理論應用：如何善用機載氣象雷達

羅羽君 譯

氣象雷達之目的為偵測、分析及迴避不良天氣與亂流，如同使用其他工具時，若要有效率地運用雷達，專業能力與飛行組員協力合作，兩者皆不可或缺。實際上，不良天氣管理主要仍須仰賴組員主動監控航程中的天氣狀況，並完全善用飛航科技，其相關要素如下：

-根據飛行組員操作手冊(FCOM)與製造商的使用手冊提出之具體特性，瞭解氣象雷達之能力與限制。

-完成飛行前簡報(航路天氣與天氣預報如圖表與線上模擬，以及飛行中天氣資訊更新

-正確地使用氣象雷達，組員定時評估雷達顯示範圍、雷達天線增益與傾角以及適時運用天氣威脅評估，在導航顯示器(ND)呈現出最準確的氣象雷達資訊。

-定期手動執行垂直與水平掃描，增加情境察覺

-正確地理解雷達顯示圖像

-下達適當飛行軌跡計畫之策略(中期)與戰略(短期)決策

如何最佳地校正氣象雷達並在對流天氣中掌控航機？

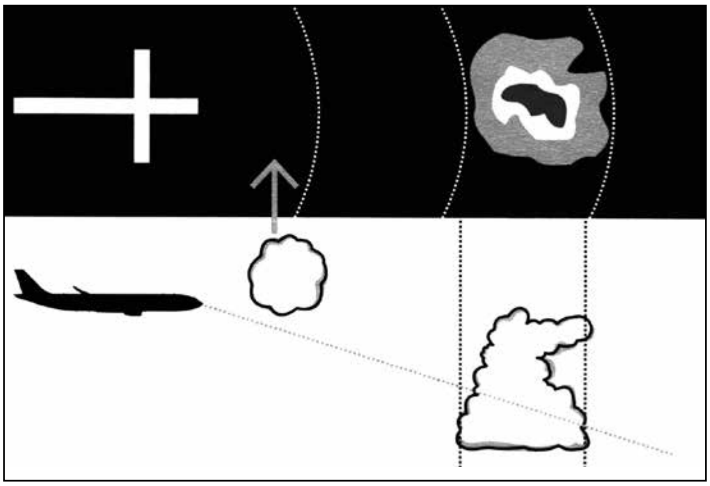
飛行計畫：天氣簡報與天氣報告的重要

飛行前聽取天氣簡報是避開危害天氣的首要步驟，包括詳細評估航線天氣及可能的緩解措施。飛行前，天氣簡報應顯示預期會出現顯著天氣活動之地區。同樣，簡報應該包含該地區的典型天氣型態評估。例如在熱帶地區，積雨雲在一日中某時刻較容易發生，強度也比較大，飛行組員在此階段可依據天氣簡報與對當地氣候學的瞭解，規劃避開活躍天氣狀況下的航路。除了選擇增添額外燃料以加強航程中應變策略與方法，更動航線也同樣是緩解天氣危害的方法。一旦起飛後，氣象雷達應開始運作並定期校正，並結合所有可用之天氣資訊，如飛行前簡報、駕駛員知識及對該地區特性的瞭解、亂流發布資訊及天氣報告更新的資料。情況許可下，天氣資訊應在航程中定期更新，由航管單位搜集之亂流地區資訊也是一種來源。

氣象雷達天線傾角

有效管理天線傾角及選擇導航顯示器的適當距離，都是獲取氣象雷達顯示資訊的重要方式。導航顯示器可能無法顯示飛行高度的天氣，僅能顯示在雷達光束照射到的天氣，如圖14.。因此，天線傾角須定期調整以掃描前方之天氣，並符合導航顯示器距離(若是最新型的雷達模型則會自動調整)，飛行組員須週期性地遵照兩個步驟，分別是一)、利用天線傾角，執行垂直掃描、二)、運用顯示器範圍之變化，水平掃描前方。

自動模式應設為偵測及衡量初始天氣顯示之預設模式(除非飛行組員操作手冊提及不一樣的做法，否則如前述)，若可能出現不良天氣(如飛行前簡報提及此情況)，人員須定時手動控制，以分析前方天氣。



(圖14)雷達光束偵測顯示圖

最佳做法

即使天線傾角會自動調整，駕駛員仍應定時調整回手動模式(MAN)以即時掃描前方天氣，如此，組員能評估對流雲的垂直結構與範圍。

影響雷達顯示相關性以及天線傾角的因素如下：

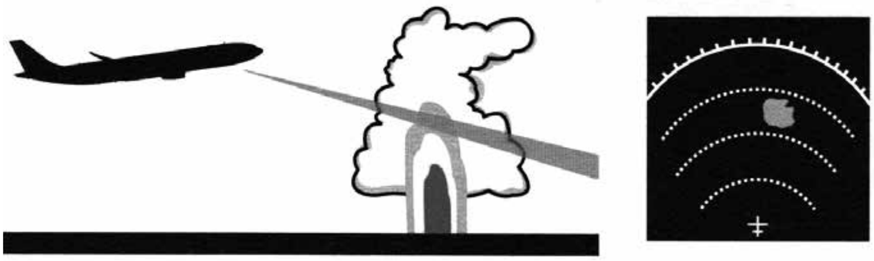
-航向變化

-高度變化或一般航空器狀況更動(如從爬升至巡航)

-雷雨形狀

-鄰近航空器的駕駛員報告

若航向或高度有變化時，天線傾角若仍保持為自動調整，其可能忽略天氣狀況或低估天氣不良程度。舉例來說，飛機起飛或爬升時，若不良天氣出現在航空器上方，天線傾角應調高以偵測不良天氣。圖15顯示雷達僅掃描到對流胞的對流頂部，原因是自動調整模式中，天線傾角設定過高；而傾角若向下，導航顯示器則顯示出較活躍的天氣活動。



掃瞄過頂

正確風暴顯示圖

圖15氣象雷達不同天線傾角設定的顯示圖

為了分析對流胞，飛行組員應操作天線傾角鈕以調整到正確位置，將雷達光束對準風暴胞反射最強之處。在高高度，雷暴可能挾帶低反射性的冰粒，若是未調整好天線傾角，導航顯示器可能只顯示對流雲的上方部分(反射性較低)，亦即掃描過雲頂，因此飛行組員可能會低估或未發現雷暴。為了獲得準確的天氣偵測資訊，氣象雷達天線應該對準較低、水汽仍存在之空層(亦即結冰高度之下)。若在較低空層出現紅色區域，天線傾角應垂直掃描該區域，而在對流胞紅色區域之上方，於高高度出現黃色或綠色區塊，可能代表該區域為劇烈亂流區。

大多飛航情況中，適當的天線傾角會使導航顯示器上方邊緣顯示地面回波，但可能使組員難以辨識實際天氣回波，快速改變天線傾角可改變地面回波的形狀與顏色，進而使地面回波在顯示器上消失，但天氣回波則不會消失，有些氣象雷達會裝設地面雜波壓抑(GCS)功能，啟動後可抑制地面回波。

顯示範圍之管理

為了保有全面的情境察覺，飛行組員必須同時監控短程與長程天氣狀況，因此組員應在監控(PM)、操縱駕駛(PF)的導航顯示器上選取不同顯示範圍。

為避開對流天氣的威脅，組員應在至少40海浬的距離前下達偏航決策，並在顯示器上選取下列範圍：

-調整監控駕駛(PM)顯示器範圍以規劃長期天氣迴避策略，若為巡航中，範圍通常是160海浬(NM)及以下

-調整駕駛操縱(PF) 顯示器範圍以監控天氣不良程度並決定迴避策略，若巡航中，通常為80海浬及以下。

駕駛員應在使用兩種顯示器後決定是否改變路線，迴避不良天氣，如此一來，可預防「死胡同效應」，亦即更動的航線在小範圍導航顯示器看來是安全路徑，但大範圍的雷達則顯示航線有不良天氣(圖16)。

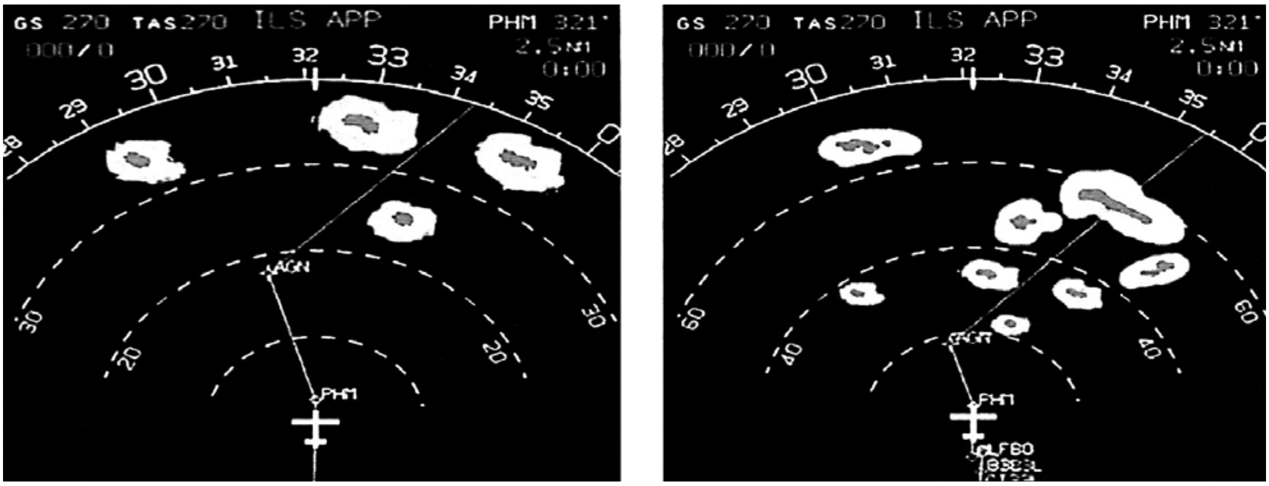
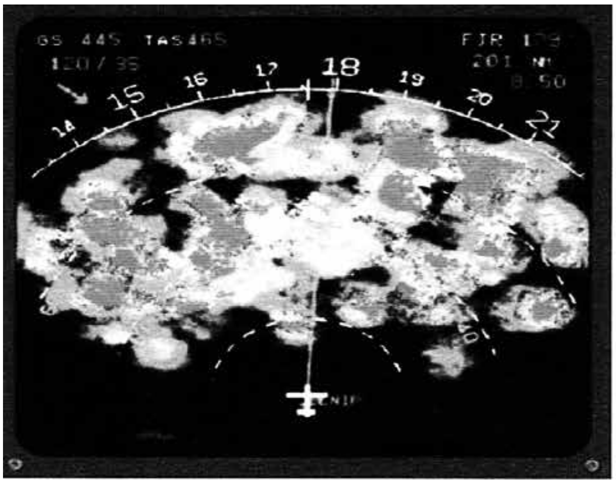


圖16. 死胡同效應

天線增益調整

根據雷達系統種類不同，雷達接收器的敏感度會有所差異。就天線增益偵測標準對流雲而言，調至自動(AUTO)處為最佳偵測位置，此外，飛行組員也可使用手動操作以分析天氣。在低高度，降低天線增益或許有助於適當的天氣分析。由於低空層較為潮濕，對流胞通常會有較高的反射性，氣象雷達相對容易顯示出紅色區域，而在較高高度、非常潮濕的大氣中出現顯著的標準大氣(ISA)差異現象(典型的印度季風)亦是同樣情況。上述這些情形中，緩慢減少天線增益對於偵測出危險地區有所助益：多數紅色區域漸漸變成黃色、黃色慢慢變成綠色，綠色逐漸消失；剩餘的紅色區域，亦即最晚變成黃色的區域，即為對流胞最活躍的部分，必須迴避該區域(圖17)。

在高高度，水分子會結冰，雲反射性較低，因此，應增加天線增益以評估天氣威脅。



增益減少
圖17 天線增益降低之效果

亂流與天氣威脅偵測

亂流有時很難預測，然而頻繁與劇烈閃電等徵兆，以及(或)特定形狀的雲(見下一段)可以作為重度亂流發生的警訊。在必要及情況許可下(根據機載氣象雷達標準)，TURB功能也可用於確認遠達40海浬(或有些雷達標準可達60海浬)處的濕亂流(圖18.)。TURB功能必須在有濕氣的環境下才能發揮作用，因此無法顯示出晴空亂流。

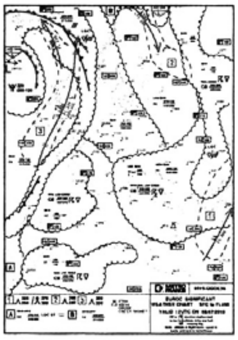
除此之外，最新一代的氣象雷達提供的目視資訊會警示飛行組員，這種雷達提供了天氣威脅評估功能，可預測如冰雹或閃電等天氣現象。

圖18 亂流偵測(紫紅色)

如何迅速、準確校正氣象雷達

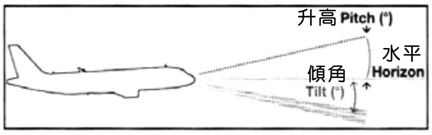
飛行前

研讀FCOM、FCTM與氣象雷達使用手冊記載之特別規定與限制。



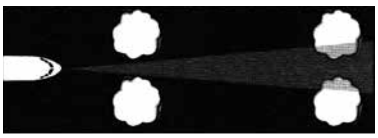
飛行前與飛行中

搜集天氣預報資訊以及飛行中定期更新資訊，例如天氣簡報、航路氣候學知識、亂流預報.....



飛 行 中

將天線傾角改成自動並設為偵測及初期天氣評估的預設模式，同時定期使用手動模式掃描及分析天氣情況。



飛行中

巡航中，採用下列顯示範圍可提供良好的天氣察覺，並預防死胡同效應：
監控駕駛導航顯示器上選取160海浬
操縱駕駛導航顯示器上選取80海浬

增益

飛行中

以天線增益自動模式操作，並定時減低增益以評估天氣不良程度。

飛行中

留意天氣威脅與危害評估功能提供的目視與口語資訊

解讀氣象雷達：如何決定有效的迴避策略？

在採取迴避方案前，飛行組員對氣象雷達顯示的分析是不可或缺的，組員可針對航路與非航路上的對流天氣狀況，開始深度分析，接著再視情況需要採取行動。

正確地理解氣象顯示資訊至關重要

氣象雷達經校正後，顯示資料應結合手邊可用之天氣資訊，如天氣圖、天氣報告及駕駛員的氣象學知識。供飛行組員參考。整合這些資料後，飛行組員得以掌握完整天氣狀況以及標明出「威脅區域」，該區域代表飛行組員預測其天氣狀況過於危險而不適合飛行。

有些導航顯示器會顯示特定資訊以警示飛行組員。除了雲的顏色外，其形狀也應列為仔細觀察項目，以偵測不良天氣狀況。不同顏色緊密相鄰的區域時常代表重度亂流之區域(圖19)。

圖19 威脅指標：不同顏色緊密相鄰的區域

某些圖像為強烈冰雹的明顯指標，同時也代表著有強烈垂直氣流(圖20)。此外，無論型態為何，迅速變化的圖形都表示活躍的天氣活動。

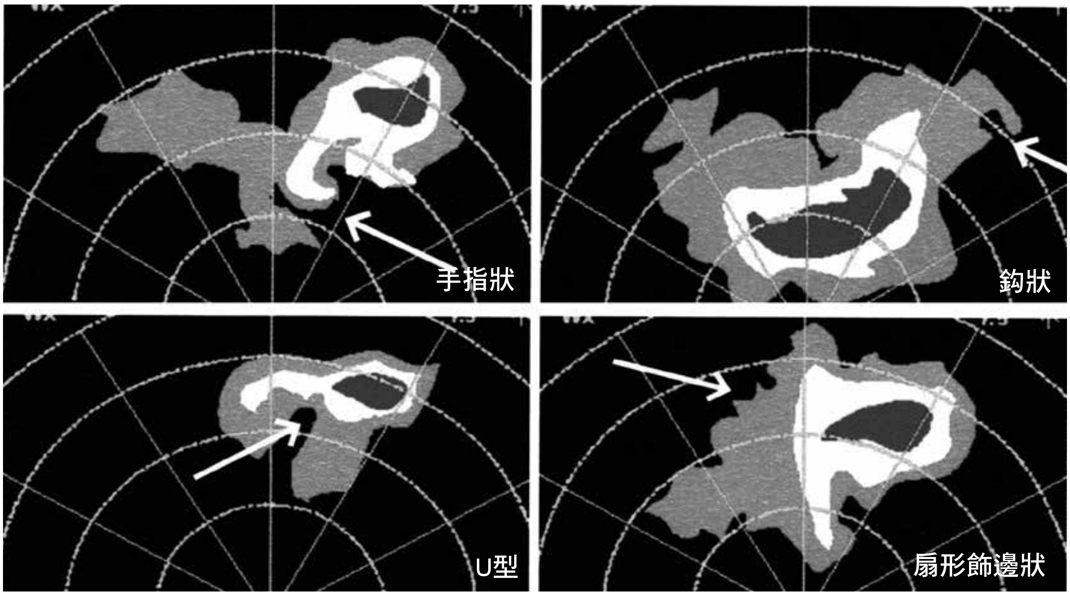


圖20.不良天氣指標之圖形

迴避策略

飛行組員須保持警覺並主動使用及調整氣象雷達，以儘早啟動迴避方案。在航空器越靠近對流天氣時，氣象雷達資訊會產出越多資訊，使下達迴避決策更加困難，因此組員應考慮與對流雲之最小距離為40海浬時即採取迴避措施。一旦下達偏離原先航線決策，在真正決定迴避軌道前，飛行組員須謹記以下建議之預防措施與限制。

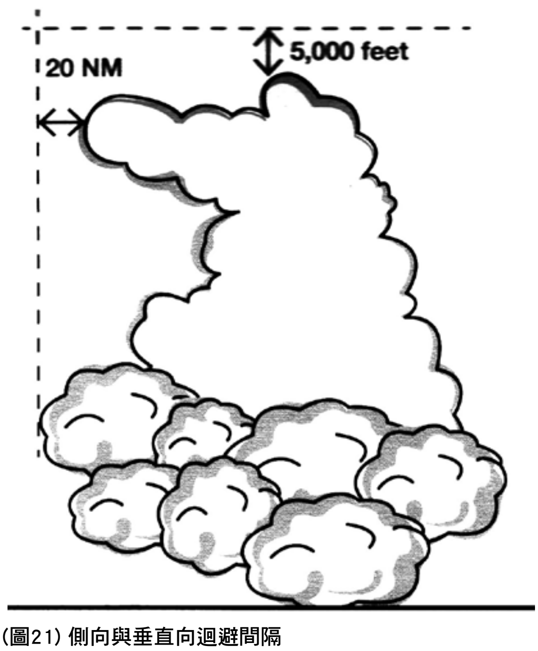
情況允許下，側向迴避方式比垂直向迴避更適當，不過由於抖振與效能邊界減少，垂直向迴避並非每次都可行(尤其是高高度)。此外有些對流雲生成快速，遠超過雷達可偵測區之上方。

>>側向迴避

- 可行情況下，建議航空器航行於積雨雲的上風處，避開風暴，通常對流雲上風處之亂流與冰雹較不明顯。
- 可行情況下，航空器應與飛行組員辨識出的「威脅區域」(如積雨雲)保持側向至少20海浬的距離(圖21)。航空器須保持額外間隔，以防對流雲變化或生長快速。
- 若航空器行經數個對流雲之間，若情況允許，航空器至少與「威脅區域」保持40海浬。

>>垂直向迴避

- 請勿試圖飛越對流雲下方，即使目視可見對流雲另一側，也不建議此做法，因為存在重度亂流、風切、微爆氣流與冰雹等潛在危害。若航空器勢必飛越對流雲下方(如進場階段時)，飛航組員應考量到所有面向，如目視判斷、氣象雷達、氣象報告、駕駛員報告等，再做最後決定。
- 若航空器必須飛越對流雲，需與雲頂保持5000英尺之垂直間隔(圖21)。



(圖21) 側向與垂直向迴避間隔
實例：劇烈天氣迴避策略的一般情境

圖22為一般氣象雷達顯示畫面，圖中存在多個劇烈天氣區域，根據顯示圖像，哪條路徑較佳呢？

航線A：

前往目的地最直接的航線，但經過天氣最劇烈、活躍的地區，因此該航線風險最大且不應列入考慮。

航線B：

該航線乍看或許是個良好的選擇，畢竟航空器不會偏離原航路過多，也避開最活躍的紅色區域。然而該飛行軌跡迴

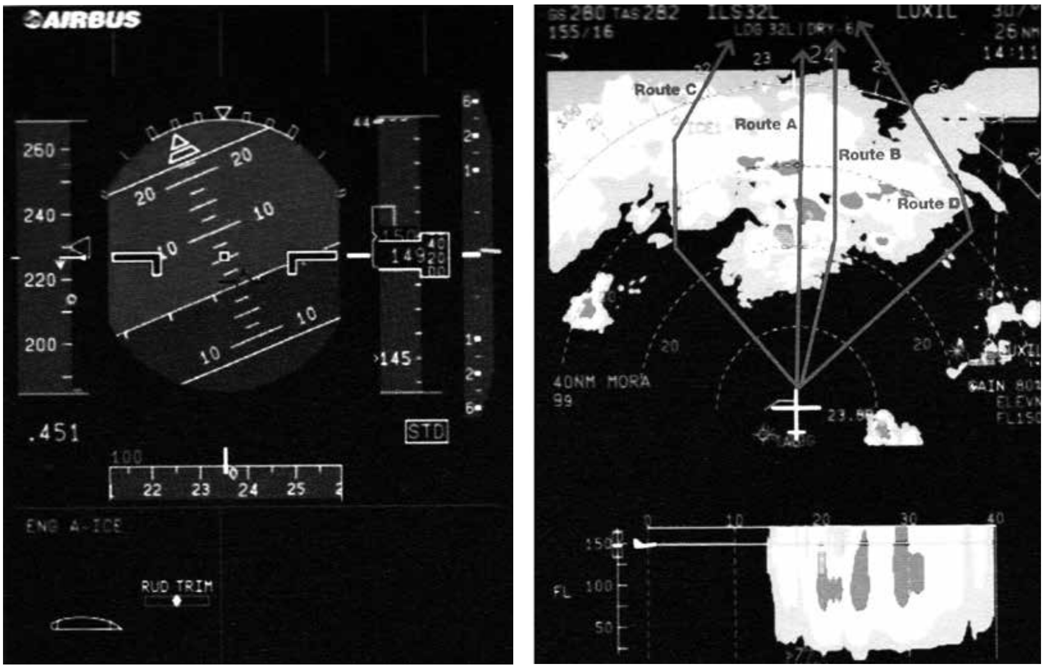
向對流地區的下風處，增加遭遇劇烈天氣的風險。此外，對流胞下方可能往上快速發展，縮小紅色區域間的間距。在考慮該航線前，飛行組員必須將雷達的天線傾角向下對準，以分析天氣並了解在對流胞間空隙下方的結構。

航線C：

由於此航線繞過大部分的風暴，且保持足夠安全間隔，此航線似乎是個可行的迴避路徑，然而，若採取此航線，飛行組員須注意左方的對流胞，觀察其是否生成迅速。除此之外，此航線與原先飛航計畫相差甚大，可能造成作業疑慮如燃料消耗或航班延誤等問題。

航線D：

就緩解風險而論，此為首選航線。在前方充斥著廣大的風暴系統時，通常會有多個選擇。在飛行組員下決策前，須掃描各對流胞的垂直結構，審慎仔細分析天氣，並考慮替代的偏航路線。



(圖22) 迴避天氣的可行路徑

無論是哪一種定位劇烈天氣的方法，如目視、雷達或天氣報告，成功執行航線規劃與迴避策略的關鍵參數即是時間。氣象雷達與更專業的增強模式，更能協助精確分析及瞭解遠方天氣狀況，並提早評估天氣情境，該系統可做為及早規劃之關鍵工具，以避免倉促決策，並協助下達繞過強烈對流胞時保持安全間隔之決策。除了善用科技外，組員也得在航程中維持警覺，掌握情境察覺。除了參考雷達畫面之外，也須定期手動垂直掃描鄰近對流胞，以及調整天線增益與傾角。另外同樣重要的是，參考氣象學基本知識、當地氣候學、天氣簡報等資訊，組員才能採取適當的行動方案，並安全、有效、舒適飛往目的地。

譯自 The Airbus Safety Magazine July 2016

PUTTING THEORY INTO PRACTICE: HOW TO MAKE AN OPTIMUM USE OF THE AIRBORNE WEATHER RADAR

The weather radar is a tool for detecting, analyzing and avoiding adverse weather and turbulence. As with any other tool, adequate skills and the crew's involvement are needed in order to use it efficiently. In fact, the management of adverse weather still relies primarily on the crew to actively monitor the meteorological situation throughout the flight, and make a full use of the available technology thank to :

- Awareness of weather radar capabilities and limitations, according to the specificities outlined in the FCOM and the manufacturer's user guide.
- Preflight briefing (knowledge of the route climatology and weather forecast – charts and online simulation) and during flight (update on weather information)
- Adapted use of the weather radar, with the crew regularly assessing the range, gain and tilt, and making use of weather threat assessment functions when available in order to display an optimum weather radar picture on the ND.
- Regular manual vertical and horizontal scanning by the crew to increase situation awareness.
- Correct understanding of the radar image displayed.
- Adequate strategic (mid-term) and tactical (short term) decision making for trajectory planning.

How to optimally tune the weather radar and manage flights in convective weather?

Flight planning: the importance of weather briefing and weather reports

Weather avoidance already starts in the briefing room before commencing the flight, with a thorough assessment of en-route weather and decisions on possible mitigation means.

Before boarding, a weather briefing should reveal areas of predicted significant weather activity. Equally, this briefing should include the assessment of typical weather patterns in the area. For example in the tropics, cumulonimbus intensity and development is greater at certain times of the day. The crew have the opportunity at this stage to plan a route to avoid active weather based on both the weather briefing and their knowledge of local climatology. Changing the flight route could be an option as well as taking additional fuel for enhanced strategic and tactical options in flight.

Once airborne, the weather radar should be used and tuned regularly in combination with all available information, e.g. preflight briefing, pilot's knowledge and experience of the area's typicality, reported turbulence, updated weather reports…If possible, the weather information should be updated in flight regularly. Information sought by ATC of turbulence encounters are an additional means.

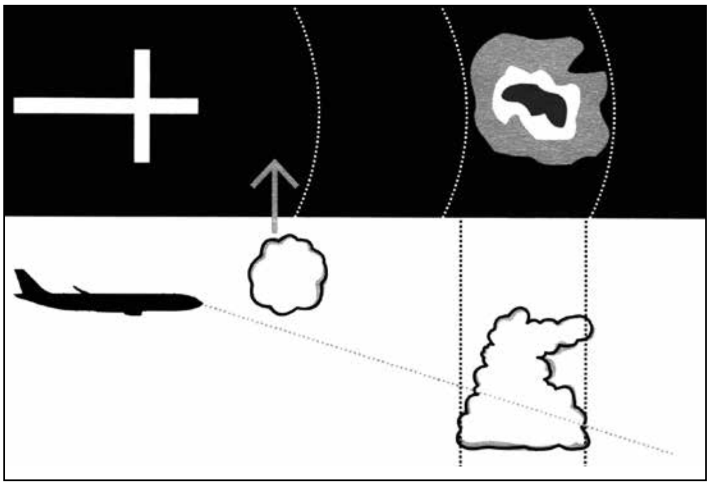
Weather radar antenna tilt

Effective management of the antenna tilt along with an appropriate ND range selection, are key tools to obtaining an informative weather radar display on the ND.

The ND might not display cells at aircraft flight level, only cells that are cut by the radar beam are shown (fig.14). For this reason, the antenna tilt needs to be adjusted up and down regularly to scan weather ahead, and it needs to be adjusted to the ND range selection (except with the most recent radar models where this adjustment is made automatically). The flight crew needs to periodically scan:

- Vertically, using the antenna tilt function
- Horizontally, using the range change.

If available, the automatic mode should be used as the default mode (unless mentioned differently in the FCOM), for detection and initial evaluation of displayed weather. Then, if adverse weather is suspected (e.g. according to information gathered during the preflight briefing), manual control should be used regularly and actively to analyze the weather ahead.



(fig.14) Display along radar beam

BEST PRACTICE

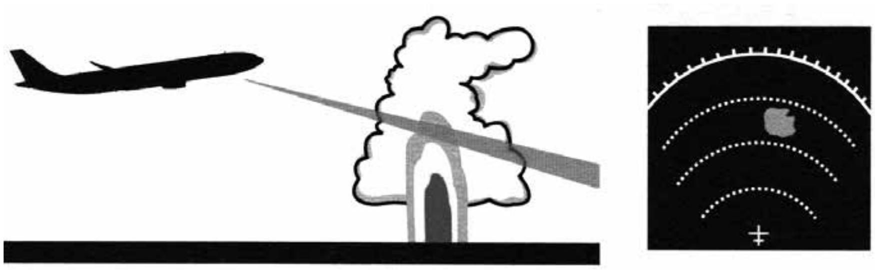
Even when the tilt is adjusted automatically, pilots are advised to reverse to the manual mode “MAN” regularly in order to scan the immediate weather ahead. This action allows the crew to assess the vertical structure and expansion of convective clouds.

Factors that can affect the relevancy of the ND display and that should trigger a tilt adjustment are:

- A heading change
- An altitude change, or even a regular flight profile change (e.g. from climb to cruise)
- The shape of thunderstorms
- A pilot report from another aircraft in the vicinity.

In the case of a change in heading or altitude, leaving the antenna tilt on auto may induce a risk of overlooking weather or underestimating the severity of the weather. For example, at take-off or in climb, the tilt should be set up if adverse weather is expected above the aircraft. Figure 15 is an example of radar overshooting a convective cell because the tilt is set incorrectly (too high in this case) while in the auto-tilt mode. When the antenna is tilted down, the ND shows a much stronger activity.

To analyze a convective cell, the flight crew should use the tilt knob to obtain a correct display and point the weather radar beam to the most reflective part of the cell. At high altitude, a thunderstorm may contain ice particles that



Overscanning

Correct storm display

(fig.15) Weather radar display at different tilt settings

have low reflectivity. If the tilt setting is not adapted, the ND may display only the upper (less reflective) part of the convective cloud (overscanning). As a result, the flight crew may underestimate or not detect a thunderstorm. In order to get accurate weather detection, the weather radar antenna should also be pointed toward lower levels (i.e. below freezing level), where water can still be found. If a red area is found at a lower level, the antenna tilt should then be used to scan the area vertically. Presence of yellow or green areas at high altitudes, above a red cell, may indicate a very turbulent area.

In most cases in flight, the adequate antenna tilt setting shows some ground returns at the top edge of the ND, which may be difficult to differentiate from genuine weather echoes. A change in antenna tilt rapidly changes the shape and color of ground returns and eventually causes them to disappear. This is not the case for weather echoes. Some weather radars are fitted with a Ground Clutter Suppress (GCS) function. When turned ON, it suppresses the ground return from the display.

Display range management

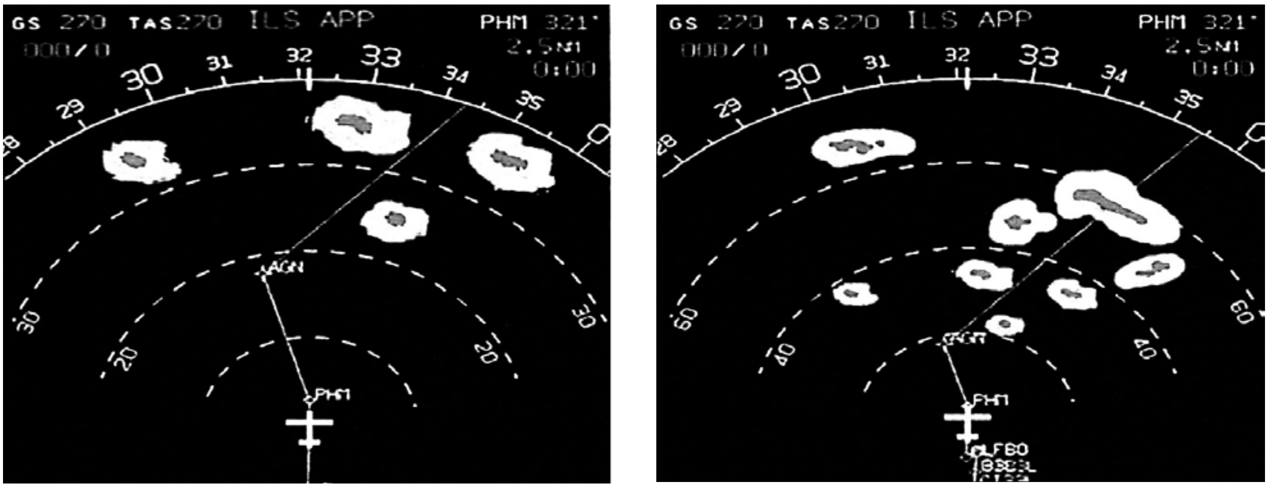
To maintain a comprehensive situation awareness, the flight crew needs to monitor both the short-distance and long-distance weather. To this end, the crew should select different ranges on the Pilot Monitoring (PM) and Pilot Flying (PF) ND.

To avoid threatening convective weather, the flight crew should make deviation decisions while still at least 40 NM away; therefore, the following ranges should be selected on the NDs:

- Pilot Monitoring (PM) adjusts ranges to plan the long-term weather avoidance strategy (in cruise, typically 160 NM and below).
- Pilot Flying (PF) adjusts ranges to monitor the severity of adverse weather, and decide on avoidance tactics (in cruise typically 80 NM and below as required).

Course changes to avoid adverse weather should be determined using both displays. This prevents the “blind allay” effect: a course change that may seem safe when using a low range ND display may reveal a blocked passage when observed at a higher range **(fig.16)**.

Gain adjustment

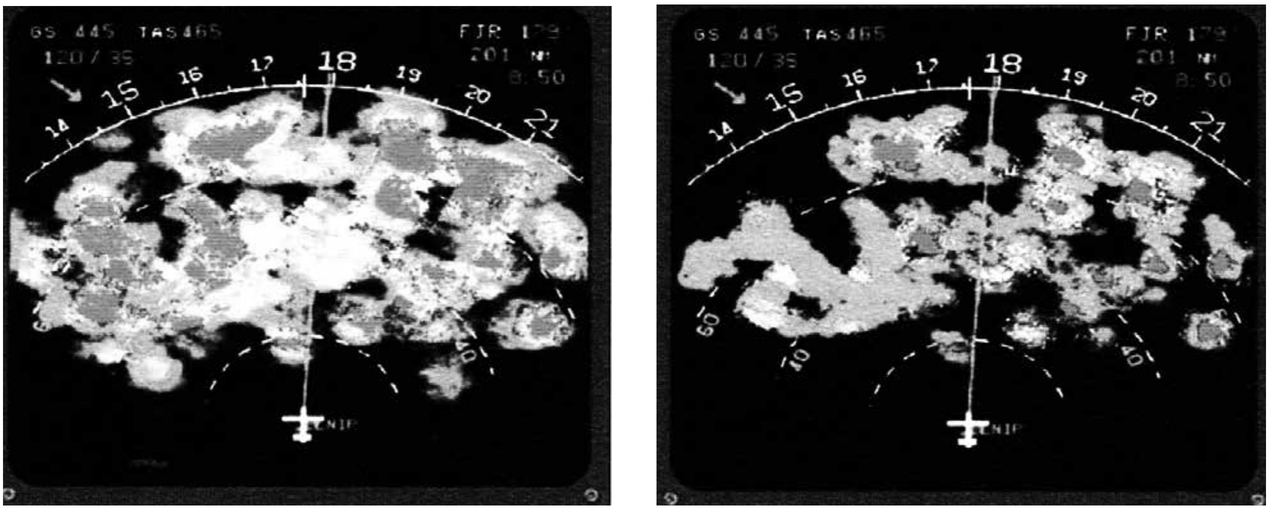


(fig.16) Blid alley effect

The sensitivity of the receiver may vary from one type of radar system to another. In the CAL (AUTO) position, the gain is in the optimum position to detect standard convective clouds. Manual settings are also available and can be used to analyze weather.

At low altitudes, reducing the gain might be justified for proper weather analysis. Due to increased humidity at lower levels, convective cells are usually more reflective and the weather radar display may have a tendency to show a lot of red areas. This can also be the case at higher altitude with significant positive ISA deviations in a very humid atmosphere (typically the Indian monsoon). In these cases, slowly reducing the gain allows the gain allows the detection of threatening areas: most red areas slowly turn yellow, the yellow areas turn green and the green areas slowly disappear. The remaining red areas - i.e. the red areas that are the last to turn yellow, - are the most active parts of the cell and must be avoided **(fig.17).**

Gain decreased



(fig.17) Effect of gain reduction

At high altitudes, water particles are frozen and clouds are less reflective. In this case, gain should be increased for threat evaluation purposes.

Turbulence and weather threats detection

Turbulence can be difficult to predict, but signs such as frequent and strong lightning and/or the specific shape of

(fig.18)Turbulence detection (in magenta)

clouds (see the next section) can alert the crew to the likely presence of severe turbulence. If necessary and when available (according to the standard of weather radar onboard), the TURB function can additionally be used to confirm the presence of wet turbulence up to 40 NM (or 60 NM depending on the radar standard) (fig.18). Remember that the TURB function needs humidity; therefore clear air turbulence will not be displayed.

In addition, the flight crew may be alerted by visual cues provided by the latest generations of weather radars that offer weather threat assessment functions, such as hail or lightning predictions.

Weather radar data understanding: how to decide on an effective avoidance strategy?

Before any avoidance maneuver is initiated, the analysis the flight crew makes of the weather radar display is essential. Doing so, the crew is able to conduct an in-depth analysis of the convective weather situation on-path and off-path and eventually, initiate action if needed.

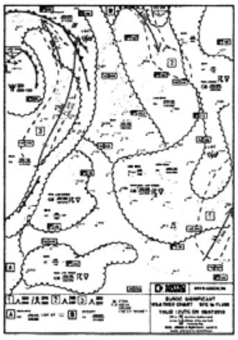
Correctly understanding the weather display is paramount

After the weather radar has been tuned correctly, the data displayed should be supplemented with the available weather charts, reports and the meteorological knowledge of the pilot. Altogether these data enable the flight crew to get a complete weather picture and establish an “area of threat”. This “area of thrat” corresponds to the zone where the flight crew estimates that the weather conditions are too dangerous to fly in.

HOW TO CORRECTLY TUNE THE WEATHER RADAR AT A GLANCE

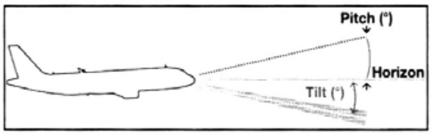
Before flight

Study the weather radar's specificities and limitations through the FCOM, FCTM and **weather radar user guide.**



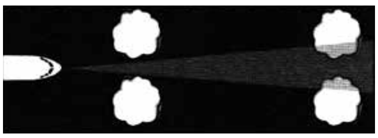
Before and during flight

Gather information about the **forecasted weather** and update regularly during flight: weather briefing, route climatology knowledge, reported turbulence…



During flight

Set the **antenna tilt** to auto as the default mode for detection and initial evaluation of weather, and periodically use the manual modes to scan and analyze the weather situation.



During flight

In cruise the combination of the following **ranges** provides good weather awareness and allows to avoid the "blind alley effect':
-160 NM on the PM ND.
-80 NM on the PF ND.

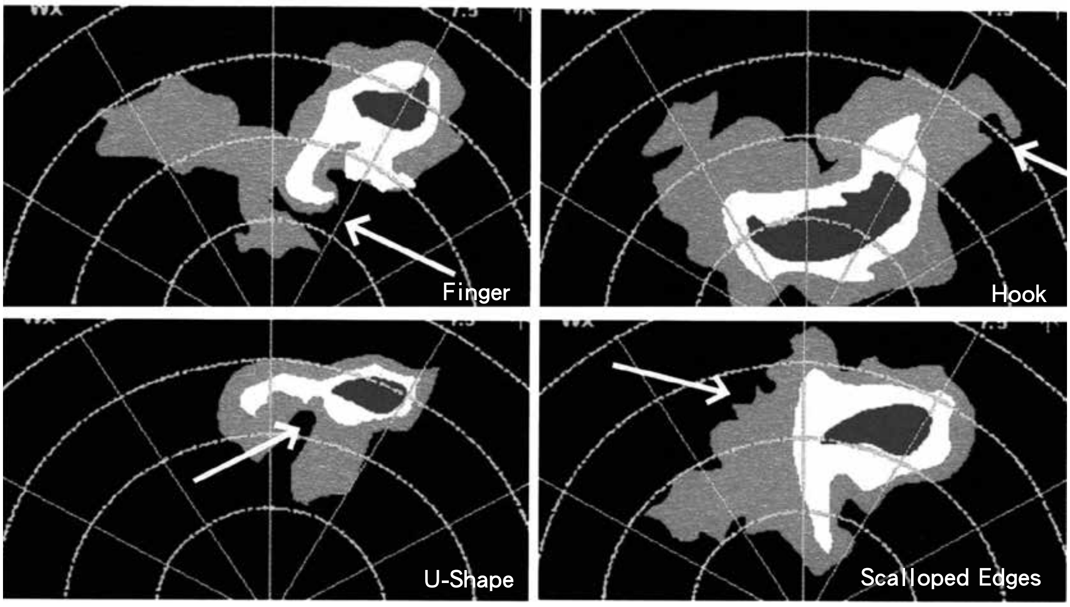
During flight

Use **gain** in AUTO/CAL mode by default, then regularly reduce the gain for weather severity assessment.

During flight

Be attentive to the visual and oral cues provided by the **weather threat and hazard assessment functions** (as installed).

(fig.19)Indication of a threat: closely spaced areas of different colors



(fig.20)Shapes indicative of adverse weather

Some ND displays contain specific cues that should alert the flight crew. Clouds shapes, in addition to colors, should be observed carefully in order to detect adverse weather conditions. Closely spaced areas of different colors usually indicate highly turbulent zones (fig.19).

Some shapes are good indicators of severe hail that also indicate strong vertical drafts (fig.20). Finally, fast changing shapes, whatever the form they take, also indicate high weather activity.

Avoidance strategy

The flight crew needs to remain vigilant and active in using and tuning the weather radar in order to be able to initiate an avoidance maneuver as early as possible. Indeed, weather radar information becomes more intense as the aircraft gets nearer the convective weather zone, thus making avoidance decisions more difficult. For this reason, crews should consider a minimum distance of 40 NM from the convective cloud to initiate the avoidance maneuver.

Once the decision to deviate course has been taken, flight crews need to bear in mind the following advisory precautions and limits before actually deciding the trajectory of the avoidance maneuver.

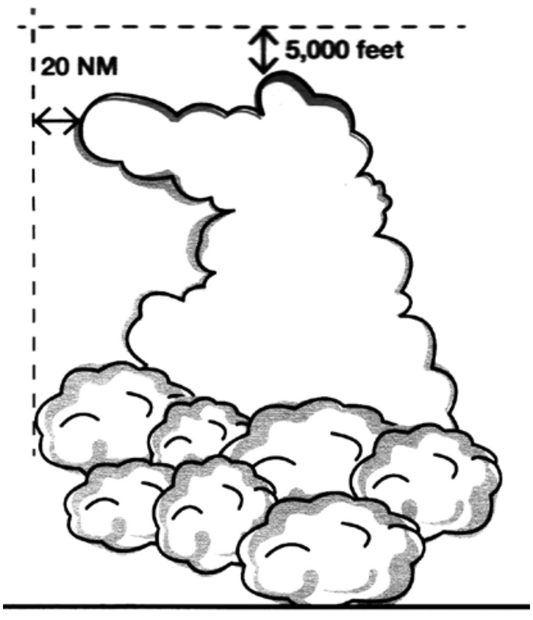
If possible, it is preferable to perform lateral avoidance instead of vertical avoidance. Indeed, vertical avoidance is not always possible (particularly at high altitude) due to the reduction of buffet and performance margins. In addition, some convective clouds may have a significant build-up speed, that extends far above the radar visible top.

*Lateral avoidance

- When possible, it is advisable to try to avoid a storm by flying on the upwind side of a cumulonimbus. Usually, there is less turbulence and hail upwind of a convective cloud.
- The "area of threat" identified by the flight crew (e.g.a cumulonimbus cloud) should be cleared by a minimum of 20 NM laterally whenever possible (fig.21). An additional margin may be applied in case the convective clouds are very dynamic or have a significant build-up speed.
- If the aircraft trajectory goes between several convective clouds, if possible maintain a margin of at least 40 NM with the identified "area of threat".

*Vertical avoidance

- Do not attempt to fly under a convective cloud, even when you can see through to the other side, due to possible severe turbulence, due to possible severe turbulence, windshear, microbursts and hail. If an aircraft must fly below a convective cloud (e.g. during approach), then the flight crew should take into account all indication (visual judgement, weather radar, weather report, pilot's report, etc) before they take the final decision.
- If overflying a convective cloud cannot be avoided, apply a vertical margin of 5000 feet (fig.21).



(fig.21) Lateral and vertical circumvention margins

Practical example: typical scenario of severe weather avoidance strategy

Figure 22 shows a typical weather radar display indicating multiple areas of severe weather. What route would look like the preferable option?

Route A:

this is the most direct route to destination but it navigates right through the most severe and active zone; therefore it is the path that carries the biggest risks and should not be an option.

Route B:

this route could be tempting since it requires little deviation to the mainstream route and it looks like the most active red areas are avoided. Nevertheless, this trajectory leads downwind of the convective area, thus increasing the risk of encountering severe weather, Additionally, the convective cells beneath might be developing fast and upwards, thus closing off the gap in between the red zones. Before this option is considered, the flight crew would need to tilt the radar antenna down to analyze weather and see what is below the apparent gap.

Route C:

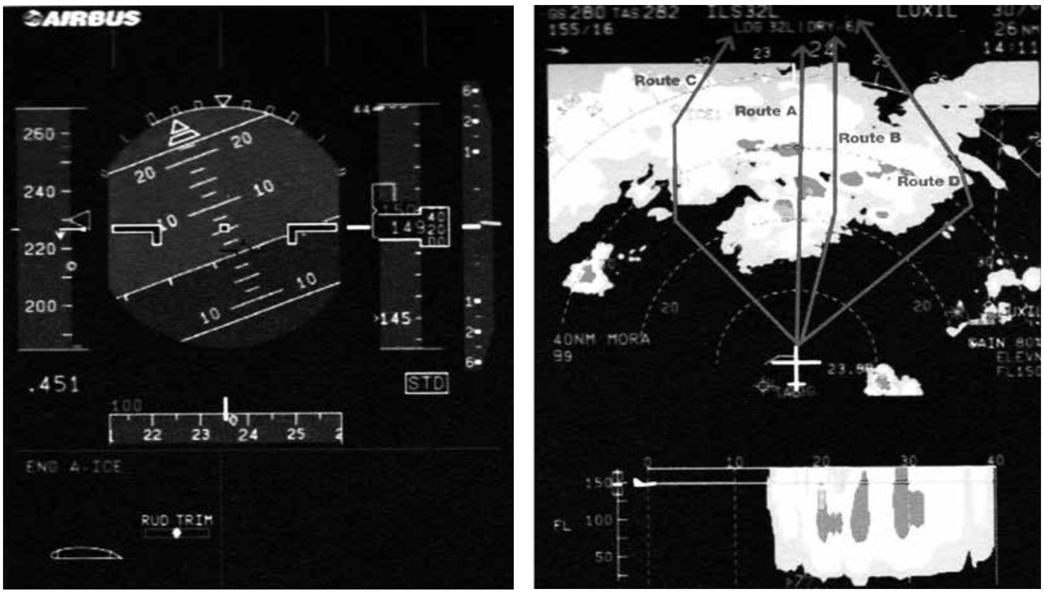
this route looks like a possible escape route because it goes around most of the storms by a wide safety margin However, while doing so, the flight crew would need to keep a look at the cell to the left of this route, and see whether it develops rapidly or not. In addition, this route leads away from the initial flight plan and therefore it could have operational implications such as fuel consumption or delays.

Route D:

this route would be the preferable option in terms of risks mitigation.

When faced with a situation where weather ahead reveals an extensive storm system, several options are always possible. Before the flight crew makes a decision, it is prudent to analyze weather carefully by scanning the vertical expansion of the various cells, and if possible, consider deviation to an alternate route.

Regardless of how you locate a severe weather area - visual, by radar, or from a report – a key parameter to successful route planning and avoidance strategy is time. The weather radar, and enhanced models more particularly, can help you to analyze and understand distant weather accurately and evaluate weather scenarios from a distance. This system is a key tool to planning ahead to avoid last-minute decisions, and making a decision on circumnavigation a nasty convective cell with a comfortable safety margin. In addition to technology, you need to stay active in maintaining situation awareness throughout the flight. Regularly complement the radar images displayed by a manual vertical scan of surrounding cells, as well as gain and tilt adjustments as required, Last but not least, adhere to you knowledge of meteorology basics, local climatology and weather briefing to adopt the best course of actions, and navigate safely, effectively and comfortably to destination.



(fig.22) Available options to avoiding weather

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