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Analysis of Ramp Damage Incidents and Implications for Future Composite Aircraft Structure

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ANALYSIS OF RAMP DAMAGE INCIDENTS AND IMPLICATIONS FOR FUTURE COMPOSITE AIRCRAFT STRUCTURE

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As aircraft manufacturers use increasing amounts of composite materials in primary aircraft structures, an understanding of how composite damage may occur is crucial. One likely setting for composite damage events is the ramp and gate areas where "ramp rash" is a common occurrence. Costly consequences to airlines and the potential to jeopardize safety are an everyday hazard. In order to better understand how such events unfold in today's operations, 104 ramp damage reports that were voluntarily submitted to the NASA Aviation Safety Reporting System (ASRS) were analyzed. Factors including environmental conditions, aircraft state, aircraft damage locations and types of ramp vehicles or equipment involved were examined in order to describe the scenarios in which damage occurs. Results provide a starting point for identifying and characterizing possible operational risks for tomorrow's advanced composite aircraft.

The manufacturers of the next generation of commercial transport airplanes are making a major shift in airframe technology. Primary components that have typically been constructed of metal are now being designed with composite materials. In the 1980s and 90s composites were widely used but never exceeded more than 12-14% of the airframe by weight. Now, in service for less than two years, the Airbus A380 is constructed with about 25% composite materials by airframe weight. Scheduled to be in service by next year, the Boeing 787 makes the most significant shift as it is produced with 50% composite structure by weight, with almost 100% of the aircraft skin/fuselage being composite materials (Boeing, 2007). It is undeniable that the use of composites provides great benefits. Weight savings alone will result in significant fuel savings, and resistance to corrosion and fatigue is expected to lengthen maintenance intervals thereby decreasing maintenance costs over the lifespan of the aircraft.

The present-day, predominately metallic, aircraft have accumulated a long service history and a knowledge base of standards and best practices from which manufacturers, regulators, and operators draw upon with confidence. In contrast, the introduction of advanced composite aircraft with very little comparable service history, present new unknowns. Huang and Lin (2005) note:

> Past reliability and structural risk studies have focused on fatigue of aging aircraft, which is mainly an issue unique to metal structures. Composite structures are fatigue and corrosion resistant, but are much more sensitive to damage threats such as hail, bird strikes and ground vehicle collisions because of brittle behavior during failure. Furthermore, there may be no visible evidence of damage to composite structures, even though significant internal damage has been sustained. (p. 2)

Such concerns provide an impetus to researchers and industry groups to investigate some of these anticipated risks. For example, the Commercial Aircraft Composite Repair Committee (CACRC) is an international industry group that shares regulatory and research updates, and develops standards for composite maintenance processes and materials. Operators in this group raise many issues, ranging from damage detection and characterization to specific repair problems. In addition, they offer valuable insights into the nature of damage threats to composite structures from their own operational experiences. Blohm (2007) gives detailed examples of damage that involves ground service vehicles, towing and docking equipment and passenger jet bridges, as well as the more typical cases of runway debris and tire separation. Figure 1 below illustrates a simplified view of the ramp environment and many of the potential everyday threats to composite aircraft structures.

Figure 1. Typical ramp and gate area with a variety of service carts, vehicles, and passenger boarding equipment.

Kim (2008) is conducting a detailed investigation of wide area blunt impact damage to composite fuselage areas that are associated with ramp activity.

> With new all-composite fuselage transport aircraft coming into service, significantly more composite skin surface area is exposed to ground vehicles and equipment. To address the difficulties that exist in being able to predict and detect the damage resulting from blunt impact, and to aid in assessing its effect on structural performance, the development of basic tools to characterize blunt impacts is needed. Of particular interest is damage that can be difficult to visually detect from the exterior, but could be extensive below the skin's outer surface. (Kim, 2008)

Another means of identifying and characterizing the current potential operational threats associated with ramp damage is through a query of the NASA Aviation Safety Reporting System (ASRS) database. Since 1976, the ASRS has been a repository of voluntary, confidential safety information provided by aviation personnel. The largest percentage of reports comes from pilots, but there is small but steady input from controllers, mechanics, ramp workers, flight attendants, dispatchers and others. Since ASRS reports are submitted voluntarily, they are subject to self-reporting biases and the data cannot be used to infer the prevalence of the specified problems within the entire National Airspace System. Nevertheless, the database provides a useful means of acquiring a large number of firsthand reports on a variety of aviation safety issues. Of particular value are the reporters' narratives that often provide great detail on the context, conditions and other personnel and organizations involved in the incident. Pertinent to the topic of ramp damage, the ASRS introduced a specialized maintenance reporting form in 1996 and began to actively encourage the reporting of ground incidents. Thus, in this study, we were able to investigate the problem from the perspective of ground personnel as well as pilots. Detailed information on the ASRS can be found on the following website. http://asrs.arc.nasa.gov/overview/summary.html

Method

Search Criteria

In order to select records that would best fit our research interest, we used the following search criteria in the ASRS Online Database query conducted in August 2008 at http://akama.arc.nasa.gov/ASRSDBOnline/QueryWizard_Begin.aspx

- Operator: Air Carrier
- Federal Aviation Regulations (FAR) Part: 121
- Flight Phase: Ground: Parked, Preflight, Pushback and Maintenance
- Event Type: Ground Encounters; Vehicles and People and Ground Excursions; Ramp
- Text: Damage (Narrative and Synopsis)

Of the 140 reports found in the initial ASRS search criteria, 36 reports were removed due to lack of damage and/or irrelevance to the ramp damage issue. The remaining 104 incidents were reported between 1999 and 2007. Aircraft type is included in each report description but there were too many different types to be able to partition the data with sufficient numbers of aircraft in each category.

Factors of Interest

Environmental Conditions. Time of day and environmental conditions were two simple factors considered to have possible impact on ramp incidents. The ASRS report form gave the options of daylight, night, dawn or dusk for time of day. Environmental conditions included options such as ice, snow, rain, fog, thunderstorm, and other.

Aircraft State. In order to better understand when aircraft damage occurred, we defined a variable called Aircraft State to capture the operational phase and whether the aircraft was parked or moving at the time of the event. This was further complicated by incidents in which aircraft that were supposed to be parked, moved due to a malfunction or error. Thus the five Aircraft State values include the following:

1. Aircraft moving: AC parked but brakes or chocks malfunction or error made
2. Aircraft moving: AC during pushback
3. Aircraft moving: AC taxiing
4. Aircraft not moving: AC parked with brake set
5. Aircraft state unknown

Ramp Vehicle/Equipment Type. A large variety of vehicles and ground equipment operate in the vicinity of aircraft on the ground, particularly during turnarounds at the gate. Collisions involving catering vehicles, baggage carts, passenger-boarding bridges, and other servicing equipment can cause significant damage. In addition, equipment employed for cargo and passenger loading and unloading are obviously an integral part of every arrival and departure. We wanted to see what types of equipment or service vehicles were involved in aircraft damage. After discovering more than 17 different types of vehicles, we collapsed them into six categories.

1. Belt or cargo loaders
2. Carts: including baggage carts, maintenance carts and oxygen carts
3. Passenger boarding equipment; jet bridge and passenger stair trucks
4. Service vehicles: including catering, fuel, lavatory, vans and various unknown ground vehicle types
5. Service/maintenance equipment: including deicing truck, lift equipment and other unknown ground equipment types
6. Tugs or tow bar

Note that when 'unknown' is applied, it meant that the reporter did not know the exact type of service vehicle or equipment was involved, or they did not actually observe the vehicle or equipment firsthand.

Aircraft Damage Location. We also wanted to learn more about where on the aircraft the damage was located. As manufacturers make the shift in airframe technology from metals to composites it will be important to know where potential danger zones may exist. The report narratives usually indicated where the main aircraft damage was located. After coding and consolidating some of the categories, the following seven damage locations were defined:

1. Doors: including aircraft door, food service doors, cargo door, avionics door and main gear doors
2. Engines: external damage including both left and right engine cowlings and thrust reverse fairings
3. Fuselage: including left, right and aft
4. Nose: including nose cone and nose gear
5. Tail: including elevator, horizontal stabilizer, rudder, tail cone, APU
6. Wings: including left and right wings, ailerons and flaps
7. Unknown: location of damage not stated

While damage location was pretty reliably reported, type of damage (e.g., composite, metallic) could not be inferred from the damage location, nor was it reported consistently in the narratives. Therefore, Environmental Factors, Aircraft State, Ramp Vehicle/Equipment Type and Aircraft Damage Location comprised our initial factors of interest. Numbers of subcategories were somewhat constrained by the total number of reports.

Results and Discussion

Analysis of Factors of Interest

Environmental Conditions. The breakdown of 'Time of Day' for the 104 reports resulted in: Daylight (52, 50%), Night (24, 23%), Dawn (4, 4%), Dusk (4, 4%) and Unknown (20, 19%). The unknown category means that damage was discovered but the time of day was not reported. From the whole set of 104 reports there were only 15 cases that cited environmental weather factors (snow, rain, fog, and ice) as a possible contributing factor. While the greater percentage of events occurred during daylight (50%) compared to non-daylight conditions (31%), this factor could easily be confounded by volume of activity in daylight versus non-daylight hours. In addition, reporters could have interpreted Time of Day as the time when they observed the damage event versus when they detected the damage versus when they filed the report. Thus, we did not try to analyze this factor any further.

Aircraft State. As shown in Figure 2, the 104 reports were also broken down by Aircraft State including the five categories described earlier. The unknown category means it was difficult to determine the aircraft state from the report. A simple comparison of Moving versus Not Moving yielded almost equal numbers of Moving (49, 47%) and Not Moving (48, 46%).

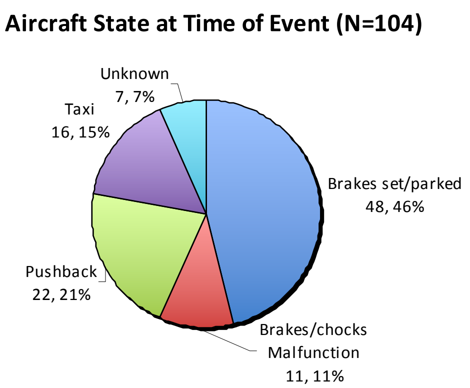

Figure 2. 104 ASRS Reports broken down by Aircraft State.

It should be noted that when an aircraft is parked with brakes set, it might seem that the cause of damage can be attributed to the ramp worker using or driving the service equipment. However, 11% of the reports describe complex situations in which flight and ground crew experienced an unexpected malfunction or error that resulted in an aircraft impact. During pushback and taxi is no simpler in terms of damage cause or initiator. For example, an impact of aircraft and tug can be due to a flight or ground crew problem, or both, and does not automatically imply one or the other is at fault. And more than one instance was cited in which a moving aircraft was "hit by a cart or object" because of a jet blast from a nearby taxiing aircraft. In short, the breakdowns identify factors to consider because they occur in actual operations, but a simple analysis of "what hit what" or "what was moving versus what was not" does not tell the whole story of how and why events occur.

Ramp Vehicle/Equipment Type. Figure 3 depicts the breakdown of 104 ASRS reports by type of ramp vehicle and equipment involved. While the large variety of types is not surprising given the ramp environment and the number of activities that must be accomplished for each flight, it immediately leads to the question of how to narrow the research focus to the most critical types of damage. In this analysis, damage can occur in many ways and we need to know which events warrant more detailed investigation.

Ramp Vehicle/Equipment Type (N=104)

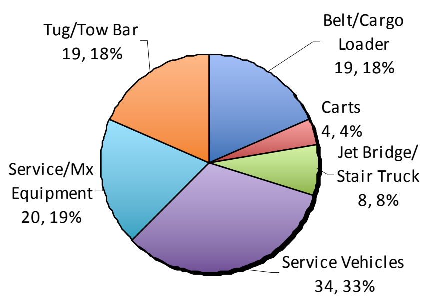

Figure 3. 104 ASRS reports broken down by Ramp Vehicle/Equipment Type.

In addition to the breakdown in Figure 3, we also considered whether Ramp Vehicle/Equipment Type was related to Aircraft State. For example, in the 49 reports where the Aircraft State was Moving, the most frequent impacts were with Service Vehicles and Tugs/Tow Bars (62%). In the 48 reports where the aircraft was Not Moving (parked), most impacts involved Belt/Cargo Loaders, Service Vehicles and Service/Mx Equipment (78%). However when considering each Ramp Vehicle/Equipment Type the following relationships emerged:

- Belt/Cargo Loaders more often involved Not Moving Aircraft (76%)
- Service/Mx Equipment more often involved Not Moving Aircraft (72%)
- Tug/Tow Bars more often involved Moving Aircraft (63%)

While Service Vehicles make up a sizeable proportion of the aircraft damage events (33%) it doesn't seem to matter if the aircraft is moving or not.

Aircraft Damage Location. Figure 4 shows the general breakdown of the 104 ASRS reports by Aircraft Damage Location. The only standout in terms of overall percentages is the 39% of incidents that result in wing damage. Given the large wing area that is exposed to ramp vehicles and objects, it is probably not surprising. Although the fuselage also covers a large expanse, targeted areas such as doors and access panels possibly constrain the hit area somewhat.

Aircraft Damage Location (N=104)

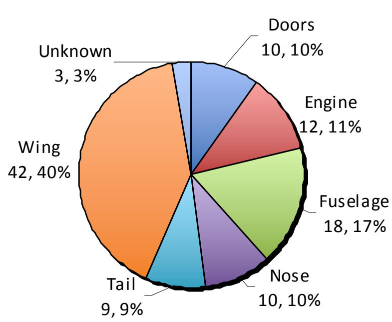

Figure 4. 104 ASRS Reports broken down by Aircraft Damage Location.

In addition to the general breakdown, we also considered whether relationships could be found between Aircraft Damage Location and Ramp Vehicle/Equipment Types. While the numbers are too small to indicate more than tendencies, the following relationships emerged when looking at each Ramp Vehicle Type:

- Service Vehicles more often impacted Wings and Fuselage (71%)
- Service/Mx Equipment more often impacted Wings and Tails (80%)

Considering each Aircraft Damage Location:

- Fuselage damage more often involved Belt/Cargo Loaders and Service Vehicles (56%)
- Nose damage more often involved Tugs/Tow Bars (80%)
- Tail damage more often involved Service/Mx Equipment (56%)
- Wing damage more often involved Service Vehicles and Service/Mx Equipment (71%)

While we can easily imagine the scenarios in which the relationships above could take place, it is important to note that very few relationships are one-to-one. Aircraft damage can be caused in multiple ways so it is important to consider this when developing awareness training and other mitigation strategies.

Conclusion

The objective of this study was to gain an understanding of what types of ramp damage scenarios occur today and how they unfold. The results are not meant to directly generalize to future advanced composite aircraft since damage risk depends on aircraft configuration and specific damage consequences. Still, the analysis of 104 ramp incidents clearly showed that ramp damage occurs in a wide variety of ways involving many different ramp vehicles and service equipment, during all times of the day and affecting nearly every part of the aircraft. Damage events can occur when the aircraft is parked and when it is moving during pushback and taxi. While some relationships among factors emerged, none were strictly one-to-one. Even when ramp activities suggest certain groupings of factors (such as a tug in the nose area during pushback, or belt loader close to the fuselage while the aircraft is parked) these relationships were only somewhat validated by the data. Partly this is because anomalies, malfunctions and errors occur thus increasing the chance of damage at unexpected times. In addition, damage events can be the outcome of a chain of events rather than a single cause. Finally, there were a number of cases where damage was reported but the actual impact event was not reported. When damage is visibly obvious, this may not pose a major problem, but non-reporting of impact events with advanced composite aircraft may have serious consequences. As Hall (2008) states, "Composite airframe structures may not visibly show damage as readily as traditional metallic structures. . . Awareness and reporting of significant impact events is essential". The data from these incident reports further underscore the need to support awareness training and reporting for all personnel who work in the ramp and gate areas; flight crews, maintenance, inspection, drivers of ramp vehicles and others.

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