雷擊之防護、檢驗與維修

龍文馨 譯

前言

雷擊會影響航空公司的營運，並且會造成所費不貲的航班延誤以及航空運輸的中斷。飛機被雷擊是相當普遍的現象，但是真正會影響到飛機持續性的安全運作則是相當罕見的。波音飛機上使用了雷擊防護設施去避免航班延誤以及中斷，同時也減低發生雷擊時之嚴重性。對於因雷擊造成的損傷，如欲增加其維修效能，維修人員必須熟悉保護雷擊設施的量測方法，正確的檢驗與維修程序。

本文

每當商用客機被閃電打到後，其結果可能是毫無影響，也可能是需要停飛修護相當長一段時間的重大損傷。對於充分了解雷擊的基本影響與正確的損害檢查步驟，可以使航空公司在接到雷擊回報後的第一時間，能夠立即反應，做出有效的修護動作。

本文可以協助維修及機組人員了解雷擊現象，並幫助航空公司了解雷擊損壞的檢查要求標準與相關有效提升效能的有效維修方法。

雷擊概述

飛機遭遇雷擊之頻率，受幾個因素影響，包括飛機飛航之地理區域及飛機穿越雷擊最頻繁之起降高度範圍的次數。雷擊發生機率因地理位置不同而有很大的變化，例如，在美國佛羅里達部分地區，平均每年約有100天的雷雨，而大部份西海岸地區平均每年就只有幾天的雷雨發生。在世界其他地方大部份的雷擊都比較傾向於在赤道附近發生。因為赤道地區之溫暖氣候會促成對流，幾乎每天皆會形成漫天的雷雨。

美國太空總署(NASA)發佈的全世界雷擊及分佈地圖顯示雷擊的地理分佈狀況(如圖1)。雷擊活動最高區域用橘色、紅色、棕色及黑色表示。活動低的區域，用白色、灰色、紫色及藍色表示。雷擊活動在海洋與極地地區最低，在溫暖的大陸地區最高。圖一縱軸之刻度數字，代表每年每平方公里的閃電次數。

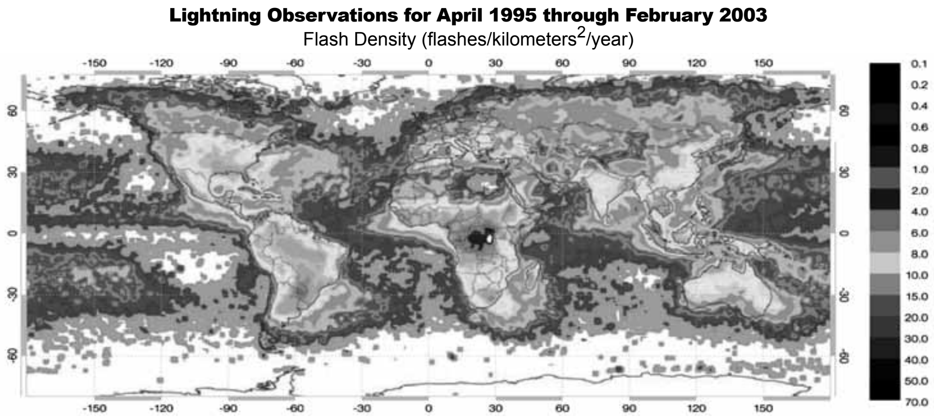


圖1. 全世界雷擊活動

本圖顯示1995年4月至2003年2月間全球雷擊之分佈圖。圖之內容為美國航空太空總署(NASA)光穿越探測器(1995年4月至2000年3月)及地表諮詢系統(1998年1月至2003年2月)儀器兩者綜合之觀測。影像為NASA提供。1995年4月至2003年2月閃電之觀測

在飛航之起飛與降落階段，更多噴射機飛經雲幕中時發生雷擊，遠較其它飛航階段為高(參見圖2)，其理由在於5000至15000英呎(1524至4572公尺)之空層中雷擊活動更為活躍(參見圖3)。

因此，當短程飛行之飛機經過閃電活躍的高發區域，是比長程飛行之飛機所經過的溫和區域來的容易遭受雷擊。

單一閃電光束可能包含1百萬伏特或3萬安培的電能。

一旦飛機被雷擊，每一架飛機所遭受損傷的雷擊數量點及型式可能都會有很大的不同。關鍵在於數個因素，例如雷擊的能量等級，飛機外形突出點及逸出點的位置，以及雷擊的時間長度(duration)等都有影響。

由於雷擊事件的發生有這些綜合型的變數在裏頭，可以預期的是如果飛機被強烈的閃電擊中的事件越多，損壞到需要執行維修的次數就一定會等比例的增加。

Cloud Orientation	Percent of Total Reported*
Above	<1%
Within	96%
Below	3%
Between	<1%
Beside	<1%

圖2.雲層飛航位置的雷擊事件統計表

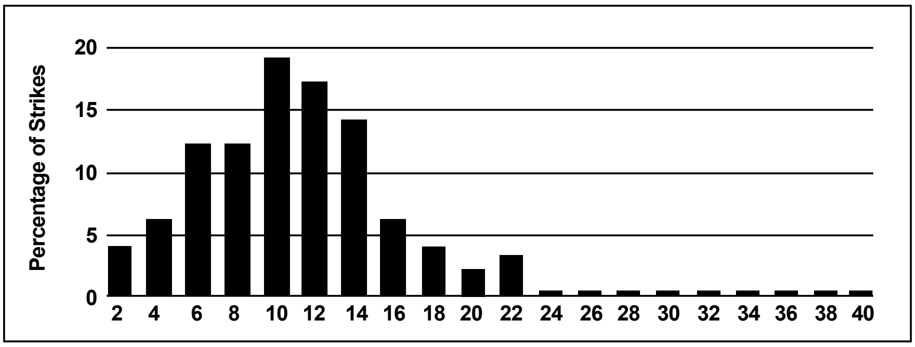


圖3.雷擊高度分佈圖

閃電/雷擊與飛機之交互作用

閃電最初打到飛機突出外形之某一點，再由另一個點逸出(參見圖4)。

典型的路徑，閃電會先接觸到機鼻雷達罩，經過前機身、機艙、到達尾翼或翼尖。

飛機在最初被雷擊的一剎那，會在機鼻或翼尖看到閃光。這是由於機身前緣及飛機結構突出點區域附近的空氣被離子化的結果。離子化的原因在於那些位置的電磁場密度增加之緣故。

雷擊後的下一個階段，在於機身附近已經產生離子化的空氣中，一個由機身伸延出的階梯先導電子束， 在附近雲層中尋找大量的閃電能量。階梯先導電子束(也被簡稱為先導電子束)是指離子化空氣的路徑，它包含由已帶電的飛機或雲層中釋放出來的電能。當飛機飛經已帶電的大氣層中，先導電子束由已形成離子化區域之飛機突出點傳導而出。

一旦飛機傳導出之先導電子束與雲層中之電子束相互銜接，就會產生接地迴路連 續的雷擊，飛機就變成這個雷擊事件構成的一部份。當雷擊打到飛機的當下，旅客及機組人員會見到一道閃光及聽見一個霹靂的聲響。一般發生嚴重事故的機會是很罕見的，因為在飛機設計當初，就已經考量過對飛機及其它敏感電子裝備的雷擊防範措施。

經歷閃電接觸機身後，飛機可以安然渡過雷擊事件。在雷擊過後，先導電子束重新再次附著於機身或其它機體結構位置，此時飛機是介於其正負電極之兩雲層區域之間的迴路上。電流流經飛機可導電之外部蒙皮及結構，再經由其他突

出點逸出，譬如說機尾，它是流向於相反電極的區域或直達地面。駕駛員偶爾會回報發生機艙內有暫時性的燈光閃爍，或者儀表被短暫的干擾功能等。

雷擊之狀況與條件

飛機遭閃電雷擊機率最高的地方在最外緣，例如翼尖、機鼻或尾舵。雷擊最常發生的高度是在飛機爬昇及降落階段，5000至15000英呎(1524至4572公尺)空域中。而20000英呎(6096公尺)以上，發生雷擊之機率將大大減低。

約百分之七十的雷擊事件發生在降雨的時候。飛機遭雷擊與環境溫度華氏32℉℉F(攝氏0℃)這兩者之間有很直接的關聯性。大部份的雷擊都發生在接近冰點的溫度。

足夠造成降雨的環境條件，也會造成電能儲存在雲層中。電能的產生與雨量及雲層之形成相互關聯，大部份影響飛機的雷擊事件則發生在春季與夏季。

雖然百分之七十的雷擊是在降雨的環境條件中產生，而且雷擊/閃電從雲層的電氣中心點五哩範圍之內，都可以影響到飛機。但是實際在機長的雷擊報告裡，約42%的雷擊事件中，同一地區內並沒有任何機長回報該區域有雷雨的形成。

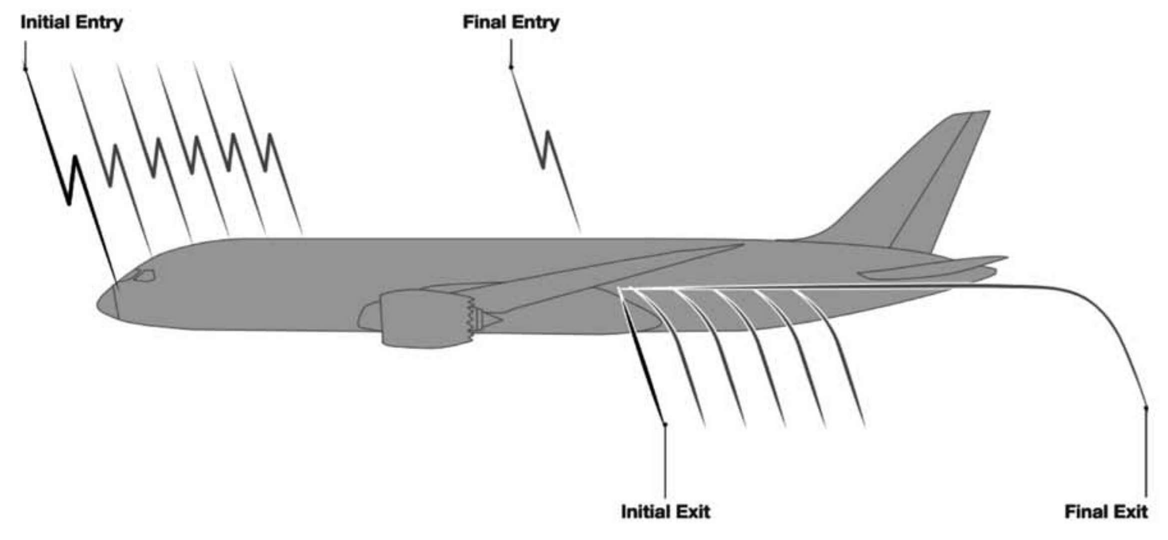


圖4. 閃電依附機身示意圖

閃電最初由機身之前緣進入產生離子化，產生雷擊之機會。 閃電之電流沿著飛機表面遊走再出去到地面，使雲中能量，經由飛機再及於地面，串成電流迴路。

雷擊之典型效應

當遭遇閃電之電流時，由鐵磁性材料所製成之飛機零組件，會有很強的磁化現象。由雷擊傳導之大量電流，流經飛機結構組件，就會造成此類磁化現象。

飛機內部電路系統之原始設計，是足以防治一般雷擊的傷害，但是如果為異常高強度之雷擊，仍然有機會可以損傷電路系統的零組件。譬如由電子控制的燃油閥、發電機、電力傳輸器及電氣分佈系統等。

商用飛機之雷擊防護

傳統飛機外部大部分零件是金屬結構，具有足夠厚度來阻擋雷擊，金屬蒙皮的厚度足以防護飛機內部空間不被雷擊侵入。金屬蒙皮具有基本保護功能，不讓電磁能量影響飛機內部的線束運作。實際上，金屬蒙皮無法杜絕所有電磁能量進入電線線路內，但是卻能保持該進入之電磁能量在一個安全的等級範圍。

透過了解雷擊的自然現象與影響，波音將之應用於飛機設計及測試，為的是要在飛機的使用年限中，能保護全機不受雷擊損傷。材料的選擇，表面處理的方法，安裝及防護特性之應用等都是減少電擊損害重要的方法。

對於最有可能被閃電襲擊的區域，設計時即納入某些雷擊防護措施。波音執行測試，以確保新機具有充份的雷擊防護，在易於遭受雷擊區域中之複合材零件，要求必須要有適當的雷擊防護。

將目前使用中的各類飛機所蒐集到的大量參考數據，作為建構雷擊防護資訊最重要的來源。波音公司再將這些資料應用在雷擊損傷控管上，作出改進措施，使業者只要遵循作適當的修護，就可以大為減少雷擊的損壞。

飛機上之雷擊防護可能包含：

- 線束之隔離網屏蔽
- 接地線
- 複合材伸展之箔片，線網、鋁焰噴塗、嵌入之金屬絲線、金屬圖像框、轉向帶、金屬箔墊襯，已作塗層之玻璃纖維及膠合鋁箔片。

▶飛機被雷擊後所需採取之措施

飛機被雷擊打到時，有可能飛航組員無法獲得任何儀器上的指示，但是如果當飛機遭到雷擊而顯而易見的被駕駛員發現時，駕駛員必須決定該航班是否繼續飛往目的地或轉降備用機場，去執行檢驗及可能的維修。

機務技術人員可以透過了解閃電的結構與飛機上殘留的痕跡來發現與辨識雷擊的損害程度。

機務人員必須意識到，雷擊有可能未在飛航記錄簿中記載， 因為機長有可能不知道該班飛機已遭遇過雷擊。擁有對雷擊的基本認識將對於機務人員執行有效之維修有所助益。

▶在商用飛機上辨識出(Identify)雷擊損傷

飛機被雷擊後，其進出機門之結構可能被影響，在金屬結構上，雷擊損傷通常顯示細微之坑洞，燃燒之印記或小小之圓孔。這些孔洞可能成群集中在某處，或是分散在大片區域中，有燒灼或變色的蒙皮，也顯示可能是雷擊之損傷。

由飛機結構損傷可以分辨出是否受到雷擊的直接效應。譬如熔穿、受熱(resistive)阻杭、結構細砂孔，機結件四週燒痕，甚至在機外突出點區域，有結構零件剝離，例如像垂直安定面、翼尖，以及水平安定面之邊緣(見圖5)，在遭受雷擊時，飛機結構也可能被震波擠裂。

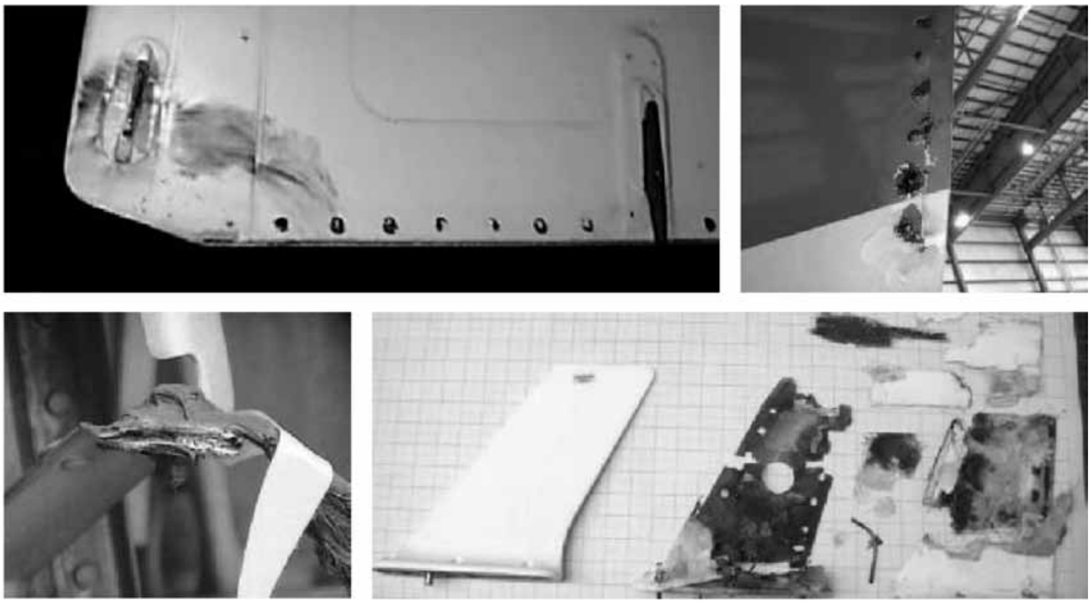


圖5.雷擊損壞實例

另外一種觀察雷擊跡象的方法，是接地線的異常損傷。由於雷擊產生高電磁力，這些接地線可能碎裂。在雷擊打到機身後，從開始到結束的這段期間，飛機航行之距離必然遠大於機身長度。所以閃電在首次由機身某點進入後，稍後由於飛機的移動，閃電必然會再由機身的其它部位再次改變位置進入機身。這方面的證據可以經由雷擊檢驗去發現，也就是在飛機機身可以看見一連串的多次燒痕。(見圖6)

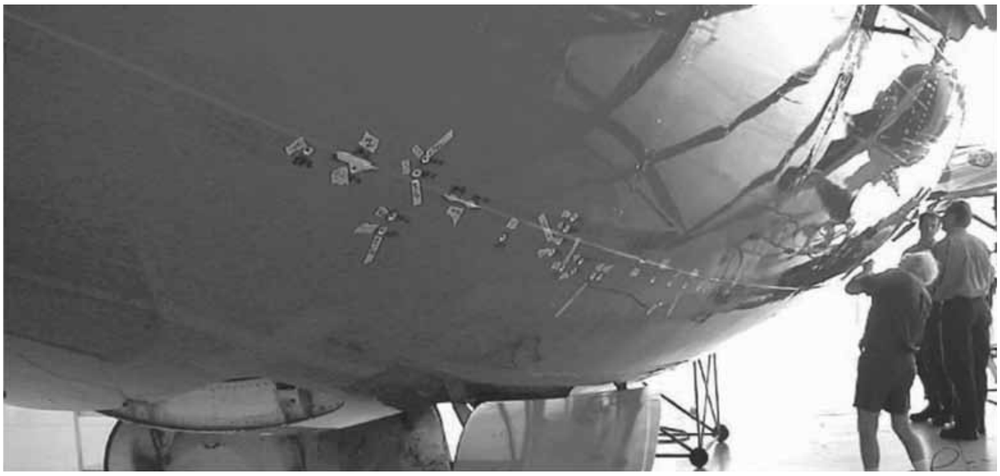


圖6. 雷擊沿著機身造成的損傷實例當雷擊沿著機身移動時，將可能造成狂亂打擊式的損傷。

如果未施以噴塗表面保護漆，或是未作適當的設計，複合材料之飛機結構還是會被雷擊損傷。

該類損傷通常呈現油漆被燒灼之型式、複材纖維損傷以及複材層面剝離。（見圖7）

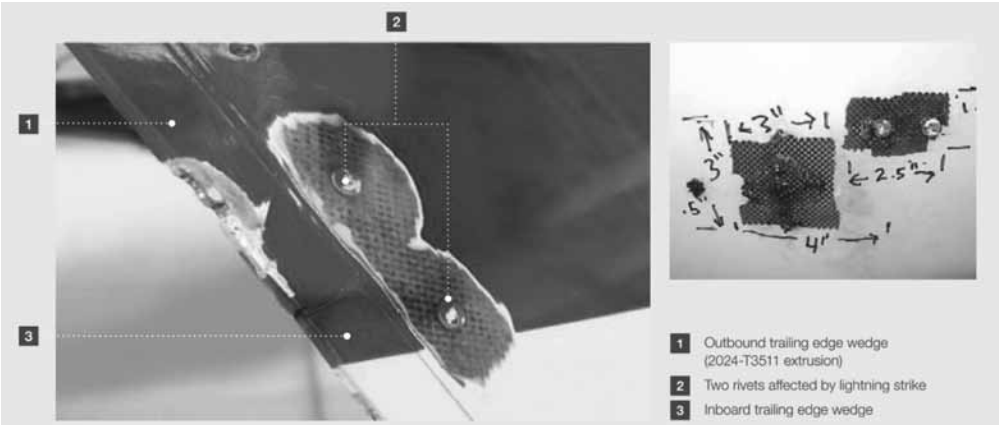


圖7. 雷擊對複材機身之損傷

複合材料結構比金屬結構更不易導電，導致高伏特電壓。圖示之損傷類型發生在雷擊防護表漆未作或是不足的情況。

1.外側尾緣楔(2024- T3511擠型件)

2.兩顆受雷擊影响的鉚釘

3.內側尾緣楔

▶雷擊結構檢查程序

如飛機遭到雷擊，必須執行雷擊狀況檢驗，以便定出雷擊之進入及逸出位置點，當仔細檢視該進入及逸出區域時，維修人員必須詳細檢視結構，找出所有發生的損壞。

在飛機放飛前，作好適用狀態檢驗，分辨出結構損壞及系統損壞是必須的。結構可能有被燒穿的孔洞，那可能導致失去艙壓或結構破裂。在下一個班次飛航之前，一些關鍵系統零組件，電線線束以及網狀接地線，皆必須確認其適航性。基於這些理由，波音建議在下一次飛航前，必須執行徹底完整的雷擊狀況檢驗，以保持飛機處於適航狀態。

飛機雷擊檢查區域係依照SAE航空建議實務(Aerospace Recommended Pracfices(ARP) 5414 (見圖8)之定義。某些特定區域較其它區域更容易遭受雷擊（見圖9)，雷擊之進入點及出口點通常發現發生在第一區，發生在第2、3兩區是相當罕見的，雷擊通常由第一區附上機體，再由第一區他處離開。飛機外部通常最有可能被打到的零組件是：

· 雷達罩 · 引擎艙 · 翼尖
· 水平安定面頂端 · 升降舵 · 垂直尾翼頂端
· 翼前緣襟翼之終端 · 後緣襟翼整流片 · 起落架
· 排廢水小管 · 天氣數據感應器(靜壓口、皮托管、攻角器導片。(AOA)、大氣溫度探管)

在第二區域，一個初始進入點或逸出點是極為罕見之事。如果真的發生，閃電的途徑可能為初始進入或逸出點被倒推而行。譬如說：雷達罩可能是一個初始進入點的區域，但是隨著飛機向前運行，閃電途徑可能沿著機身一路後推至雷達罩之後方。

在檢驗第一及第二區時即使未見損傷，高度建議同時也檢視第三區。

總而言之，必須在第1，2或3區確認出雷擊進入及逸出點，所以各點周圍附近區域必須徹底的檢視，並視需求予以維修。

區域編號	描述	定義
1A	初始迴擊區	閃電迴路在飛機表面可以發生初次迴擊,但是無法長期滯留之區域
1B	初始迴擊停留區	閃電迴路在飛機表面可以發生初次迴擊,且可以較長滯留時間之區域(產生電弧)
1C	初始迴擊過渡區	閃電迴路在飛機表面可以讓初次迴擊的強度降低,但是無法長期滯留之區域
2A	雷擊滑行區	閃電迴路在飛機表面可以讓後續迴擊滑行,但是無法長期滯留之區域
2B	雷擊滑行停留區	閃電迴路在飛機表面可以讓後續迴擊滑行, 且可以較長滯留時間之區域(產生電弧)
3	第1及第2區以外之雷擊位置	此區包含不在1A、1B、1C、2A或2B區域之所有機體表面，此區域不太可能有任何雷擊迴路附著進入，這個區域橫跨其他區域之間以及緊臨大量雷擊電流的進出點.

圖8.雷擊區域之定義〔SAE航太建議實務5414所定義之飛機雷擊分區〕

依各區域檢查雷擊表面

波音提供雷擊檢驗程序，希望確保飛機外部表面未遭損傷。航空公司須參照適用之維護程序作為檢驗/維修之參考資料。

※對第1與第2區域執行典型的外部表面檢查。

※檢查飛機所有外部表面

· 仔細檢查外部表面，找出雷擊進入口及逸出口位置。檢視在某一表面停頓及其它表面又開始傳導之區域。
· 檢查金屬與非金屬結構是否有損傷
· 對於複合材料結構，用非破壞性儀器檢驗方法或用敲擊測試檢查脫層情況。
· 在第二區域檢查皮托管，攻角感應器，靜壓口及它們四周區域之表面檢查時，未發現進入口及逸出口位置，則應檢查第三區雷擊損傷跡象。

檢查第3區域，方法如同檢查第1區及2區域，第3區域額外增加之檢驗項目包含

※檢查所有外部之燈具，去找出：

· 破碎之燈具組合件
· 破碎或裂開之情況

※其它可見之損傷

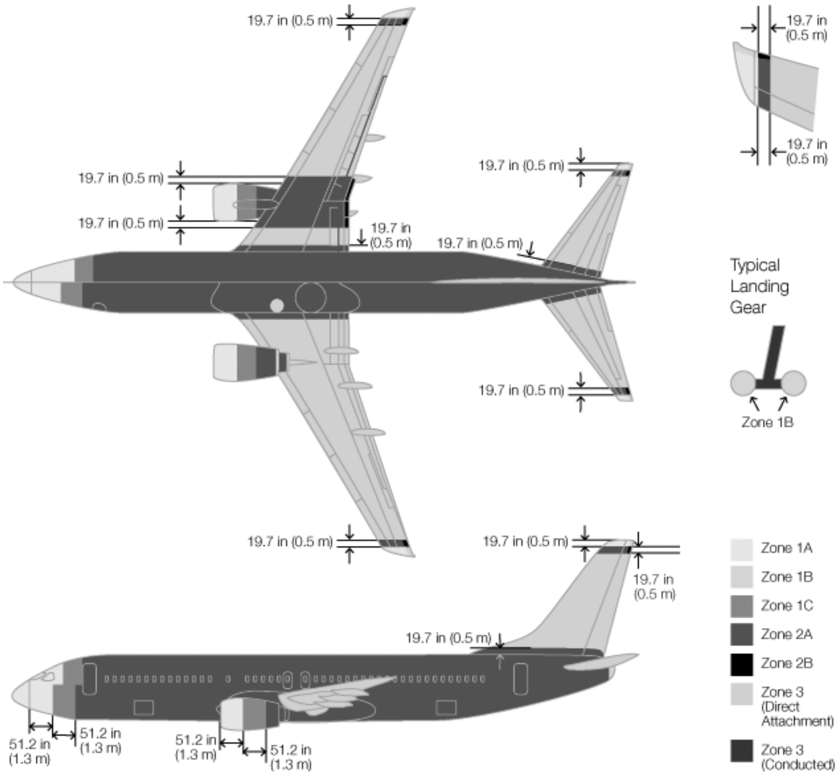


圖9. 飛機雷擊區域示意圖〔飛機易遭受雷擊區域分為區域1~3，第1區域為初始雷擊點最有可能觸碰之區塊，第2區域為滑過、位移的痕跡區塊，第3區域為經歷雷擊電流傳導，卻不留下任何雷擊痕跡的區塊.〕

· 檢查飛操面是否有雷擊損傷的跡象，執行必要的操作檢查

· 檢查起落架門

· 檢查備份磁羅盤

· 檢查燃油計量系統之精確性

· 檢查靜電釋放刷

注意：這是檢查程序之大綱，維護人員還是應該遵循該機型之飛機維護手冊AMM第五章

飛機內部零組件檢查

如果雷擊造成系統功能失常，使用該系統適用之飛機維修手冊AMM章節，對該受影響之系統執行全面性之檢查。

如果飛航組員報告其磁羅盤有非常大之偏異時，則僅須對備份磁羅盤系統執行檢查，使用內建軟體之測試裝備，必須確定燃油存量系統是精確無誤的。

無線電與導航系統之操作測試

飛機遭到雷擊後，要作何等層級之檢查取決於飛航組員資訊以及遭致意外後飛機之情況如何。

例如：假如雷擊後，飛航組員操作所有導航及通訊系統而未發現任何不良情況，通常即不須要對操作系統再作檢查。

至於飛航中，飛航組員未作動之系統或是系統中已發現有不良之情況，則需額外依照其相關之飛機維修手冊AMM所規範之操作測試程序來執行測試。

此外，即使在雷擊後，飛行中已作動之系統，並未發現任何不良故障，但是其後所作之檢驗發現在該系統天線附近有雷擊損傷，則該系統可能須作額外之測試。

波音維修程序提供內部零組件檢驗之邏輯流程係遵照與上述相仿之程序(參見圖10)。

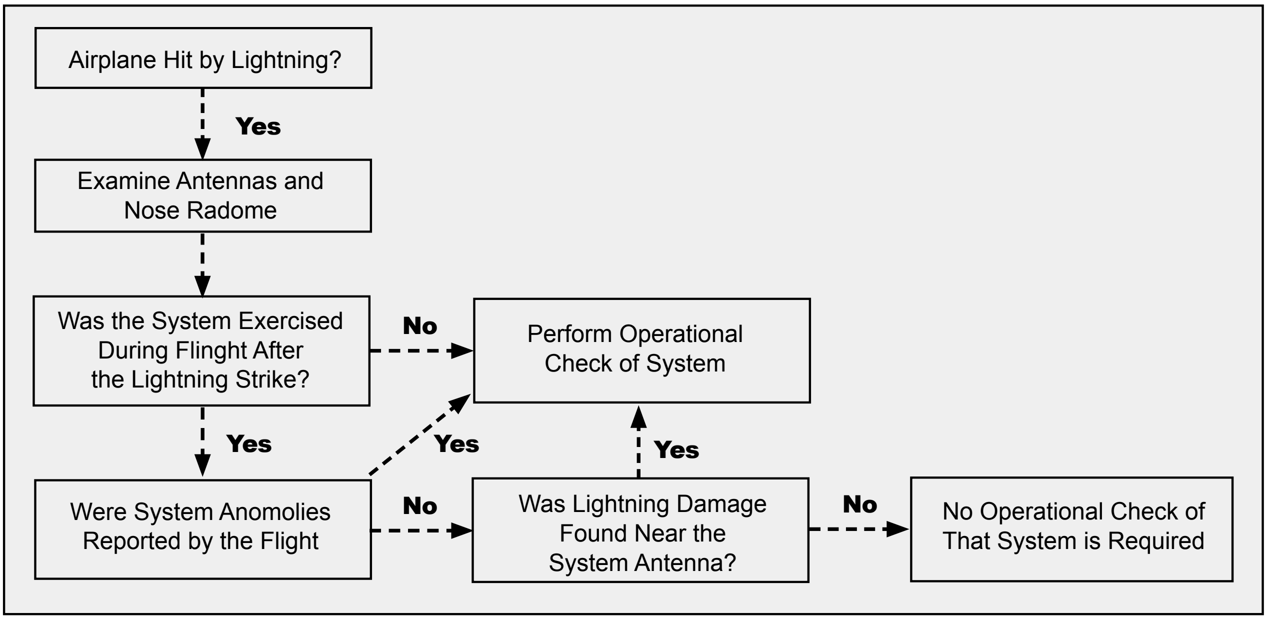


圖10. 內部零組件之檢驗流程圖

雷擊之結構維修

一般雷擊損傷限制以及適用之維修程序之詳細資訊，應可於每種機型結構維修手冊中查得。於雷擊之後，維修人員應當恢復飛機原先之結構完整性，最後之負載強度(Ultimate)，防護性表面塗層，以及使用原材質。

為了回應客戶之訓練需求，波音已發展出結構維修手冊維修課程，提供維修技術人員及工程師對於評估及維修雷擊損傷之訓練。

課程包含損傷類型，防止雷擊之設計原則，損傷檢驗方法，允許之損傷限度、維修以及回復原始防護之方法。欲增加對於飛機雷擊效應的瞭解，以及檢驗方法之訓練，可透過波音代表接洽。

完成本課程後之學員應足以：

· 辨認雷擊原因及其機制
· 辨認飛機上易遭受雷擊之區域
· 描述防止雷擊之設計原則
· 於雷擊後執行適當之檢驗
· 對於已受雷擊影響區域，制定出特定之施工程序
· 了解回復雷擊防範機制及減少雷擊之需求程序

如需查出可用之標準維修訓練資訊，請洽www.myboeingtraining.com

結語：

航空公司應當瞭解飛機遭雷擊時之導電情況，避免將飛機曝露在易遭雷擊之環境下，波音公司已將周延的雷擊防制措施納入設計，雷擊仍然可能影響航空公司之營運，造成昂貴的班機延誤或航班中斷，清楚瞭解適當的檢驗及維修程序，可增進維修人員的效率，確保所有因雷擊造成的損傷都被查明及修復。

譯自波音Aero Quarterly 04/12

Lightning Strikes : Protection, Inspection, and Repair

Lightning strikes can affect airline operations and cause costly delays and service interruptions. Strikes to airplanes are relatively common but rarely result in a significant impact to the continued safe operation of the airplane. Lightning protection is used on Boeing airplanes to avoid delays and interruptions as well as reduce the significance of the strike. To increase the effectiveness of repairs to damage caused by lightning, maintenance personnel must be familiar with lightning protection measures, proper inspection, and repair procedures.

Greg Sweers, Bruce Birch, John Gokcen

When commercial airplanes are struck by lightning, the result can range from no damage to serious damage that requires extensive repairs that can take the airplane out of service for an extended period of time. Having an understanding of the typical effects of lightning strikes and proper damage inspection procedures can prepare operators to act quickly when a lightning strike is reported to apply the most effective maintenance actions.

This article helps maintenance and flight crews understand lightning-strike phenomena and helps operators understand lightning-strike damage inspection requirements and associated effective repairs that improve lightning-strike maintenance efficiency.

While Boeing airplanes incorporate extensive lightning-strike protection, strikes can cause costly delays and service interruptions.

Lightning overview

The frequency of lightning strikes that an airplane experiences is affected by several factors, including the geographic area where the airplane operates and how often the airplane passes through takeoff and landing altitudes, which is where lightning activity is most prevalent.

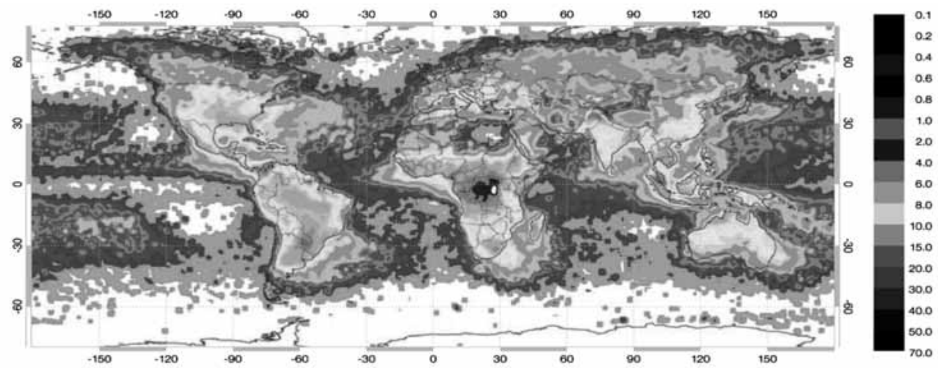
Lightning activity can vary greatly by geographic location. For example, in the United States, parts of Florida average 100 thunderstorm days per year, while most of the West Coast averages only 10 thunderstorm days per year. In the rest of the world, lightning tends to occur most near the equator because the warmth in this region contributes to convection, creating widespread thunderstorms nearly daily. The world lightning map by NASA shows the geographic distribution of lightning (see fig. 1). Areas of highest activity are shown in orange, red, brown, and black. Areas of low activity are white, gray, purple, and blue. Lightning activity is lowest over the oceans and polar areas. It is highest over warm continental areas. The numbered scale represents lightning flashes per square kilometer per year.

Figure 1: Worldwide lightning activity

This map shows the global distribution of lightning April 1995–February 2003 from the combined observations of the National Aeronautics and Space Administration (NASA) optical transient detector (April 1995–March 2000) and land information systems (January 1998–February 2003) instruments. Image courtesy of NASA.

Lightning Observations for April 1995 through February 2003

Flash Density (flashes/kilometers²/year)



More jet airplane lightning strikes occur while in clouds, during the climb and descent phases of flight, than any other flight phase (see fig. 2). The reason is that lightning activity is more prevalent between 5,000 to 15,000 feet (1,524 to 4,572 meters) altitude (see fig. 3). Airplanes that fly short routes in areas with high incidence of lightning activity are likely to be struck more often than long-haul airplanes operating in more benign lightning environments.

Figure 2: Airplane lightning strikes by cloud orientation

Most airplane lightning strikes occur when an airplane is flying in clouds.

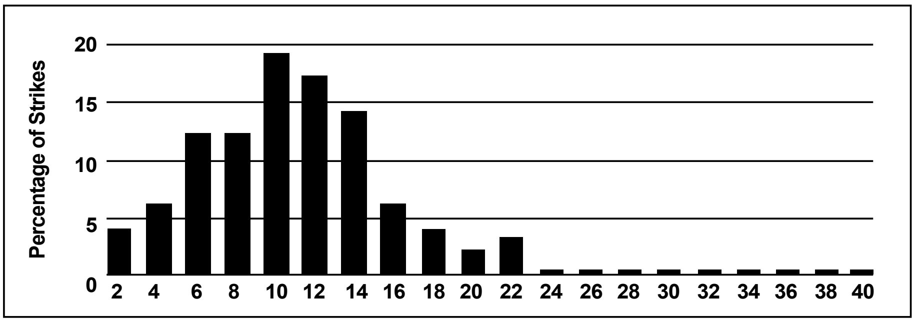
Cloud Orientation	Percent of Total Reported*
Above	<1%
Within	96%
Below	3%
Between	<1%
Beside	<1%

*Sixty-two strikes did not report orientation of clouds during strike event.

Source: Figure 2 is adapted from Airlines Lightning Strike Reports Project: Pilot Reports and Lightning Effects by J. Anderson Plummer, Lightning Technologies Inc., Aug. 2001. Data was gathered from airlines with 881 strikes reported.

Figure 3: Distribution of lightning strikes by altitude

A survey of U.S. commercial jets showed that most lightning strikes occur between altitudes of 5,000 feet (1,524 meters) and 15,000 feet (4,572 meters).



Source: The data in figures 3 and 4 was adapted from data in Lightning Protection of Aircraft by Franklin A. Fisher, J. Anderson Plummer, and Rodney A. Perala, 2nd ed., Lightning Technologies Inc., 2004.

Lightning-strike conditons

The highest probability for lightning attachment to an airplane is the outer extremities, such as the wing tip, nose, or rudder. Lightning strikes occur most often during the climb and descent phases of flight at an altitude of 5,000 to 15,000 feet (1,524 to 4,572 meters). The probability of a lightning strike decreases significantly above 20,000 feet (6,096 meters).

Seventy percent of all lightning strikes occur during the presence of rain. There is a strong relationship between temperatures around 32 degrees F (0 degrees C) and lightning strikes to airplanes. Most lightning strikes to airplanes occur at near freezing temperatures.

Conditions that cause precipitation may also cause electrical storage of energy in clouds. This availability of electrical energy is associated with precipitation and cloud creation. Most lightning strikes affecting airplanes occur during spring and summer.

Although 70 percent of lightning-strike events occur during precipitation, lightning can affect airplanes up to five miles away from the electrical center of the cloud. Approximately 42 percent of the lightning strikes reported by airline pilots were experienced with no thunderstorms reported in the immediate area by the pilots.

A single bolt of lightning can contain as much as 1 million volts or 30,000 amps. The amount and type of damage an airplane experiences when struck by lightning can vary greatly, depending on factors such as the energy level of the strike, the attachment and exit locations, and the duration of the strike.

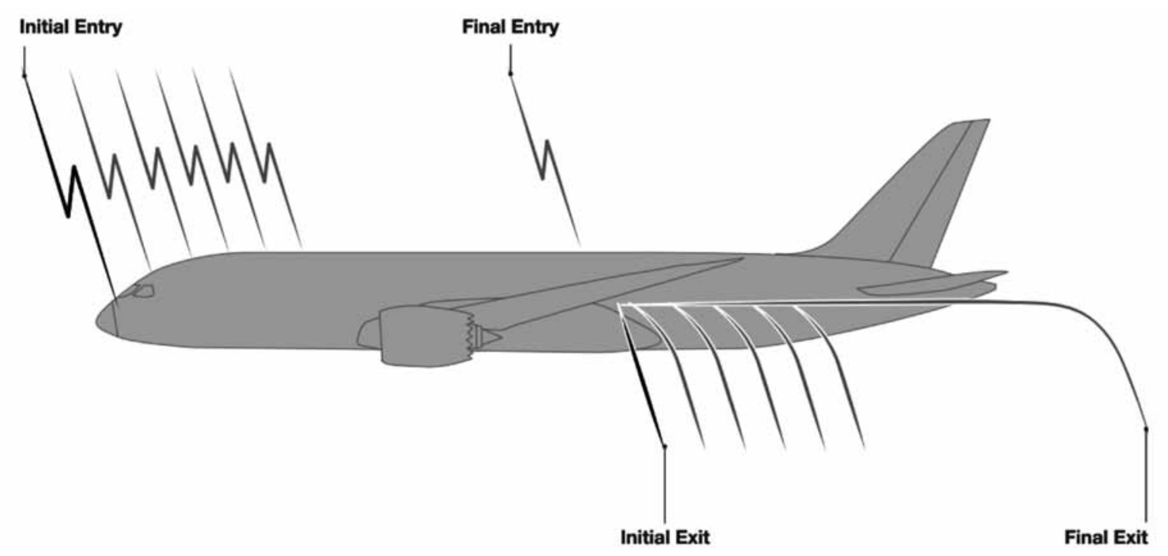
Because of these variations among lightning-strike events, it can be expected that the more often an airplane gets hit by severe lightning, the more likely it is that some of those events will result in damage levels that may require repair.

Lightning interaction with airplanes

Lightning initially attaches to an airplane extremity at one spot and exits from another (see fig. 4). Typically, first attachment is to the radome, forward fuselage, nacelle, empennage, or wing tip.

Figure 4: How lightning attaches to an airplane

Lightning is initiated at the airplane's leading edges, which ionize, creating a strike opportunity. Lightning currents travel along the airplane and exit to the ground, forming a circuit with the airplane between the cloud energy and the ground.



During the initial stages of a lightning strike on an airplane, a glow may be seen on the nose or wing tips caused by ionization of the air surrounding the leading edges or sharp points on the airplane's structure. This ionization is caused by an increase in the electromagnetic field density at those locations.

In the next stage of the strike, a stepped leader may extend off the airplane from an ionized area seeking the large amount of lightning energy in a nearby cloud. Stepped leaders (also referred to as "leaders") refer to the path of ionized air containing a charge emanating from a charged airplane or cloud. With the airplane flying through the charged atmosphere, leaders propagate from the airplane extremities where ionized areas have formed. Once the leader from the airplane meets a leader from the cloud, a strike to the ground can continue and the airplane becomes part of the event. At this point, passengers and crew may see a flash and hear a loud noise when lightning strikes the airplane. Significant events are rare because of the lightning protection engineered into the airplane and its sensitive electronic components.

After attachment, the airplane flies through the lightning event. As the strike pulses, the leader reattaches itself to the fuselage or other structure at other locations while the airplane is in the electric circuit between the cloud regions of opposite polarity. Current travels through the airplane's conductive exterior skin and structure and exits out another extremity, such as the tail, seeking the opposite polarity or ground. Pilots may occasionally report temporary flickering of lights or short-lived interference with instruments.

Typical effects of lightning strikes

Airplane components made of ferromagnetic material may become strongly magnetized when subjected to lightning currents. Large current flowing from the lightning strike in the airplane structure can cause this magnetization.

While the electrical system in an airplane is designed to be resistant to lightning strikes, a strike of unusually high intensity can damage components such as electrically controlled fuel valves, generators, power feeders, and electrical distribution systems.

Commercial airplane lightning protection

Most of the external parts of legacy airplanes are metal structure with sufficient thickness to be resistant to a lightning strike. This metal assembly is their basic protection. The thickness of the metal surface is sufficient to protect the airplane's internal spaces from a lightning strike. The metal skin also protects against the entrance of electromagnetic energy into the electrical wires of the airplane. While the metal skin does not prevent all electromagnetic energy from entering the electrical wiring, it can keep the energy to a satisfactory level.

By understanding nature and the effects of lightning strikes, Boeing works to design and test its commercial airplanes for lightning-strike protection to ensure protection is provided throughout their service lives. Material selection, finish selection, installation, and application of protective features are important methods of lightning-strike damage reduction.

Areas that have the greatest likelihood of a direct lightning attachment incorporate some type of lightning protection. Boeing performs testing that ensures the adequacy of lightning protection. Composite parts that are in lightning-strike prone areas must have appropriate lightning protection.

The large amount of data gathered from airplanes in service constitutes an important source of lightning-strike protection information that Boeing uses to make improvements in lightning-strike damage control that will reduce significant lightning-strike damage if proper maintenance is performed.

Lightning protection on airplanes may include:

•Wire bundle shields.

•Ground straps.

•Composite structure expanded foils, wire mesh, aluminum flame spray coating, embedded metallic wire, metallic picture frames, diverter strips, metallic foil liners, coated glass fabric, and bonded aluminum foil.

Required actions following a lightning strike to an airplane

Lightning strikes to airplanes may occur without indication to the flight crew. When an airplane is struck by lightning and the strike is evident to the pilot, the pilot must determine whether the flight will continue to its destination or be diverted to an alternate airport for inspection and possible repair.

Technicians may find and identify lightning-strike damage by understanding the mechanisms of lightning and its attachment to airplanes. Technicians must be aware that lightning strikes may not be reported in the flight log because the pilots may not have known that a lightning strike occurred on the airplane. Having a basic understanding of lightning strikes will assist technicians in performing effective maintenance.

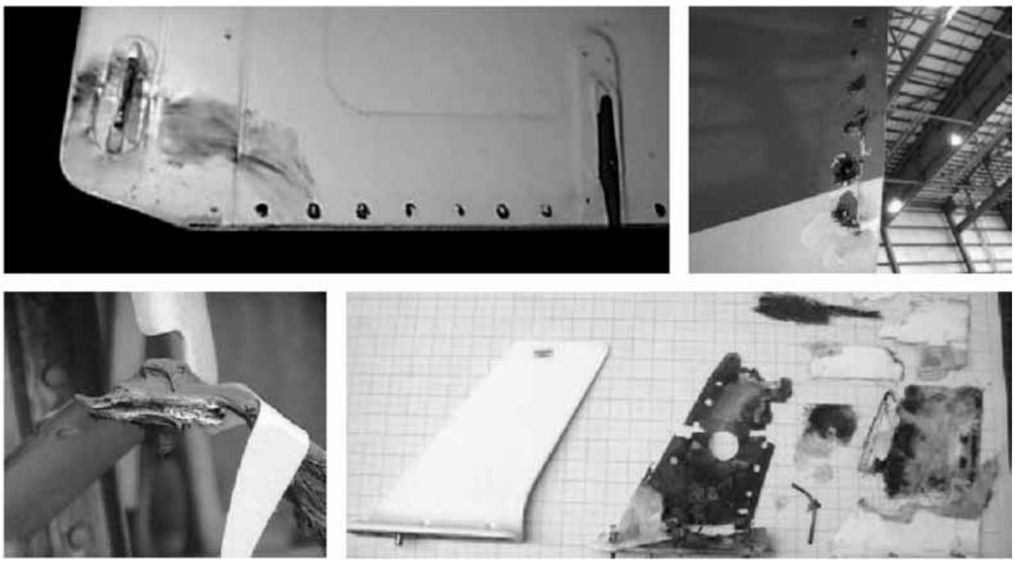
Identifying lightning-strike damage on a commercial airplane

Lightning strikes to airplanes can affect structure at the entrance and exit points. In metal structures, lightning damage usually shows as pits, burn marks, or small circular holes. These holes can be grouped in one location or divided around a large area. Burned or discolored skin also shows lightning-strike damage.

Direct effects of a lightning strike can be identified by damage to the airplane's structure, such as melt through, resistive heating, pitting to structure, burn indications around fasteners, and even missing structure at the airplane's extremities, such as the vertical stabilizer, wing tips, and horizontal stabilizer edges (see fig. 5). Airplane structure can also be crushed by the shock waves present during the lightning strike. Another indication of lightning strike is damage caused to bonding straps. These straps can become crushed during a lightning strike due to the high electromagnetic forces.

Figure 5: Lightning protection and strike damage

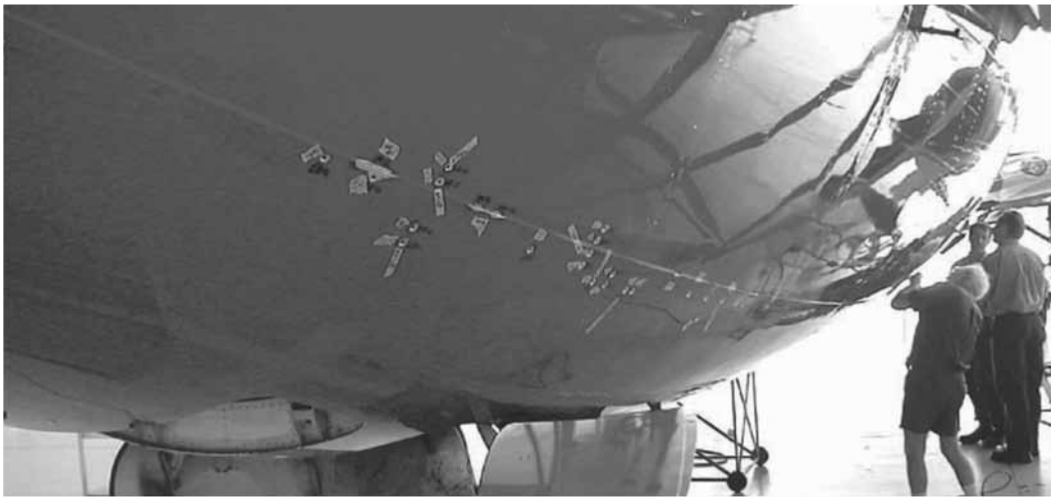
Clockwise from upper left: Lightning damage to a horizontal stabilizer, rudder, antenna, and bond jumper.



Because the airplane flies more than its own length during the time it takes a strike to begin and finish, the entry point will change as the flash reattaches to other spots aft of the initial entry point. Evidence of this is seen in strike inspections where multiple burns are seen along the airplane's fuselage (see fig. 6).

Figure 6: Damage caused by lightning moving along an airplane

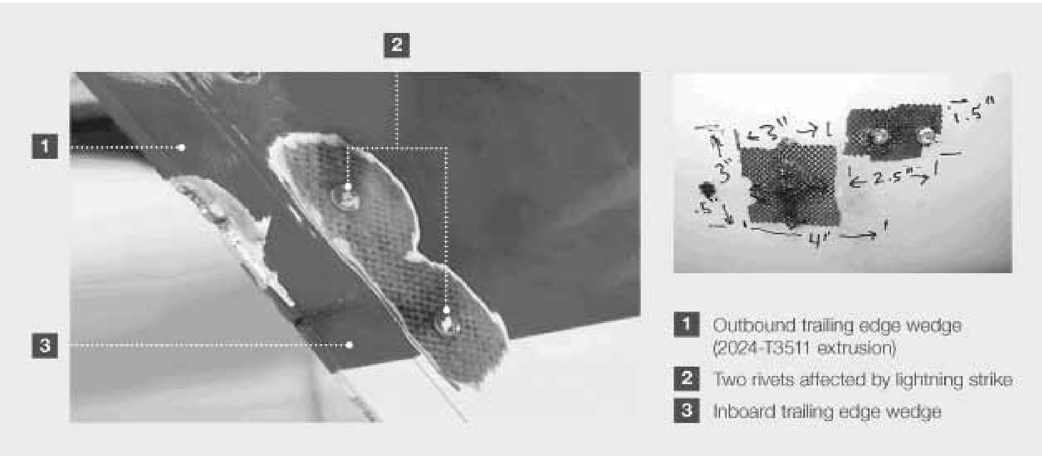
When a lightning strike moves along an airplane, it can cause “swept stroke” damage.



Lightning can also damage composite airplane structures if protection finish is not applied, properly designed, or adequate. This damage is often in the form of burnt paint, damaged fiber, and composite layer removal (see fig. 7).

Figure 7: Lightning damage to a composite airplane

Composite structures are less conductive than metal, causing higher voltages. This is the type of damage that can occur if a lightning protection finish is not applied or is inadequate.



Lightning-strike structural inspection procedures

If lightning strikes an airplane, a lightning-strike conditional inspection must be performed to locate the lightning-strike entrance and exit points. When looking at the areas of entrance and exit, maintenance personnel should examine the structure carefully to find all of the damage that has occurred.

The conditional inspection is necessary to identify any structural damage and system damage prior to return to service. The structure may have burn holes that can lead to pressurization loss or cracks. The critical system components, wire bundles, and bonding straps must be verified as airworthy prior to flight. For these reasons, Boeing recommends that a complete lightning-strike conditional inspection should be performed prior to the next flight to maintain the airplane in an airworthy condition.

- •Radome.
- •Nacelles.
- •Wing tips.
- •Horizontal stabilizer tips.
- •Elevators.
- •Vertical fin tips.
- •Ends of the leading edge flaps.
- •Trailing edge flap track fairings.
- •Landing gear.
- •Water waste masts.
- •Air data sensors (pitot probes, static ports, angle of attack [AOA] vane, total air temperature probe).

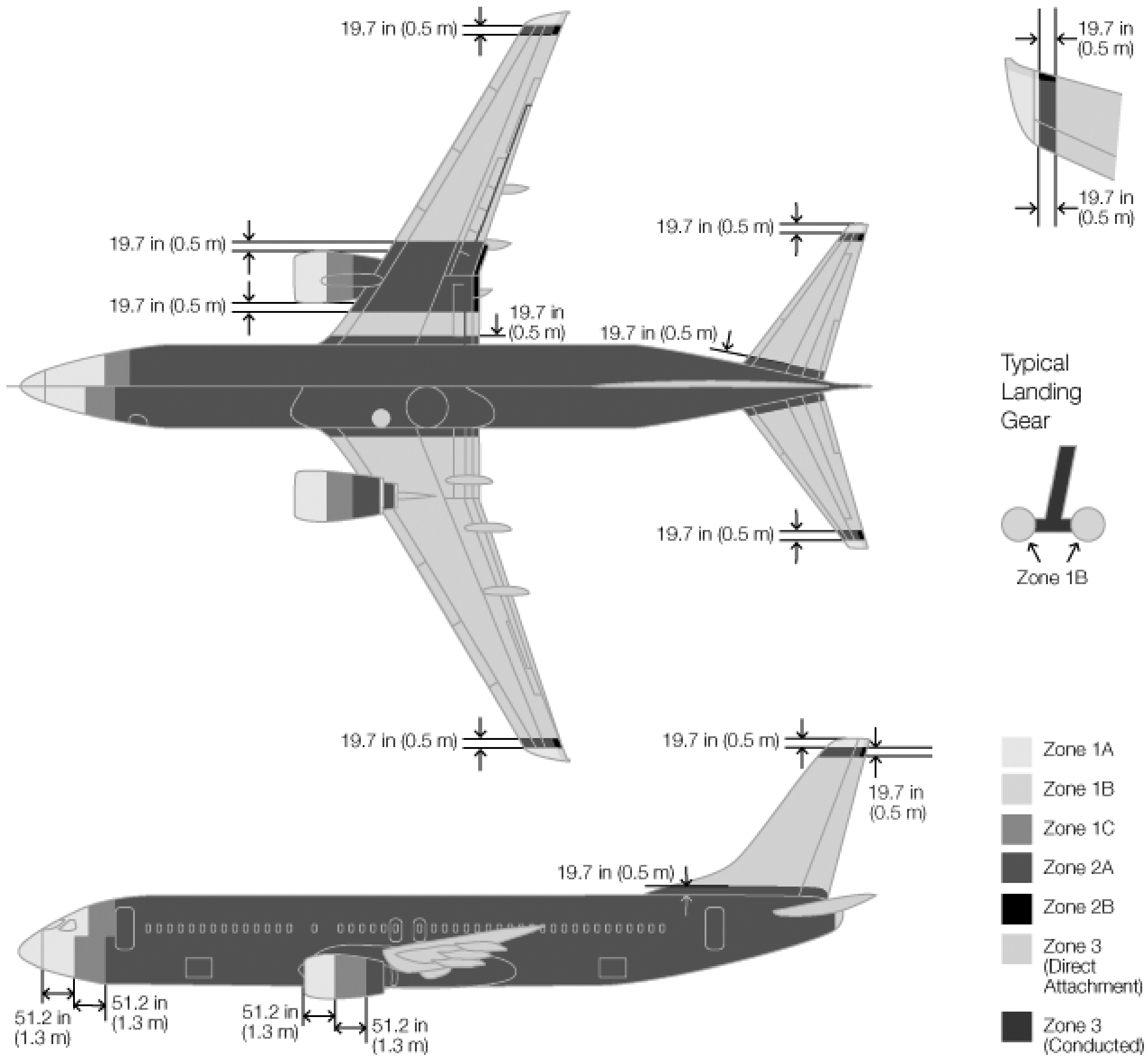
Figure 8: Lightning zone definitions

Airplane lightning zones as defined by SAE Aerospace Recommended Practices 5414.

Zone Designation	Description	Definition
1A	First return stroke zone	All areas of the airplane surfaces where a first return is likely during lightning channel attachment with a low expectation of flash hang on.
1B	First return stroke zone with a long hang on	All areas of the airplane surfaces where a first return is likely during lightning channel attachment with a low expectation of flash hang on.
1C	Transition zone for first return stroke	All areas of the airplane surfaces where a first return stroke of reduced amplitude is likely during lightning channel attachment with a low expectation of flash hang on.
2A	Swept stroke zone	All areas of the airplane surfaces where a first return of reduced amplitude is likely during lightning channel attachment with a low expectation of flash hang on.
1B	Swept stroke zone with long hang on	All areas of the airplane surfaces into which a lightning channel carry subsequent return stroke is likely to be swept with a high expectation of flash hang on.
3	Strike locations other than Zone 1 and Zone 2	Those surfaces not in Zone 1A, 1B, 1C, 2A, or 2B, where any attachment of the lightning channel is unlikely, and those portions of the airplane that lie beneath or between the other zones and/or conduct a substantial amount of electrical current between direct or swept stroke attachment points.

Figure 9: Airplane lightning zones

Areas of an airplane that are prone to lightning strikes are indicated by zone. Zone 1 indicates an area likely to be affected by the initial attachment of a strike. Zone 2 indicates a swept, or moving, attachment. Zone 3 indicates areas that may experience conducted currents without the actual attachment of a lightning strike.



In Zone 2, an initial entry or exit point is a rare event, but in such a case, a lightning channel may be pushed back from an initial entry or exit point. As an example, the radome may be the area of an initial entry point, but the lightning channel may be pushed back along the fuselage aft of the radome by the forward motion of the airplane.

A Zone 3 examination is highly recommended even if no damage is found during the Zone 1 and Zone 2 examinations. In summary, any entrance and exit points must be identified in Zones 1, 2, or 3 so that the immediate areas around them can be thoroughly examined and repaired if necessary.

lightning-strike surfaces examination by zone

Boeing provides lightning-strike inspection procedures to ensure external surfaces have not been damaged.

Operators should refer to applicable maintenance procedures as the authoritative source for inspection/repair instructions. Typical procedures provided include the following general guidance.

•Perform typical external surface examination for Zone 1 and Zone 2.

•Examine all airplane external surfaces:

-Examine the external surfaces carefully to find the entrance and exit points of the lightning strike and look in the areas where one surface stops and another surface starts.

-Examine the metallic and nonmetallic structure for damage.

-For composite structure, delamination can be detected by instrumental non-destructive inspection methods or by a tap test.

-For Zone 2, examine the pitot probes, AOA sensors, static ports, and their surrounding areas for damage.

If the entrance and exit points are not found during the examination of Zones 1 and 2, the Zone 3 surface areas should be examined for signs of lightning-strike damage. Inspections of Zone 3 are similar to Zones 1 and 2. Additional inspections for Zone 3 include:

•Examine all of the external lights, looking for:

-Broken light assemblies.

-Broken or cracked lenses.

-Other visible damage.

•Examine the flight control surfaces for signs of lightning-strike damage and perform necessary operational checks.

•Examine landing gear doors.

•Check the standby magnetic compass.

•Check the fuel quantity system for accuracy.

•Examine the static dischargers.

Note: This is an outline of inspection procedures. Maintenance personnel should consult chapter five of the Aircraft Maintenance Manual (AMM) for the airplane model being inspected.

Airplane internal components examination

If a lightning strike has caused a system malfunction, perform a full examination of the affected system with the use of the applicable AMM section for that system.

Perform a check of the standby compass system only if the flight crew reported a very large compass deviation.

Make sure the fuel quantity system is accurate using the built-in test equipment.

Operation tests of radio and navigation systems

The level of checks after a lightning strike to the airplane is determined by flight crew information and the airplane condition after the incident.

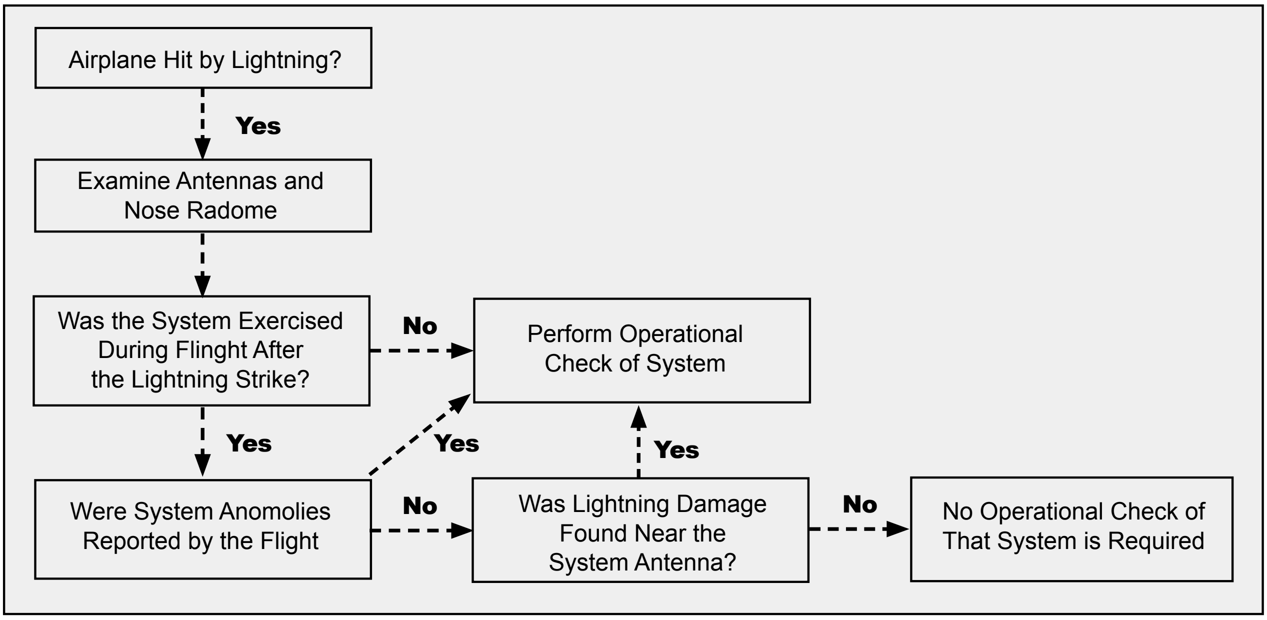
For example, if all the navigation and communications systems are operated by the flight crew in flight after the lightning strike and no anomalies are found, checks to the operated systems would not normally be required.

For systems not operated by the flight crew in flight or systems where anomalies were found, additional operational test procedures, as specified in the respective AMM, may be required. In addition, even if a system were operated in flight after the lightning strike and no anomalies were found, but subsequent inspections showed lightning damage near that system antenna, additional checks of that system may be required.

Logic flow for inspection of internal components in maintenance procedures provided by Boeing follow a similar process (see fig. 10).

Figure 10: Conditional inspection flowchart of internal components

Boeing recommends that a lightning-strike conditional inspection be performed prior to the next flight to maintain the airplane in an airworthy condition.



Lightning-strike structural repairs

Detailed information and procedures for common lightning allowable damage limits and applicable rework or repairs can be found in the structural repair manual (SRM) for each airplane model. Maintenance personnel should restore the original structural integrity, ultimate load strength, protective finish, and materials after a lightning strike.

In response to customer requests for training, Boeing has developed an SRM repair course to give maintenance technicians and engineers training in assessing and repairing airplane lightning-strike damage. Topics include the types of damage, lightning-strike protection design principles, damage inspection methods, allowable damage limits, repairs, and restoration of protective methods. Additional training on understanding lightning effects on airplanes and inspection instructions may be requested through the Boeing airlines representative. Upon completion of the course, the student will be able to:

- Identify causes and mechanisms of lightning strikes.
- Identify lightning-strike-prone areas on the airplane.
- Describe lightning-strike-protection design principles.
- Perform appropriate inspections after lightning strikes.
- Identify specific rework procedures for areas that are affected by lightning strikes.
- Understand requirements for restoration of lightning-strike protection and reduction.

For more information on available standard maintenance training, please contact www.myboeingtraining.com.

Summary

Operators should be aware of the conditions that are conducive to lightning strikes on airplanes and avoid exposing airplanes unnecessarily to lightning-prone environments. While Boeing airplanes incorporate extensive lightning-strike protection, lightning strikes can still affect airline operations and cause costly delays or service interruptions. A clear understanding of proper inspection and repair procedures can increase the effectiveness of maintenance personnel and ensure that all damage caused by lightning is identified and repaired.

From Boeing Quarterly 04/12