# 惡劣天氣及其對飛航安全的影響

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## 簡介

客機遭遇惡劣天氣案例似乎有增加的趨勢，造成機體損傷，最壞的幾次案例造成飛機及生命的損失。風暴頻率及威力增強，可能與最近氣候變化有關，對這議題仍在持續研究當中。

近年有兩次重大事故，機上的乘客均全數罹難，熱帶地區的惡劣天氣在這兩起事件中扮演重要的角色。最近的一起是2014年7月14日在馬里的一架Swiftair MD83，另一起是2009年6月1日墜毀大西洋的法航A330，而惡劣天氣正是這兩起意外的肇因，雖然機型不同，但都依賴於自動化飛行，且機組人員經驗都很豐富（A330為heavy crew，有3位飛行員值勤）。

關於兩起事故的肇因的有些類似之處：

・兩架飛機穿越中尺度對流系統（MCS）。
・事故都發生在晚上。
・飛行組員無法將飛機從惡劣天氣（積冰）造成的失速情況中恢復。
・飛行監測均無疏忽。

此外，在2014年12月28日亞航編號QZ8501班機在卡

**尋獲法航447的垂直尾翼**

里馬塔海峽失蹤，雖然最終的事故調查報告尚未公佈，但惡劣天氣可能是一個重要因素。

## 惡劣天氣預報監測與通報

惡劣天氣包括多種類影響飛行安全的天氣現象，從相對溫和的霧，到在熱帶地區常見的爆發性對流風暴。在極端情況下，這些風暴能產生向上和向下的氣流，遠遠超過一架客機的爬升性能，而其頂部的有時達到60000英尺，

甚至有些較小的風暴沒有發展到一般的巡航高度，但它產生的晴空亂流和高空風切仍會造成不良影響，要在這樣的天氣形態下成功引導航機，有賴於飛航簽派員、飛航管制員和飛行機組員的共同努力，各類人員各自有一組不同的經驗和資料：飛航簽派員能夠預先得知飛行計畫航路上的天氣預報和觀測資料。

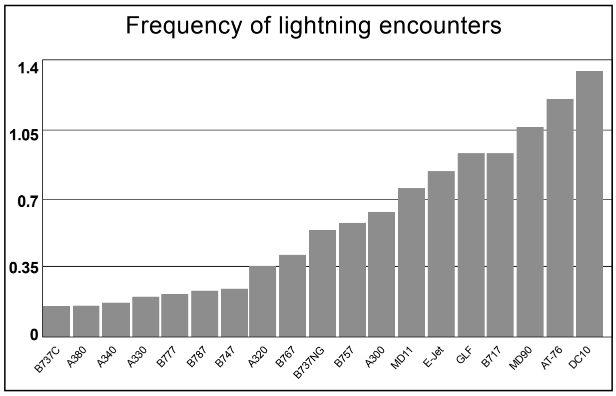
飛航管制員能夠看到他們負責區域的氣象雷達和衛星圖像，並且可以接收其他航空器所報告遭遇到的惡劣天氣情況，飛航機組員僅有有限的天氣資訊，但可以直接利用機載氣象雷達，以及雖然簡單但非常有效的以肉眼觀測天氣。

**在正前方的雷暴對流胞**


然而在一些案例中這樣的安全機制可能會失效，氣象預報可能有誤，在一些案例中，有時顯著天氣圖沒有標示壞天氣的區域，或有時標示了很大範圍的壞天氣區域使得資訊太模糊而不實用。地面與衛星天氣資料可能過期，特別是長途飛行時，簽派員使用的資訊可能是在航班抵達目的地10小時前的天氣資料；最即時的機載天氣雷達並非總是能偵測到危害天氣，它的效力有賴機組人員正確操作以提供最佳的視角。

飛機常在沒有任何預警的情況下遭遇強烈亂流，特別在南歐阿爾卑斯山。機組員設定雷達掃描角度太淺，意味著快速發展的對流不容易被雷達發覺，直到飛機接近危險時才驚覺，這造成數起導致了組員和乘客受傷的事件，阿爾卑斯山擁擠的空域加劇了這個困擾，因為避免惡劣天氣而偏航的飛機可能過於接近其他航情。管理天氣和航情帶來的雙重威脅，需要管制員和飛行機組員之間的良好溝通和規劃。

進一步的問題是，在某些情況下，對流風暴可產生寬廣、密集及以非常小的冰晶組成的雲，這些冰晶小到用



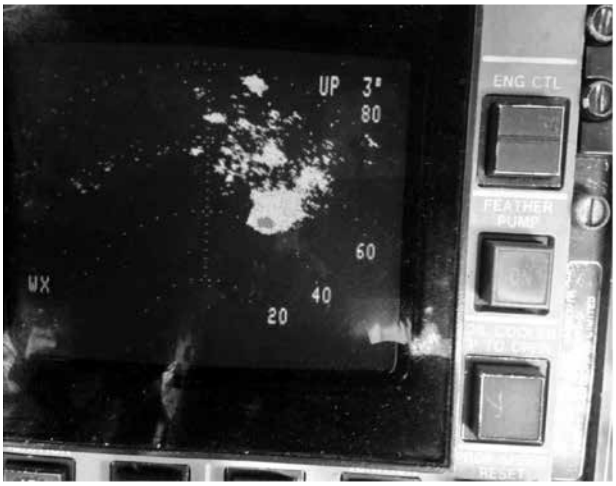

**全球所有航班依照機型分類，於 2014年3月 - 2015年5月間在航程中，飛機周圍10公里內有遭遇雷擊的百分比，牛津大學大氣海洋及地球物理系Simon Proud博士提供。**

雷達無法偵測到，並且對沒有心理準備飛行機組員造成困擾，法航447航班就是從被冰晶堵塞空速計開始，一連串的事件最後導致失事，有部分航班也受到因皮托管堵塞的不可靠空速讀數影響，其他幾架航班則經歷因發動機內部表面的積冰造成的問題。因此，雷達對惡劣天氣並分可以完全依賴萬的預警系統 - 飛行機組員在操作設定和解讀數據的技巧非常重要。

## 機組人員使用機載雷達的方法

在航行中，飛行員迴避天氣的工具僅有氣象雷達和肉眼，雷達使用和解讀對於飛行安全至關重要，每一位飛行員學習使用氣象雷達，作為他們的CPL/ MPL/ ATPL課程的一部分。然而隨著技術的改變，很難保持最新的課程。此外，飛行模擬器往往無法以天氣雷達為訓練目的，因此駕駛員所得到的資訊，受限於飛機說明手冊、訓練時的簡介或線上飛行時的經驗，且雷達變得更加自動化，對飛行員來說操作起來太簡單了，只需打開設備開關就不用管它了。

**用機載雷達探測惡劣天氣**




**對於飛行員獲取最多的資訊用於決策，並提高環境察覺能力，他們必須手動控制天氣雷達（角度、增益、範圍…等）。掃描對流活動的回波最多部分，確定其中最強的對流位置，不能只靠氣象雷達的自動模式。**

**這正是被偵測到的天氣**

在駕駛員的論壇有一些非官方線上資源和影片，可用於提昇並補充飛行員的知識。終究責任有賴個別的飛行員，要確保他們充分利用其機載雷達，知道如何使用安裝於機上的設備，並解讀這些設備提供的訊息，在沒有正式的訓練和複訓的情況下，這僅可能透過平時的飛行來練習。

同樣重要的是，是裝備的限制，有兩個主要的問題，首先，冰晶和冰雹的雷達反射率較低，使得天氣偵測在高高度的地方較困難，它基本上是掃描重要的是要掃描一個對流系統的“濕”部分來確定最活躍的區域，而這都在較低的高度被發現。但是必須理解在高高度綠色的雷達回波，可能有冰晶、冰雹和亂流等危險的情況。其次，雷達偵測範圍的適當用法及信號衰減的修正，是確保飛行員不會飛進“死胡同”或在其他活躍區“躲起來”之對流的重要資訊。利用這些資訊，駕駛員應該依據高度運用建議的側邊隔離，可能是數十海裡，並且最好是在上風處。

未來應該可預見強化的戰略和戰術工具，機組員可運用透過運作控制和監督（OCS）及即時氣象資料直接導向駕駛艙。最後，即使所有的戰略（飛行計畫/飛行守視）和戰術（雷達/即時資料/肉眼）偵測失效，飛行員可能必須採取行動減輕惡劣天氣的影響。我們看到近來大型客機在飛行中失去控制（LOC-I）的失事事件。最重要的事，所有飛行員熟悉必要的應變，然而，AF447的事故中顯示，仍有“置之不理”的地方；儘管亂流，空速計不可靠的跡象顯露出來，只是維持基準俯仰姿態和推力平飛，可使飛機安全飛行，直到機組員以檢查表診斷出問題所在。

隨著時間演進飛行模擬器逼真度會逐漸提高，將可以做不同情境飛機姿態訓練。在“bizjet”社群，一些組織已經開始使用小型軍方退役的後掠翼飛機訓練和重新體驗飛機姿態改正。近日FAA授權定期訓練商用航空器駕駛和EASA目前正在制定規則做同樣的訓練。這可能需要時間更新飛行模擬器軟體，但最近發生的意外事件顯示，避免LOC-I最重要的一項因素是避免或解除的失速的狀況。在過去的幾年中，大型商用運輸機的製造商已經更新了他們的建議和程序，面對失速的情況積極取得卸載翼，這是最好的提示。此外，在翼下發動機考慮俯仰效應和第二次失速的風險，推力不要使用預設值。一般來說，最新姿態改正建議應該是所有飛行員從基本訓練時就熟悉的，所有飛機都有自己機型的程序和特性，但最基本的是使用適當的推力，必要時鬆開操縱桿、滾轉最後恢復到水平飛行。

飛行員對於雷達的使用、雷達的限制及飛機性能有通盤的了解，以確保在動態和活躍的大氣中安全飛行。

## 運作控制和監督

如果歐洲運營商被要求遵守積極和警覺的運作控制和監督的方法，AF447與AH5017航班意外事件或許能避免。

其他國家及國際民航組織(ICAO)簽署國確實有符合國際規範的健全系統；值得注意的是這些在美國聯邦法規14 CFR Part 121和E、M、N、P、T、U小章中，明確規定了運作控制和監督的要求，標題分別是：

- 飛行簽放（起飛前）
- 飛行追蹤（航行中）

在這兩項規定所要下，飛航安全是由合格的地面上的人員計畫與監督。這包括(並非全部)適航評估，燃料需求

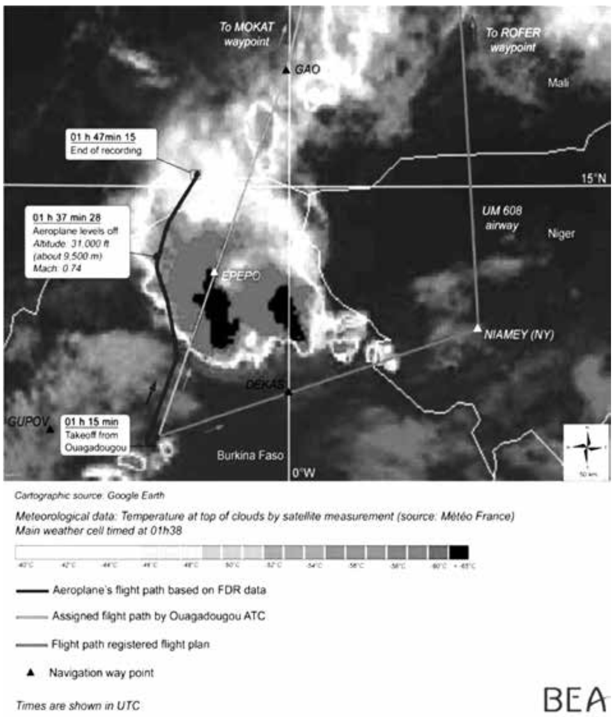
（減少備用燃油適用）、天氣觀測和預報、效能、機組員健康和避免疲勞、飛航通告及航管溝通。這監督增進飛航安全，並有助航班調度決策，但它不會影響機上駕駛作出的任何決定。

If we look at the case of AF447, active flight watch, of a flight planned to transit the Inter Tropical Convergence Zone (ITCZ), could have alerted the crew to an encounter with adverse weather of extreme convectivity on their planned route, by ground based personnel.

如果我們檢視AF447事件主動的飛行守視，航班計畫飛行穿越間熱帶輻合區（ITCZ），地面人員可能已經警告機組員可能在計畫航路上遭遇極端惡劣對流天氣。

在AH5017事件中，起飛航路（SID）被瓦加杜古(布吉納法索)管制員從計畫的 Niamey(NY)到ROFER改為由EPOPO到GAO。這直接把AH5017送進中尺度對流系統，雖然雷達導引他繞過一個對流胞，但這偏航並不足以避免由對流胞引起的亂流。這航班受限於航班簽放系統，航路改變沒有運行控制中心（飛行簽派）的批准無法被允許。

在歐洲沒有像FAA系統這樣的運行監督的系統，並且也沒規定敘述有關作業單位應該如何遵守作業管制和監管




**法國航空失事調查局(BEA) AH5017中期報告提供**

要求的“航班的啟動、延續、終止和改道”，請見EASA AIR OPS Znnex III AMC1 ORO.GEN.110（C），以及對這規則的矛盾：

## GM1 ORO.GEN.110(c)作業責任

**作業控制**

(a) ORO.GEN.110(c) 並不意味認證飛航簽派員或全程飛航守視系統的需求?

諷刺的是2014年1月EASA的意見“修訂飛行記錄器和水下定位設備要求”與偵測座艙語音飛航資料記錄器(CVFDR) 有關，然而並不關心缺乏監督方法，這不但可能避免損失一個航班，並且在最小15分鐘的時間間隔內追蹤它的實際位置。

AF447在南大西洋已經失蹤兩年，AH5027在撒哈拉大沙漠失蹤23個小時；而MH370自2014年3月8日仍下落不明。

## 總結

最近一些備受矚目的事件和事故，遭遇惡劣天氣可能是重要因素。為了讓操作員及飛行員在面對惡劣的天氣時能做出最好的判斷，他們需要多層的防禦系統，包括戰略（飛行計畫/飛行守視）和戰術（雷達/即時資料/航管協助）以及肉眼作為最後的手段。對於機組員，經常性天氣雷達操作訓練可以提高利用這寶貴工具的信心，並且面臨惡劣天氣時更警覺。雷達不是“統包方案”，需要加強對雷達知識及其最佳設定，才能正確解讀雷達所顯示的天氣。同樣重要的是，隨著技術改進必須訓練及更新明瞭雷達使用限制。同時無論是在基礎訓練、複訓和換裝給證都更加重視傳統飛行員的應變技巧，當機組員發現在航行中遭遇天氣而感到不安時，這將會很有價值。

目前的歐盟法規已有輕量的運作控制和監督，強化運作監督，類似於美國聯邦法規Part 121的一個徹底的手段，也許透過ACARS提供最新的天氣資訊，這對長途航班特別重要，因為航路天氣可能已與飛行計畫時的預報有顯著的不同。此外，這種運作監督的方法對於最壞情況，搜索一架“消失”的班機可能有所助益。

當空域變得日益擁擠，遭遇天氣的機會可能增加，部分原因是缺乏替代航路。我們認為除了加強飛行員訓練外，更多的運作監督可能會在某種程度上緩解此風險。

*譯自Air Safety Group 2015年九月*

# Adverse Weather and its Effects on Air Safety

Air Safety Group Sep

**Courtesy of Capt. Michael**

## Introduction

Airliners versus adverse weather encounters appear to be increasing, with resulting damage to airframes and, in the worst cases, loss of the aeroplane and life. The increased frequency and convective violence associated with storm clouds, of late, may be associated with climate change and research on this subject continues.

In recent years there have been two major accidents, both with loss of life to all on-board, in which adverse weather in the tropics has played a role. The most recent was a Swiftair MD83 on the 14th July 2014, in Mali and the other was an Air France A330 on the 1st June 2009 that crashed into the Atlantic Ocean. Adverse weather was a causal factor in both accidents. Though the aeroplane types differed, both relied on automatics for managed flight and the flight crew were experienced (heavy crew, 3 pilots on the A330).

There are similarities with regards to the causal factors in both accidents:

- Both aeroplanes penetrated mesoscale convective systems (MCS).
- Both accidents were at night.
- Both accidents were caused by the flight crew's inability to recover from a stall situation induced by adverse weather (Icing - ICI).
- Neither flight was subjected to a regulatory and administered flight watch oversight.

**Recovery of the vertical stabiliser AF447**

*Additionally, on the 28th December 2014 Air Asia flight QZ8501 was lost in the Karimata Straights and though a final accident investigation report is yet to be published, adverse weather may have been a contributory factor*

## Adverse Weather Forecasting Detection and Notification

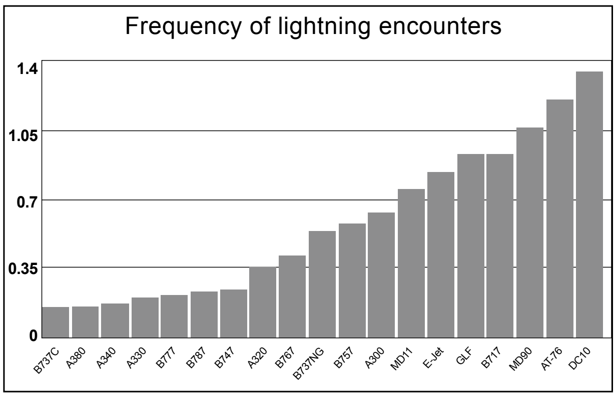
Adverse weather is a catchall for a large variety of atmospheric phenomenon that can affect the safety of a flight. These range from the relatively benign, such as fog, to the explosively energetic convective storms that are commonplace in the tropics. In extreme cases, these storms can produce up- and down-drafts that far exceed the climb performance of an airliner whilst their tops sometimes reach 60,000ft. Even smaller storms that do not reach typical cruise altitudes can produce ill effects through clear air turbulence and high altitude wind shear. Successfully navigating such weather relies on a concerted effort from flight planners, Air Traffic Controllers (ATC) and the flight crew themselves. Each of these groups has access to a distinct set of experience and data: Planners will be able to access weather forecasts and observations that can indicate likely conditions along a planned route.

ATC may be able to see weather radar or satellite images for their sector and they will receive reports from other aircraft that encounter adverse weather conditions. Flight crews have limited external weather information but can make direct observations of conditions using the on-board weather radar as well as simple, but often very effective, visual observations.


In some cases, this safety mechanism can break down, though. Weather forecasts can be wrong, in some cases the 'significant weather' charts miss regions of bad weather while at other times they may show such large regions of bad weather as to be too vague to be practicable. Ground and satellite-based weather data can be out-of-date, particularly in the case of long-haul flights: The weather information used by the flight planners may be 10 hours old by the time an aircraft is close to its destination. Lastly, on-board weather radar does not always detect adverse weather: Its efficacy relies upon the flight crew correctly manipulating the radar settings to provide an optimum view of the conditions ahead.

A common occurrence, particularly south of the European Alps, is for an aircraft to encounter heavy turbulence without any warning. The crew using a radar tilt setting that is too shallow, meaning that rapidly building convection is not seen by radar until the aircraft is dangerously close to it, often causes these surprise encounters. This has, in a number of cases, led to crew and passenger injuries. For some regions, such as the Alps, the problem is exacerbated by the congested airspace: Deviating to avoid bad weather may bring an aircraft too close to other traffic. Managing the dual threat posed by weather and traffic requires good communication and planning between ATC and flight crews.

**The percentage of all flights (global), subdivided by aircraft type that passed within 10km of a lightning strike. Measured during March 2014 – May 2015. Courtesy of Dr Simon Proud, AOPP, University of Oxford.**



A further problem is that, in some cases, convective storms can produce broad, dense, clouds composed of very small ice crystals – too small to be detected by radar. The crystals are, however, still capable of causing difficulties for the unprepared flight crew. The chain of events that resulted in the loss of Air France flight 447 began with airspeed sensors obstructed by ice crystals. Several other flights have also suffered from unreliable airspeed due to pitot tube obstruction whilst others have experienced engine difficulties caused by ice crystals building up on internal surfaces. Radar, therefore, cannot be relied upon to be a foolproof warning system for bad weather – the skill of the flight crew in manipulating its settings and interpreting the data it displays is vitally important.

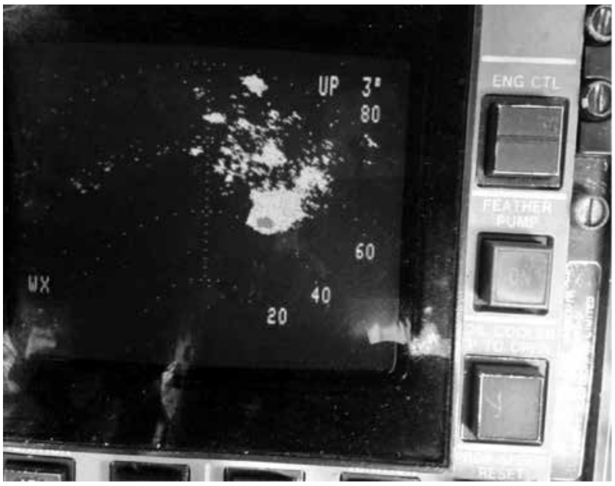
## Use of Airborne Radar by Aircrew

In flight, the only equipment pilots have at their disposal for tactical weather avoidance are the on-board weather radar and the naked eye. Radar use and interpretation is vital to flight safety. Every pilot studies the use of weather radar as part of their CPL/MPL/ATPL course. However, as technologies change, it is difficult for course syllabi to remain current. Furthermore, flight simulators are often unable to replicate the weather radar for training purposes. Consequently, pilots can be limited to the information available in aircraft manuals, instruction during training or learning by osmosis during line flying. Radars themselves are becoming more automated and it is all too easy for pilots to simply switch the device on and leave it alone.

#### Storm cell right on the centre line


For pilots to maximise the information available for decision making and to enhance their situational awareness, they must manipulate the weather radar's controls (tilt, gain, range etc.). The need to scan the most reflective part of convective activity, to identify where the most intense convection can be found, cannot always be left to the automatic modes of weather radars.

#### Adverse weather detected by airborne radar




#### And this is what was detected

There are some (unofficial) online resources and videos which can be used to improve pilots' knowledge and supplement that found in operators' literature. Ultimately, responsibility lies with individual pilots to ensure that they make the most of their on-board radars, know how to use the equipment installed and understand how to interpret the information presented to them. In the absence of formal training or recurrent training, this may only be possible through regular in-flight practice.

Just as important, is understanding the limitations of the fitted equipment; there are two main issues. Firstly, the low reflectivity of ice crystals and hail can make weather detection difficult at high altitude. It is essential to scan the 'wet' part of a convective system – which will be found much lower down – to identify the most active regions. But, it must also be understood that speckled green returns at high altitude can indicate dangerous conditions with ice crystals, hail and turbulence. Secondly, appropriate use of the radar's range and an appreciation of signal attenuation are vital in ensuring that pilots do not fly down 'blind alleys' or mis-identify 'hidden' areas of convection behind other areas of activity. Using this information, pilots should apply the recommended lateral separation which, depending on altitude, can be many tens of nautical miles and should, ideally, be upwind.

The future should see enhanced strategic and tactical tools becoming available to crews via Operational Control and Supervision (OCS) and live weather data streamed direct to the flight deck. Finally, if all strategic (flight planning/flight watch) and tactical (radar/live data/visual) measures fail, pilots may have to resort to mitigating the effects of adverse weather. We have seen recent incidents of large transport aircraft suffering Loss of Control In-flight (LOC-I). It is essential that all pilots are familiar with the required responses. However, as the AF447 accident shows, there is still a place for 'sitting on our hands'; notwithstanding the turbulence, when the unreliable airspeed indications first manifested themselves, simply maintaining the datum pitch attitude and thrust setting for level flight may have kept the aircraft flying safely until the checklist allowed the crew to diagnose the problem.

In time, the fidelity of flight simulators will improve and meaningful upset training should become possible. In the 'bizjet' community, some organisations are already using small, ex-military, swept wing aircraft to train and refresh upset recoveries. Recently, the FAA mandated recurrent upset training for commercial pilots and EASA are currently going through a rule making process to do the same. This will likely require simulator software to be updated and will take time but, as recent incidents show, the single most important element in avoiding LOC-I is avoiding or exiting the aerodynamic stall. In the last few years, the manufacturers of large commercial transport aircraft have updated their advice and procedures. In terms of the stall, this is best achieved by prompt, positive action to unload the wing. Furthermore, in the case of underwing engines, thrust is not used initially due to the pitch effect and risk of a secondary stall. More generally, current upset recovery advice should be familiar to all pilots from their basic training. All aircraft have their own type- specific procedures and characteristics but the essence is to unload the wings if necessary, roll wings level and recover to level flight; thrust or power is used as appropriate.

Pilots must have a comprehensive knowledge of radar use, radar limitations, aircraft performance datums and basic recovery techniques to ensure safe flight in the dynamic and energetic atmosphere in which we operate.

## Operational Control and Supervision

The accidents involving AF447 and AH5017 flights could have been averted if European operators were required to comply with vigorous and vigilant operational control and supervision methodologies.

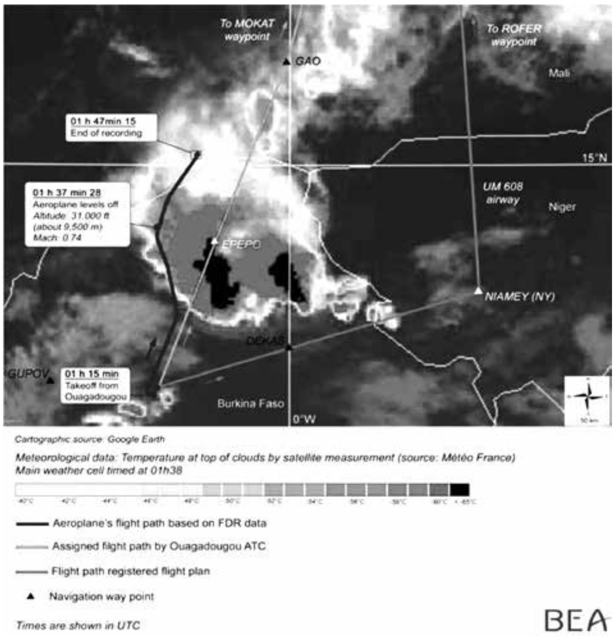
Other countries and ICAO signatories do have robust systems that are compliant with national regulations; notable amongst these is the USA with 14 CFR Part 121 and subparts E,M,N,P,T,U where the requirements for operational control and supervision is clearly defined, the high level headings of which are:

- Flight Release (Pre Flight) 121 subpart F
- Flight Following (In-Flight) 121 subpart U

Under these two headings requirements for the safety of a flight are planned and supervised by qualified people on the ground. This includes, but is not exhaustive; the assessments of airworthiness, fuel requirements (RCF as applicable), weather observed and forecast, performance, crew fitness and avoidance of fatigue, NOTAM and ATM liaison. This oversight augments the safety of a flight and assists the commander of a flight in his decision making; it does not override any decision made by the aeroplane commander.

If we look at the case of AF447, active flight watch, of a flight planned to transit the Inter Tropical Convergence Zone (ITCZ), could have alerted the crew to an encounter with adverse weather of extreme convectivity on their planned route, by ground based personnel.

In the case of AH5017 the departure routing (SID) was changed by the Ouagadougou controller from the planned Niamey (NY) ROFER, to EPOPO GAO. This routed AH5017 into the teeth of a mesoscale convective system and though radar was used to guide the flight around a highly convective storm cell, the proximity of the deviation was insufficient to avert aerodynamic upset caused by it. Had this flight been subject to a flight release system the route alteration could not have been allowed without approval of the operational control centre




**Courtesy of the BEA AH5017 Interim Report**

(flight dispatch).

In Europe we have no such operational oversight as the FAA system and no descriptive regulations as to how an operator should comply with an operational control and supervision requirement for the "Initiation, Continuation, Termination and Diversion of a flight" see EASA AIR OPS Annex III AMC1 ORO.GEN.110(c) and then the contradiction to this rule:

## GM1 ORO.GEN.110(c) Operator responsibilities

**OPERATIONAL CONTROL**

(a) ORO.GEN.110(c) does not imply a requirement for licensed flight dispatchers or a full flight watch system.

?

It is an irony that EASA opinion 01/2014 *"Amendment of requirements for flight recorders and underwater locating devices"* concerns the detection of the CVFDR post-crash, yet there is no concern at the lack of supervision methodologies that could potentially avert the loss of a flight as well as track the actual position of it, at a minimum of 15 minute intervals.

AF447 was lost for two years under the South Atlantic Ocean and AH5027 was lost for 23 hours in the Saharan Desert; MH370 is still missing since the 8th March 2014.

## Summary

There have recently been some high profile incidents and accidents in which adverse weather encounters were or may have been a contributory factor. For operators and pilots to be able to make sound judgements about the optimum course of action when faced with severe weather, they need a multi-layered defence system consisting of strategic (flight planning/ flight watch), tactical (weather radar/live data/ATC) and, as a last resort, physical (visual) mitigations.

For crews, regular recurrent weather radar training might improve confidence in using this valuable tool and also situational awareness when confronted with adverse weather encounters. The radar is far from a 'turnkey solution' and requires an enhanced knowledge about the specific radar and its use in terms of optimum settings to correctly interrogate and interpret the weather display. It is also vitally important that the limitations of the radar are trained and updated as technologies improve. Also placing more emphasis on traditional pilot handling skills, both in basic training and in recurrent and initial type conversion, would be of value if a crew were to find themselves with an in-flight upset following a weather encounter.

Current EU regulations make for lightweight operational control and supervision. Improved operational oversight, similar to FAR Part 121, is a thorough means to provide up-to-date weather information, perhaps via the ACARS, which is of particular relevance for long-haul flights where the weather in-flight may be significantly different from the planning forecasts. Furthermore, this method of operational oversight might also be of benefit in the worst-case of a 'lost' flight in finding the most likely location to begin a search.

With airspace becoming ever-more-congested it is possible that weather encounters may increase, in part due to lack of alternative routings. We consider that greater operational oversight along with enhanced pilot training may go some way towards mitigating this risk.

*Air Safety Group September 2015*