現場之安全：可協調當地政府提供安全警戒等工作。

c.資料之安全：如航空器、個人、天氣、航管等之資料。

d.失事現場旅行之安排。

(4)初步失事現場活動。

(5)調查之組織工作。。

(6)飛機殘骸/失事現場之管理。

(7)調查進度會議。

(8)事實資料之發佈：包括緊急安全行動。

(9)關閉失事現場。

(10)失事現場外之測試工作。

(11)調查事實/分析報告：參考 annex 13 並建議飛安改善行動。

(12)聽證會：

a.聽證會的目：協助調查小組在決定失事之可能原因及預防失事事件再發生、增進運輸安全。

b.會議開放社會大眾：主要參加人員為：律師、傳播媒體工作者、顧問、失事事件受害者及其家人等。

c.NTSB 舉辦之公聽會典型參加人員或單位：

--FAA

--肇事航空公司

--航空器/發動機製造廠

--駕駛員、管制員、空服員及機務維修人員工會等

--其它相關之專業人員

(13)終結報告。

# 第五章 結　語

航空器失事調查人員除了必須具備航空相關領域的專業知識外，尚需瞭解調查作業的規則與技巧，並對國際上的新觀念、規則與慣例保持密切之接觸；且調查人員更應具備公正、客觀、負責之觀念並以積極及正向之態度以預防飛安之著眼點面對工作上之各項挑戰，秉持失事原因鑑定之科學精神完成各項調查工作。

本次參訓的學員，來自世界各國，成員的背景不同、專長也不盡相同，這樣的組合可以藉由彼此之互動、知識及經驗的交換，達到經驗交流之目的，同時也可瞭解其它國家之失事調查單位的工作重點及長處可供我參考。此外學員經由多日之相處建立了良好之關係，更為日後奠定相互學習、資源分享之管道。

南加州飛安學院的各種訓練課程總計 25 門，內容涵蓋面廣泛，是為培訓調查人員的不錯選擇，但在課程之安排與選取上應配合受訓人員之經歷、背景及專長等，以達事半功倍之效果。另外上課之期程不宜過長以免造成影響學習效果。如此次連續四週並接受三種不同課程之訓練對學員來說較顯吃力，若可分開來上，一次以兩週較為適宜。

# 附件

# 人為因素分析及分類系統—Swiss Cheese Model

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Washington, DC 20591

# The Human Factors Analysis and Classification System–HFACS

Scott A. Shappell
FAA Civil Aeromedical Institute
Oklahoma City, OK 73125
Douglas A. Wiegmann
University of Illinois at Urbana-Champaign
Institute of Aviation
Savoy, IL 61874

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[2]University of Illinois at Urbana-Champaign, Institute of Aviation,
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16 Abstract

Human error has been implicated in 70 to 80% of all civil and military aviation accidents. Yet, most accident reporting systems are not designed around any theoretical framework of human error As a result, most accident databases are not conducive to a traditional human error analysis, making the identification of intervention strategies onerous. What is required is a general human error framework around which new investigative methods can be designed and existing accident databases restructured. Indeed, a comprehensive human factors analysis and classification system (HFACS) has recently been developed to meet those needs. Specifically, the HFACS framework has been used within the military, commercial, and general aviation sectors to systematically examine underlying human causal factors and to improve aviation accident investigations. This paper describes the development and theoretical underpinnings of HFACS in the hope that it will help safety professionals reduce the aviation accident rate through systematic, data-driven investment strategies and objective evaluation of intervention programs

17 Key Words
Aviation, Human Error, Accident Investigation, Database Analysis

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# THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM–HFACS

## INTRODUCTION

Sadly, the annals of aviation history are littered with accidents and tragic losses Since the late 1950s, however, the drive to reduce the accident rate has yielded unprecedented levels of safety to a point where it is now safer to fly in a commercial airliner than to drive a car or even walk across a busy New York city street. Still, while the aviation accident rate has declined tremendously since the first flights nearly a century ago, the cost of aviation accidents in both lives and dollars has steadily risen As a result, the effort to reduce the accident rate still further has taken on new meaning within both military and civilian aviation

Even with all the innovations and improvements realized in the last several decades, one fundamental question remains generally unanswered: "Why do aircraft crash?" The answer may not be as straightforward as one might think In the early years of aviation, it could reasonably be said that, more often than not, the aircraft killed the pilot That is, the aircraft were intrinsically unforgiving and, relative to their modern counterparts, mechanically unsafe. However, the modern era of aviation has witnessed an ironic reversal of sorts It now appears to some that the aircrew themselves are more deadly than the aircraft they fly (Mason, 1993; cited in Murray, 1997). In fact, estimates in the literature indicate that between 70 and 80 percent of aviation accidents can be attributed, at least in part, to human error (Shappell & Wiegmann, 1996). Still, to off-handedly attribute accidents solely to aircrew error is like telling patients they are simply "sick" without examining the underlying causes or further defining the illness.

So what really constitutes that 70-80 % of human error repeatedly referred to in the literature? Some would have us believe that human error and "pilot" error are synonymous. Yet, simply writing off aviation accidents merely to pilot error is an overly simplistic, if not naive, approach to accident causation. After all, it is well established that accidents cannot be attributed to a single cause, or in most instances, even a single individual (Heinrich, Petersen, and Roos, 1980). In fact, even the identification of a "primary" cause is fraught with problems Rather, aviation accidents are the end result of a number of causes, only the last of which are the unsafe acts of the aircrew (Reason, 1990, Shappell & Wiegmann, 1997a, Heinrich, Peterson, & Roos, 1980; Bird, 1974)

The challenge for accident investigators and analysts alike is how best to identify and mitigate the causal sequence of events, in particular that 70-80 % associated with human error. Armed with this challenge, those interested in accident causation are left with a growing list of investigative schemes to chose from. In fact, there are nearly as many approaches to accident causation as there are those involved in the process (Senders & Moray, 1991) Nevertheless, a comprehensive framework for identifying and analyzing human error continues to elude safety professionals and theorists alike Consequently, interventions cannot be accurately targeted at specific human causal factors nor can their effectiveness be objectively measured and assessed. Instead, safety professionals are left with the status quo. That is, they are left with interest/fad-driven research resulting in intervention strategies that peck around the edges of accident causation, but do little to reduce the overall accident rate. What is needed is a framework around which a needs-based, data-driven safety program can be developed (Wiegmann & Shappell, 1997).

### Reason's "Swiss Cheese" Model of Human Error

One particularly appealing approach to the genesis of human error is the one proposed by James Reason (1990). Generally referred to as the "Swiss cheese" model of human error, Reason describes four levels of human failure, each influencing the next (Figure 1) Working backwards in time from the accident, the first level depicts those *Unsafe Acts* of Operators that ultimately led to the accident[1]. More commonly referred to in aviation as aircrew/pilot error, this level is where most accident investigations have focused their efforts and consequently, where most causal factors are uncovered

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[1] Reason's original work involved operators of a nuclear power plant. However, for the purposes of this manuscript, the operators here refer to aircrew, maintainers, supervisors and other humans involved in aviation

After all, it is typically the actions or inactions of aircrew that are directly linked to the accident For instance, failing to properly scan the aircraft's instruments while in instrument meteorological conditions (IMC) or penetrating IMC when authorized only for visual meteorological conditions (VMC) may yield relatively immediate, and potentially grave, consequences Represented as "holes" in the cheese, these active failures are typically the last unsafe acts committed by aircrew.

However, what makes the "Swiss cheese" model particularly useful in accident investigation, is that it forces investigators to address latent failures within the causal sequence of events as well. As their name suggests, latent failures, unlike their active counterparts, may lie dormant or undetected for hours, days, weeks, or even longer, until one day they adversely affect the unsuspecting aircrew. Consequently, they may be overlooked by investigators with even the best intentions.

Within this concept of latent failures, Reason described three more levels of human failure. The first involves the condition of the aircrew as it affects performance. Referred to as *Preconditions for Unsafe Acts*, this level involves conditions such as mental fatigue and poor communication and coordination practices, often referred to as crew resource management (CRM). Not surprising, if fatigued aircrew fail to communicate and coordinate their activities with others in the cockpit or individuals external to the aircraft (e.g., air traffic control, maintenance, etc.), poor decisions are made and errors often result.

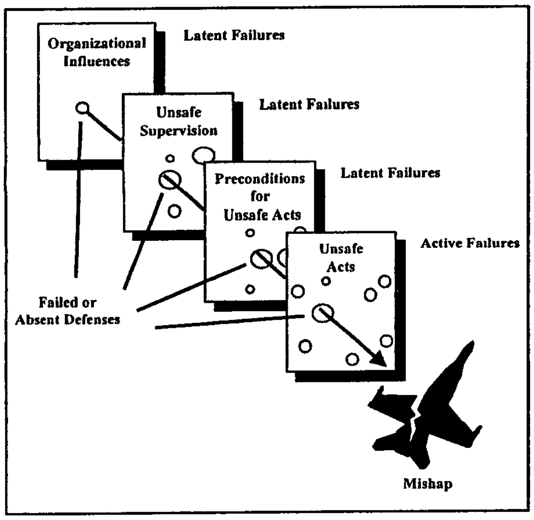

**Figure 1.** *The "Swiss cheese" model of human error causation (adapted from Reason, 1990).*

But exactly why did communication and coordination break down in the first place? This is perhaps where Reason's work departed from more traditional approaches to human error. In many instances, the breakdown in good CRM practices can be traced back to instances of *Unsafe Supervision*, the third level of human failure. If, for example, two inexperienced (and perhaps even below average pilots) are paired with each other and sent on a flight into known adverse weather at night, is anyone really surprised by a tragic outcome? To make matters worse, if this questionable manning practice is coupled with the lack of quality CRM training, the potential for miscommunication and ultimately, aircrew errors, is magnified In a sense then, the crew was "set up" for failure as crew coordination and ultimately performance would be compromised. This is not to lessen the role played by the aircrew, only that intervention and mitigation strategies might lie higher within the system.

Reason's model didn't stop at the supervisory level either; the organization itself can impact performance at all levels. For instance, in times of fiscal austerity, funding is often cut, and as a result, training and flight time are curtailed. Consequently, supervisors are often left with no alternative but to task "non-proficient" aviators with complex tasks. Not surprisingly then, in the absence of good CRM training, communication and coordination failures will begin to appear as will a myriad of other preconditions, all of which will affect performance and elicit aircrew errors. Therefore, it makes sense that, if the accident rate is going to be reduced beyond current levels, investigators and analysts alike must examine the accident sequence in its entirety and expand it beyond the cockpit Ultimately, causal factors at all levels within the organization must be addressed if any accident investigation and prevention system is going to succeed.

In many ways, Reason's "Swiss cheese" model of accident causation has revolutionized common views of accident causation. Unfortunately, however, it is simply a theory with few details on how to apply it in a real-world setting In other words, the theory never defines what the "holes in the cheese" really are, at least within the context of everyday operations Ultimately, one needs to know what these system failures or "holes" are, so that they can be identified during accident investigations or better yet, detected and corrected before an accident occurs.

The balance of this paper will attempt to describe the "holes in the cheese." However, rather than attempt to define the holes using esoteric theories with little or no practical applicability, the original framework (called the *Taxonomy of Unsafe Operations*) was developed using over 300 Naval aviation accidents obtained from the U.S. Naval Safety Center (Shappell & Wiegmann, 1997a). The original taxonomy has since been refined using input and data from other military (U S. Army Safety Center and the U S. Air Force Safety Center) and civilian organizations (National Transportation Safety Board and the Federal Aviation Administration). The result was the development of the Human Factors Analysis and Classification System (HFACS)

## THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM

Drawing upon Reason's (1990) concept of latent and active failures, HFACS describes four levels of failure: 1) Unsafe Acts, 2) Preconditions for Unsafe Acts, 3) Unsafe Supervision, and 4) Organizational Influences A brief description of the major components and causal categories follows, beginning with the level most closely tied to the accident, i.e. unsafe acts.

### Unsafe Acts

The unsafe acts of aircrew can be loosely classified into two categories: errors and violations (Reason, 1990) In general, errors represent the mental or physical activities of individuals that fail to achieve their intended outcome Not surprising, given the fact that human beings by their very nature make errors, these unsafe acts dominate most accident databases. Violations, on the other hand, refer to the willful disregard for the rules and regulations that govern the safety of flight. The bane of many organizations, the prediction and prevention of these appalling and purely "preventable" unsafe acts, continue to elude managers and researchers alike

Still, distinguishing between errors and violations does not provide the level of granularity required of most accident investigations Therefore, the categories of errors and violations were expanded here (Figure 2), as elsewhere (Reason, 1990; Rasmussen, 1982), to include three basic error types (skill-based, decision, and perceptual) and two forms of violations (routine and exceptional).

### Errors

Skill-based errors. Skill-based behavior within the context of aviation is best described as "stick-and-rudder" and other basic flight skills that occur without significant conscious thought As a result, these skill-based actions are particularly vulnerable to failures of attention and/or memory. In fact, attention failures have been linked to many skill-based errors such as the breakdown in visual scan patterns, task fixation, the inadvertent activation of controls, and the misordering of steps in a procedure, among others (Table 1). A classic example is an aircraft's crew that becomes so fixated on trouble-shooting a burned out warning light that they do not notice their fatal

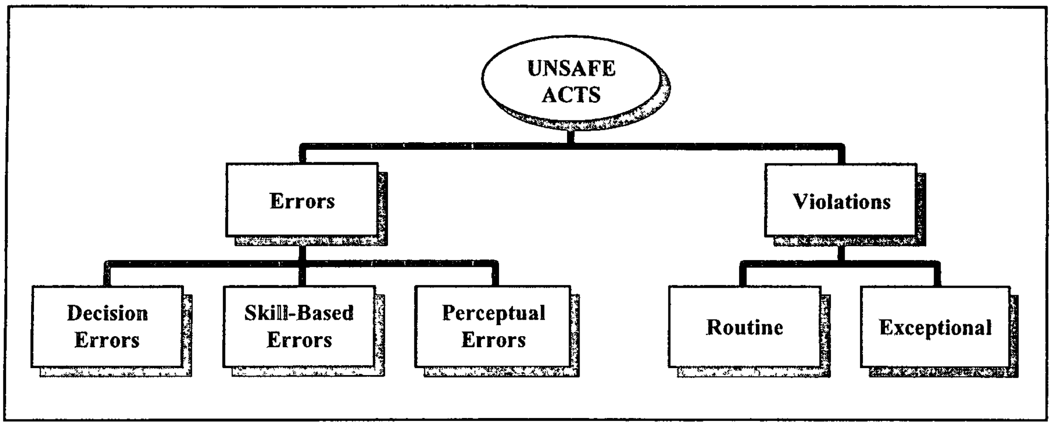

**Figure 2.** *Categories of unsafe acts committed by aircrews.*

**TABLE 1.** Selected examples of Unsafe Acts of Pilot Operators (Note: This is not a complete listing)

**ERRORS**

**Skill-based Errors**
- Breakdown in visual scan
- Failed to prioritize attention
- Inadvertent use of flight controls
- Omitted step in procedure
- Omitted checklist item
- Poor technique
- Over-controlled the aircraft

**Decision Errors**
- Improper procedure
- Misdiagnosed emergency
- Wrong response to emergency
- Exceeded ability
- Inappropriate maneuver
- Poor decision

**Perceptual Errors (due to)**
- Misjudged distance/altitude/airspeed
- Spatial disorientation
- Visual illusion

**VIOLATIONS**
- Failed to adhere to brief
- Failed to use the radar altimeter
- Flew an unauthorized approach
- Violated training rules
- Flew an overaggressive maneuver
- Failed to properly prepare for the flight
- Briefed unauthorized flight
- Not current/qualified for the mission
- Intentionally exceeded the limits of the aircraft
- Continued low-altitude flight in VMC
- Unauthorized low-altitude canyon running

descent into the terrain. Perhaps a bit closer to home, consider the hapless soul who locks himself out of the car or misses his exit because he was either distracted, in a hurry, or daydreaming. These are both examples of attention failures that commonly occur during highly automatized behavior. Unfortunately, while at home or driving around town these attention/ memory failures may be frustrating, in the air they can become catastrophic.

In contrast to attention failures, memory failures often appear as omitted items in a checklist, place losing, or forgotten intentions. For example, most of us have experienced going to the refrigerator only to forget what we went for. Likewise, it is not difficult to imagine that when under stress during inflight emergencies, critical steps in emergency procedures can be missed. However, even when not particularly stressed, individuals have forgotten to set the flaps on approach or lower the landing gear – at a minimum, an embarrassing gaffe.

The third, and final, type of skill-based errors identified in many accident investigations involves technique errors. Regardless of one's training, experience, and educational background, the manner in which one carries out a specific sequence of events may vary greatly. That is, two pilots with identical training, flight grades, and experience may differ significantly in the manner in which they maneuver their aircraft. While one pilot may fly smoothly with the grace of a soaring eagle, others may fly with the darting, rough transitions of a sparrow. Nevertheless, while both may be safe and equally adept at flying, the techniques they employ could set them up for specific failure modes. In fact, such techniques are as much a factor of innate ability and aptitude as they are an overt expression of one's own personality, making efforts at the prevention and mitigation of technique errors difficult, at best.

*Decision errors.* The second error form, decision errors, represents intentional behavior that proceeds as intended, yet the plan proves inadequate or inappropriate for the situation. Often referred to as "honest mistakes," these unsafe acts represent the actions or inactions of individuals whose "hearts are in the right place," but they either did not have the appropriate knowledge or just simply chose poorly.

Perhaps the most heavily investigated of all error forms, decision errors can be grouped into three general categories. procedural errors, poor choices, and problem solving errors (Table 1). Procedural decision errors (Orasanu, 1993), or rule-based mistakes, as described by Rasmussen (1982), occur during highly structured tasks of the sorts, if X, then do Y Aviation, particularly within the military and commercial sectors, by its very nature is highly structured, and consequently, much of pilot decision making is procedural. There are very explicit procedures to be performed at virtually all phases of flight. Still, errors can, and often do, occur when a situation is either not recognized or misdiagnosed, and the wrong procedure is applied This is particularly true when pilots are placed in highly time-critical emergencies like an engine malfunction on takeoff

However, even in aviation, not all situations have corresponding procedures to deal with them. Therefore, many situations require a choice to be made among multiple response options. Consider the pilot flying home after a long week away from the family who unexpectedly confronts a line of thunderstorms directly in his path. He can choose to fly around the weather, divert to another field until the weather passes, or penetrate the weather hoping to quickly transition through it. Confronted with situations such as this, choice decision errors (Orasanu, 1993), or knowledge-based mistakes as they are otherwise known (Rasmussen, 1986), may occur. This is particularly true when there is insufficient experience, time, or other outside pressures that may preclude correct decisions. Put simply, sometimes we chose well, and sometimes we don't

Finally, there are occasions when a problem is not well understood, and formal procedures and response options are not available It is during these ill-defined situations that the invention of a novel solution is required. In a sense, individuals find themselves where no one has been before, and in many ways, must literally fly by the seats of their pants. Individuals placed in this situation must resort to slow and effortful reasoning processes where time is a luxury rarely afforded Not surprisingly, while this type of decision making is more infrequent then other forms, the relative proportion of problem-solving errors committed is markedly higher

*Perceptual errors* Not unexpectedly, when one's perception of the world differs from reality, errors can, and often do, occur Typically, perceptual errors occur when sensory input is degraded or "unusual," as is the case with visual illusions and spatial disorientation or when aircrew simply misjudge the aircraft's altitude, attitude, or airspeed (Table 1). Visual illusions, for example, occur when the brain tries to "fill in the gaps" with what it feels belongs in a visually impoverished environment, like that seen at night or when flying in adverse weather. Likewise, spatial disorientation occurs when the vestibular system cannot resolve one's orientation in space and therefore makes a "best guess" — typically when visual (horizon) cues are absent at night or when flying in adverse weather. In either event, the unsuspecting individual often is left to make a decision that is based on faulty information and the potential for committing an error is elevated.

It is important to note, however, that it is not the illusion or disorientation that is classified as a perceptual error. Rather, it is the pilot's erroneous response to the illusion or disorientation For example, many unsuspecting pilots have experienced "black-hole" approaches, only to fly a perfectly good aircraft into the terrain or water This continues to occur, even though it is well known that flying at night over dark, featureless terrain (e g., a lake or field devoid of trees), will produce the illusion that the aircraft is actually higher than it is. As a result, pilots are taught to rely on their primary instruments, rather than the outside world, particularly during the approach phase of flight. Even so, some pilots fail to monitor their instruments when flying at night. Tragically, these aircrew and others who have been fooled by illusions and other disorientating flight regimes may end up involved in a fatal aircraft accident.

### Violations

By definition, errors occur within the rules and regulations espoused by an organization; typically dominating most accident databases In contrast, violations represent a willful disregard for the rules and regulations that govern safe flight and, fortunately, occur much less frequently since they often involve fatalities (Shappell et al , 1999b).

While there are many ways to distinguish between types of violations, two distinct forms have been identified, based on their etiology, that will help the safety professional when identifying accident causal factors. The first, routine violations, tend to be habitual by nature and often tolerated by governing authority (Reason, 1990). Consider, for example, the individual who drives consistently 5-10 mph faster than allowed by law or someone who routinely flies in marginal weather when authorized for visual meteorological conditions only While both are certainly against the governing regulations, many others do the same thing. Furthermore, individuals who drive 64 mph in a 55 mph zone, almost always drive 64 in a 55 mph zone. That is, they "routinely" violate the speed limit. The same can typically be said of the pilot who routinely flies into marginal weather.

What makes matters worse, these violations (commonly referred to as "bending" the rules) are often tolerated and, in effect, sanctioned by supervisory authority (i.e., you're not likely to get a traffic citation until you exceed the posted speed limit by more than 10 mph). If, however, the local authorities started handing out traffic citations for exceeding the speed limit on the highway by 9 mph or less (as is often done on military installations), then it is less likely that individuals would violate the rules Therefore, by definition, if a routine violation is identified, one must look further up the supervisory chain to identify those individuals in authority who are not enforcing the rules.

On the other hand, unlike routine violations, exceptional violations appear as isolated departures from authority, not necessarily indicative of individual's typical behavior pattern nor condoned by management (Reason, 1990). For example, an isolated instance of driving 105 mph in a 55 mph zone is considered an exceptional violation. Likewise, flying under a bridge or engaging in other prohibited maneuvers, like low-level canyon running, would constitute an exceptional violation However, it is important to note that, while most exceptional violations are appalling, they are not considered "exceptional" because of their extreme nature. Rather, they are considered exceptional because they are neither typical of the individual nor condoned by authority. Still, what makes exceptional violations particularly difficult for any organization to deal with is that they are not indicative of an individual's behavioral repertoire and, as such, are particularly difficult to predict. In fact, when individuals are confronted with evidence of their dreadful behavior and asked to explain it, they are often left with little explanation. Indeed, those individuals who survived such excursions from the norm clearly knew that, if caught, dire consequences would follow. Still, defying all logic, many otherwise model citizens have been down this potentially tragic road.

### Preconditions for Unsafe Acts

Arguably, the unsafe acts of pilots can be directly linked to nearly 80 % of all aviation accidents However, simply focusing on unsafe acts is like focusing on a fever without understanding the underlying disease causing it Thus, investigators must dig deeper into why the unsafe acts took place. As a first step, two major subdivisions of unsafe aircrew conditions were developed. substandard conditions of operators and the substandard practices they commit (Figure 3).

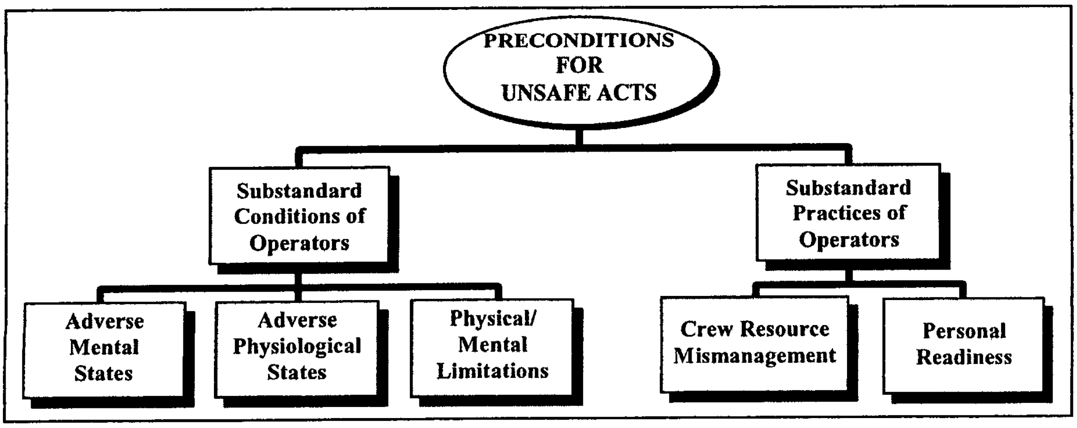

**Figure 3.** *Categories of preconditions of unsafe acts.*

### Substandard Conditions of Operators

*Adverse mental states* Being prepared mentally is critical in nearly every endeavor, but perhaps even more so in aviation. As such, the category of Adverse Mental States was created to account for those mental conditions that affect performance (Table 2). Principal among these are the loss of situational awareness, task fixation, distraction, and *mental* fatigue due to sleep loss or other stressors Also included in this category are personality traits and pernicious attitudes such as overconfidence, complacency, and misplaced motivation.

Predictably, if an individual is mentally tired for whatever reason, the likelihood increase that an error will occur. In a similar fashion, overconfidence and other pernicious attitudes such as arrogance and impulsivity will influence the likelihood that a violation will be committed. Clearly then, any framework of human error must account for preexisting adverse mental states in the causal chain of events

*Adverse physiological states* The second category, adverse physiological states, refers to those medical or physiological conditions that preclude safe operations (Table 2) Particularly important to aviation are such conditions as visual illusions and spatial disorientation as described earlier, as well as *physical* fatigue, and the myriad of pharmacological and medical abnormalities known to affect performance.

The effects of visual illusions and spatial disorientation are well known to most aviators. However, less well known to aviators, and often overlooked are the effects on cockpit performance of simply being ill Nearly all of us have gone to work ill, dosed with over-the-counter medications, and have generally performed well. Consider however, the pilot suffering from the common head cold. Unfortunately, most aviators view a head cold as only a minor inconvenience that can be easily remedied using over-the counter antihistamines, acetaminophen, and other non-prescription pharmaceuticals. In fact, when

**TABLE 2.** Selected examples of Unsafe Aircrew Conditions (Note: This is not a complete listing)

| SUBSTANDARD CONDITIONS OF OPERATORS | SUBSTANDARD PRACTICE OF OPERATORS |
|---|---|
| **Adverse Mental States** | **Crew Resource Management** |
| Channelized attention | Failed to back-up |
| Complacency | Failed to communicate/coordinate |
| Distraction | Failed to conduct adequate brief |
| Mental fatigue | Failed to use all available resources |
| Get-home-itis | Failure of leadership |
| Haste | Misinterpretation of traffic calls |
| Loss of situational awareness | **Personal Readiness** |
| Misplaced motivation | Excessive physical training |
| Task saturation | Self-medicating |
| **Adverse Physiological States** | Violation of crew rest requirement |
| Impaired physiological state | Violation of bottle-to-throttle requirement |
| Medical illness | |
| Physiological incapacitation | |
| Physical fatigue | |
| **Physical/Mental Limitation** | |
| Insufficient reaction time | |
| Visual limitation | |
| Incompatible intelligence/aptitude | |
| Incompatible physical capability | |

confronted with a stuffy nose, aviators typically are only concerned with the effects of a painful sinus block as cabin altitude changes. Then again, it is not the overt symptoms that local flight surgeons are concerned with. Rather, it is the accompanying inner ear infection and the increased likelihood of spatial disorientation when entering instrument meteorological conditions that is alarming - not to mention the side-effects of antihistamines, fatigue, and sleep loss on pilot decision-making. Therefore, it is incumbent upon any safety professional to account for these sometimes subtle medical conditions within the causal chain of events.

*Physical/Mental Limitations.* The third, and final, substandard condition involves individual physical/ mental limitations (Table 2). Specifically, this category refers to those instances when mission requirements exceed the capabilities of the individual at the controls. For example, the human visual system is severely limited at night; yet, like driving a car, drivers do not necessarily slow down or take additional precautions. In aviation, while slowing down isn't always an option, paying additional attention to basic flight instruments and increasing one's vigilance will often increase the safety margin. Unfortunately, when precautions are not taken, the result can be catastrophic, as pilots will often fail to see other aircraft, obstacles, or power lines due to the size or contrast of the object in the visual field.

Similarly, there are occasions when the time required to complete a task or maneuver exceeds an individual's capacity. Individuals vary widely in their ability to process and respond to information. Nevertheless, good pilots are typically noted for their ability to respond quickly and accurately. It is well documented, however, that if individuals are required to respond quickly (i.e., less time is available to consider all the possibilities or choices thoroughly), the probability of making an error goes up markedly. Consequently, it should be no surprise that when faced with the need for rapid processing and reaction times, as is the case in most aviation emergencies, all forms of error would be exacerbated.

In addition to the basic sensory and information processing limitations described above, there are at least two additional instances of physical/mental limitations that need to be addressed, albeit they are often overlooked by most safety professionals. These limitations involve individuals who simply are not compatible with aviation, because they are either unsuited physically or do not possess the aptitude to fly. For example, some individuals simply don't have the physical strength to operate in the potentially high-G environment of aviation, or for anthropometric reasons, simply have difficulty reaching the controls. In other words, cockpits have traditionally not been designed with all shapes, sizes, and physical abilities in mind. Likewise, not everyone has the mental ability or aptitude for flying aircraft Just as not all of us can be concert pianists or NFL linebackers, not everyone has the innate ability to pilot an aircraft – a vocation that requires the unique ability to make decisions quickly and respond accurately in life threatening situations. The difficult task for the safety professional is identifying whether aptitude might have contributed to the accident causal sequence.

**Substandard Practices of Operators**

Clearly then, numerous substandard conditions of operators can, and do, lead to the commission of unsafe acts. Nevertheless, there are a number of things that we do to ourselves that set up these substandard conditions. Generally speaking, the substandard practices of operators can be summed up in two categories: crew resource mismanagement and personal readiness

*Crew Resource Mismanagement.* Good communication skills and team coordination have been the mantra of industrial/organizational and personnel psychology for decades. Not surprising then, crew resource management has been a cornerstone of aviation for the last few decades (Helmreich & Foushee, 1993). As a result, the category of crew resource mismanagement was created to account for occurrences of poor coordination among personnel. Within the context of aviation, this includes coordination both within and between aircraft with air traffic control facilities and maintenance control, as well as with facility and other support personnel as necessary. But aircrew coordination does not stop with the aircrew in flight. It also includes coordination before and after the flight with the brief and debrief of the aircrew.

It is not difficult to envision a scenario where the lack of crew coordination has led to confusion and poor decision making in the cockpit, resulting in an accident In fact, aviation accident databases are replete with instances of poor coordination among aircrew. One of the more tragic examples was the crash of a civilian airliner at night in the Florida Everglades in 1972 as the crew was busily trying to troubleshoot what amounted to a burnt out indicator light. Unfortunately, no one in the cockpit was monitoring the aircraft's altitude as the altitude hold was inadvertently disconnected Ideally, the crew would have coordinated the trouble-shooting task ensuring that at least one crewmember was monitoring basic flight instruments and "flying" the aircraft. Tragically, this was not the case, as they entered a slow, unrecognized, descent into the everglades resulting in numerous fatalities

*Personal Readiness.* In aviation, or for that matter in any occupational setting, individuals are expected to show up for work ready to perform at optimal levels Nevertheless, in aviation as in other professions, personal readiness failures occur when individuals fail to prepare physically or mentally for duty. For instance, violations of crew rest requirements, bottle-to-brief rules, and self-medicating all will affect performance on the job and are particularly detrimental in the aircraft. It is not hard to imagine that, when individuals violate crew rest requirements, they run the risk of mental fatigue and other adverse mental states, which ultimately lead to errors and accidents. Note however, that violations that affect personal readiness are not considered "unsafe act, violation" since they typically do not happen in the cockpit, nor are they necessarily active failures with direct and immediate consequences.

Still, not all personal readiness failures occur as a result of violations of governing rules or regulations. For example, running 10 miles before piloting an aircraft may not be against any existing regulations, yet it may impair the physical and mental capabilities of the individual enough to degrade performance and elicit unsafe acts. Likewise, the traditional "candy bar and coke" lunch of the modern businessman may sound good but may not be sufficient to sustain performance in the rigorous environment of aviation While there may be no rules governing such behavior, pilots must use good judgment when deciding whether they are "fit" to fly an aircraft.

### Unsafe Supervision

Recall that in addition to those causal factors associated with the pilot/operator, Reason (1990) traced the causal chain of events back up the supervisory chain of command. As such, we have identified four categories of unsafe supervision: inadequate supervision, planned inappropriate operations, failure to correct a known problem, and supervisory violations (Figure 4) Each is described briefly below.

*Inadequate Supervision.* The role of any supervisor is to provide the opportunity to succeed To do this, the supervisor, no matter at what level of operation, must provide guidance, training opportunities, leadership, and motivation, as well as the proper role model to be emulated. Unfortunately, this is not always the case. For example, it is not difficult to conceive of a situation where adequate crew resource management training was either not provided, or the opportunity to attend such training was not afforded to a particular aircrew member. Conceivably, aircrew coordination skills would be compromised and if the aircraft were put into an adverse situation (an emergency for instance), the risk of an error being committed would be exacerbated and the potential for an accident would increase markedly.

In a similar vein, sound professional guidance and oversight is an essential ingredient of any successful organization. While empowering individuals to make decisions and function independently is certainly essential, this does not divorce the supervisor from accountability. The lack of guidance and oversight

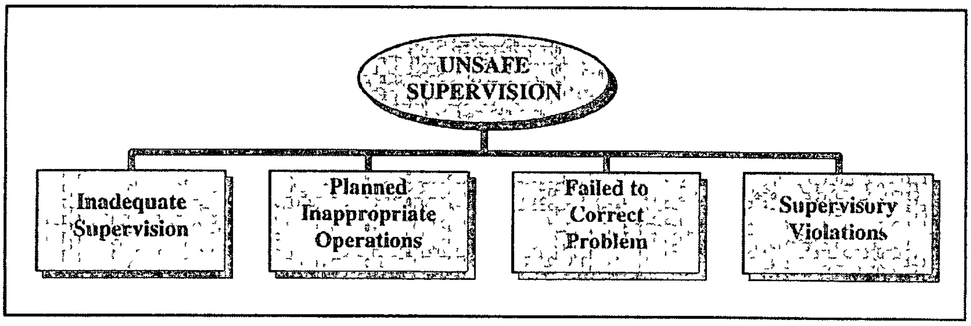

Figure 4 Categories of unsafe supervision.

has proven to be the breeding ground for many of the violations that have crept into the cockpit. As such, any thorough investigation of accident causal factors must consider the role supervision plays (i.e., whether the supervision was inappropriate or did not occur at all) in the genesis of human error (Table 3).

*Planned Inappropriate Operations.* Occasionally, the operational tempo and/or the scheduling of aircrew is such that individuals are put at unacceptable risk, crew rest is jeopardized, and ultimately performance is adversely affected. Such operations, though arguably unavoidable during emergencies, are unacceptable during normal operations. Therefore, the second category of unsafe supervision, planned inappropriate operations, was created to account for these failures (Table 3).

Take, for example, the issue of improper crew pairing. It is well known that when very senior, dictatorial captains are paired with very junior, weak co-pilots, communication and coordination problems are likely to occur. Commonly referred to as the trans-cockpit authority gradient, such conditions likely contributed to the tragic crash of a commercial airliner into the Potomac River outside of Washington, DC, in January of 1982 (NTSB, 1982). In that accident, the captain of the aircraft repeatedly rebuffed the first officer when the latter indicated that the engine instruments did not appear normal. Undaunted, the captain continued a fatal takeoff in icing conditions with less than adequate takeoff thrust The aircraft stalled and plummeted into the icy river, killing the crew and many of the passengers.

Clearly, the captain and crew were held accountable. They died in the accident and cannot shed light on causation; but, what was the role of the supervisory chain? Perhaps crew pairing was equally responsible. Although not specifically addressed in the report, such issues are clearly worth exploring in many accidents. In fact, in that particular accident, several other training and manning issues were identified.

*Failure to Correct a Known Problem.* The third category of known unsafe supervision, Failed to Correct a Known Problem, refers to those instances when deficiencies among individuals, equipment, training or other related safety areas are "known" to the supervisor, yet are allowed to continue unabated (Table 3). For example, it is not uncommon for accident investigators to interview the pilot's friends, colleagues, and supervisors after a fatal crash only to find out that they "knew it would happen to him some day." If the supervisor knew that a pilot was incapable of flying safely, and allowed the flight anyway, he clearly did the pilot no favors. The failure to correct the behavior, either through remedial training or, if necessary, removal from flight status, essentially signed the pilot's death warrant - not to mention that of others who may have been on board.

**TABLE 3.** Selected examples of Unsafe Supervision (Note: This is not a complete listing)

**Inadequate Supervision**
- Failed to provide guidance
- Failed to provide operational doctrine
- Failed to provide oversight
- Failed to provide training
- Failed to track qualifications
- Failed to track performance

**Planned Inappropriate Operations**
- Failed to provide correct data
- Failed to provide adequate brief time
- Improper manning
- Mission not in accordance with rules/regulations
- Provided inadequate opportunity for crew rest

**Failed to Correct a Known Problem**
- Failed to correct document in error
- Failed to identify an at-risk aviator
- Failed to initiate corrective action
- Failed to report unsafe tendencies

**Supervisory Violations**
- Authorized unnecessary hazard
- Failed to enforce rules and regulations
- Authorized unqualified crew for flight

Likewise, the failure to consistently correct or discipline inappropriate behavior certainly fosters an unsafe atmosphere and promotes the violation of rules. Aviation history is rich with by reports of aviators who tell hair-raising stories of their exploits and barnstorming low-level flights (the infamous "been there, done that"). While entertaining to some, they often serve to promulgate a perception of tolerance and "one-up-manship" until one day someone ties the low altitude flight record of ground-level! Indeed, the failure to report these unsafe tendencies and initiate corrective actions is yet another example of the failure to correct known problems

*Supervisory Violations* Supervisory violations, on the other hand, are reserved for those instances when existing rules and regulations are willfully disregarded by supervisors (Table 3). Although arguably rare, supervisors have been known occasionally to violate the rules and doctrine when managing their assets. For instance, there have been occasions when individuals were permitted to operate an aircraft without current qualifications or license. Likewise, it can be argued that failing to enforce existing rules and regulations or flaunting authority are also violations at the supervisory level While rare and possibly difficult to cull out, such practices are a flagrant violation of the rules and invariably set the stage for the tragic sequence of events that predictably follow.

### Organizational Influences

As noted previously, fallible decisions of upper-level management directly affect supervisory practices, as well as the conditions and actions of operators. Unfortunately, these organizational errors often go unnoticed by safety professionals, due in large part to the lack of a clear framework from which to investigate them. Generally speaking, the most elusive of latent failures revolve around issues related to resource management, organizational climate, and operational processes, as detailed below in Figure 5.

*Resource Management* This category encompasses the realm of corporate-level decision making regarding the allocation and maintenance of organizational assets such as human resources (personnel), monetary assets, and equipment/facilities (Table 4) Generally, corporate decisions about how such resources should be managed center around two distinct objectives – the goal of safety and the goal of on-time, cost-effective operations In times of prosperity, both objectives can be easily balanced and satisfied in full However, as we mentioned earlier, there may also be times of fiscal austerity that demand some give and take between the two. Unfortunately, history tells us that safety is often the loser in such battles and, as some can attest to very well, safety and training are often the first to be cut in organizations having financial difficulties. If cutbacks in such areas are too severe, flight proficiency may suffer, and the best pilots may leave the organization for greener pastures

Excessive cost-cutting could also result in reduced funding for new equipment or may lead to the purchase of equipment that is sub optimal and inadequately designed for the type of operations flown by the company Other trickle-down effects include poorly maintained equipment and workspaces, and the failure to correct known design flaws in existing equipment. The result is a scenario involving unseasoned, less-skilled pilots flying old and poorly maintained aircraft under the least desirable conditions and schedules. The ramifications for aviation safety are not hard to imagine.

*Climate.* Organizational Climate refers to a broad class of organizational variables that influence worker performance. Formally, it was defined as the "situationally based consistencies in the organization's treatment of individuals" (Jones, 1988). In general, however, organizational climate can be viewed as the working atmosphere within the organization. One telltale sign of an organization's climate is its structure,

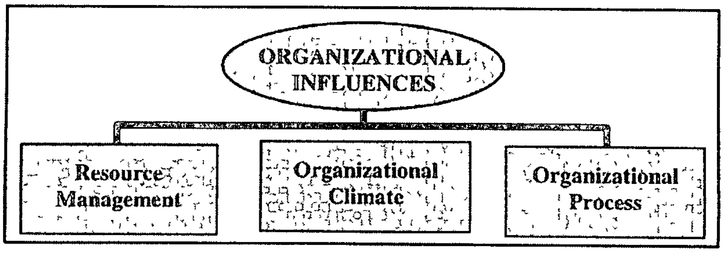

**Figure 5**. *Organizational factors influencing accidents*

**TABLE 4.** Selected examples of Organizational Influences (Note: This is not a complete listing)

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- **Resource/Acquisition Management**
  - Human Resources
    - Selection
    - Staffing/manning
    - Training
  - Monetary/budget resources
    - Excessive cost cutting
    - Lack of funding
  - Equipment/facility resources
    - Poor design
    - Purchasing of unsuitable equipment
- **Organizational Climate**
  - Structure
    - Chain-of-command
    - Delegation of authority
    - Communication
    - Formal accountability for actions
  - Policies
    - Hiring and firing
    - Promotion
    - Drugs and alcohol
  - Culture
    - Norms and rules
    - Values and beliefs
    - Organizational justice
- **Organizational Process**
  - Operations
    - Operational tempo
    - Time pressure
    - Production quotas
    - Incentives
    - Measurement/appraisal
    - Schedules
    - Deficient planning
  - Procedures
    - Standards
    - Clearly defined objectives
    - Documentation
    - Instructions
  - Oversight
    - Risk management
    - Safety programs

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as reflected in the chain-of-command, delegation of authority and responsibility, communication channels, and formal accountability for actions (Table 4). Just like in the cockpit, communication and coordination are vital within an organization If management and staff within an organization are not communicating, or if no one knows who is in charge, organizational safety clearly suffers and accidents do happen (Muchinsky, 1997).

An organization's policies and culture are also good indicators of its climate. Policies are official guidelines that direct management's decisions about such things as hiring and firing, promotion, retention, raises, sick leave, drugs and alcohol, overtime, accident investigations, and the use of safety equipment. Culture, on the other hand, refers to the unofficial or unspoken rules, values, attitudes, beliefs, and customs of an organization. Culture is "the way things really get done around here."

When policies are ill-defined, adversarial, or conflicting, or when they are supplanted by unofficial rules and values, confusion abounds within the organization. Indeed, there are some corporate managers who are quick to give "lip service" to official safety policies while in a public forum, but then overlook such policies when operating behind the scenes. However, the Third Law of Thermodynamics tells us that, "order and harmony cannot be produced by such chaos and disharmony". Safety is bound to suffer under such conditions.

*Operational Process* This category refers to corporate decisions and rules that govern the everyday activities within an organization, including the establishment and use of standardized operating procedures and formal methods for maintaining checks and balances (oversight) between the workforce and management. For example, such factors as operational tempo, time pressures, incentive systems, and work schedules are all factors that can adversely affect safety (Table 4). As stated earlier, there may be instances when those within the upper echelon of an organization determine that it is necessary to increase the operational tempo to a point that overextends a supervisor's staffing capabilities. Therefore, a supervisor may resort to the use of inadequate scheduling procedures that jeopardize crew rest and produce sub optimal crew pairings, putting aircrew at an increased risk of a mishap However, organizations should have official procedures in place to address such contingencies as well as oversight programs to monitor such risks.

Regrettably, not all organizations have these procedures nor do they engage in an active process of monitoring aircrew errors and human factor problems via anonymous reporting systems and safety audits As such, supervisors and managers are often unaware of the problems before an accident occurs Indeed, it has been said that "an accident is one incident to many" (Reinhart, 1996). It is incumbent upon any organization to fervently seek out the "holes in the cheese" and plug them up, before they create a window of opportunity for catastrophe to strike

## CONCLUSION

It is our belief that the Human Factors Analysis and Classification System (HFACS) framework bridges the gap between theory and practice by providing investigators with a comprehensive, user-friendly tool for identifying and classifying the human causes of aviation accidents. The system, which is based upon Reason's (1990) model of latent and active failures (Shappell & Wiegmann, 1997a), encompasses all aspects of human error, including the conditions of operators and organizational failure. Still, HFACS and any other framework only contributes to an already burgeoning list of human error taxonomies if it does not prove useful in the operational setting. In these regards, HFACS has recently been employed by the U.S. Navy, Marine Corps, Army, Air Force, and Coast Guard for use in aviation accident investigation and analysis. To date, HFACS has been applied to the analysis of human factors data from approximately 1,000 military aviation accidents. Throughout this process, the reliability and content validity of HFACS has been repeatedly tested and demonstrated (Shappell & Wiegmann, 1997c).

Given that accident databases can be reliably analyzed using HFACS, the next logical question is whether anything unique will be identified Early indications within the military suggest that the HFACS framework has been instrumental in the identification and analysis of global human factors safety issues (e.g., trends in aircrew proficiency, Shappell, et al , 1999), specific accident types (e.g , controlled flight into terrain, CFIT; Shappell & Wiegmann, 1997b), and human factors problems such as CRM failures (Wiegmann & Shappell, 1999). Consequently, the systematic application of HFACS to the analysis of human factors accident data has afforded the U S Navy/Marine Corps (for which the original taxonomy was developed) the ability to develop objective, data-driven intervention strategies. In a sense, HFACS has illuminated those areas ripe for intervention rather than relying on individual research interests not necessarily tied to saving lives or preventing aircraft losses.

Additionally, the HFACS framework and the insights gleaned from database analyses have been used to develop innovative accident investigation methods that have enhanced both the quantity and quality of the human factors information gathered during accident investigations. However, not only are safety professionals better suited to examine human error in the field but, using HFACS, they can now track those areas (*the holes in the cheese*) responsible for the accidents as well. Only now is it possible to track the success or failure of specific intervention programs designed to reduce specific types of human error and subsequent aviation accidents. In so doing, research investments and safety programs can be either readjusted or reinforced to meet the changing needs of aviation safety.

Recently, these accident analysis and investigative techniques, developed and proven in the military, have been applied to the analysis and investigation of U.S. civil aviation accidents (Shappell & Wiegmann, 1999). Specifically, the HFACS framework is currently being used to systematically analyze both commercial and General Aviation accident data to explore the underlying human factors problems associated with these events. The framework is also being employed to develop improved methods and techniques for investigating human factors issues during actual civil aviation accident investigations by Federal Aviation Administration and National Transportation Safety Board officials. Initial results of this project have begun to highlight human factors areas in need of further safety research. In addition, like their military counterparts, it is anticipated that HFACS will provide the fundamental information and tools needed to develop a more effective and accessible human factors accident database for civil aviation.

In summary, the development of the HFACS framework has proven to be a valuable first step in the establishment of a larger military and civil aviation safety program. The ultimate goal of this, and any other, safety program is to reduce the aviation accident rate through systematic, data-driven investment.

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