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Revision 0

Updated Commercial Aviation Non-Airport Crash Density Values Using Data Obtained from the U.S. National Transportation Safety Board for 2000 through 2019

William C. Walker

March 2026

OAK RIDGE
National Laboratory

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Nuclear Facility Safety Division

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ACRONYMS AND ABBREVIATIONS

AC	Air Carrier
ACRAM	Aircraft Crash Risk Analysis Methodology
ANS	American Nuclear Society
APR	Approach
ARTCC	Air Route Traffic Control Center
CA	commercial aviation
CAROL	Case Analysis and Reporting Online
CFR	Code of Federal Regulation
CONUS	Contiguous United States
DOE	Department of Energy
EMG	emergency descent
ENR	enroute
FAA	Federal Aviation Administration
IAF	initial approach fix
ICAO	International Civil Aviation Organization
ICL	initial climb
IFR	Instrument Flight Rules
LDG	landing
LLNL	Lawrence Livermore National Laboratory
MNV	maneuvering
NTSB	National Transportation Safety Board
PBT	pushback/towing
PIM	post-impact
STD	standing
TOF	takeoff
TXI	taxi
UND	uncontrolled descent
UNK	unknown
VFR	Visual Flight Rules

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ABSTRACT

This report updates the enroute aircraft crash density inputs used in Department of Energy (DOE) Standard 3014 hazard analyses by replacing legacy Aircraft Crash Risk Analysis Methodology (ACRAM) Standard values with estimates derived from contemporary Federal Aviation Administration (FAA) operations data and National Transportation Safety Board (NTSB) accident records over a recent 20-year period. For each Air Route Traffic Control Center (ARTCC), annual flight density is computed from ARTCC-handled operations and the ARTCC's coverage area. A Contiguous United States (CONUS)-wide enroute crash probability per operation, p, is then estimated for Part 121 (Air Carrier) and Part 135 (Air Taxi) and applied to each ARTCC's flight density to obtain crash density:

$$\rho_{\text{crash}} = p \times \rho_{\text{flight}} \text{(crashes per year per square mile)}$$

For Part 121, there were $k = 3$ fatal enroute crashes across $n = 476{,}176{,}975$ operations, giving a point estimate $\hat{p} = k/n = 6.30 \times 10^{-9}$ crashes per operation. The 95 percent Beta distribution confidence interval is calculated to be 1.30E-09 to 1.84E-08 crashes per operation, highlighting substantial statistical uncertainty inherent in such rare events.

For Part 135, there were $k = 75$ fatal enroute crashes across $n = 171{,}588{,}634$ operations, yielding $\hat{p} = 4.37 \times 10^{-7}$ crashes per operation. Relative to the ACRAM Standard, the updated Part 121 crash densities decrease by more than an order of magnitude, and the updated Part 135 crash densities decrease markedly (the crash probability fell by approximately 74 percent). Because the current Part 135 estimate is based on fatal accidents only, whereas ACRAM's scheduled Part 135 tabulations appear to include all scheduled accidents irrespective of damage level, direct comparisons should be interpreted with caution. Across ARTCCs, changes in flight density vary; however, the reduction in crash probabilities predominates, so that most ARTCCs exhibit lower enroute crash densities than previously published.

Helicopter involvement in Part 135 enroute events is noted to be non-negligible which differs from analysis documented in the ACRAM Standard. The updated crash densities presented here will be used by the American Nuclear Society (ANS) for the development of ANS standard 2.36, *Accident Analysis for Aircraft Crash into Reactor and Nonreactor Nuclear Facilities*.

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1. DATA COLLECTION AND HANDLING

1.1 RECEIPT OF CA ACCIDENT / INCIDENT DATA

In response to a data request, the National Transportation Safety Board (NTSB) provided the following Commercial Aviation (CA) Accident/Incident Data (Federal Aviation Regulations Part 91) for calendar years 2008 through 2019:

- NTSB Accident Number
- Accident date
- Accident location (city, state, if available)
- Latitude
- Longitude
- Injury severity (e.g., non-fatal, fatal(1), fatal(2), etc.)
- Aircraft damage (e.g., minor, substantial, destroyed, etc.)
- Aircraft make (e.g., Beech, Cessna, Piper, etc.)
- Aircraft model (e.g., 172, PA32RT, FALCON 50, etc.)
- Number of engines (e.g., 1, 2, 3, 4, etc.)
- Engine type (e.g., reciprocating, turbo prop, turbo fan, turbo jet, electric, etc.)
- Broad phase of flight (e.g., landing, takeoff, climb, approach, cruise, maneuvering, go-around, etc.)
- Event type (Accident, Incident, etc.)

The CA accident data for calendar years 2000 through 2007 was downloaded directly from the NTSB website using the Case Analysis and Reporting Online (CAROL) query tool.

1.2 ORGANIZING THE CA ACCIDENT DATA BY PHASES OF OPERATION

Preparation of the CA Accident / Incident data for analysis was handled in a manner consistent with the analytical methodology employed by the Lawrence Livermore National Laboratory (LLNL) 1996 Report, *Data Development Technical Support Document for the Aircraft Crash Risk Analysis Methodology (ACRAM) Standard* [Ref. 1] and Table B-15 of Department of Energy (DOE) Standard 3014-2006, *Accident Analysis for Aircraft Crash into Hazardous Facilities* [Ref. 2]. As noted in Chapter 2 of the ACRAM Standard:

> *The ACRAM Standard defines three flight phases, takeoff, landing, and in-flight or enroute. Takeoff is defined as encompassing the actual takeoff roll and the initial climb phase. Landing is defined as including the landing approach, and the actual landing roll. Enroute or in-flight is defined as including the climb to cruise, cruise or enroute, and the descent from cruise flight phases. To meet the needs of the ACRAM Standard, crash rates for the flight phases used in the ACRAM Standard must be determined. This is also done by combining the accidents occurring in the takeoff and initial climb phases into the ACRAM takeoff accident rate. The ACRAM in-flight accident rate was determined by combining the accidents occurring in the climb to cruise, cruise/enroute, and descent from cruise phases. The ACRAM landing accident rate was determined by combining the accidents occurring during the landing approach and the landing flight phase.*

Table 1 summarizes the Phases of Flight as specified by the International Civil Aviation Organization (ICAO) [Ref. 3] and as employed by the NTSB. As noted in Table 1, only the following phases are associated with non-airport operations:

- Enroute (ENR),
- Maneuvering (MNV),
- Emergency Descent (EMG), and
- Uncontrolled Descent (UND)

Table 1. Broad Phases of Flight

NTSB Phase of Flight	Abbrev.	Description	Airport Operation / Non-Airport Operation
STANDING	STD	Prior to pushback or taxi, or after arrival, at the gate, ramp, or parking area, while the aircraft is stationary.	N/A
PUSHBACK / TOWING	PBT	Aircraft is moving in the gate, ramp, or parking area, assisted by a tow vehicle (tug).	N/A
TAXI	TXI	The aircraft is moving on the aerodrome surface under its own power prior to takeoff or after landing.	N/A
TAKEOFF	TOF	From the application of takeoff power, through rotation and to an altitude of 35 feet above runway elevation.	Airport Operation
INITIAL CLIMB	ICL	From the end of the Takeoff subphase to the first prescribed power reduction, or until reaching 1,000 feet above runway elevation or the VFR pattern, whichever comes first.	Airport Operation
EN ROUTE	ENR	Instrument Flight Rules (IFR): From completion of Initial Climb through cruise altitude and completion of controlled descent to the Initial Approach Fix (IAF). Visual Flight Rules (VFR): From completion of Initial Climb through cruise and controlled descent to the VFR pattern altitude or 1,000 feet above runway elevation, whichever comes first.	**Non-Airport Operation**
MANEUVERING	MNV	Low altitude/aerobatic flight operations.	**Non-Airport Operation**

Table 1. Broad Phases of Flight (continued)

NTSB Phase of Flight	Abbrev.	Description	Airport Operation / Non-Airport Operation
APPROACH	APR	Instrument Flight Rules (IFR): From the Initial Approach Fix (IAF) to the beginning of the landing flare. Visual Flight Rules (VFR): From the point of VFR pattern entry, or 1,000 feet above the runway elevation, to the beginning of the landing flare.	Airport Operation
LANDING	LDG	From the beginning of the landing flare until aircraft exits the landing runway, comes to a stop on the runway, or when power is applied for takeoff in the case of a touch-and-go landing.	Airport Operation
EMERGENCY DESCENT	EMG	A controlled descent during any airborne phase in response to a perceived emergency situation.	**Non-Airport Operation**
UNCONTROLLED DESCENT	UND	A descent during any airborne phase in which the aircraft does not sustain controlled flight.	**Non-Airport Operation**
POST-IMPACT	PIM	Any of that portion of the flight which occurs after impact with a person, object, obstacle or terrain.	N/A
UNKNOWN	UNK	Phase of flight is not discernible from the information available.	N/A

Note: Phase of Flight categories were obtained from the ICAO Publication, *Phase of Flight: Definitions and Usage Notes* [Reference 3]

1.3 FILTERING THE NTSB CA ACCIDENT DATA

It is noted that the NTSB definition of an accident includes events which do not necessarily involve an aircraft crash. As noted in 49 CFR Part 830.2, an accident is defined as follows:

> **Aircraft Accident** means an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage. For purposes of this part, the definition of "aircraft accident" includes "unmanned aircraft accident," as defined herein.

1.3.1 Filtering the 2008-2019 CA Accident Data

The 2008-2019 CA incident/accident data from the NTSB was already filtered such that the accidents associated with the enroute phase of operation were solely provided.

Table 2.15 of the ACRAM Standard calculated the 14 CFR 121 various phase of flight crash rates for Off-Airport* events where the aircraft was destroyed or the damage to the airframe was considered be a major write-off. In recognition of the severity of an accident event that would incur a destruction of the

* The use of "Off-Airport" in the ACRAM Standard is synonymous with the term "Non-Airport" as used in this report.

aircraft or major damage to the airframe that would incur a write-off of the aircraft**, non-fatal accidents were filtered out from further consideration**.

The ACRAM Standard was less restrictive in considering which accidents should be included in the determination of the accident rate [crashes/operation] for the various phases of flight.

- As noted in Table 2.21 of the ACRAM Standard, the 14 CFR 135 accident tabulations (which includes the Enroute crash rate) are only for "scheduled" 14 CFR 135 flights. A comparison of ACRAM Standard Table 2.17 (Scheduled Commuter Aircraft Accidents) and Table 2.18 (Non-scheduled Air Taxi Accidents) reveal that there are significantly more accidents associated with non-scheduled Air Taxi aviation operations than scheduled Commuter Aircraft Accidents. For the period 1980-1993, the ACRAM Standard tabulated a total of 80 fatal accidents involving scheduled Commuter Aircraft and a total of 414 fatal accidents involving non-scheduled Air Taxi operations. In recognition of the significant contribution of non-scheduled Air Taxi accidents to the overall number of 14 CFR 135 fatalities, the data obtained from the NTSB for the current analysis **will include both scheduled Air Commuter and non-scheduled Air Taxi operations**.

- ACRAM Table 2.20 and ACRAM Table 2.21 imply that all scheduled 14 CFR 135 accidents were included in the aircraft accident rate [accidents/operation]. This differed from the 14 CFR 121 analysis documented in the ACRAM Standard which restricted the analysis of the off-airport crash rate calculation to only those aircraft that were destroyed or the airframe sustained major damage and was written off. Although the scheduled 14 CFR 135 accident data used for the development of the ACRAM Standard is not available for review, it is assumed the inclusion of scheduled 14 CFR 135 accidents that were classified as "Minor" or "None" did not involve an enroute aircraft crash. Accordingly, the analysis of the contemporary data **will be limited to accidents involving at least one fatality**, which is consistent with the treatment of the 14 CFR 121 data analysis.

- ACRAM Table 2.27 provides a representative listing of aircraft associated with scheduled 14 CFR 135 aviation operations. A review of the listed aircraft reveals that all are classified as fixed wing aircraft. None of the listed aircraft are classified as rotary wing aircraft (i.e., helicopters). A review of the NTSB accident data for 2000-2019 reveals that almost half of all enroute 14 CFR 135 fatal accidents involve helicopter aviation.

  DOE Standard 3014 provides for a separate analysis of helicopter overflights. Page 45 of DOE Standard 3014 notes that the helicopter analysis is a site-specific calculation in consideration of local overflights. These local helicopter flights are described as including either planned overflights associated with facility operations, e.g., security flights or flights associated with area operations, e.g., spraying flights.

  Consideration of 14 CFR 135 non-local helicopter overflights do not seem to be addressed by site-specific helicopter analysis required by DOE Standard 3014. Therefore, the data analysis of the 14 CFR 135 data in this report **will include accidents for both fixed wing and rotary wing aviation**.

Finally, the crash density analysis to be documented in this report is limited to the contiguous United States (CONUS) ARTCCs. Therefore, **accidents which were documented to have occurred outside of the CONUS were filtered out from further consideration**. This included accidents listed as occurring in Alaska, Hawaii, Puerto Rico, in foreign countries (e.g., Canada, Mexico), over the Atlantic Ocean, and over the Pacific Ocean. Aviation accidents which occurred in the Gulf of Mexico were not filtered out since these events are typically within the coverage area of a CONUS ARTCC.

1.3.2 Filtering the 2000-2007 CA Accident Data

The 2000-2007 CA accident data downloaded from the NTSB CAROL Query Tool were similarly filtered to eliminate accidents which did not involve at least one fatality. The data from the CAROL Query Tool included all accidents regardless of the phase of operation/phase of flight. Therefore, the accident report for each 14 CFR 121 and 14 CFR 135 accident involving a fatality was reviewed to determine applicable phase of operation/phase of flight.

Similar to 2008-2019 data analysis, the 2000-2007 data was filtered to exclude non-CONUS accidents. Table 2 summarizes the CONUS Enroute Phase of Operation Commercial Aviation fatal accidents.

Table 2. Summary of CONUS Enroute Commercial Aviation Accidents

	Enroute Fatal Crashes		
	2000-2007	**2008-2019**	**Total**
Part 121	2	1	3
Part 135	45	30	75
TOTAL	**47**	**31**	**78**

2. ARTCC AIR CARRIER AND AIR TAXI OPERATIONS DATA (2000-2019)

The Federal Aviation Administration (FAA) provided the ANS 2.36 working group with Air Carrier (14 CFR 121) and Air Taxi (14 CFR 135) aircraft operations data for the years 2000 through 2019 (see Table 3 and Table 4). The ARTCCs in Table 3 and Table 4 are associated with the CONUS, and as such do not include Alaska and Hawaii aircraft operations (see Figure 1).

Figure 1. ARTCCs and Airspace Boundaries within the CONUS

Table 3. ARTCC Air Carrier Aircraft Operations Data and Calculated Crash Density [2000-2019]

ICAO Code	ARTCC	Departures	Domestic Overs	Oceanic Overs	Total Aircraft Handled	Estimated Coverage Area (mi^2)	Air Carrier Flight Density ($AC/yr/mi^2$)	Air Carrier Crash Density ($crash/yr/mi^2$)
		$[D_{AC}]$	$[DO_{AC}]$	$[OO_{AC}]$	$N_{AC} = [2*D_{AC}+(DO_{AC}+OO_{AC})]$	A_{ARTCC}	$N_{AC}/A_{ARTCC}/20$	
KZAB	Albuquerque	5,643,312	8,982,911	-	20,269,535	230,954	4.4	3E-08
KZAU	Chicago	9,836,377	8,902,022	-	28,574,776	102,735	13.9	9E-08
KZBW	Boston	7,014,432	4,348,384	-	18,377,248	143,952	6.4	4E-08
KZDC	Washington	8,216,680	10,528,808	13	26,962,181	125,370	10.8	7E-08
KZDV	Denver	4,560,475	12,375,920	-	21,496,870	262,297	4.1	3E-08
KZFW	Ft. Worth	7,786,060	8,163,716	-	23,735,836	161,031	7.4	5E-08
KZHU	Houston	7,293,756	3,810,203	1,888,536	20,286,251	360,805	2.8	2E-08
KZID	Indianapolis	3,903,607	15,856,129	5	23,663,348	90,178	13.1	8E-08
KZJX	Jacksonville	6,707,820	12,426,966	-	25,842,606	191,500	6.7	4E-08
KZKC	Kansas City	3,698,940	12,881,377	-	20,279,257	170,523	5.9	4E-08
KZLA	Los Angeles	12,468,157	2,872,049	519,047	28,327,410	176,030	8.0	5E-08
KZLC	Salt Lake	2,984,235	10,785,329	32	16,753,831	418,373	2.0	1E-08
KZMA	Miami	9,250,428	3,424,825	7,304,632	29,230,313	559,485	2.6	2E-08
KZME	Memphis	4,555,801	15,110,081	-	24,221,683	140,979	8.6	5E-08
KZMP	Minneapolis	4,147,793	11,353,736	-	19,649,322	385,773	2.5	2E-08
KZNY	New York	12,958,118	6,631,114	3,442,502	35,989,852	115,528	15.6	1E-07
KZOA	Oakland	6,787,708	2,740,217	4,377,476	20,693,109	175,872	5.9	4E-08
KZOB	Cleveland	5,878,376	14,804,471	-	26,561,223	89,666	14.8	9E-08
KZSE	Seattle	5,937,017	1,249,656	2	13,123,692	263,972	2.5	2E-08
KZTL	Atlanta	11,417,072	9,304,488	-	32,138,632	105,895	15.2	1E-07
	TOTAL	**141,046,164**	**176,552,402**	**17,532,245**	**476,176,975**	**4,270,917**	**5.6**	**4E-08**

Table 4. ARTCC Air Taxi Aircraft Operations Data and Calculated Crash Density [2000-2019]

ICAO Code	ARTCC	Departures	Domestic Overs	Oceanic Overs	Total Aircraft Handled	Estimated Coverage Area (mi^2)	Air Taxi Flight Density (AT/yr/mi^2)	Air Taxi Crash Density (crash/yr/mi^2)
		[D_{AT}]	*[DO_{AT}]*	*[OO_{AT}]*	$N_{AT} = [2*D_{AT}+(DO_{AT}+OO_{AT})]$	A_{ARTCC}	$N_{AT}/A_{ARTCC}/20$	
KZAB	Albuquerque	1,801,150	774,829	-	4,377,129	230,954	0.9	4E-07
KZAU	Chicago	5,597,003	1,529,534	-	12,723,540	102,735	6.2	3E-06
KZBW	Boston	4,504,399	1,097,794	-	10,106,592	143,952	3.5	2E-06
KZDC	Washington	4,813,014	2,170,026	-	11,796,054	125,370	4.7	2E-06
KZDV	Denver	3,159,064	921,031	-	7,239,159	262,297	1.4	6E-07
KZFW	Ft. Worth	2,981,583	1,365,278	-	7,328,444	161,031	2.3	1E-06
KZHU	Houston	4,238,717	528,980	21,902	9,028,316	360,805	1.3	5E-07
KZID	Indianapolis	4,191,088	4,909,471	-	13,291,647	90,178	7.4	3E-06
KZJX	Jacksonville	2,632,080	1,783,819	-	7,047,979	191,500	1.8	8E-07
KZKC	Kansas City	2,551,070	1,680,727	-	6,782,867	170,523	2.0	9E-07
KZLA	Los Angeles	2,874,814	498,521	3,704	6,251,853	176,030	1.8	8E-07
KZLC	Salt Lake	2,516,109	773,982	2	5,806,202	418,373	0.7	3E-07
KZMA	Miami	2,813,533	81,277	676,282	6,384,625	559,485	0.6	2E-07
KZME	Memphis	1,511,671	1,897,384	-	4,920,726	140,979	1.7	8E-07
KZMP	Minneapolis	4,435,810	1,013,167	-	9,884,787	385,773	1.3	6E-07
KZNY	New York	4,360,866	1,065,841	832,898	10,620,471	115,528	4.6	2E-06
KZOA	Oakland	2,152,285	418,343	51,923	4,774,836	175,872	1.4	6E-07
KZOB	Cleveland	5,427,116	4,492,949	-	15,347,181	89,666	8.6	4E-06
KZSE	Seattle	2,761,595	103,813	-	5,627,003	263,972	1.1	5E-07
KZTL	Atlanta	5,005,008	2,239,207	-	12,249,223	105,895	5.8	3E-06
	TOTAL	**70,327,975**	**29,345,973**	**1,586,711**	**171,588,634**	**4,270,917**	**2.0**	**9E-07**

Table 3 and Table 4 include aircraft operations data associated with the following:

(1) Departures that originated within the ARTCC, and
(2) Oceanic Overs and Domestic Overs, which are flights that originate from outside of the ARTCC area and pass through the ARTCC without landing.

The total number of aircraft operations conducted in an ARTCC are equal to the number of Departures multiplied by two plus the number of Overs. This definition assumes that the number of Departures is equal to the number of landings within the respective ARTCC.

In addition to the ARTCC aircraft operations data, the FAA also provided an estimate of the coverage area associated with each CONUS ARTCC. As noted in Figure 1, the coverage area overlaps with adjacent significant bodies of water (e.g., coastal portions of the Atlantic Ocean, the Pacific Ocean, the Gulf of Mexico, and U.S. portions of the Great Lakes).

The flight density is the total number of operations conducted within the ARTCC divided by the coverage area of the ARTCC and divided by the number of years spanning the data (e.g., 20 years), yielding a flight density value with units of # of aircraft operations per year per square mile.

The calculation of crash density values requires the derivation of a CONUS enroute crash probability value, P, which has units of #crashes/operation. Table 5 documents the calculation of the enroute crash rate for Air Carrier and Air Taxi operations.

Table 5. Calculation of CONUS Enroute Crash Rate [2000-2019]

	Total Number of Operations	Number of CONUS Enroute Crashes	Enroute Crash Rate
	from Table 3 and Table 4	*from Table 2*	*[crashes/operation]*
Air Carrier	476,176,975	3	6.30E-09
Air Taxi	171,588,634	75	4.37E-07

The ACRAM Standard does not provide a detailed uncertainty analysis associated with the calculation of ARTCC specific crash density values. DOE Standard 3014 addresses the relative uncertainty associated with the calculated ARTCC-specific data by only reporting non-airport crash density values to one significant digit in Table B-15 of the standard. As such, the crash density values in Table 3 and Table 4 are similarly only reported to one significant digit to address uncertainty.

Using the data in Table 5, a 95 percent confidence interval for the crash rate can be estimated for the 2000-2019 data set by using the following equation (for an assumed beta distribution):

$$B\left(\frac{\alpha}{2}, x, n-x+1\right) < p < B\left(\frac{\alpha}{2}, x+1, n-x\right) \qquad \text{Eqn. 1}$$

where,

$B(p; v, w)$	= p^{th} quantile from a beta distribution with shape parameters v and w.
α	= 1 - Confidence Interval, 1 - 0.95 = 0.05 [--]
x	= Number of Enroute crashes [crashes]
n	= Number of Total Operations [operations]
p	= Mean crash rate [crashes/operation]

Using Equation 1, the 95 percent Confidence Interval for the Air Carrier enroute crash rate is calculated to be 1.30E-09 to 1.84E-08 crashes per operation and the 95 percent Confidence Interval for the Air Taxi enroute crash rate is calculated to be 3.44E-07 to 5.48E-07 crashes per operation.

Using the CONUS enroute crash probability, ARTCC-specific crash densities can be calculated by multiplying the ARTCC flight density value by the CONUS aircraft crash rate per Equation 2.

$$\rho_{crash,ARTCC} = P_{CONUS} * \rho_{flight,ARTCC} \qquad \text{Eqn. 2}$$

where,

$\rho_{crash,ARTCC}$ = ARTCC-specific enroute crash density [crashes/yr/mi^2]
$\rho_{flight,ARTCC}$ = ARTCC-specific flight density [operations/yr/mi^2]
P_{CONUS} = CONUS crash probability [crashes/operation]

The last column in Table 3 and Table 4 report the enroute crash density values for the CONUS ARTCCs.

3. COMPARISON OF CURRENT ARTCC CRASH DENSITY VALUES WITH ACRAM STANDARD AND DOE STANDARD 3014 VALUES

As noted below in Table 6, the CONUS crash rates for both Air Carrier and Air Taxi have significantly decreased in comparison with the previous ACRAM Standard analysis. However, the decreased crash rates are somewhat offset by an increase in overall CONUS flight densities, more so with Air Taxis than with Air Carriers.

Table 6. Comparison of Aircraft Crash Rates and CONUS Flight Density Values

Parameter	Units	ACRAM value	2000-2019 Data Analysis	% change
Air Carrier Enroute Crash Rate	enroute crashes/operation	1.70E-07 *(ACRAM Table 2.15)*	6.30E-09 *(Table 5 above)*	-96%
Air Carrier CONUS Flight Density	operations/yr/mi^2	5.062 *(ACRAM Table 5.2)*	5.6 *(Table 3 above)*	+10%
Air Taxi Enroute Crash Rate	enroute crashes/operation	1.67E-06 *(ACRAM Table 2.21)*	4.37E-07 *(Table 5 above)*	-74%
Air Taxi CONUS Flight Density	operations/yr/mi^2	1.336 *(ACRAM Table 5.2)*	2.0 *(Table 4 above)*	+50%

The net effect of the decrease in the aircraft crash rates and increase in aircraft flight densities is illustrated in Figure 2 and Figure 3.

In general, the Air Carrier crash densities in Figure 2 have decreased by approximately an order of magnitude across all ARTCCs as compared to the values reported in Table B-15 of DOE Standard 3014-96. This decrease is attributable to a decrease in annual enroute Air Carrier crashes. [For the current analysis, 3 enroute crashes over a period of 20 years yielded an annualized enroute crash rate of 0.15 crashes/year. Per Table 2-15 and Table 2-16 of the ACRAM Standard, 24 enroute crashes were incurred from 1974-1993 (a 20-year period), yielding an annualized crash rate of 1.2 crashes/year.]

The Air Taxi crash densities in Figure 3 also illustrate a general decrease for most ARTCCs, but not as significant as the Air Carriers crash densities. As noted in Table 6, the estimated Air Taxi flight density during the period 2000-2019 has increased 50 percent as compared to the rate from the ACRAM Standard. Yet the air taxi crash rate per operation in the period 2000-2019 is 74 percent lower than air taxi crash rate from the ACRAM Standard. The decrease in Air Taxi crash rate in the 2000-2019 period as compared to the ACRAM Standard may in part be explained by the methodology used in this report in which only fatal non-airport accidents were evaluated, whereas ACRAM's scheduled Part 135 rate appears to include all scheduled accidents, which reduces direct comparability and partially explains the observed rate decrease. However, non-airport accidents are not expected to include a significant number of accidents which do not include a fatality. Therefore the decrease in the Air Taxi crash rate is likely attributed to contributing factors such as improved pilot training, aircraft maintenance practices, and other airline operations practices.

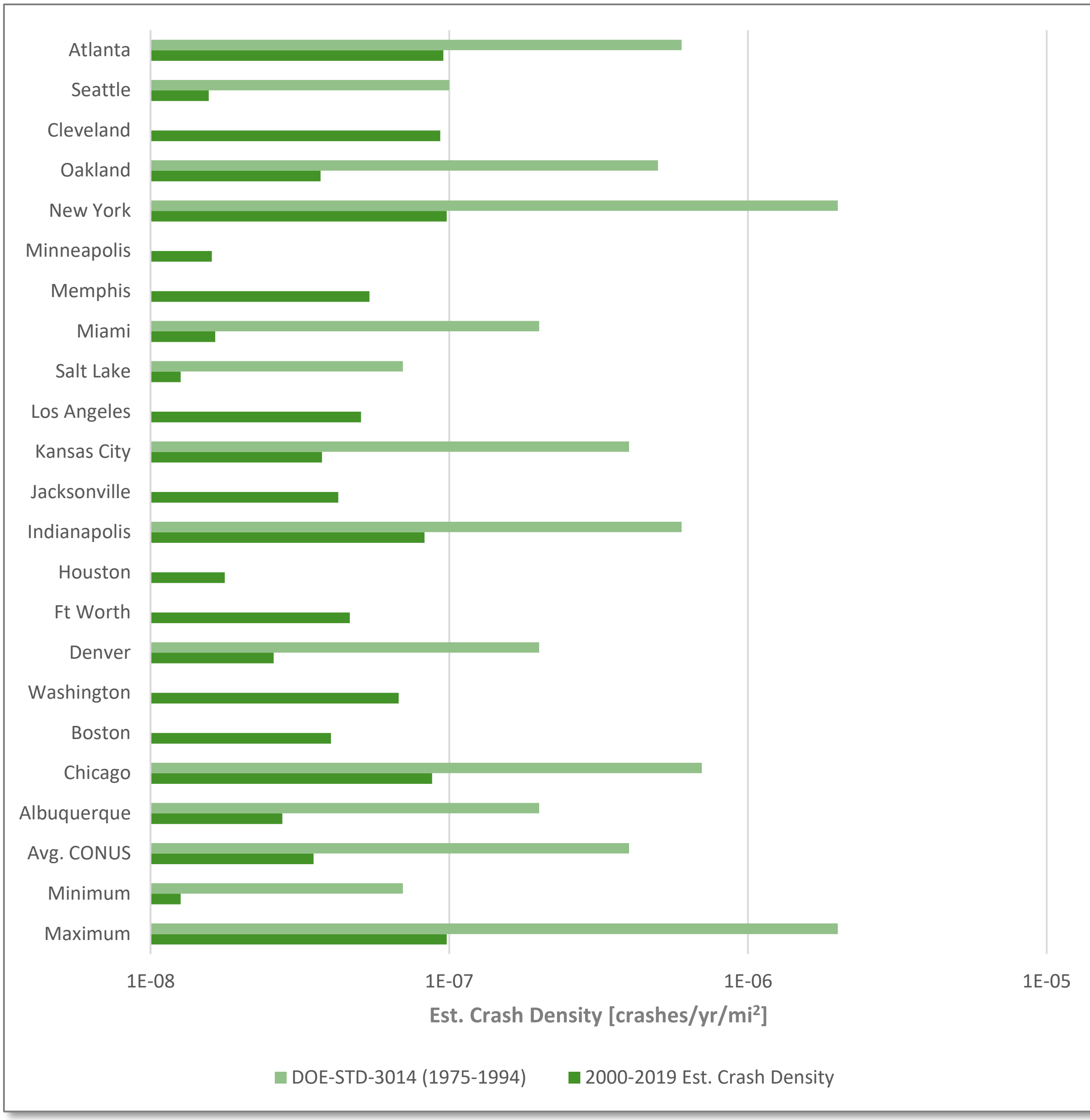

Figure 2. Comparison of Estimated Air Carrier Enroute Crash Densities

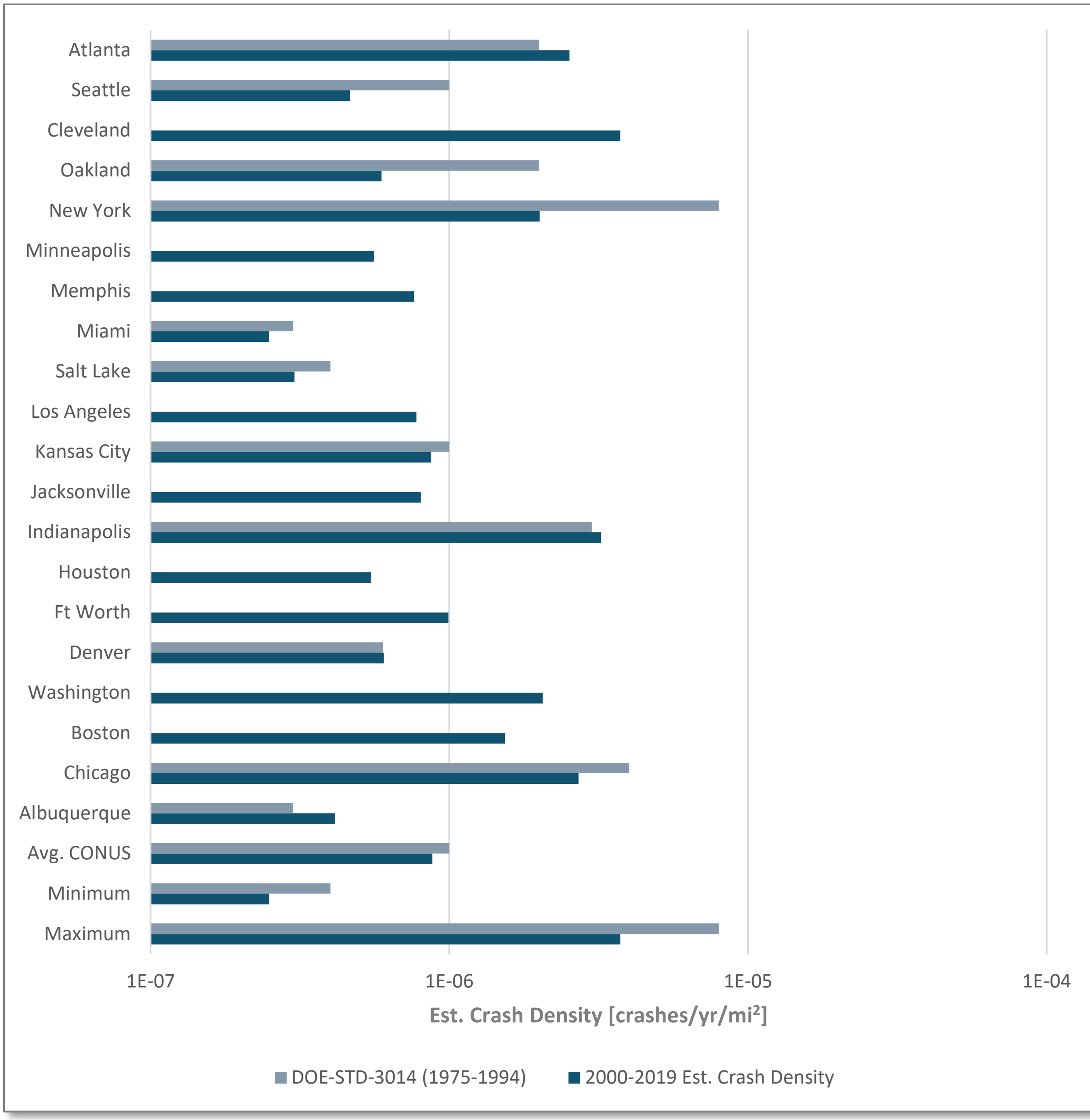

Figure 3. Comparison of Estimated Air Taxi Enroute Crash Densities

3.1 EFFECT OF HELICOPTER CRASHES ON THE OVERALL AIR TAXI CRASH RATE

As previously noted, helicopters comprise a significant portion of the overall number of enroute CONUS Air Taxi crashes. Table 7 summarizes the number of enroute CONUS Air Taxis crashes from 2000-2019 reports for fixed wing aircraft (airplanes) and rotary wing aircraft (helicopters). Overall, helicopters account for 47 percent of all CONUS enroute Air Taxi crashes.

As illustrated in Figure 4, the fixed wing aircraft had annual crash instances significantly higher in the early 2000s, and notably decreasing after 2006. From 2010-1019, there were only nine fixed wing enroute Air Taxi crashes as compared to 15 rotary wing enroute Air Taxi crashes. As the current trend (2010-2019) implies, rotary wing enroute Air Taxi crashes are the predominant aviation category for enroute CONUS Air Taxi crashes.

3.2 COMPARISON OF ACRAM STANDARD DESCRIPTION OF AIR TAXI AIRCRAFT

As previously noted, ACRAM Standard Table 2.27 only provides data for aircraft associated with scheduled Air Taxi operations. Besides not including rotary wing aircraft (which typically are involved with non-scheduled operations), it is apparent that the fixed wing aircraft are not representative of the aircraft that are involved with CONUS enroute crashes. As observed in Figure 5, more than 75 percent of all enroute CONUS Air Taxi fixed wing crashes involve Piper and Cessna aircraft, two of most prevalent fabricators of small non-Air Carrier aircraft.

The aircraft characteristics associated with calculating the effective impact area (e.g., wingspan, impact angle, skid distance) are significantly different for these types of aircraft than those listed in the ACRAM Standard. As noted in Table 8 and Figure 6, the distribution of all Part 135 aircraft wingspans (airplane and helicopters) varies from 32.3-ft to 57-ft. In general the mean wingspan of fixed-wing Air Taxi aircraft (40.7-ft) are slightly larger than the mean wingspan of Air Taxi helicopters (35.8-ft).

In addition to the difference in wingspan, it is implied in the data analysis that Air Taxi skid distance and Air Taxi mean cotangent impact angle are suitable candidates for re-tabulation. Currently, these parameters are grouped under Commercial Aviation, which includes the skid and impact angle characteristics of 14 CFR 121 aircraft. It is recommended that additional analysis be undertaken to determine Air Taxi specific values for mean skid distance and mean cotangent of the impact angle.

Table 7. Summary of Air Taxi Airplane and Helicopter Crashes

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	TOTAL	% of TOTAL
All Aircraft	9	3	7	5	9	6	5	1	4	2	0	6	3	1	1	4	2	3	1	3	75	100%
Airplane	7	2	5	0	4	6	4	1	1	1	0	3	2	1	0	1	2	0	0	0	40	53%
Helicopter	2	1	2	5	5	0	1	0	3	1	0	3	1	0	1	3	0	3	1	3	35	47%

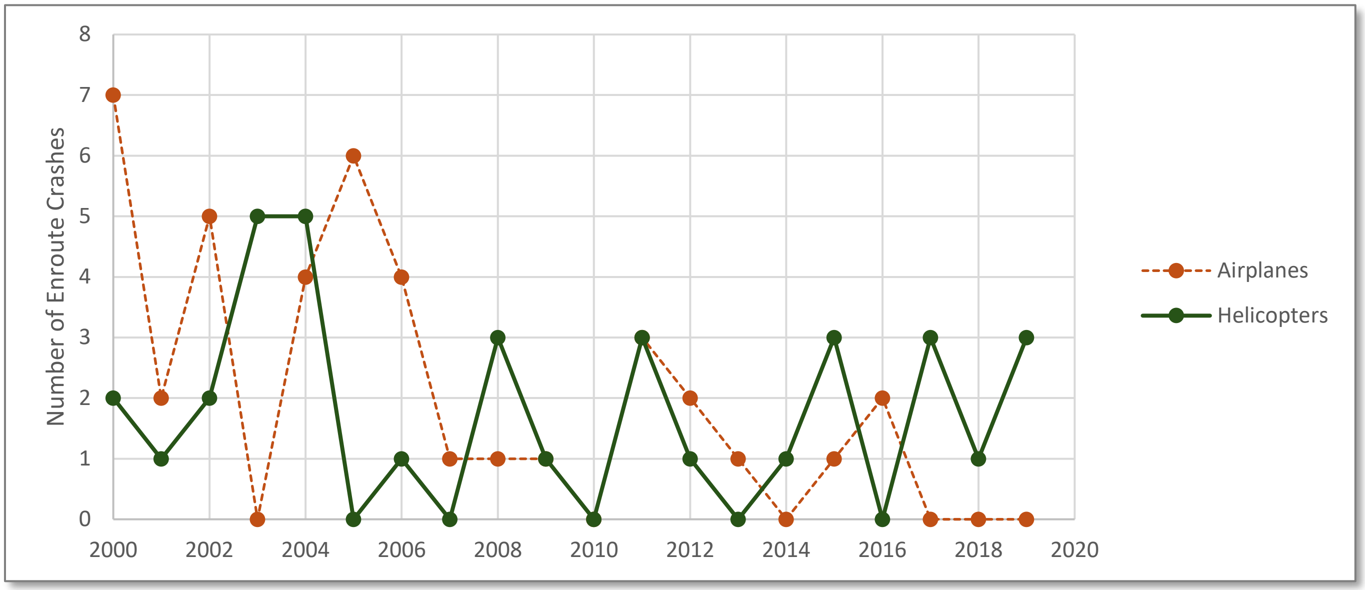

Figure 4. Comparison of Air Taxi Enroute Crashes: Airplanes and Helicopters

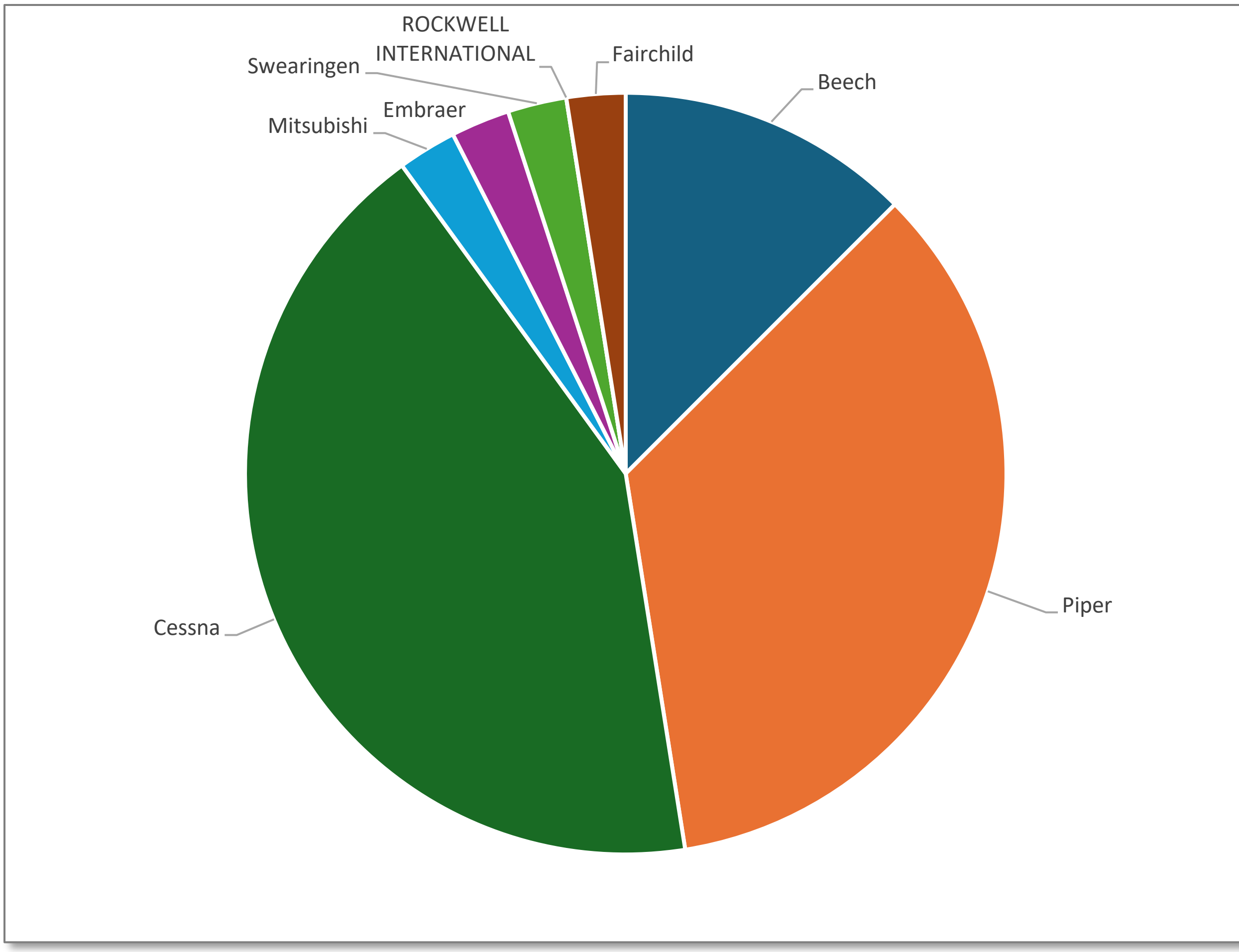

Figure 5. Distribution by Manufacturer of Fixed Wing CONUS Enroute Crashes [2000-2019]

Table 8. Summary of Wingspan Distribution for CONUS Enroute Air Taxi Crashes [2000-2019]

	Mean	SD	Min	Median	Max
All Part 135	38.37	5.86	32.33	36.08	57.00
Airplanes	40.66	6.93	32.82	38.91	57.00
Helicopter	35.76	2.56	32.33	35.08	44.00

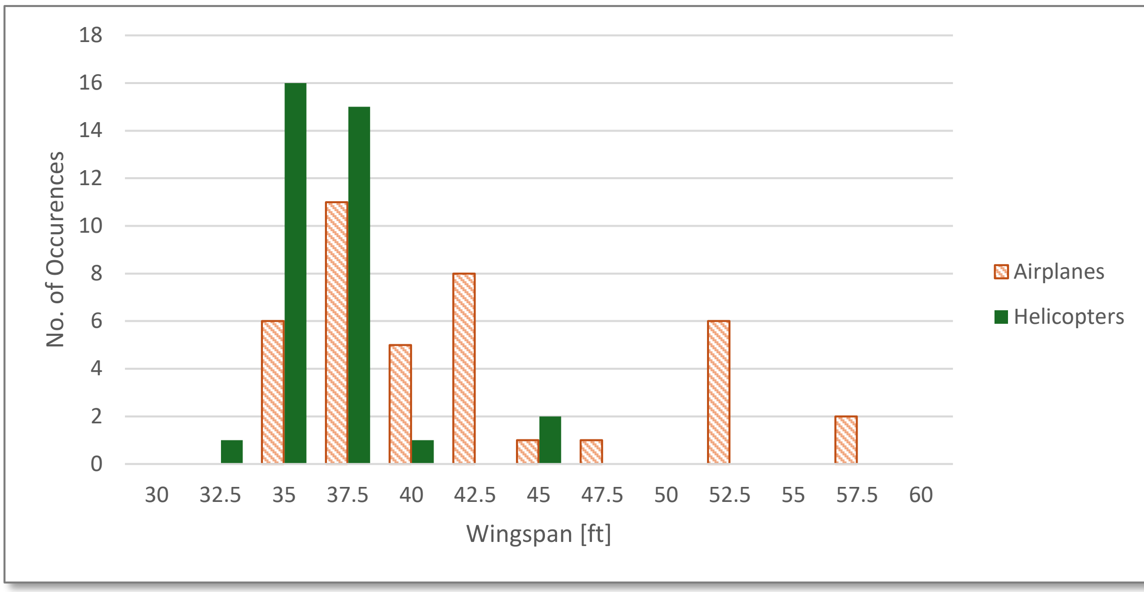

Figure 6. Histogram of Air Taxi CONUS Enroute Air Taxi Crashes [2000-2019]

4. REFERENCES

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2. U. S. Department of Energy. *Accident Analysis for Aircraft Crash Into Hazardous Facilities*. 2006. DOE Standard 3014-2006.

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APPENDIX A. NTSB CONUS ENROUTE CRASH LISTING FOR 14 CFR 121 AND 14 CFR 135 OPERATIONS [2000-2019]

APPENDIX A. NTSB CONUS ENROUTE CRASH LISTING FOR 14 CFR 121 AND 14 CFR 135 OPERATIONS [2000-2019]

Table A.1. 14 CFR 121 Enroute Crashes [2000-2019]

NTSB Number	Date	City	State	Fatalities	NTSB Phase
DCA19MA086	23-Feb-19	Trinity Bay	Texas	3	Enroute – descent
DCA06MA010	19-Dec-05	Miami	Florida	20	Descent – uncontrolled
DCA00MA023	31-Jan-00	Port Hueneme	California	88	Descent – uncontrolled

Table A.2. 14 CFR 135 Enroute Crashes [2000-2019]

NTSB Number	Year	Date	City	State	Fatalities	NTSB Phase	Aircraft Manufacturer	Aircraft Model	Aircraft Category
FTW00FA083	2000	16-Feb-00	McAlester	OK	1	Maneuvering	Cessna	182M	Airplane
FTW00FA091	2000	10-Mar-00	Dalhart	TX	4	Maneuvering	Eurocopter	BO105S-CBS-5	Helicopter
MIA00FA221	2000	17-Jul-00	Hernando	MS	1	Cruise	Beech	58	Airplane
DCA00MA080	2000	09-Aug-00	Burlington TWP	NJ	11	Cruise	Piper	PA-31-350	Airplane
SEA01FA001	2000	09-Oct-00	Lummi Island	WA	1	Maneuvering	Cessna	208B	Airplane
DEN01FA003	2000	10-Oct-00	Grants	NM	1	Cruise	Cessna	R-182	Airplane
SEA01FA100	2000	16-Nov-00	Cambridge	ID	2	Maneuvering	Cessna	U206F	Airplane
NYC01FA056	2000	14-Dec-00	Chesterfield	NH	1	Cruise	Cessna	310Q	Airplane
FTW01FAMS1	2000	26-Dec-00	High Island 116		1	Cruise	Bell	206B	Helicopter
ATL01FA019	2001	11-Jan-01	Vandiver	AL	1	Cruise	Cessna	206H	Airplane
LAX01MA272	2001	10-Aug-01	Meadview	AZ	6	Maneuvering	Eurocopter	AS350-B2	Helicopter
DEN01FA161	2001	24-Sep-01	Pagosa Springs	CO	2	Maneuvering	Piper	PA-31-350	Airplane
MIA02FA048	2002	01-Jan-02	Hollywood	FL	1	Descent – Normal	Piper	PA-31-350	Airplane
ATL02FA048	2002	16-Feb-02	New Smyrna Bch.	FL	2	Cruise – Normal	Bell	206L-1	Helicopter
MIA02FA067	2002	14-Mar-02	Broadway	NC	1	Cruise – Normal	Piper	PA32R-300	Airplane
CHI02FA093	2002	15-Mar-02	Alma	WI	1	Cruise	Cessna	208B	Airplane
CHI02FA288	2002	09-Sep-02	Doland	SD	4	Cruise	Bell	206L-1	Helicopter
ATL03FA008	2002	23-Oct-02	Spanish Fort	AL	1	Cruise – Normal	Cessna	208B	Airplane
FTW03FA055	2002	03-Dec-02	Tajique	NM	1	Descent	Cessna	421C	Airplane
FTW03FA097	2003	16-Feb-03	MI 700		2	Cruise	Bell	407	Helicopter
FTW03LA163	2003	29-May-03	Brazos Blk 532		1	Cruise	Robinson	R44	Helicopter
LAX03MA292	2003	20-Sep-03	GrandCanyonWest	AZ	7	Maneuvering	Aerospatiale	AS350BA	Helicopter
FTW04FA007	2003	10-Oct-03	W. Cameron 509		3	Maneuvering	Bell	206L-3	Helicopter
FTW04FA029	2003	01-Dec-03	High Island 573		1	Cruise	Bell	407	Helicopter
LAX04FA102	2004	21-Jan-04	Big Pine	CA	1	Cruise – Normal	Piper	PA-32R-300	Airplane
FTW04FA097	2004	21-Mar-04	Pyote	TX	4	Cruise – Normal	Bell	407	Helicopter
DCA04MA030	2004	23-Mar-04	Gulf of Mexico		10	Cruise	Sikorsky	S-76A++	Helicopter
NYC04FA093	2004	25-Mar-04	Pittsfield	MA	1	Cruise	Mitsubishi	MU-2B-36	Airplane
CHI04FA107	2004	20-Apr-04	Boonville	IN	1	Cruise – Normal	Bell	206L-1	Helicopter
FTW04FA168	2004	24-Jun-04	Vermillion Bay	LA	3	Cruise	Bell	206-L1	Helicopter

Table A.2. 14 CFR 135 Enroute Crashes [2000-2019] (continued)

NTSB Number	Year	Date	City	State	Fatalities	NTSB Phase	Aircraft Manufacturer	Aircraft Model	Aircraft Category
SEA04FA166	2004	17-Aug-04	Neihart	MT	2	Cruise	Beech	BE-99	Airplane
SEA04MA167	2004	21-Aug-04	Battle Mountain	NV	5	Cruise	Bell	407	Helicopter
FTW04FA235	2004	09-Sep-04	Rachel	TX	1	Descent	Piper	PA-32R-300	Airplane
NYC05FA042	2005	13-Jan-05	Swanzey	NH	1	Cruise	Embraer	EMB-110P1	Airplane
LAX05FA092	2005	10-Feb-05	Lebec	CA	2	Cruise – Normal	Cessna	P210N	Airplane
DEN05FA087	2005	09-Jun-05	Telluride	CO	1	Climb – to Cruise	Piper	PA-34-200T	Airplane
SEA05FA158	2005	04-Aug-05	Renton	WA	2	Maneuvering	Cessna	150M	Airplane
CHI06FA026	2005	08-Nov-05	Ankeny	IA	2	Cruise	Piper	PA-31-350	Airplane
CHI06FA030	2005	09-Nov-05	Bloomington	IL	1	Cruise	Piper	PA-23-160	Airplane
ATL06FA045	2006	08-Feb-06	Paris	TN	1	Descent	Swearingen	SA-226-TC	Airplane
SEA06FA055	2006	22-Feb-06	Goldendale	WA	2	Descent	Cessna	182P	Airplane
DFW06FA083	2006	14-Mar-06	Patterson	LA	2	Cruise	Bell	206L-1	Helicopter
SEA06FA115	2006	08-Jun-06	Mullan	ID	2	Maneuvering	Cessna	TU206G	Airplane
SEA06FA139	2006	10-Jul-06	Easton	WA	1	Cruise	Piper	PA-31-350	Airplane
DEN07MA134	2007	05-Aug-07	Ruidoso	NM	5	Maneuvering	Beech	E90B	Airplane
SEA08FA146	2008	30-May-08	Monticello	UT	2	Maneuvering-low-alt flying	Cessna	172R	Airplane
DEN08FA101	2008	08-Jun-08	Huntsville	TX	4	Enroute-climb to cruise	Bell	407	Helicopter
CEN09MA019	2008	15-Oct-08	Aurora	IL	4	Enroute-cruise	Bell	222	Helicopter
CEN09FA086	2008	11-Dec-08	Sabine Pass	TX	5	Enroute-cruise	Bell	206L-4	Helicopter
CEN09MA117	2009	04-Jan-09	Morgan City	LA	8	Enroute-cruise	Sikorsky	S-76C	Helicopter
ERA09MA447	2009	08-Aug-09	Hoboken	NJ	9	Enroute-cruise	Piper	PA-32R-300	Airplane
ERA11FA312	2011	25-May-11	Murphy	NC	4	Enroute-cruise	Beech	58	Airplane
CEN11FA599	2011	26-Aug-11	Mosby	MO	4	Enroute	Eurocopter	AS350 B2	Helicopter
CEN12FA097	2011	03-Dec-11	St. Ignace	MI	2	Maneuvering	Piper	PA-32-260	Airplane
DCA12MA020	2011	07-Dec-11	Las Vegas	NV	5	Enroute-cruise	Eurocopter	AS350 B2	Helicopter
CEN12FA100	2011	09-Dec-11	Sioux Falls	SD	4	Maneuvering	Cessna	421C	Airplane
ERA12MA122	2011	26-Dec-11	Green Cove Springs	FL	3	Maneuvering	Bell	206B	Helicopter
CEN13FA049	2012	06-Nov-12	Wichita	KS	1	Enroute-climb to cruise	Cessna	208B	Airplane
CEN13FA096	2012	10-Dec-12	Compton	IL	3	Enroute-cruise	MBB	BK 117 A-3	Helicopter

Table A.2. 14 CFR 135 Enroute Crashes [2000-2019] (continued)

NTSB Number	Year	Date	City	State	Fatalities	NTSB Phase	Aircraft Manufacturer	Aircraft Model	Aircraft Category
WPR13FA072	2012	18-Dec-12	Payson	AZ	1	Enroute-cruise	Piper	Pa-31-350	Airplane
WPR14FA044	2013	06-Nov-13	Donnelly	ID	3	Maneuvering	Cessna	U206F	Airplane
CEN14FA122	2014	27-Jan-14	Silt	CO	3	Maneuvering-low-alt flying	Bell	206L 3	Helicopter
CEN15FA171	2015	12-Mar-15	Eufaula	OK	1	Enroute-cruise	Eurocopter	AS 350 B2	Helicopter
ERA15FA313	2015	16-Aug-15	Hicksville	NY	1	Enroute-cruise	Beech	C35	Airplane
WPR16FA037	2015	10-Dec-15	McFarland	CA	4	Enroute	Bell	407	Helicopter
WPR16FA040	2015	15-Dec-15	Superior	AZ	2	Maneuvering-low-alt flying	AIRBUS Helicopters	AS350	Helicopter
WPR16FA153	2016	29-Jul-16	McKinleyville	CA	4	Enroute-climb to cruise	Piper	PA-31T	Airplane
ERA17FA066	2016	05-Dec-16	Camilla	GA	1	Maneuvering	Fairchild	SA227	Airplane
CEN17FA100	2017	06-Feb-17	Galveston	TX	1	Enroute-descent	Bell	206B	Helicopter
ERA17MA316	2017	08-Sep-17	Hertford	NC	4	Enroute-cruise	EUROCOPTER DEUTSCHLAND GMBH	MBB BK 117	Helicopter
CEN18FA033	2017	19-Nov-17	Stuttgart	AR	3	Enroute-cruise	Bell	407	Helicopter
CEN18FA215	2018	09-Jun-18	Oshkosh	WI	1	Maneuvering-low-alt flying	Robinson	R44	Helicopter
CEN19FA072	2019	29-Jan-19	Zaleski	OH	3	Enroute	Bell	407	Helicopter
CEN19FA095	2019	10-Mar-19	Galliano	LA	2	Enroute-cruise	Bell	407	Helicopter
CEN20FA035	2019	07-Dec-19	Gulf of Mexico	GM	2	Enroute-cruise	Bell	407	Helicopter

APPENDIX B. ANALYSIS OF AIRCRAFT ASSOCIATED WITH CONUS ENROUTE 14 CFR 135 CRASHES [2000-2019]

APPENDIX B. ANALYSIS OF AIRCRAFT ASSOCIATED WITH CONUS ENROUTE 14 CFR 135 CRASHES [2000-2019]

Table B.1. Summary of Types of Aircraft Involved in 14 CFR 135 Enroute Crashes [2000-2019]

Aircraft Manufacturer	Aircraft Type	Number
Aerospatiale	Helicopter	1
AIRBUS Helicopters	Helicopter	1
Beech	Airplane	5
Bell	Helicopter	22
Cessna	Airplane	17
Embraer	Airplane	1
Eurocopter	Helicopter	5
Eurocopter Deutschland GMBH	Helicopter	1
Fairchild	Airplane	1
MBB	Helicopter	1
Mitsubishi	Airplane	1
Piper	Airplane	14
Robinson	Helicopter	2
Rockwell International	Airplane	0
Sikorsky	Helicopter	2
Swearingen	Airplane	1
TOTAL		**75**

Table B.2. Summary of Fixed Wing Aircraft Involved in 14 CFR 135 Enroute Crashes [2000-2019]

Aircraft Manufacturer	Aircraft Type	Number
Beech	Airplane	5
Cessna	Airplane	17
Embraer	Airplane	1
Fairchild	Airplane	1
Mitsubishi	Airplane	1
Piper	Airplane	14
Rockwell International	Airplane	0
Swearingen	Airplane	1
TOTAL		**40**

Table B.3. Summary of Rotary Wing Aircraft Involved in 14 CFR 135 Enroute Crashes [2000-2019]

Aircraft Manufacturer	Aircraft Type	Number
Aerospatiale	Helicopter	1
AIRBUS Helicopters	Helicopter	1
Bell	Helicopter	22
Eurocopter	Helicopter	5
Eurocopter Deutschland GMBH	Helicopter	1
MBB	Helicopter	1
Robinson	Helicopter	2
Sikorsky	Helicopter	2
TOTAL		**35**

Table B.4. Wingspan Data for Aircraft Involved in 14 CFR 135 Enroute Crashes [2000-2019]

NTSB Number	Aircraft Manufacturer	Aircraft Model	Wingspan	Aircraft Type
MIA00FA221	Beech	58	37.83	Airplane
SEA04FA166	Beech	BE-99	45.83	Airplane
DEN07MA134	Beech	E90B	50.25	Airplane
ERA11FA312	Beech	58	37.83	Airplane
ERA15FA313	Beech	C35	32.82	Airplane
FTW00FA083	Cessna	182M	36.00	Airplane
SEA01FA001	Cessna	208B	52.08	Airplane
DEN01FA003	Cessna	R-182	36.00	Airplane
SEA01FA100	Cessna	U206F	36.00	Airplane
NYC01FA056	Cessna	310Q	36.75	Airplane
ATL01FA019	Cessna	206H	36.00	Airplane
CHI02FA093	Cessna	208B	52.08	Airplane
ATL03FA008	Cessna	208B	52.08	Airplane
FTW03FA055	Cessna	421C	41.17	Airplane
LAX05FA092	Cessna	P210N	36.75	Airplane
SEA05FA158	Cessna	150M	33.33	Airplane
SEA06FA055	Cessna	182P	36.00	Airplane
SEA06FA115	Cessna	TU206G	36.00	Airplane
SEA08FA146	Cessna	172R	36.08	Airplane
CEN12FA100	Cessna	421C	41.17	Airplane
CEN13FA049	Cessna	208B	52.08	Airplane
WPR14FA044	Cessna	U206F	36.00	Airplane
NYC05FA042	Embraer	EMB-110P1	50.33	Airplane
ERA17FA066	Fairchild	SA227	57.00	Airplane
NYC04FA093	Mitsubishi	MU-2B-36	39.17	Airplane
DCA00MA080	Piper	PA-31-350	40.67	Airplane
DEN01FA161	Piper	PA-31-350	40.67	Airplane
MIA02FA048	Piper	PA-31-350	40.67	Airplane
MIA02FA067	Piper	PA32R-300	32.83	Airplane
LAX04FA102	Piper	PA-32R-300	32.83	Airplane
FTW04FA235	Piper	PA-32R-300	32.83	Airplane
DEN05FA087	Piper	PA-34-200T	38.91	Airplane
CHI06FA026	Piper	PA-31-350	40.67	Airplane
CHI06FA030	Piper	PA-23-160	37.00	Airplane
SEA06FA139	Piper	PA-31-350	40.67	Airplane
ERA09MA447	Piper	PA-32R-300	32.83	Airplane
CEN12FA097	Piper	PA-32-260	38.92	Airplane
WPR13FA072	Piper	Pa-31-350	40.67	Airplane
WPR16FA153	Piper	PA-31T	42.58	Airplane
ATL06FA045	Swearingen	SA-226-TC	57.00	Airplane

Table B.4. Wingspan Data for Aircraft Involved in 14 CFR 135 Enroute Crashes [2000-2019] (continued)

NTSB Number	Aircraft Manufacturer	Aircraft Model	Wingspan	Aircraft Type
LAX03MA292	Aerospatiale	AS350BA	35.08	Helicopter
WPR16FA040	AIRBUS Helicopters	AS350	35.08	Helicopter
FTW01FAMS1	Bell	206B	33.33	Helicopter
ATL02FA048	Bell	206L-1	37.00	Helicopter
CHI02FA288	Bell	206L-1	37.00	Helicopter
FTW03FA097	Bell	407	35.00	Helicopter
FTW04FA007	Bell	206L-3	37.00	Helicopter
FTW04FA029	Bell	407	35.00	Helicopter
FTW04FA097	Bell	407	35.00	Helicopter
CHI04FA107	Bell	206L-1	37.00	Helicopter
FTW04FA168	Bell	206-L1	37.00	Helicopter
SEA04MA167	Bell	407	35.00	Helicopter
DFW06FA083	Bell	206L-1	37.00	Helicopter
DEN08FA101	Bell	407	35.00	Helicopter
CEN09MA019	Bell	222	40.00	Helicopter
CEN09FA086	Bell	206L-4	33.33	Helicopter
ERA12MA122	Bell	206B	33.33	Helicopter
CEN14FA122	Bell	206L 3	37.00	Helicopter
WPR16FA037	Bell	407	35.00	Helicopter
CEN17FA100	Bell	206B	33.33	Helicopter
CEN18FA033	Bell	407	35.00	Helicopter
CEN19FA072	Bell	407	35.00	Helicopter
CEN19FA095	Bell	407	35.00	Helicopter
CEN20FA035	Bell	407	35.00	Helicopter
FTW00FA091	Eurocopter	BO105S-CBS-5	32.33	Helicopter
LAX01MA272	Eurocopter	AS350-B2	35.08	Helicopter
CEN11FA599	Eurocopter	AS350 B2	35.08	Helicopter
DCA12MA020	Eurocopter	AS350 B2	35.08	Helicopter
CEN15FA171	Eurocopter	AS 350 B2	35.08	Helicopter
ERA17MA316	Eurocopter Deutschland GMBH	MBB BK 117	36.08	Helicopter
CEN13FA096	MBB	BK 117 A-3	36.08	Helicopter
FTW03LA163	Robinson	R44	33.17	Helicopter
CEN18FA215	Robinson	R44	33.17	Helicopter
DCA04MA030	Sikorsky	S-76A++	44.00	Helicopter
CEN09MA117	Sikorsky	S-76C	44.00	Helicopter