Going The Distance

Aircraft And Lightning, How Far is Far Enough?

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***Abstract*---With the limited data that is available this document serves the purpose to illustrate why aircraft should remain 25 nautical miles (NM) away from thunderstorms. There has been no extensive research on aircraft flying in or near thunderstorms since the 1980s, so data presented is from just normal naturally occurring lightning strikes. The studies show that 95-99% of all lightning strikes are within a 10 NM range; however, while uncommon, there are lightning strikes that can range from 20 to 30 NM [1][2]. Most aircraft agencies stress a 20 to 25 NM distance from thunderstorms. Finally in this paper we take a look at probability and risk estimations for an aircraft being struck by lightning and at what distances from storms is an acceptable level of risk reached. From the risk analysis of the two test cases we can see there are instances that indicate an acceptable level of risk within 25 NM, however it is not until then that a satisfactory level is reached across the board. Because of the studies and the risk assessment provided it seems reasonable why most pilots and aircraft agencies stress a 20 to 25 NM limit for avoiding thunderstorms.**

I. Introduction

Currently, while not an official mandate most groups suggest that aircraft avoid thunderstorms by 20 to 25 nautical miles (NM). In this paper we will look into why that is. Two different studies will then be viewed with respect to lightning strike distances, and the types of lightning produced by those storms. Then, avoidance procedures practiced by different agencies are overviewed. Finally, a Hazard Risk Assessment will be made based on the limited data available to determine whether or not the current suggested limit is ideal.

II. Lightning Strike Distances

Nailing down the distance that lightning will travel is incredibly difficult, if not impossible to do. Storm intensity, direction of the wind, charge density, as well as a bit of random chance all play into where a bolt of lightning will strike. Most lightning strikes range just a couple miles in length, however they can be as long as 20 or 30 miles. In 2002 and in and 2012 two studies were conducted to see how far away lightning strikes from a storm. The results, further looked into in the following section, were that 95 – 99% of all lightning activity was within a 10 NM range from the producing thunderstorm [1][2].

A. 3-D lightning data and weather radar data to determine the distance that naturally occurring lightning travels from thunderstorms

In 2002 First Lieutenant Lee A. Nelson of the United States Air Force performed a study combining 3-D lightning data and weather radar data to determine the distance that naturally occurring lightning travels from thunderstorms. The study was conducted from June 2001 – March 2002, and has results from 19,623 lightning strikes. The results are as follows: 90% of flashes were less than 16km (8.6 NM), 95% of the flashes were less than 19km (10.4 NM) and 99% of flashes were less than 30km (16.1 NM). The mean average distance from flash origin point was 7.2km (4 NM). The max however stretched out to 46km (25 NM). It is also worth noting that flashes that came from the origin to the furthest LDAR data point in a lightning flash, Fig. 1, had a higher average and longest length for the 99th percentile than those that came from the flash origin traveled from the edge of the 40-dBZ echo, Fig. 2.

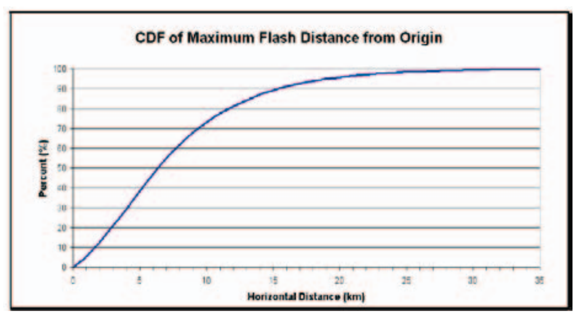

Fig. 1. CDF of Maximum Flash Distance from Origin [1].

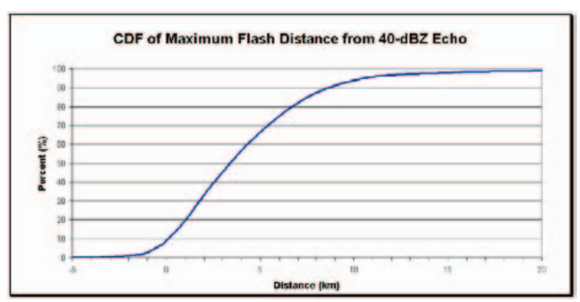

Fig. 2. CDF of Maximum Flash Distance from 40-dBZ Echo [1].

B. Determining characteristics of Anvil and thunderstorm lightning for use in the Lightning Launch Control Criteria at Cape Canaveral Air Force Station and Kennedy Space Center

Another study was conducted in 2012 by Zachary Tamurian from Florida State University [2], his goal was to determine the characteristics of Anvil and Thunderstorm lightning for use in the Lightning Launch Control Criteria (LLCC) at Cape Canaveral Air Force Station and Kennedy Space Center. He tested with varying types of reflectivity's and lightning locations to try to determine if the LLCC was too strict on launches criteria. The studies he performed and the results are as follows:

Fig. 3 shows the distance frequency distribution of the 1175 Intra-Cloud flashes that extended outside the edge of a thunderstorm cloud at 0 dBZ. Over 98% extended ≤ 10 NM with a mean distance of 3.89 NM. 1.71% extended beyond 10 NM, and a small percentage of flashes about 1% extended ≥ 15 NM. Fig. 4 shows the cumulative Intra-Cloud flash probability distribution. It indicates an increase in percentage for flashes extending ≥ 5 NM from the thunderstorm cloud edge, and Outer-Cloud Intra-Cloud flashes that are ≤ 5 NM occur 65% of the time.

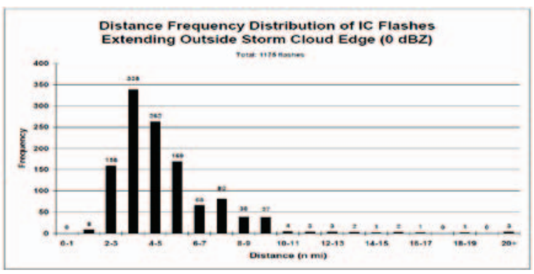

Fig. 3. Distance frequency distribution of the 1175 IC flashes extending outside the storm cloud edge (0 dBZ) [2].

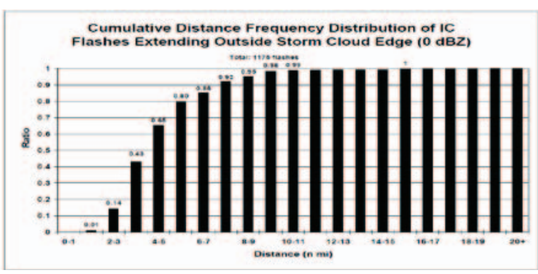

Fig. 4. Cumulative probability distribution of 1175 IC flashes that extend beyond the thunderstorm cloud edge (0 dBZ) [2].

TABLE I. PROBABILITY OF IC FLASHES EXTENDING OUTSIDE STORM CLOUD EDGE OF A DISTANCE EQUAL OR LESS THAN THE VALUE LISTED [2]

Distance (n mi)	Cum. prob. of flash ≤ distance (%)
3	16.37
5	63.97
7	87.17
9	95.17
10	**96.93**
12	98.67
15	99.56

a. Values are based on extreme value theory.

Most lightning occurs in a storm's core region (i.e., ≥ 30 dBZ region); however, dissipating storms in environments of moderately strong upper level wind shear can transfer charge to the attached anvil cloud region, any may remain electrically charged for several hours, posing a threat for triggered lightning if penetrated by a launch or landing vehicle. Charge separation from the convective core may stimulate a spontaneous flash in the anvil. Distance that the first anvil flash, typically Intra-Cloud, traveled from the cores of 100 anvils was measured in Fig. 5**.** Almost half, 48%, of initial anvil flashes were within 3 – 6 NM of the storm core. In Fig. 6 it shows that some flashes ~8% propagate over 10 NM from the edge of the core.

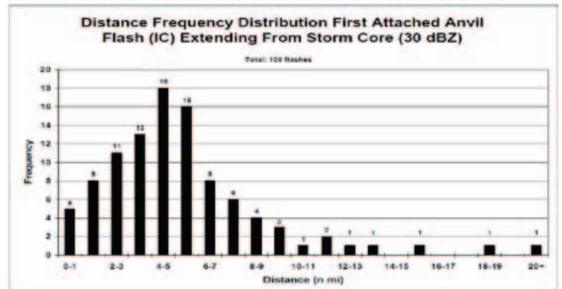

Fig. 5. Distance distribution of the first anvil flash (IC) from the thunderstorm core (30 dBZ). The total number of flashes is 100 [2].

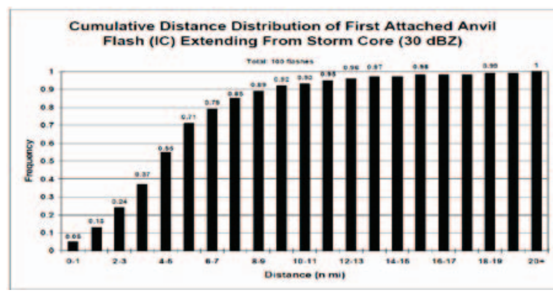

Fig. 6. Cumulative probability distribution of the first anvil flash (IC; 100 flashes) from the thunderstorm core (30 dBZ) [2].

TABLE II. PROBABILITY OF THE FIRST ATTACHED ANVIL IC FLASH EXTENDING FROM THE STORM CORE OF A DISTANCE EQUAL OR LESS THAN THE VALUE LISTED [2]

Distance (n mi)	Cum. prob. of flash ≤ distance (%)
3	26.30
5	55.67
7	75.97
9	87.23
10	**90.65**
12	94.82
15	97.82
18	99.01

b. Values are based on extreme value theory.

For the propagation distance of 895 Intra-Cloud flashes that initiated inside the core and remained inside the attached anvil, Fig 7, 105 strikes, or about 12%, extended ≥10 NM from the edge of the convective core. In this criteria, 9 strikes, or roughly 1%, extended beyond 25 NM. For this case the 99th percentile distance isn't reached until 24 NM from the core of the storm.

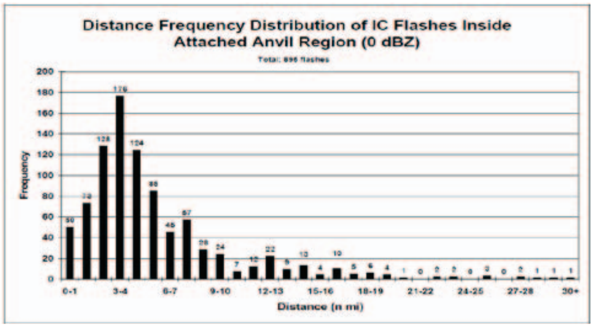

Fig. 7. Distance frequency distribution of IC lightning inside the anvil (0 dBZ) of 895 flashes [2].

TABLE III. PROBABILITY OF AN IC FLASH INSIDE THE ANVIL REGION MEASURED FROM THE STORM CORE [2]

Distance (n mi)	Cum. prob. of flash ≤ distance (%)
3	31.01
5	58.73
7	75.98
9	85.61
10	**88.46**
12	92.78
15	96.05
18	97.67
21	98.55
25	99.17

c. Values are based on extreme value theory.

Lightning extending outside the attached anvil cloud is rather infrequent. Out of 100 anvils only 200 strikes fitting this criteria occurred over the 14 flash day period, Fig. 8. Around 37% of flashes observed were between 0 and 1 NM outside of the 0 dBZ reflectivity threshold. 1.5% extended ≥ 10 NM.

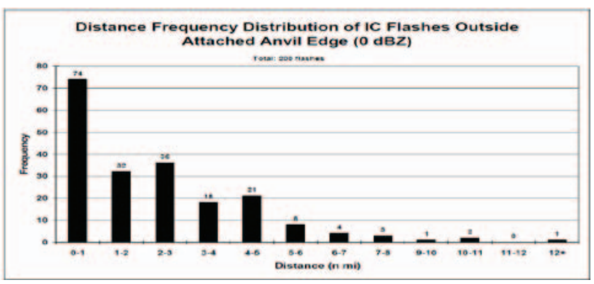

Fig. 8. Distance frequency distribution of 200 IC flashes extending outside the edge of the attached anvil (0 dBZ) [2].

TABLE IV. PROBABILITY OF IC FLASHES EXTENDING OUTSIDE THE ATTACHED ANVIL CLOUD EDGE [2]

Distance (n mi)	Cum. prob. of flash ≤ distance (%)
3	73.76
5	93.69
7	95.91
9	98.15
10	**98.71**
12	99.33

d. Values are based on extreme value theory.

In the last study with Intra-Cloud flashes, fig. 9, flashes outside detached anvil edges were looked at, and of the 20 flashes over 6 flash day's 95% ≤ 4 NM, and 5% between 6 and 7 NM.

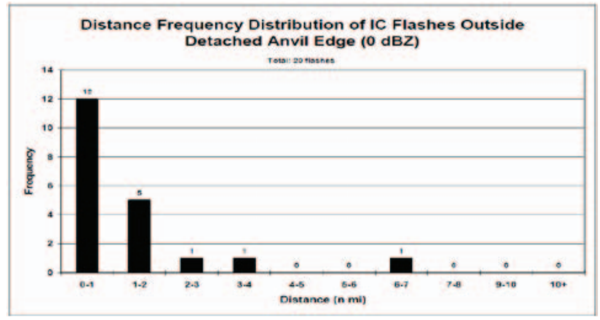

Fig. 9. Distance frequency distribution of the 20 IC flashes that initiated in a detached anvil and extended perpendicular and outside the edge of the detached anvil (0 dBZ) [2].

We now consider Cloud-to-Ground Flashes that remain under or extend laterally away from the attached anvil region. 120 Cloud-to-Ground were located for Fig. 10. The distances vary greatly, both from the convective core and the anvil edge, 52% of flashes ≤ 10 NM; 10% flashes ≥ 15 NM. Bolts from the blue can originate in the storm core or anvil. From the data set of 120 flashes, 5 originated in the anvil, extended ≤ 3 NM outside the anvil edge, and occurred less than 5 minutes before the anvil detached. The other 115 flashes propagated from the core (30 dBZ) and into the attached anvil cloud but didn't extend further than the cloud edge. All 5 anvils that received a prior Cloud-to-Ground flash prior to detachment produced a single flash outside its edge within 5 minutes of detachment. Based on this criteria it would have to be ≥ 30 NM away to reach the 99th percentile.

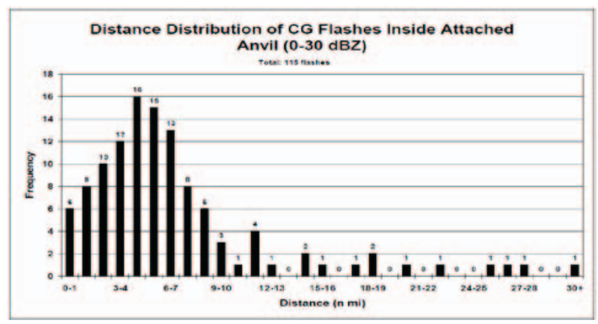

Fig. 10. Distance frequency distribution of CG flashes inside the attached anvil edge. 115 CG flashes were inside, and five were outside the edge of the attached anvil [2].

TABLE V. PROBABILITY OF CG FLASHES EXTENDING ALONG THE ATTACHED ANVIL MOTION (I.E., ≥ 0 DBZ) [2]

Distance (n mi)	Cum. prob. of flash ≤ distance (%)
3	23.98
5	49.86
7	68.18
9	79.47
10	**82.63**
12	88.69
15	93.31
18	95.78
21	97.21
24	98.07
27	98.62
30	98.99

e. Values are based on extreme value theory.

80 Cloud-to-Ground were measured in these criteria, 3 of which were positive Cloud-to-Ground strikes. In Fig. 12 it can be seen that 100% of the strikes were within 10 NM. Fig. 13 uses the same dataset at Fig. 11, but it measures the flashes extending outside the precipitation (18 dBZ). Two Cloud-to-Ground flashes extended outside of 10 NM from the precipitation, 11 and 13 NM, and both were positive polarity. Over half of the flashes were under 1 NM. The mean distance of 2.83 NM was calculated between the precipitation threshold (18 dBZ) and the cloud edge (0 dBZ).

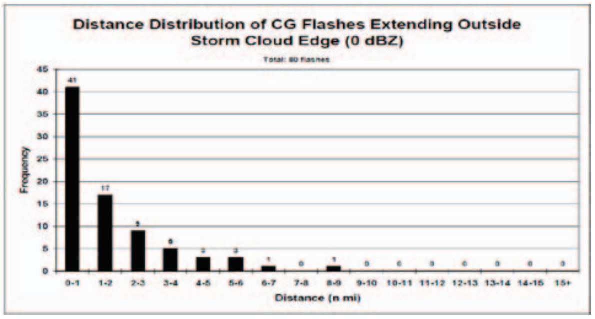

Fig. 11. Distance distribution of the 80 CG flashes extending outside the edge of the thunderstorm cloud (0 dBZ), i.e., bolts from the blue [2].

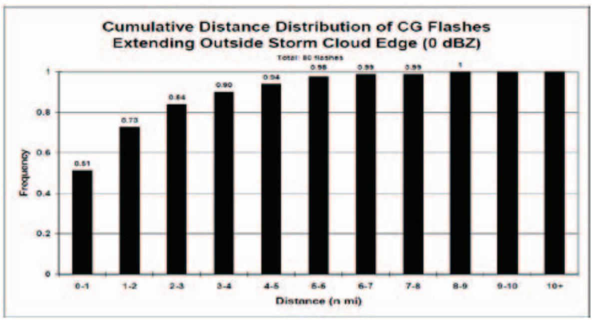

Fig. 12. Cumulative probability distribution of 80 CG flashes extending outside the edge of the thunderstorm cloud (0 dBZ) [2].

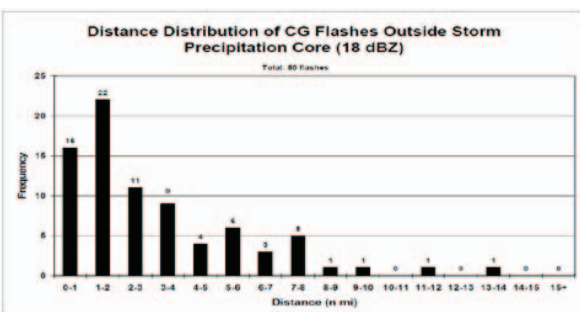

Fig. 13. Distance distribution of the 80 CG flashes extending outside the thunderstorm precipitation threshold (18 dBZ) [2].

TABLE VI. PROBABILITY OF CG FLASHES EXTENDING OUTSIDE THE STORM PRECIPITATION THRESHOLD (18 DBZ) [2]

Distance (n mi)	Cum. prob. of flash ≤ distance (%)
3	60.75
5	82.42
7	91.74
9	95.83
10	**96.96**
12	98.31
15	99.22

f. Values are based on extreme value theory.

The study concludes that out of 1175 IC flashes only 1.71% extended ≥ 10 NM outside cloud edge. For Cloud to ground flashes roughly 2% propagated ≥ 10 NM from precipitation. The large majority of Cloud-to-Ground strikes (94%) occurred ≤5 NM from cloud edge. No bolts from the blue extended ≥10 NM from cloud edge. Finally, the probability of any type of lightning extending > 10 NM from cloud edge of thunderstorm cell is (1.14%); and from edge of anvil (0.29%).

C. *Thunderstorm Avoidance Recommendations*

This section will mostly comprise of different aircraft agencies and the guidelines that they provide when it comes to thunderstorm avoidance policy.

a) Advisory Circular 00-24C from the U.S. Department of Transportation FAA

- Do avoid by at least 20 miles any thunderstorm identified as severe or giving an intense radar echo. This is especially true under the anvil of a large cumulonimbus [3].

b) Lightning Technologies Inc. Lightning protection of Aircraft

- Circumnavigation of visible thunderstorm conditions, as indicated by visual observations and/or airborne weather radar displays. Ideally, these conditions should be kept at a distance of 25 miles or more, but traffic constraints often limit this distance [4].

c) Major Airline

- When flying above 23,000 feet avoid all echoes by 20 nautical miles [5].

d) US Military

- 2010 the military issued a memo stating that MAFFS aircraft configured with a nozzle extending out from the aircraft should avoid thunderstorms by 25 nautical miles [5].

e) EUROCONTROL (European Organization for the Safety of Air Navigation)

- A cumulonimbus cloud be cleared by a minimum of 5,000 feet vertically and 20 nautical miles laterally to minimize risk of encountering severe turbulence [6].

III. Probability of Lightning Striking Aircraft

Using the Price & Rind data from the graph below, fig. 14, from [7] which was a study done to see if more Cloud-to-Ground lightning was occurring dependent on the size of the cold cloud layer, or from location of the storm on the globe, we created Table VII. Using this in conjunction with lightning data maps, fig. 15, we were able to then, break them further into positive and negative lightning.

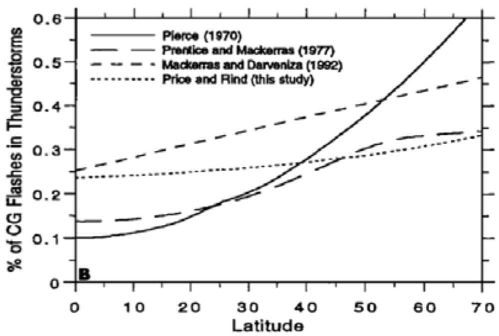

Fig. 14. Percentages of CG lightning in thunderstorms dependent on latitude on the globe [7].

TABLE VII. Percentages of CG and IC lightning in thunderstorms dependent on latitude location on the globe.

Latitude	% CG flashes	% IC flashes
0	0.24	0.76
10	0.242	0.758
20	0.246	0.754
30	0.25	0.75
40	0.27	0.73
50	0.29	0.71
60	0.31	0.69
70	0.34	0.66

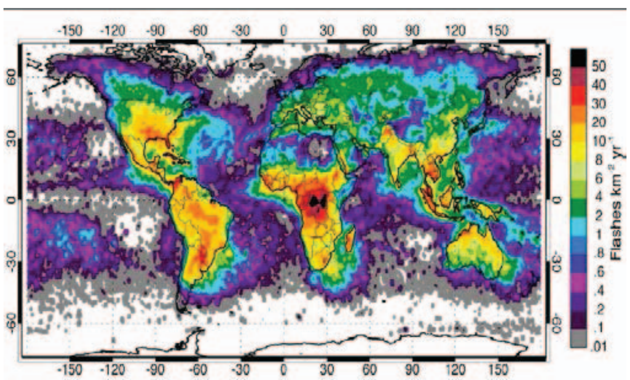

Fig. 15. Data from NASA's space-based optical sensors revealing the uneven distribution of worldwide lightning strikes. Units: flashes/km^2/yr. Image credit: NSSTC Lightning Team [8].

Tables VIII & IX**,** show the breakdown of the flash densities split into Cloud-to-Ground and Intra-Cloud lightning into each latitudinal region. From there this can be broken down farther into the split of negative and positive lightning for both by taking the 90-95% of lightning to be negative, and 5-10% of lightning to be positive for each of the two cases. For this probability estimation 90% negative and 10% positive lightning were used.

TABLE VIII. Percentages of positive and negative Cloud to Ground lightning dependent on latitude

	Flash Density															
	0.01	0.1	0.2	0.4	0.6	0.8	1	2	4	6	8	10	20	30	40	50
L 0	0.0024	0.024	0.048	0.096	0.144	0.192	0.24	0.48	0.96	1.44	1.92	2.4	4.8	7.2	9.6	12
A 10	0.00242	0.0242	0.048	0.097	0.1452	0.1936	0.242	0.484	0.968	1.452	1.936	2.42	4.84	7.26	9.68	12.1
T 20	0.00246	0.0246	0.049	0.098	0.1476	0.1968	0.246	0.492	0.984	1.476	1.968	2.46	4.92	7.38	9.84	12.3
I 30	0.0025	0.025	0.05	0.1	0.15	0.2	0.25	0.5	1	1.5	2	2.5	5	7.5	10	12.5
T 40	0.0027	0.027	0.054	0.108	0.162	0.216	0.27	0.54	1.08	1.62	2.16	2.7	5.4	8.1	10.8	13.5
U 50	0.0029	0.029	0.058	0.116	0.174	0.232	0.29	0.58	1.16	1.74	2.32	2.9	5.8	8.7	11.6	14.5
D 60	0.0031	0.031	0.062	0.124	0.186	0.248	0.31	0.62	1.24	1.86	2.48	3.1	6.2	9.3	12.4	15.5
E 70	0.0034	0.034	0.068	0.136	0.204	0.272	0.34	0.68	1.36	2.04	2.72	3.4	6.8	10.2	13.6	17

TABLE IX. Percentages of positive and negative Intra Cloud lightning dependent on latitude.

	Flash Density															
	0.01	0.1	0.2	0.4	0.6	0.8	1	2	4	6	8	10	20	30	40	50
L 0	0.0076	0.076	0.152	0.304	0.456	0.608	0.76	1.52	3.04	4.56	6.08	7.6	15.2	22.8	30.4	38
A 10	0.00758	0.0758	0.152	0.303	0.4548	0.6064	0.758	1.516	3.032	4.548	6.064	7.58	15.16	22.74	30.32	37.9
T 20	0.00754	0.0754	0.151	0.302	0.4524	0.6032	0.754	1.508	3.016	4.524	6.032	7.54	15.08	22.62	30.16	37.7
I 30	0.0075	0.075	0.15	0.3	0.45	0.6	0.75	1.5	3	4.5	6	7.5	15	22.5	30	37.5
T 40	0.0073	0.073	0.146	0.292	0.438	0.584	0.73	1.46	2.92	4.38	5.84	7.3	14.6	21.9	29.2	36.5
U 50	0.0071	0.071	0.142	0.284	0.426	0.568	0.71	1.42	2.84	4.26	5.68	7.1	14.2	21.3	28.4	35.5
D 60	0.0069	0.069	0.138	0.276	0.414	0.552	0.69	1.38	2.76	4.14	5.52	6.9	13.8	20.7	27.6	34.5
E 70	0.0066	0.066	0.132	0.264	0.396	0.528	0.66	1.32	2.64	3.96	5.28	6.6	13.2	19.8	26.4	33

Using this data, as well as yearly flight hours of an aircraft, the dimensions of the aircraft and intensity of the lightning to determine rolling sphere attractable area of the aircraft, the ratio Cloud-to-Ground or Intra-Cloud strikes Positive or negative with the total strikes in the area, and the percentage that lightning exceeds certain limits in that area to determine a probability and Hazard Risk Index (HRI) value according to Table X [9]. For this paper and probability assessments below, data taken from [1] will be used for both as a baseline case. To increase the accuracy for a specific location, data on lightning distribution and distances would be required.

The equation used is below:

$$P_0 = \frac{\text{Flight hours per year}}{\text{Total year hours}} * A_A * F_d * L_R * \%\ \text{chance strike exceeding "X" NM.} \quad (1)$$

- P_o=Probability of Aircraft being Struck by Lightning exceeding X NM
- Flight Hours per year for Aircraft
- A_A= Surface area of Aircraft that attracts Lightning (upper and lower surfaces)
    - dimensions of the aircraft
    - rolling sphere attractable area of the aircraft

- L_R= Ratio Cloud-to-Ground or Intra-Cloud strikes Positive or negative with the total strikes in the area,
- F_d= Flash Density
- % Chance Strike Exceeding "X" NM = percentage that lightning exceeds certain limits in that area

TABLE X. HAZARD RISK PROBABILITY CHART [9]

The results below show the HRI values for two locations Central Africa at 0˚ latitude and has a flash density of 50 strikes per square kilometer and in South Florida which is at 30˚ latitude, and a flash density of 10 strikes per square kilometer. For these two test cases we chose arbitrary values for the strength of the strikes, a low and a high, and two in between values. For negative lightning we chose 5 kA and 20 kA. For positive lightning we chose 65 kA and 200 kA. When looking at the HRI values those in red have a high probability of occurring and as the colors change from red to yellow to orange, and lastly green decreases the odds of the event happening. For aircraft we look at the catastrophic category, which means the loss of the aircraft, to determine the risk.

Hazard Severity Category		Hazard Probability* Frequent $>10^{-4}$	Probable 10^{-4} to 10^{-5}	Occasional 10^{-5} to 10^{-6}	Remote 10^{-6} to 10^{-7}	Improbable $<10^{-7}$
CATASTROPHIC - [illegible]	I	HRI 1	HRI 2	HRI 4	HRI 8	HRI 11
CRITICAL - [illegible]	II	HRI 3	HRI 5	HRI 6	HRI 10	HRI 15
MARGINAL - [illegible]	III	HRI 7	HRI 9	HRI 12	HRI 14	HRI 17
NEGLIGIBLE - [illegible]	IV	HRI 13	HRI 16	HRI 18	HRI 19	HRI 20

Hazard Risk Index	Safety Risk
1 - 3	HIGH
4 - 7	SERIOUS
8 - 10	MEDIUM
11	LOW
12 - 20	VERY LOW

* Probability per aircraft flight hour

TABLE XI. HAZARD RISK INDEX FROM CENTRAL AFRICA

Probability of aircraft being struck by lightning

Cloud-to-Ground Strikes						Intra-Cloud Strikes					
Negative Strike		HRI	Positive Strike		HRI	Negative Strike		HRI	Positive Strike		HRI
8.6NM	7.14182E-06	HRI 8	8.6NM	2.06589E-07	HRI 11	8.6NM	7.16166E-05	HRI 4	8.6NM	2.07163E-06	HRI 8
10.4NM	3.57091E-06	HRI 8	10.4NM	1.03294E-07	HRI 11	10.4NM	3.58083E-05	HRI 4	10.4NM	1.03581E-06	HRI 8
16.1NM	7.14182E-07	HRI 11	16.1NM	2.06589E-08	HRI 11	16.1NM	7.16166E-06	HRI 8	16.1NM	2.07163E-07	HRI 11
25NM	3.63951E-09	HRI 11	25NM	1.05279E-10	HRI 11	25NM	3.64962E-08	HRI 11	25NM	1.05571E-09	HRI 11
Based on	5	(kA) Strike	Based on	200	(kA) Strike	Based on	5	(kA) Strike	Based on	200	(kA) Strike

Probability of aircraft being struck by lightning

Cloud-to-Ground Strikes						Intra-Cloud Strikes					
Negative Strike		HRI	Positive Strike		HRI	Negative Strike		HRI	Positive Strike		HRI
8.6NM	1.11069E-05	HRI 4	8.6NM	1.84559E-07	HRI 11	8.6NM	0.000111378	HRI 2	8.6NM	1.85072E-06	HRI 11
10.4NM	5.55347E-06	HRI 8	10.4NM	9.22794E-08	HRI 11	10.4NM	5.5689E-05	HRI 4	10.4NM	9.25358E-07	HRI 8
16.1NM	1.11069E-06	HRI 8	16.1NM	1.84559E-08	HRI 11	16.1NM	1.11378E-05	HRI 4	16.1NM	1.85072E-07	HRI 11
25NM	5.66017E-09	HRI 11	25NM	9.40523E-11	HRI 11	25NM	5.67589E-08	HRI 11	25NM	9.43136E-10	HRI 11
Based on	20	(kA) Strike	Based on	65	(kA) Strike	Based on	20	(kA) Strike	Based on	65	(kA) Strike

TABLE XII. HAZARD RISK INDEX FROM SOUTH FLORIDA

Probability of aircraft being struck by lightning

Cloud-to-Ground Strikes						Intra-Cloud Strikes					
Negative Strike		HRI	Positive Strike		HRI	Negative Strike		HRI	Positive Strike		HRI
8.6NM	1.54987E-06	HRI 8	8.6NM	4.483277E-08	HRI 11	8.6NM	1.39489E-05	HRI 4	8.6NM	4.03494E-07	HRI 11
10.4NM	7.74937E-07	HRI 11	10.4NM	2.24163E-08	HRI 11	10.4NM	6.97443E-06	HRI 8	10.4NM	2.01747E-07	HRI 11
16.1NM	1.54987E-07	HRI 11	16.1NM	4.483277E-09	HRI 11	16.1NM	1.39489E-06	HRI 8	16.1NM	4.03494E-08	HRI 11
25NM	7.89825E-10	HRI 11	25NM	2.2847E-11	HRI 11	25NM	7.10843E-09	HRI 11	25NM	2.05623E-10	HRI 11
Based on	5	(kA) Strike	Based on	200	(kA) Strike	Based on	5	(kA) Strike	Based on	200	(kA) Strike

Probability of aircraft being struck by lightning

Cloud-to-Ground Strikes						Intra-Cloud Strikes					
Negative Strike		HRI	Positive Strike		HRI	Negative Strike		HRI	Positive Strike		HRI
8.6NM	2.41036E-06	HRI 8	8.6NM	4.00518E-08	HRI 11	8.6NM	2.16933E-05	HRI 4	8.6NM	3.60467E-07	HRI 11
10.4NM	1.20518E-06	HRI 8	10.4NM	2.00259E-08	HRI 11	10.4NM	1.08466E-05	HRI 4	10.4NM	1.80233E-07	HRI 11
16.1NM	2.41036E-07	HRI 11	16.1NM	4.00518E-09	HRI 11	16.1NM	2.16933E-06	HRI 8	16.1NM	3.60467E-08	HRI 11
25NM	1.22833E-09	HRI 11	25NM	2.04107E-11	HRI 11	25NM	1.1055E-08	HRI 11	25NM	1.83696E-10	HRI 11
Based on	20	(kA) Strike	Based on	65	(kA) Strike	Based on	20	(kA) Strike	Based on	65	(kA) Strike

IV. CONCLUSION

In tables XIII and XIV we can see the results from these test cases. While in both of these scenarios there are instances where an aircraft is in the "Improbable" or HRI 11 region at distances much closer to the storm, they do not suffice this condition completely until out at 25 NM. From the studies presented they show that only 1-5% of lightning flashes ever reach outside of the 10 NM range. Even with such a low percentage of strikes reaching past 10 NM the risk level is still not satisfactory. An acceptable level is not reached across the board until out at 25 NM. Because of these hazards and the risk assessment provided it seems reasonable why most pilots and aircraft agencies stress a 20 to 25 NM limit for avoiding thunderstorms.

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