INVESTIGATION OF CAUSES OF AIRCRAFT WINGTIP COLLISIONS ON THE GROUND

An Applied Research Paper

Andrew Smyth

Master of City and Regional Planning
College of Design
Georgia Institute of Technology

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Introduction

Today's economy relies heavily on air travel for both business, personal and freight movements. Air traffic has quadrupled from 1978-2010 with nearly 14 million air carrier operations in 2015 (Federal Aviation Administration). Incidents are bound to happen since airports are complicated intricately connected places with aircraft, ground service vehicles and people are always moving. Getting an aircraft into the sky involves more than just fueling and getting passengers onboard. It involves dozens of individuals at multiple companies to work together effectively and safely. In-flight catering items must be restocked, checked luggage and cargo ushered throughout the airfield and loaded, fuel is pumped, the cabin is cleaned and lavatories are serviced all while an aircraft is on the ground preparing for the next flight. Airports are routinely active throughout the day with early morning departures and late night arrivals.

Aircraft are expensive to buy, operate and maintain and therefore are constantly on the move to be profitable. Aircraft are taxiing at higher speeds to meet increasingly tight turnaround schedules with the average turnaround time of 50 minutes for most carriers (Coy 2006). Airlines are continually trying to reduce this time but has remained unchanged over time. At highly constrained airports like Los Angeles International and San Francisco International, aircraft are even towed in to gates increasing taxi times for proper placement at gates. Aircraft must fit in to predetermined gate sizes (Federal Aviation Administration 1988). New aircraft are also becoming larger in all dimensions. These new designs have increased capacity that stretches design limits and has led to aircraft with larger wingspans. The new
777 - X is so wide that it will have folding wingtips when it enters in to service in 2020 (The Boeing Company 2017).

Most accidents occur during take off and landing and when aircraft are on the ground (Flight Safety Foundation). Missing, disabled and crashed aircraft are making the news all too often. Incidents involving less catastrophic damage but certainly causing headaches and time delays for those involved are when aircraft collide with other aircraft or stationary objects on the ground. There have been 414 incidents involving wings and wingtips since 1979. There isn’t an overall trend in the number of accidents per year but since 2014 the number of incidents has decreased.

Although the physical damages to the aircraft involved are significantly less substantial than other types of accidents, there are still consequences to the incidents including flight delays or cancelations, passenger inconvenience and discomfort (Zemla 2011). Among others are taking the aircraft out of revenue service, which, depending on the aircraft and airline can be a logistical and costly nightmare. Resources for stranded passengers depend largely on individual airline policies.

Ground operations are extremely complex requiring coordination among numerous companies and stakeholders. This is often overlooked by the traveling public that want to get to their destination quickly and comfortably. However, these crews are vital for the safe completion of the flight, and often are a contributing factor to the cause of these wing accidents. This report attempts to find a common element to the 414 wing incidents that occurred between 1979 and 2017.
Recent and Notable Accidents

The following events have had media exposure from social media and other news outlets. These events are some of the more notable or recent events with the latest occurring within the last few weeks. Many of these accidents also occurred outside of the United States which will not be reflected in the data used in this report. International accident statistics were not easily available so it is unknown whether the United States has more incidents than foreign countries.

» April 11, 2011, John F. Kennedy International (New York, New York): An Air France Airbus A380 heading to the runway for departure to Paris struck the tail of a Delta Bombardier CRJ-700. The A380’s left wing hit the much smaller aircraft and spun it nearly ninety degrees. Closed circuit video of the accident was available soon after the incident. The smaller aircraft was parked at the gate. There were 586 passengers and crew on board both aircraft with no injuries reported. The Delta aircraft stopped just short of its final parking location while waiting for clearance when the A380 taxied behind it. The Air France crew did not report seeing the Delta jet. The Air France crew was also not concerned with this type of incident. There was also concern over the airport lights and weather limiting visibility. The A380 is designed with taxi aid cameras, however they do not show the aircraft’s wingtips. Another influential factor was that the hold location of the Delta jet was also not approved for arriving aircraft and was supposed to be used for departing aircraft (CBS News 2011, Towle 2011).

» August 30, 2015, Oakland International (Oakland, California): Two Southwest aircraft made wingtip contact when one was being pushed back from the gate. One aircraft had no passengers and the other was on the way to John Wayne International, Orange County, California. Both aircraft had considerable damage and were removed from revenue service (Utehs 2017).

» November 30, 2016, Chhatrapati Shivaji International (Mumbai, India): An IndiGo Airbus A320 wingtip contacted a Kuwait Airways Airbus A330 during normal taxi
operations at the airport. The impact was so minor that a passenger of the IndiGo flight alerted the flight crew who immediately returned the aircraft to the gate. While the Kuwait Airways flight was waiting for air traffic control clearance for departure, the IndiGo flight passed behind where wingtip clearance was not met. The passing aircraft did not follow the correct procedures and was not supposed to pass an aircraft at that point. The aircraft waiting departure was also larger and protruded further into the taxiway system than other aircraft (Kraft 2016, Sinhal 2016).

» JANUARY 2, 2017, TORONTO PEARSON INTERNATIONAL (TORONTO, CANADA): A Pakistan International Airline Boeing 777 struck an Air France Boeing 777 while taxiing to its gate. No injuries were reported but passengers were left waiting for an extended period on the plane and for luggage. The incident was so minor that passengers did not realize what occurred. The next flights for each aircraft were cancelled without accommodations for the passengers. This incident was extremely frustrating for passengers because of the limited release of information from the airlines (McLaughlin 2017).

» FEBRUARY 16, 2017, PHOENIX SKY HARBOR INTERNATIONAL (PHOENIX, ARIZONA): A Southwest Airlines Boeing 737 was taxiing to a gate when it clipped the wing of a Frontier Airlines Airbus A320 that was being pushed back from the gate. There was a fuel leak onboard the Frontier Airlines aircraft and both aircraft had emergency evacuations that escalated the situation. No injuries were reported but both aircraft were removed from service. Passengers were accommodated on later flights at the airlines’ expense within a timely manner (Mutzabaugh 2017).

» MARCH 30, 2017, SINGAPORE CHANGI INTERNATIONAL (SINGAPORE, MALAYSIA): A Scoot Airlines Boeing 787 was taxiing when an Emirates Airbus A380’s wingtip fence did significant damage to the other aircraft. The Emirates aircraft was in the process of being pushed back. Limited information is available for this incident since the investigation is in the primary stages (Sile 2017).
Process

The aircraft incidents were pulled from the Federal Aviation Administration’s Aviation Safety Information Analysis and Sharing (ASIAS) program. The program allows for inquiries to incidents within the aviation industry. The system was designed for “the open exchange of safety information in order to continuously improve aviation safety.” The database used was the Accident and Incident Data System and has over 100,000 accidents and incidents from 1978 onwards. All entries in the system occurred within the U.S. The keywords of “wing” and “wingtip” were searched. In addition, other criteria such as phase of flight (Ground Taxi, Ground Ramp, and Taxi), Flight Conduct (Air Carrier / Commercial, Foreign Air Carrier, Air Taxi / Commuter and Scheduled Aircraft) were chosen. The search was personally conducted via the database’s online program.

The narratives listed in the reports varied in quality and quantity; some were extremely brief with few words and others more detailed and thorough. When information was not as expected or detailed enough, the applicable airports¹ were contacted for more information. Many airports have their own reporting system for incidents. However, the narratives that were not detailed were typically older incidents, prior to 1990. This led to the issue of documentation and document storage. Many airports may have had reports but were not easily accessible or might not be available due to the limited severity of these incidents. The limited severity of the

¹ Airports that responded include Anchorage (ANC), Atlanta (ATL), Birmingham (BHM), Cedar Rapids (CID), Charlotte (CLT), Chicago-Midway (MDW), Dayton (DAY), Denver (DEN), Des Moines (DSM), Detroit Metropolitan (DTW), Flint (FNT), Fort Lauderdale (FLL), Houston Airports System (HOU, IAD), Knoxville (TYS), Los Angeles (LAX), Louisville (SDF), Memphis (MEM), Milwaukee (MKE), Mobile (MOB), Port Authority of New York and New Jersey (EWR, JFK, LGA), and San Jose (SJC).
incidents has an effect on the quality of the documentation. The smaller accidents are simply not recorded as thoroughly as larger accidents.

The National Transportation Safety Board (NTSB), the leading investigative branch of the transportation industry typically is called on to investigate transportation accidents. However, it will only investigate incidents if there are serious injuries or substantial damage to the aircraft. Since these wing and wingtip incidents typically have minimal damage and minor injuries the NTSB has not investigated any incidents found in the ASIAS system.

After using the system and obtaining the correct data, the database returned 414 incidents at U.S. commercial service airports of all sizes from 1979 to 2017.

Overview of Accidents

Most incidents occurred during taxiing operations on the various taxiways on the ramp. This includes during movement in and out of the gate area. Table 1 displays the stage of flight when the incidents occurred. They also occurred throughout the day and night, and in most cases, weather and visibility were not factors.

Table 1
Number of incidents based on the phase of flight during incident occurrence

<table>
<thead>
<tr>
<th>Phase of Flight</th>
<th>Number of Incidents</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Taxi, Other Airplane</td>
<td>335</td>
<td>76.83%</td>
</tr>
<tr>
<td>Ground-Ramp</td>
<td>52</td>
<td>11.93%</td>
</tr>
<tr>
<td>Taxi</td>
<td>25</td>
<td>5.73%</td>
</tr>
</tbody>
</table>

Notes: May not add to 414 due to missing information.
Source: FAA Accident and Incident Data System, 2017

The most accidents occurred in 1999 with 22 individual accidents and the lowest in 2006 with 2 incidents. By aircraft model, Table 2, an overwhelming amount of Boeing 727 were
involved in incidents, nearly three times the next most frequent aircraft, the Boeing 737 with
39. Table 3 shows that Delta, American and United Air Lines have a significant portion of
incidents. This was expected since a majority of U.S. flights are operated by these carriers. Table
4 shows the domestic revenue passenger miles for March 2016 through February 2017.
Revenue passenger miles is the number of miles traveled by paying passengers and is used to
determine the intensity of the airline market.

Table 2
Number of incidents based on aircraft model

<table>
<thead>
<tr>
<th>Aircraft Model</th>
<th>Number of Incidents</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing 727</td>
<td>92</td>
<td>21.10%</td>
</tr>
<tr>
<td>Boeing 737</td>
<td>39</td>
<td>8.94%</td>
</tr>
<tr>
<td>McDonnell-Douglas DC-9</td>
<td>37</td>
<td>8.49%</td>
</tr>
<tr>
<td>Bombardier CRJ Series</td>
<td>32</td>
<td>7.34%</td>
</tr>
<tr>
<td>McDonnell-Douglas MD-80</td>
<td>29</td>
<td>6.65%</td>
</tr>
<tr>
<td>Boeing 747</td>
<td>20</td>
<td>4.59%</td>
</tr>
<tr>
<td>Boeing 767</td>
<td>10</td>
<td>2.29%</td>
</tr>
<tr>
<td>McDonnell-Douglas DC-8</td>
<td>10</td>
<td>2.29%</td>
</tr>
</tbody>
</table>

Notes: Aircraft with less than 10 incidents have been omitted. May not add to 414 due to missing information.
Source: FAA Accident and Incident Data System, 2017

Table 3
Number of incidents based on airline model

<table>
<thead>
<tr>
<th>Airline Operator</th>
<th>Number of Incidents</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta Air Lines</td>
<td>33</td>
<td>7.57%</td>
</tr>
<tr>
<td>American Airlines</td>
<td>24</td>
<td>5.50%</td>
</tr>
<tr>
<td>United Air Lines</td>
<td>24</td>
<td>5.50%</td>
</tr>
<tr>
<td>Republic Airlines</td>
<td>15</td>
<td>3.44%</td>
</tr>
<tr>
<td>Northwest Airlines</td>
<td>14</td>
<td>3.21%</td>
</tr>
<tr>
<td>SkyWest Airlines</td>
<td>12</td>
<td>2.75%</td>
</tr>
<tr>
<td>US Airways</td>
<td>12</td>
<td>2.75%</td>
</tr>
<tr>
<td>Continental Airlines</td>
<td>11</td>
<td>2.52%</td>
</tr>
<tr>
<td>Southwest Airlines</td>
<td>11</td>
<td>2.52%</td>
</tr>
</tbody>
</table>

Notes: Aircraft with less than 11 incidents have been omitted. May not add to 414 due to missing information.
Source: FAA Accident and Incident Data System, 2017
The State of New York had the most incidents with 37 followed by California at 32. A state by state list of accident numbers is included as Appendix 1. The states with the highest number of incidents all have an airline hub. This also includes former airline hubs.

Table 4
Available passenger miles by US Airline

<table>
<thead>
<tr>
<th>Airline</th>
<th>Passenger Miles$^1$</th>
<th>Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>American</td>
<td>125.49</td>
<td>19.0%</td>
</tr>
<tr>
<td>Southwest</td>
<td>121.51</td>
<td>18.4%</td>
</tr>
<tr>
<td>Delta</td>
<td>111.49</td>
<td>16.8%</td>
</tr>
<tr>
<td>United</td>
<td>96.13</td>
<td>14.5%</td>
</tr>
</tbody>
</table>

Notes: 1 – in Billions
Source: Domestic Revenue Passenger Miles March 2016 – February 2017, Bureau of Transportation Statistics

Nearly all the incidents experienced minor damage with only 20 having substantial damage. Under the Code of Federal Regulations, an aircraft which sustains substantial damage when the structural integrity or flight performance of the aircraft is compromised. Substantial damage requires the major repair or replacement of an affected component. The financial cost to repair damage is not used to determine the damage category. Table 5 compares the two damage categories.

Table 5
Amount of damage that occurred during incident

<table>
<thead>
<tr>
<th>Damage Category</th>
<th>Number of Incidents</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor</td>
<td>382</td>
<td>87.61%</td>
</tr>
<tr>
<td>Substantial</td>
<td>20</td>
<td>4.59%</td>
</tr>
</tbody>
</table>

Notes: May not add to 414 due to missing information.
Source: FAA Accident and Incident Data System, 2017
Data Analysis

There are a few observed patterns in the data. The first is that a significant number of incidents occurred in the Boeing 727 aircraft. As mentioned, most incidents occurred during ground taxiing operations. A series of incidents occurred where the aircrafts were unable to stop during icy conditions leading to a crash. Among the objects hit included jet bridges, baggage carts and aircraft tugs. In addition, catering and fuel trucks were often hit during push back. Deicing equipment was also involved during airport operation in freezing temperatures.

There was not enough information to determine if weather was a factor in most incidents. When weather was noted, it contained vague descriptions of rain and sometimes snow. In most cases, weather was not considered a causing factor.
When an incident involved another aircraft, the part hit was often another wing. Other areas included the nose and tail. Seldom did the wing hit the fuselage of another aircraft. Many large airports usually have a phase of construction occurring. When construction activity was located near aircraft movement areas, construction equipment was also collided with. At other airports with limited room, terminals and other buildings that are in close proximity to aircraft were often exposed to these hazards.

Those at fault are a variety of operators, including the flight crew but often the incidents were caused by the ground crew. Ground crews include those marshalling the aircraft, bag loaders, and other catering and service operators. Miscommunication between individuals of the ground crew is the likely cause for most incidents. Discussion of these reasons is in the next sections.

Despite having a significant portion of aircraft in operation, Airbus does not have a proportionate amount of incidents. This is likely, though, because Airbus has only recently become a player in the civil aviation market. Only since 2000 has Airbus produced significant number of aircraft and market share. Also, one of the major civil airplane manufacturers has since been purchased and gone out of business. McDonnell-Douglas, though, does have a significant amount of aircraft still in operation with the MD 80-series.

There are currently 514 commercial service airports in the United States. Most airports have not had a wingtip collision issue and no one airport has a significant portion of the incidents. All states with high number of accidents had an airline hub. The 1990s also had the highest rate of incidents. As seen in Figure 2, the number of air carrier operations has not
changed significantly over time. Airlines are phasing out smaller airplanes and instead using larger aircraft but operating less of them allowing for the same number of seats available.

*Figure 2*

Annual aircraft operations at U.S. commercial service airports

Source: FAA OPSNET, Operations and Performance Data, 2017

**Ground Crew at Fault**

On numerous occasions when the ground crew is at fault the main reason is communication between the ground handlers and the primary marshal. The primary marshal is the lead and stands at the nose of the aircraft. Often during pushback team members can lose sight of each other blocked by the fuselage or engines. If a crew member observes a pending accident, the emergency stop signal needs to be displayed to the flight crew and tug operator to stop the aircraft. Often, if circumstances are seen before the accident, by time the brakes are applied and the aircraft is stopped the accident has already occurred. Aircraft tugs do have their own brakes but their main function is to push the aircraft, not stop it in an emergency. The aircraft’s brakes cannot be applied by the tug.
Ground crew contractors (catering, fuel and other turn around services) were the primary cause of incidents. In most cases, trucks and other pieces of equipment were left unattended at inappropriate areas. These vehicles remained inside the apron safety lines, aircraft parking envelope or the equipment restraint lines. Airline ground crews have rigorous training to ensure safe operations on the airfield. While contractors have their own training, it is not as rigorous as the airlines.

Ground vehicles within the safety lines pose a threat even if just inside (Smith 2015). The clearances allowed at densely operated airports is minimal. These lines limit the parking areas for ground equipment and typically follow an aircraft’s outline. Figure 3 shows the outlines of these safety lines.

*Figure 3*
*Ramp safety lines surround an aircraft in white and red stripes*

When the marshalling ground crew is at fault for not noticing, it is likely due to complacency with not having an issue in the many times the crew completes the process each day and the redundant safety procedures in place. Ground crews often cater to ten aircraft turn
arounds per day, although this changes depending on airline and route length. There is not enough detail in each report to determine a correlation between the type of route and therefore the amount of turn arounds each crew completes.

There is a trend at smaller and infrequently visited airports where airlines are shifting toward contracting ground service to outside vendors. Individual employees can work for a variety of different airlines at the same airport on the same day. Each airline has specific procedures and different equipment that can disturb the workflow by adjusting to new processes. Airlines are continuously trying to reduce turnaround times for aircraft. Southwest has managed to reduce the time to 35 minutes compared to the industry average of 50.

The job is physically and mentally demanding yet are among the lowest paid at an airport. The combination of low pay and high stress leads to a high turnover rate. The ground crew turnover rate is higher when an outside vendor is the contractor versus in-house (airline) ground crews. A team with high turnover does not work as efficiently as a team that has been together for an extended period of time.

Flight Crew at Fault

When entering the gate area there are two methods for doing so; automatic guidance and direction from an aircraft marshal. The first method called stand guidance system involves a variety of sensors that detect the aircraft’s location and determine when the aircraft is on the centerline and the correct parking location. However this method only determines if the aircraft is in the appropriate location, not other objects (Lacagnina 2007). In many instances, catering
trucks, baggage carts and jet bridges are commonly left within the aircraft movement area. This leads to dependence on other ground crew for emergency stopping instructions.

Fully loaded aircraft can be over one million pounds. They take time to stop especially with high temperature brakes after landing. There is a delay in the time the marshal can see a wing walker’s stop signal and when the marshal can direct an aircraft to stop.

The cockpit has limited visibility especially during times of inclement weather. In most aircraft the pilots cannot see the ends of the wings to determine proper clearance and are completely dependent on others following appropriate procedures for clearance. There is a lot of things occurring on the airfield at all times. Since the human eye can detect movement easily, the ability to see a wing walker’s stop signal can also be buried among the chaos of an airfield. A wing walker is a member of the ground crew who walks at the wingtips to ensure wing clearance is achieved during aircraft movements at the gate.

Bringing an aircraft from approach speeds to taxiing speeds takes an incredible amount of braking force in nearly 30 seconds. This is a drastic change in speeds. Aircraft brakes translate kinetic energy to heat (George 2007). The carbon composite brakes heat up to 750 degrees Celsius on the runway and are 500 degrees Celsius at arrival at the gate. Even differences in wind patterns can cause one side of the aircraft’s gear to cool faster and thus have different performance after landing. It takes considerable amount of time before brakes are back to full stopping potential, upwards of 100 minutes (Mackness 2002). So bringing an aircraft to an emergency stop after landing is even more difficult (HoSang 1975).
Low-Wing Aircraft

As mentioned, the Boeing 727 has a significant amount of incidents throughout its operational history. The first commercial flight of the industry leader was in early 1964 and was designed for the short to medium haul routes with a typical configuration for 155 passengers. Boeing made 1,832 of these aircraft from 1963 to 1984. The aircraft was extremely popular with the airlines throughout the late 1990s.

The 727-series aircraft was involved in 92 wing incidents with most occurring at airline hubs. Each of the main airline has had at least three incidents, Table 6 shows the amount of incidents by airline. The airliner was a popular choice and was used on one of every ten flights in the U.S.

Table 6
The Boeing 727-series fleet sizes by airline

<table>
<thead>
<tr>
<th>Airline</th>
<th>Number of Incidents</th>
<th>Number in Fleet</th>
</tr>
</thead>
<tbody>
<tr>
<td>American</td>
<td>11</td>
<td>182</td>
</tr>
<tr>
<td>Continental</td>
<td>3</td>
<td>31</td>
</tr>
<tr>
<td>Delta</td>
<td>13</td>
<td>130</td>
</tr>
<tr>
<td>Eastern</td>
<td>6</td>
<td>75</td>
</tr>
<tr>
<td>Northwest</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>Trans World (TWA)</td>
<td>4</td>
<td>61</td>
</tr>
<tr>
<td>United</td>
<td>10</td>
<td>75</td>
</tr>
</tbody>
</table>

Source: FAA Aircraft Registration, 2017

The 727 was designed for smaller airports that might not have traditional ground handling equipment. The aircraft is a low-wing aircraft with the wing tips reaching a maximum height of 11’5” above the ground. However the wing starts at 4’9” above the ground. This height allows for convenient boarding by airport supplied air stairs or those already installed in the aircraft. The height also allows easy access to fuel tanks for refueling and baggage and cargo handling.
The engines are mounted at the rear of the aircraft which allows for wings to be lower to the ground but reduces the aircraft’s useable fuselage length. Figure 4 shows a Boeing 737 with wing mounted engines (top) and a MD-88 with fuselage mounted engines (bottom). The engines are outlined in red. Moving the engines rearward also allowed for cleaner wings with full length slats and flaps that improve low speed flight characteristics. Lower speeds allowed for excellent short field performance at smaller airfields. Since the aircraft frequently visited relatively unimproved airfields compared to today’s standards, the aircraft was subject to more damaging foreign object debris. Pod mounted under the wing engines had more severe jet blast at ground level.

*Figure 4
Aircraft with wing mounted engines have lower ground clearance than those mounted on the fuselage*

![Figure 4](image)

*Source: Delta Airlines, 2017*

All of these characteristics make for prime opportunities to have interactions with ground equipment. Traditional baggage carts are 6’6.5” tall. Although low enough to clear the wingtips, the cart would come in to contact with the wing at approximately the halfway point between the fuselage and wingtip, an area where baggage carts are likely to be located during loading and unloading.
At airline hubs the airport likely has a distribution network of fuel pipelines only requiring pumping trucks to refuel aircraft. The maximum height of these trucks are also within the critical zone of where the aircraft wings are. Also within this zone is catering trucks. Since most of these incidents occurred at current or former airline hubs it is not surprising that aircraft collided with fueling and catering trucks.

Low-wing aircraft are characterized by having the wing below the fuselage. As mentioned, this gives better access for ground handling operations. The 727 is much lower than most other narrow-body aircraft even among other rear mounted engine aircraft like the MD80/90/DC-9 and 717. Therefore, the likely cause for the numerous incidents involving the 727 aircraft is due to the close proximity to the ground and ground operations and equipment. With the exception of the DC-9, the MD80/90 and Boeing 717 are still in active service.

The 727 is no longer in commercial passenger service within the United States. American Airlines retired its fleet in 2002 after nearly 38 years of service (PR Newswire 2002a). At the peak, the airline had 182 in its fleet. Delta retired its fleet of 131 aircraft in 2003 (PR Newswire 2002b). Both of these airlines replaced the 727 with 737-series (McCartney and Kravetz 1996). Another legacy airline, United, retired its fleet if 75 by year end 2003 (World Airline News 2001). The three airlines cited the aircraft’s age and maintenance requirements as well as the three pilot crew required to operate the aircraft as the need to retire the aircraft. Many former passenger aircraft were converted to freighters by FedEx. FedEx discontinued using the aircraft in 2013 after using the aircraft for 35 years (Tadena and Sechler 2012). FedEx was the last major carrier to use the aircraft.
Annual operations since the removal from airline service allowed the aircraft to become virtually obsolete (PR Newswire 2001). Shown in Figure 5, there was a sharp decline after the major carriers retired them. Records available show the 727 had 1.6 million operations in 2000 or nearly ten percent of the annual air carrier operations for the year. For the year’s end, 2016 had 17,074 operations. Currently, there are only 26 Boeing 727 aircraft registered in the U.S.

*Figure 5*
*Boeing 727-series aircraft annual operations since 2000*

Low-wing aircraft have a high number of incidents. Shown below, the top five aircraft all have low-wing designs. In general, these aircraft are used for short to medium haul routes.

*Table 7* shows the amount of accidents by aircraft model.
Table 7
Top five aircraft models are all low-wing design

<table>
<thead>
<tr>
<th>Aircraft Model</th>
<th>Number of Incidents</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing 727</td>
<td>92</td>
<td>21.10%</td>
</tr>
<tr>
<td>Boeing 737</td>
<td>39</td>
<td>8.94%</td>
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<td>37</td>
<td>8.49%</td>
</tr>
<tr>
<td>Bombardier CRJ Series</td>
<td>32</td>
<td>7.34%</td>
</tr>
<tr>
<td>McDonnell-Douglas MD-80</td>
<td>29</td>
<td>6.65%</td>
</tr>
</tbody>
</table>

Source: FAA Accident and Incident Data System, 2017

There are additional low-wing aircraft consisting of mainly commuter and regional aircraft with typically less than 75 passengers. If the main reason for these incidents to occur was due to the low wing heights other smaller aircraft like commuter and regional jets should have high rates. However, they have a standard incident rate. These aircraft have wing heights similar to the 727. These smaller aircraft have smaller wingspans and do not extend as far out. If the airport or ground handler is using a bag conveyor cart in to position for proper loading, the baggage cart would be just outside the wingtip. For these types of aircraft, many bags are not checked and instead are loaded at the gate by hand which eliminates the need for a large bag cart in the first place.

Data Limitations

There were numerous problems with the data. First, any report prior to January 1, 1995 was limited to 160 characters. Any report following this date the full narrative is available. Some have highly technical details such as gate and time and others are extremely brief. When available, other sources such as police reports and airport reports were able to supplement the narrative, though this was an extremely limited amount.
These incidents are also limited to commercial aviation and do not include general aviation and corporate/chartered aircraft. Acquiring general aviation incident reports would be nearly impossible. There are over 14,000 public and private use airports within the U.S. It is also unlikely that there is a formal procedure for reporting safety incidents at many of these smaller general aviation airports. Data acquisition is difficult for smaller airfields and aircraft because there is no legislative requirement for recording or reporting an accident that doesn’t involve substantial damage or serious injuries.

**Significant Literature and Industry Publications**

When the industry was preparing for the introduction of the Airbus A380 in 2006-2008 there were strong concerns over its implementation at U.S. airports (Federal Aviation Administration 1998). The A380 is the largest passenger aircraft ever produced capable of transporting over 500 passengers 8,000 nautical miles. The large wingspan and lack of visibility were concerning especially at already congested and capacity limited airports. The target for this airplane were large international hubs like New York (JFK) and Los Angeles (LAX). Taxiway wandering studies were conducted at airports that had regularly scheduled 747-400 aircraft (Scholz 2003). Airports chosen were Anchorage (ANC), New York (JFK) and San Francisco (SFO). A taxiway wandering study analyzes how an aircraft uses an available taxiway compared to the centerline. It determines if aircraft move off the centerline and by what distance.

The studies indicate that aircraft do wander off the middle taxiway line for various reasons but primarily to avoid the “bumps” of the centerline taxiway lights (Marchi and Cohen-Nir 2003). Others include the inability to see exactly where the nose landing gear is on the
taxiway. Normally this is not an issue, however, when non-standard taxiways are used the margin of error becomes smaller. Most airports that accommodate these aircraft were built for less demanding aircraft in the early days of flying. As mentioned, aircraft are becoming wider in a never-ending battle against efficiency.

Studies note that these new aircraft are designed to meet the most rigorous standards such as runway length where there is no alternative. Taxiway and shoulder widths can be adjusted within reason and due process. These new large aircraft required adjustments to this new group of aircraft called Aircraft Design Group VI (ADG VI). Standards affected included increasing taxiway widths from 75 feet to 100 feet and increasing shoulders to 40 feet, up from the standard 30 feet. For this ADG, other clearance zones were adjusted including taxiway safety areas, object and obstacle free zones.

This is where the Modifications of Standards for object free areas come in to play. The standard clearance for taxiways is 36 feet for ADG VI. In constricted airports like JFK (designed for ADG V) the clearance would be reduced to 7 feet which is an 81 percent reduction (Federal Aviation Administration 1998). Seeing this as a major concern, JFK put restrictions on the taxi routes for ADG VI aircraft. Other areas of concern were parallel taxiways where the clearance was reduced 92 percent to just 5 feet of clearance between aircraft wingtips. Airports are restricted to allowing certain aircraft to operate parallel a new large aircraft like the A380 or Boeing 747-8. These studies also note that aircraft do wander from the taxiway centerline and at these minimalclearances the likelihood of incidents is significant.

The processes mentioned above are called a modification of standard. The FAA understands that not all airports are physically able to accommodate all the geometrical
requirements. The modification of standards allows an airport to petition the FAA for approval with justification ensuring safety is paramount.

In a never-ending effort to increase aircraft performance and efficiency, aircraft are being designed with increased wingspans. In 2012, MIT conducted a study that investigated the tradeoff between increasing wingspans and accommodating them at airports (Hansman and Bishop 2012). Similar research about accommodating larger aircraft was completed prior to the 747-8 and A380 entry to commercial service. These publications mainly focused on the movement of aircraft around the airport and once they are parked at the gate. There is limited information on the maneuverability of the aircraft in to and out of the gate.

Future Research Needs

In some instances the flight crew was unable to determine the correct taxi guidelines due to the glare and the indiscernible difference between old and new guidelines. The old guidelines had simply been painted black. Although sufficient during daytime operations, the glare from the lights resembled the new lines as both appeared white. Since the incident, the airport has permanently removed traces of the previous lines by grinding down the markings to the original surface. All future airport projects should use this technique when any airfield markings are no longer necessary. The FAA strongly endorses the physical removal of markings when not used any more. Though they strongly suggest this method, there is no requirement to do so.

In a significant number of incidents the time between an emergency situation was noticed and the time when breaking signal was shown (if at all) was significantly delayed. Many
times this was due to the marshal unable to see both wing walkers simultaneously. Typically the marshal is also the push back tug driver. In addition to guiding the aircraft backwards he is responsible for monitoring both wing walkers. Adding an additional ground crew member strictly for maintaining sight on the wing walkers would relieve the marshal of this duty. This fourth person would then notify the tug operator to stop.

In addition to this fourth crew member, the push back speeds should be reduced to reflect the actual time required to stop a fully loaded aircraft. Delays between the wing walkers and the tug operator can be significant. Many instances the braking distance was more than the distance before impact. This decreased speed should also apply to taxiing into the gate.

To ensure braking distance is reduced once the emergency stopping signal is produced, an adequate paved surface needs to be present. On runways, grooves remove standing water and prevent hydroplaning and return the pavement to near dry pavement friction levels (Yager 1969). The taxi speeds of aircraft are not high enough to suspect hydroplaning as decreased braking performance. Grooves at critical areas on the apron would prevent standing water and decrease stopping distances in dry conditions. These grooves can be standard grooving versus more expensive and time consuming trapezoidal grooving (Pasindu and Fwa 2015). During pushback only the tug’s brakes would be applied.

Many of the incidents involved inadequate communication between flight crew and ground crew. Increased coordination should be considered as a low cost opportunity for increasing safety. During push back the ground crew and flight crew are in communication via a hard wired headset worn by the tug operation. When taxiing in to the gate there is no verbal communication between flight crew and ground crew. New procedures should be explored
such as a radio channel per gate that would enable verbal communication between the two crews. This is occasionally used by airlines but mainly for pushback clearances and taxi instructions not for maneuvering (Thornburg 2016).

In addition to these procedural and facility recommendations, the way the individual airports handle these types of incidents vary widely. Each handles it a bit differently; some require outside documentation from police agencies and some prefer to have the FAA investigate the incident. The standard reporting form provides all the necessary information but often parts are not utilized. Future reporting should be thorough and each section be completed in entirety.

In 2013, a dissertation was completed that examined the improvement of airport operations by using technology influenced gate assignments (Kim 2013). The project expands on previous research using passenger travel times but didn’t account for ramp operations and congestions. This idea could be further expanded to include specific aircraft characteristics included width and airport geometry specifications. Using this method, aircraft could avoid or identify hotspots for specific airports.

Conclusion

In 2016, there were 14,544,132 air carrier operations throughout the United States with no fatalities; an impressive accomplishment (Reed 2016). An accident is caused by more than one particular event but a series of events. It is the culmination of multiple mishaps that when combined cause an accident. There were numerous accidents in 2016 including running off the runway and wingtip collisions (Reed 2016). Since 1979 there have been 414 incidents involving
all types of aircraft but with a surprisingly high number involving the Boeing 727. Some even occurred within the past year and one as recent as March 30, 2017.

There is always more than one reason for an accident to occur but in these situations the ground crew was a common element. Miscommunication or the lack of visual aids allowed contact between aircraft. Improperly parked vehicles including catering trucks and baggage carts also continue to pose a risk to aircraft during pushback. The flight crew also lacks the sightlines from the cockpit to the wingtips to ensure clearance increasing his dependence on the ground crew. Beyond this, the tug’s brakes are not adequately able to stop the aircraft if an emergency is imminent. Communication between the flight crew and ground crew is essential to smooth and safe operations.

Like many other aircraft the Boeing 727 has a wing that is low to the ground to facilitate ground handling. This convenience has come at a cost to passengers when they collide with other planes or ground equipment which has taken place 92 times nearly three times as many as the next most common aircraft. Although the 727 is no longer used in commercial service the concept of low-wing aircraft continues.

Airlines can determine their own way of handling these kinds of incidents. Typically, passengers are placed on placed on the next available flight but can become an issue when the route is long-haul or occurs infrequently. In addition, these accidents remove the aircraft from revenue service which can have rippling effects within an airline (Peterson, Neels et al. 2013).

Aircraft are getting wider which means the likelihood of colliding with other aircraft or objects is expected to increase as they fit in to the same size gates decreasing clearances. New large aircraft wingspans had to be investigated prior to entry in to service in the mid-2000s.
These aircraft are now regulated to certain taxiways and have other taxiing procedures to ensure compliance with spacing (Barnett, Ball et al. 2015). Even so, these new large aircraft have had significant impacts with smaller aircraft and have occurred where these procedures were in place.

There are things airports can do to mitigate the likelihood of these events occurring such as ensuring compliance with the latest taxiway clear areas (Airport Cooperative Research Program 2011). In addition, using the proper sized gate for the aircraft will ensure clearances. Maintaining and correcting taxiway and lead-in lines markings also would allow aircraft to maintain these distances. These 414 incidents only cover commercial service airports within the U.S. but can be expanded internationally if the data was available. There would likely be similar patterns similar expressed since the aviation system is similar throughout the world.
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