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Weight and Balance Behavior of a Freighter Aircraft During Cargo Fire Test Evaluations

February 2014

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16. Abstract

The Federal Aviation Administration Airport Technology Research & Development Branch conducted a Full-Scale Cargo Fire Research Project that involved a series of firefighting-related tests with an Airbus A310 cargo aircraft. One test included a study of the weight and balance characteristics of the aircraft during a fire attack. Aircraft are sensitive to loading configurations; therefore, personnel working on and around the aircraft must ensure the aircraft remains within aircraft manufacturer's recommended weight and balance guidelines during loading and unloading. Aircraft Rescue and Firefighting (ARFF) personnel must be equally aware of these weight and balance guidelines when responding to an aircraft accident or incident. Depending on the severity, impacts or abrupt movements affecting the aircraft during the event can cause a shift in load, which would adversely affect the weight and balance. Freighter aircraft are particularly susceptible to weight and balance issues due to cargo weight and varying locations on the aircraft in which the cargo can be placed.

The research effort focused on many factors involving aircraft stabilization and identified the issues ARFF should consider to prevent an aircraft tail tip from occurring. Researchers documented changes in the aircraft height at four locations around the aircraft to see how the introduction of water and agent affected aircraft balance during full-scale fire tests to determine the weight and balance behavior of the aircraft. However, throughout the numerous fire test scenarios that were conducted, researchers were unable to identify any significant changes in the aircraft's height. When the tests were complete, researchers purposely attempted to create the conditions necessary to tail-tip the aircraft. Researchers successfully achieved a tail tip after adding roughly 6200 gallons of water to the aircraft and concentrating the weight of the water to the aft of the aircraft, thereby causing a tail-heavy condition.

A review of aircraft weight and balance industry practices identified several pieces of equipment that could aid ARFF personnel in maintaining aircraft stability during emergency responses. This report identifies factors of aircraft stabilization for aircraft rescue and firefighting personnel as well as equipment that could aid firefighting personnel in maintaining aircraft stability during emergency responses.

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LIST OF ACRONYMS

A&P	Airframe and Powerplant
ARFF	Aircraft Rescue and Firefighting
ASPN	Aircraft skin-penetrating nozzle
CG	Center of gravity
FAA	Federal Aviation Administration
GPM	Gallons per minute
HRET	High-reach extendable turret
PHL	Philadelphia International Airport
SBCFD	San Bernardino County Fire Department
ULD	Unit load device
UPS	United Parcel Service

EXECUTIVE SUMMARY

The Federal Aviation Administration Airport Technology Research & Development Branch conducted a Full-Scale Cargo Fire Research Project that involved a series of firefighting-related tests with an Airbus 310 cargo aircraft. One test included a study of the weight and balance characteristics of the aircraft during a fire attack. Aircraft are sensitive to loading configurations; therefore, personnel working on and around the aircraft must ensure the aircraft remains within aircraft manufacturer's recommended weight and balance guidelines during loading and unloading. Aircraft Rescue and Firefighting (ARFF) personnel must be equally aware of these weight and balance guidelines when responding to an aircraft accident or incident. Depending on the severity, impacts or abrupt movements affecting the aircraft during the event can cause a shift in load, which would adversely affect the weight and balance. Freighter aircraft are particularly susceptible to weight and balance issues due to cargo weight and varying locations on the aircraft in which the cargo can be placed. Unstable loads and the weight of water and foam that firefighters may introduce into the aircraft during an incident can all have adverse effects on the weight and balance of an aircraft. In extreme situations where excessive weight is concentrated towards the aft end of the aircraft, the aircraft tail can tip to the ground, causing a major shift in the loading of the aircraft and creating a potentially dangerous situation for firefighters operating in or around the aircraft.

The research effort focused on many factors involving aircraft stabilization and identified the issues ARFF personnel should consider to prevent an aircraft tail tip from occurring. During full-scale fire tests, researchers documented changes in the aircraft height at four locations around the aircraft and observed how the introduction of water and agent affected aircraft balance to determine the weight and balance behavior of the aircraft.

Throughout the numerous fire test scenarios that were conducted, researchers were unable to identify any significant changes in the aircraft's height. Four sets of chains and ruled pipes were hung from locations underneath the aircraft. As the loading of the aircraft changed, the height readings on each rule would change. The team recorded height readings before and after each fire test and the amount of water applied to the fire. The biggest change in height was documented at 2.95 inches upward at the nose of the aircraft during a test that took place in the forward lower cargo compartment of the aircraft when 690 gallons of water and foam was sprayed into the aircraft. When the fire tests were complete, researchers purposely attempted to create the conditions necessary to tail-tip the aircraft. Researchers successfully achieved a tail tip after adding roughly 6200 gallons of water to the aircraft and concentrating the weight of the water to the aft of the aircraft, which caused a tail-heavy condition.

A review of aircraft weight and balance concerns addressed the importance of water removal from the aircraft during firefighting operations. A review of industry practices identified several pieces of equipment that could aid ARFF personnel in maintaining aircraft stability during emergency responses to help prevent tail tips. This included the use of tail posts and tail stands.

INTRODUCTION

The Federal Aviation Administration Airport Technology Research & Development Branch conducted a Full-Scale Cargo Fire Research Project that involved a series of firefighting-related tests with an Airbus A310 cargo aircraft. One test included a study of the weight and balance characteristics of the aircraft during a fire attack. All aircraft are sensitive to loading configurations, and loading personnel must ensure the recommended weight and balance guidelines are met. Freighter aircraft are carefully loaded to maintain stability and to remain within load limits for both ground and flight operations. A hard landing or other event can be severe enough to cause structural weaknesses or failures to the aircraft, which can cause a shift in the load, thereby affecting weight and balance distribution. In extreme situations where excessive weight is concentrated towards the aft end of the aircraft, the aircraft tail can tip to the ground, causing a major shift in the loading of the aircraft and creating a potentially dangerous situation for firefighters that may be operating in or around the aircraft.

PURPOSE.

The research effort examined many factors including aircraft stabilization, understanding the behavior of an aircraft when filling the aircraft with water during firefighting applications, and identifying the issues Aircraft Rescue and Firefighting (ARFF) personnel should watch for to prevent an aircraft tail tip from occurring. Additionally, this report documents the steps taken to cause an aircraft tail tip in a controlled situation. The research effort used data from incidents and Federal Aviation Administration (FAA) testing to provide ARFF personnel with knowledge that applies to the development of an Incident Action Plan and other safety management practices to prevent or predict tail tip.

BACKGROUND.

In February of 2006, an incident occurred at Philadelphia International Airport (PHL) involving United Parcel Service (UPS) Flight 1307. During this incident, ARFF personnel worked for over 4 hours to bring the fire under control [1]. As shown in figure 1, there was a great potential for injury to the numerous ARFF personnel present around the aircraft if the aircraft's tail tipped during forcible entry or firefighting efforts. Accident investigators indicated that they were surprised that the aircraft did not tail tip or simply break apart [1] due to the amount of weight in the tail of the aircraft from the combination of cargo and water. The crown of the fuselage had large holes from fire burnthrough. Despite these conditions, the aircraft remained in one piece, balanced on its landing gear during the entire incident. If the aircraft had tail-tipped when the aircraft skin-penetrating nozzle (ASPN) on the high-reach extendable turret (HRET) penetrated the skin of the aircraft, the ASPN could have snapped off or the ARFF vehicle could have experienced serious damage, and the safety of the vehicle operator could have been compromised.

Figure 1. The PHL ARFF and Philadelphia Fire Department Personnel
(Courtesy of Greg Masi)

From 2010 to 2012, a team from the FAA Airport Technology Research & Development Branch conducted a Full-Scale Cargo Fire Research Project with an A310, donated by FedEx. A component of this research program was to further investigate the parameters leading to aircraft instability during firefighting. During the full-scale fire tests, the team monitored the aircraft's weight and balance behavior to see how the introduction of water affected it. The team recorded height measurements during each of the 11 test scenarios conducted to observe changes in the aircraft's weight and balance behavior.

OBJECTIVES.

The objectives of the research were to

- demonstrate the importance of aircraft stability and the devices used by airports to aid with aircraft stability.

- determine the change in the aircraft's weight and balance behavior by measuring changes in aircraft height at various locations when the aircraft is filled with water during fire extinguishment operations.

- analyze how the location of water discharge into the aircraft affects behavior and balance of the airplane.

- document the steps taken to intentionally tail-tip the aircraft.

DISCUSSION

AIRCRAFT STABILITY.

The "Aircraft Weight and Balance Handbook" [2] discusses using state-of-the-art technology and materials to achieve aircraft balance. The designers must determine the thresholds of maximum weight based on the amount of lift provided by the design and the operational conditions under which the aircraft operates. Once weight and balance parameters have been determined, the responsibility for maintaining weight and balance shifts to the Airframe and Powerplant (A&P) mechanic. The A&P mechanic is required to maintain detailed records of any changes to weight and balance created by repairs or alterations to the aircraft. The responsibility for weight and balance in preparation for and during flight falls with the pilot in command of the aircraft. The pilot must be aware of the maximum weight allowed on the aircraft for taxi, takeoff, and landing, as well as the aircraft center of gravity (CG) limits. Numerous rules and formulas are available to provide the safe operating weights, load configurations, and CG based on the altitude of the airport, temperature, wind, runway length, and conditions.

Proper weight and balance of an aircraft, or the lack thereof, is based on the physical law of the lever [2]. A lever can only balance when the weight on one side of the fulcrum multiplied by its arm is equal to the weight on the other side of the fulcrum multiplied by its arm. Figure 2 shows the law of the lever, as expressed in an algebraic sum of the moment.

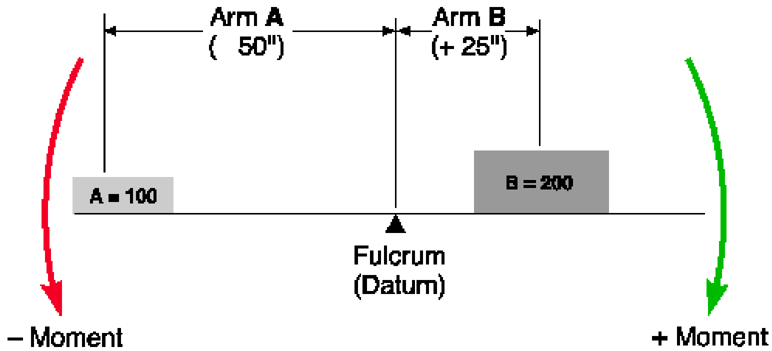

Figure 2. Law of the Lever [2]

The law of the lever determines the stability of the aircraft in any situation [2]. For an aircraft on its wheels, the main landing gear generally is the fulcrum. Too much weight loaded into the forward part of the aircraft can cause the nose landing gear to collapse, putting the aircraft in a nose-down position. Conversely, too much weight to the aft can cause a tail tip. Both the nose-down and tail-down positions pivot from the main landing gear.

There are too many factors initially unavailable to ARFF personnel to calculate the stability of the aircraft during initial analysis of an aircraft incident. Some of the factors include:

- the loaded weight of the aircraft
- the quantity of fuel onboard and its location

· any load shift during the emergency event
· any structural damage due to the emergency event

WATER REMOVAL. A change in an aircraft's weight and balance may be due to an accumulation of water in the bilge from firefighting efforts. Figure 3 shows the bilge with the floor removed in an MD-11 aircraft in the FedEx Maintenance Facility at Los Angeles International Airport. An aircraft bilge has a series of drains. The drains are very small, approximately 1/8 inch in diameter, and are designed to release water from condensation or spilled liquid freight. During fire conditions, soot and debris can block the drains. Aircraft are generally designed to have separate forward and aft bilges. This division is created from the space made for stowing the main landing gear. If water enters one bilge, it cannot drain back to the other bilge.

Figure 3. The Bilge of the Aircraft Below the Lower Cargo Compartment
With the Floor Removed

The main cargo compartment of the aircraft is equipped with low-volume floor drains routed directly into the bilges. These drains remove rainwater that enters the aircraft through open doors while loading cargo. They also handle any liquid spilled or introduced during aircraft cleaning. During firefighting operations, the amount of water discharged into the aircraft can overwhelm these drains. If enough water builds up in the main cargo compartment, it may eventually flow to drains in the opposite end of the aircraft, causing water to make its way into all bilges.

During scene assessment, firefighters must determine the condition, position, and weight and balance behavior of the aircraft. Firefighters should make this assessment prior to penetrating the aircraft with an ASPN. Since every aircraft incident is different, there is no general rule on how to conduct such an assessment. Common sense and experience must prevail. If the conditions are such that firefighters use an ASPN to penetrate the aircraft and subsequently discharge water or foam, they may need to take additional action to drain the added water. They may create drains in the aircraft bilge with a pick-headed axe or a Halligan bar and maul to drain the added water.

AIRCRAFT STABILIZATION METHODS. Any aircraft under the control of the fire department should have the wheels chocked to avoid unintended movement. If the flight crew is still in control of the aircraft, all actions taken by the fire department should be coordinated through the cockpit. If the flight crew is not in control and an emergency exists on the aircraft, the ARFF department should take steps to secure the aircraft from unintended movement.

Working with the cargo carriers at the airport helps the ARFF departments in determining what resources are available to stabilize an aircraft. The cargo carriers may have a number of options available to assist the fire department in aircraft stabilization. Each cargo carrier has different procedures for routine and emergency operations, with different resources available for each. Even the two largest cargo carriers, UPS and FedEx, use different methods and equipment for stabilizing equipment during loading and unloading.

Tail Posts and Tail Stands. Certain aircraft may be equipped to accept a tail post or tail stand. Figure 4 shows a FedEx Boeing 727 aircraft equipped with a tail post. The tail post is not designed to support the tail of an aircraft but to serve as a visual indicator of weight and balance behavior of the aircraft. When installed, it hangs down from the aircraft and does not touch the ground. The distance from the ground changes as the aircraft is loaded. If the aircraft is not designed with a tail post, no attempt should be made to install a tail post because it is likely to cause more damage and create a new safety hazard.

Figure 4. Tail Post Installed on a FedEx B-727

UPS uses a variety of tail stands to support the tail of an aircraft. Tail stands are mounted before loading and offloading operations of certain aircraft. Tail stands sometimes serve as a stabilization tool for an aircraft with an onboard fire. Figures 5 and 6 show tail stands installed on a UPS B-747 and a UPS DC-8, respectively. The tail stands are not placed under the aircraft, but are attached into the receiving system on equipped aircraft. The receiving system is a structurally reinforced mounting point designed to support the part of the aircraft attached to the tail stand. Figure 7 shows the engagement point between the tail stand and the aircraft. A tail stand may be easier to use for stabilizing smaller aircraft. Figure 8 shows a Citation Jet that was involved in an accident with a push back. The tail stand was put in place as part of the aircraft stabilization and recovery efforts.

Figure 5. Tail Stand Attached to a UPS B-747 (Courtesy K. Hoff, UPS Safety)

Figure 6. Tail Stand Attached to a UPS DC-8 (Courtesy K. Hoff, UPS Safety)

Figure 7. Tail Stand Attachment Point
(Courtesy of Mike Clancy, City of Billings, Logan International Airport, Montana)

Figure 8. Tail Stand Attached to a Citation Jet During Recovery Efforts

If the responding ARFF personnel work with the cargo carrier team, they can quickly determine if there is a method of stabilizing the aircraft in place to enhance safety operations. If the ARFF incident commander determines that the incident scene is safe enough to allow people close to the aircraft, the cargo carrier maintenance crew may have the opportunity to install a tail stand if the aircraft is so equipped.

Ramps. Most FedEx ramps and some other cargo ramps are equipped with nose tie-down positions, located at designated aircraft parking locations on which freighter aircraft are loaded and unloaded. If a fire occurs when the aircraft is at one of these locations, the nose landing gear is either already tethered or can be tethered to the ramp, preventing tail tip. Figure 9 shows a FedEx MD-11 with the nose landing gear tethered to a tie down on the ramp at their Global Super Hub at Memphis International Airport.

Figure 9. A FedEx MD-11 at Memphis International Airport With Nose Landing Gear Tie Down

Counterbalances. Another system that may be available at an airport is a portable anchoring device nicknamed the Pet Rock. The Pet Rock used by FedEx at Dulles International Airport, as shown in figure 10, uses heavy counterbalances to hold the nose landing gear in position, thereby preventing a tail tip. If available, the use of this type of device can be an effective method to prevent a tail tip. This device is common at airports with FedEx operations, but may not be available at other stations. Other cargo operators may have devices that serve a similar function, such as an aircraft tug.

Figure 10. A FedEx Pet Rock Portable Anchoring Device at Dulles International Airport

TAIL TIP. The danger of a tail tip or fuselage fracture is present throughout the firefighting effort, including during the evidence preservation and investigation phases. When the ARFF personnel drain the water in the bilge, the aircraft is stabilized and the danger is mitigated. The bilge is the lowest portion of the fuselage, located between the cargo holds and the aircraft skin. During an incident like the one involving UPS Flight 1307 [1], emergency response personnel should immediately identify and isolate high-risk areas beneath the aircraft fuselage and wings to prevent responders, investigators, and unauthorized personnel from accessing any area that may be a danger zone.

Figure 11 shows PHL ARFF and other emergency response personnel walking under and around the rear of the aircraft. Although at this point in the incident, the aircraft may have been declared safe and free from hazards associated with the fire, the photograph shows the length of unsupported fuselage aft of the main landing gear. Even if water was not present, additional structural failure, such as the burnthrough area on the top of the fuselage, can reduce the structural integrity of the fuselage, making a tail tip or fractured fuselage possible.

Figure 11. United Parcel Service Flight 1307 After the Fire was Extinguished
(Courtesy of the Philadelphia Fire Department)

Several factors can contribute to a tail tip. These may include:

- improper cargo load
- an explosion
- mechanical failure
- crash
- rough landing
- structural damage from an onboard fire

A tail tip may cause fuel release, cargo shift, structural failure, and/or rupture of pressurized hydraulic lines. These factors can create new hazards to manage.

The forward and mid portion of the aircraft are supported by landing gear. The tail section is supported by the cantilever formed by the main landing gear and the weight from the rest of the aircraft. Aircraft generally have a weight bias towards the center-to-forward part of the aircraft. As firefighters discharge water into an aircraft, the added weight of the water affects the weight and balance of the aircraft. A typical ASPN discharges a minimum of 250 gallons per minute (GPM) into the aircraft. The weight of the water is 8.35 lb per gallon. At 250 GPM, 2087.5 lb of water is added to the aircraft in 1 minute. The water streams into the bilge and settles at the low point. As the amount of water increases, the weight begins to travel the length of the aircraft. The additional weight could cause a shift in the CG of the aircraft toward the rear of the main landing gear, causing the nose to rise and the tail to drop. If the weight continues to increase toward the tail of the aircraft, a tail tip is possible. In this situation, the aircraft's nose landing gear comes off the ground and the tail touches the ground. This is a dangerous condition for emergency responders who may be working on or around the aircraft. The first and best monitoring point to evaluate the forward-to-aft weight distribution of the aircraft is the nose landing gear. As the aircraft gets heavy in the tail, the hydraulic piston of the nose landing gear strut will have an increasingly larger visible section. As shown in figure 12, the amount of exposed hydraulic piston of the nose landing gear strut can be an indicator of aircraft weight and balance behavior.

Figure 12. Nose Landing Gear Strut as Weight and Balance Monitoring Point

The aforementioned methods for monitoring aircraft balance and securing the nose landing gear to the ramp, as well as the jacking and recovery procedures are described in the Aircraft Recovery Manual provided by the manufacturers. Monitoring the balance of the aircraft during an emergency is an important consideration that must be included in the safety plan. The initial and immediate concern during a tail tip is for the safety of emergency personnel working inside, under, or on the aircraft. ARFF personnel instinctively want to gain access to the burning structure, which, in this case, is the aircraft. In varying circumstances, ARFF personnel can be on ground ladders, standing on wings, or onboard the aircraft during firefighting operations. As previously discussed, the weight of water added to the aircraft during firefighting efforts may cause the balance of the aircraft to shift. This shift in balance combined with other conditions inside the aircraft could cause the aircraft to tip onto its tail.

EXPERIMENTAL SETUP

TEST AIRCRAFT.

The test aircraft, shown in figure 13, was an A310-203F donated by FedEx. This aircraft is frame number 254, delivered June 1, 1983, and first flew for Lufthansa as a passenger aircraft. FedEx acquired the aircraft on July 18, 1994, and then converted the aircraft to a freighter aircraft with tail number N407FE. After finishing the aircraft's flight life, FedEx decommissioned the aircraft at the Southern California Logistics Airport in Victorville, California. FedEx harvested many of the aircraft's parts, including engines and electronic components, to support the remainder of the FedEx A310 fleet. At the completion of the salvage process, FedEx transferred ownership of the aircraft to the FAA for use in the FAA ARFF Research Program full-scale cargo fire testing. Different extinguishing tactics were tested with cargo containers using three different test zones (figure 14). The first test zone was in the forward part of the main cargo compartment; the second test zone was in the aft section of the main cargo compartment; and the third zone was in the forward lower cargo compartment.

Figure 13. The FAA A310 Test Aircraft

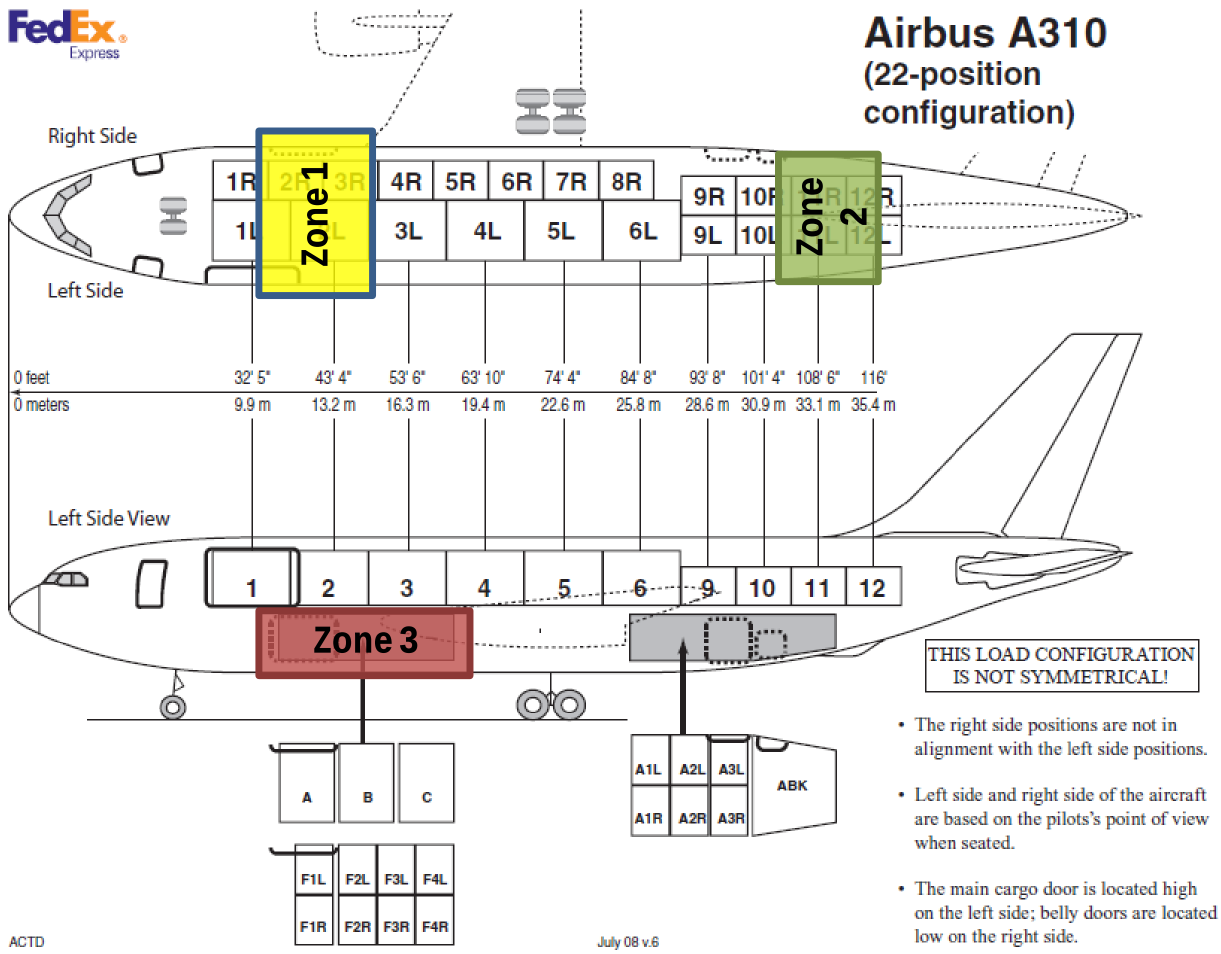

Figure 14. Test Zone Locations

<u>TEST UNIT LOAD DEVICES</u>.

Containerized cargo is transported within unit load devices (ULD), which are generally either enclosed cargo containers or open pallets. Specialized ULDs are used to transport livestock, racehorses, and wild animals. The ULD containers are manufactured in a variety of sizes and shapes and are specified for particular aircraft by the carrier. The International Air Transport Association designates a three-letter code classification to identify each type of ULD. The first letter in the code gives the ULD category, the second letter describes the base dimension of the container, and the third letter describes the shape of the container. The tests used four different types of ULD containers, as shown in figure 15. A modified half section of an AAY ULD container simulated a half-width container (figure 15(a)). An intact AAY ULD container represented a full-width container (figure 15(b)). Lower cargo compartment tests used an LD3 ULD container (figure 15(c)). The base of an AAY container was used to represent a pallet ULD (figure 15(d)).

Figure 15. (a) A Half-Width ULD Container, (b) a Full-Width ULD Container, (c) an LD3 Container, and (d) a Pallet

TEST APPARATUS.

Two different HRET/ASPN technologies were used to apply water into the aircraft through the ASPN. The first was the FAA Oshkosh Striker® with a Snozzle® 652 HRET system, shown in figure 16. This HRET consists of a 65-foot boom with two high-flow turrets and an ASPN. The ASPN attaches to the end of the boom and rotates into position through a hydraulic servo. It then penetrates the aircraft through the extension of the HRET boom. This ASPN can apply agent at a minimum flow rate of 250 GPM. The second HRET technology used was the Rosenbauer Stinger® mounted on a Panther vehicle, shown in figure 17. The Stinger® HRET has a 54-foot boom. It also has an ASPN attached to a lance and creates a 250-GPM spray. The piercing lance is retracted inside the tube when not in use to protect the piercing tip. The lance is hydraulically fired with amplified hydraulic flow from the three hydraulic accumulators.

Figure 16. Snozzle® 652 HRET

Figure 17. Rosenbauer Stinger® HRET

WEIGHT AND BALANCE.

The A310 is a tail-heavy aircraft, and the removal or loss of the aircraft engines increases the chances of altering the aircraft's balance when water enters the aircraft. To monitor the aircraft weight and balance behavior, basic height measuring devices were installed around the test aircraft at four locations. Four sets of chains and ruled pipes, shown in figure 18, hung from locations underneath the aircraft. Two were placed at points on each of the wings, one from the tail, and one from the nose of the aircraft. The bottom of the chain attached to a pipe with an adhesive-backed rule running the length of it. The ruled pipe loosely hung into a larger pipe to create a measuring gauge. As the loading of the aircraft changed, the height readings on each pipe rule also changed. The team recorded height readings before and after each fire evolution. In addition, the team measured the amount of water applied to the fire to determine how water from that test fire affected overall weight and balance behavior of the aircraft.

(a) Chain attached to aircraft nose (b) Ruled pipe

Figure 18. Weight and Balance Measuring Devices

To control the outflow of water, all existing bilge drains were sealed. This simulated the clogging of the drain holes with washed-down soot and debris from a fire. Three external bilge drains, one shown in figure 19, were installed in the bottom of the aircraft and were used to control the flow of the remaining water inside the bilge. The bilge drains remained closed until the vertical displacement of the aircraft was measured.

Figure 19. Bilge Drain

RESULTS

CONTAINER EXTINGUISHMENT.

Table 1 shows the changes in the aircraft's height at each of the measuring gauges after each test. Unlike real incidents, the amount of water discharged into the aircraft was limited due test parameters. In the Zone 1 tests, the HRET/ASPN penetrated the ULD containers and directly applied water to the fire inside the ULD container. Table 1 shows that, for the most part, the aircraft nose tilted upward, causing the tail to lower. Zone 2 tests used indirect attacks on the containers. In an indirect attack, the ASPN penetrated the aircraft fuselage, into the cargo compartment, but did not penetrate the skin of the container. For the Zone 2 tests, the tail shifted down, while the nose of the aircraft rose. The team observed the most significant change in height for all Zone 2 tests when the nose of the aircraft rose 2.95 inches after 690 gallons of water were discharged inside the aircraft. Greater changes in height were observed in the Zone 2 tests since the water was being sprayed throughout the entire aircraft, which allowed the water to be drained inside the bilges. Zone 3 tests compared the effect of piercing the aircraft at the lower forward cargo compartment versus using the ASPN to discharge directly into the container. For the Zone 3 tests, the team recorded the height change for two scenarios. As expected, the aircraft shifted down in the nose when water entered into the aircraft, but the changes were not significant.

Table 1. Changes in Heights After Each Test

Test Zone	Nose (inches)	Right Wing (inches)	Tail (inches)	Left Wing (inches)	Amount of Water Used (gallons)
1	0.88	0	-0.75	0.25	575
1	2.38	0.25	-1.63	0.19	718.8
1	-0.15	-0.4	0.45	0	517.5
1	0.9	0	0.1	1	345
1	0.75	0.05	-0.35	0.05	345
1	0.35	0.1	0	0.05	373.8
1	0.05	-0.5	-1.35	-0.05	375
1	-0.1	0.05	0.2	0	375
1	1	0.2	-0.5	0.05	375
1	0.4	0.05	-0.2	0	375
1	0.65	0.05	-0.45	0.05	375
1	1.3	0.15	-0.95	0.15	375
1	0.8	0.05	-0.3	0.05	517.5
1	0.2	0.05	-0.05	0	517.5
1	-0.05	0.05	0.4	0	517.5
2	-0.75	0.1	0.95	0.2	395.8
2	-2.2	0.1	2	0	625
2	-0.25	0.05	0.35	0.1	625
2	-1	0	0.9	0.05	609.5
2	-1	0.1	1	0	690
2	-1.35	0	1.2	0	690
2	0.45	0.15	0.1	0.05	753.3
2	0.7	0.15	-0.25	0.1	730.3
2	0.5	0.05	-0.2	0.05	690
3	0.75	0.05	-0.5	0	387.5
3	1.3	0.2	-0.85	0.1	500
2	-0.55	0.05	0.6	-0.05	750
2	1	0.05	0.15	0.05	517.5
2	-2.95	0.05	0.4	0.05	690

FORCED TAIL TIP.

After the fire tests were completed the research team attempted to intentionally tail-tip the aircraft by rapidly introducing large quantities of water into the aft portion of the main cargo compartment. The intent of the tail-tip test was to gain an understanding of how much water could induce a tail tip and to determine if there were any warning signs associated with the aircraft. The results of this tail tip test should be cautiously regarded. The experiment was intended to provide information to ARFF personnel in monitoring aircraft stability or preventing a tail tip. The results presented do not represent the behavior of an intact, operating aircraft, as there are many unique factors to each individual scenario. These characteristics were noted for the test aircraft at the time of the tail tip, which may or may not have influenced the outcome.

The subject aircraft had

- empty cargo compartments.
- empty water and waste tanks.
- empty fuel tanks.
- wing vents removed.
- both engines removed.
- horizontal and vertical stabilizers removed.
- flaps and ailerons removed.
- been out of service for over 1 year without service to the nose strut, although the strut appeared to be operating smoothly.
- significant equipment (excess weight) salvaged from the cockpit and avionics compartment.

The nose landing gear strut served as the primary indicator for the forward-to-aft weight and balance behavior of the aircraft. As shown in figure 20, prior to introducing any water, the direction of the nose landing gear tires faced slightly to the left. The nose landing gear tire sidewalls bulged slightly, indicating that they carried the weight of the aircraft.

Figure 20. Nose Landing Gear Strut Prior to Forced Tail Tip

Before running the test, a safety area was established, which included the positioning of the ARFF vehicle, and the bilge drains were closed. The FAA Striker® was positioned on the port side of the aircraft, and the Snozzle® HRET was positioned pointing toward one of the rear, left windows of the aircraft. Research personnel removed the window blank to discharge water into the aircraft without having to penetrate the fuselage, as shown in figure 21. The ARFF vehicle was clear of all portions of the aircraft when it tipped. The main landing gears were all braced to the rear to prevent any backward roll. The FAA Striker® discharged its entire water supply of 2500 gallons into the aircraft. After that discharge, the nose landing gear had approximately 0.75 to 1 inch of exposed hydraulic piston.

Figure 21. The FAA Striker®

After depleting the water supply of the FAA Striker®, San Bernardino County Fire Department (SBCFD) Station 319 brought and positioned Red 4, an Oshkosh Striker® with a Snozzle® 501 HRET system. While ARFF personnel positioned Red 4, the amount of exposed hydraulic piston decreased. This could be because water in the main cargo compartment had time to spread throughout the aircraft. As shown in figure 22, Red 4 discharged 3000 gallons of water through the same window on the left rear side of the aircraft. When Red 4 completed its discharge, approximately 1 inch of exposed hydraulic piston in the nose landing gear strut was visible. The forwardmost bilge was then opened, and as water drained, the amount of exposed chrome steadily increased. After 4 minutes and 30 seconds with the forward bilge drain opened, over 10 inches of chrome was exposed, as shown in figure 23. At this time, research personnel opened the middle bilge drain. The amount of exposed hydraulic piston did not change significantly after the middle bilge drain was opened and the forward bilge was completely drained.

Figure 22. The SBCFD Red 4 Discharging

Figure 23. Nose Landing Gear Strut After Opening Forward Bilge Drain

As shown in figure 24, SBCFD Red 3 provided the final discharge. This vehicle had approximately 700 gallons available. Since it was not equipped with an HRET, discharge continued using the roof turret into the window opening. Due to the method of water application, the amount of water that actually made it into the aircraft cannot be accurately determined, only estimated. At the conclusion of the discharge, the nose landing gear was slightly off the ground. This was evident when the nose landing gear centered itself from the slight left turn position after the weight of the water in the aft section reduced the vertical load on the nose landing gear.

Figure 24. The SBCFD Red 3 Discharging

After a few seconds, the aircraft slowly began to tip. The motion was not violent or rapid, but rather a gradual change in the incline. As shown in figure 25, the nose landing gear lifted from the ground. When the tail hit the ground, it made a loud thump, bounced a little, and then settled, as shown in figures 26 and 27.

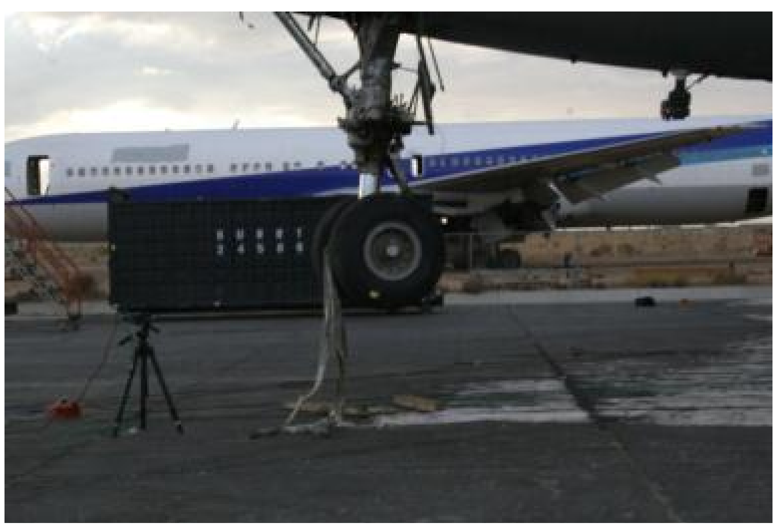

Figure 25. Nose Landing Gear Rising

Figure 26. Tail Coming to Rest

Figure 27. Full View of Tail Tip

CONCLUDING REMARKS

Weight and balance is clearly a critical factor for every aircraft, fixed wing or rotor, small frame or large frame. Firefighters may not have the specific data relative to weight, airframe damage, or interior conditions upon arrival at an aircraft fire. They will need to use instinct, experience, observation, and knowledge to make decisions that may affect the weight and balance of an aircraft.

During a review of aircraft stabilization and available airport equipment, the following findings were determined.

- During emergency operations, the safety officer should establish a safety hazard zone under the aircraft. When certain operations require personnel entering this area, it should occur under the supervision of appropriate personnel and with the right resources, after being deemed safe for the intended operation.

- During any emergency operations, including firefighting, aircraft stabilization, and aircraft recovery, emergency response personnel should monitor the nose landing gear as an indicator to any longitudinal changes to the aircraft. As the weight of the aircraft tail increases, weight on the nose landing gear decreases. The visible hydraulic piston on the nose landing gear strut increases as the tail dips. If the amount of visible chrome increases, Aircraft Rescue and Firefighting (ARFF) personnel should create drains in the aircraft bilges towards the rear of the aircraft to drain the aircraft and keep it stable.

- Equipment such as tail stands or tails posts can be useful tools for ARFF personnel in preventing an aircraft to tail tip. ARFF personnel should communicate with airport personnel to know about the availability of this equipment.

- The easiest way to create drains in the aircraft bilge is with a pick-headed axe or a Halligan bar and maul. ARFF personnel should make the first holes on the bottom of the aircraft close to the position involved in fire. These holes should be pierced in the bilges of lower cargo compartments between rivet lines, avoiding where the skin is attached to structural members. Additional drains should be created at the other end of the aircraft, as the water will make its way into both bilges.

- It may be possible for ARFF personnel to modify a technique from maritime firefighting where they monitor the draft readings marked on the sides of ships to maintain a sense of any changes to the weight of the ship by marking the strut of the aircraft landing gear with a marker, paint, or tape. Marking a baseline can highlight the change in compression of the nose landing gear strut.

Weight and balance behavior changes of an Airbus 310 were measured during a cargo-fire research effort conducted by the Federal Aviation Administration Airport Technology Research & Development Branch. The following results were determined from the collected data and observations of the intentional tail tip exercise.

- No significant changes in height were observed at the different parts of the aircraft during the interior fire tests, most likely due to the lower volumes of water discharged.

- The maximum change in height from the measured locations was 2.95 inches, where the nose of the aircraft shifted upward after 690 gallons of water was added into the aircraft in Zone 2.

An intentional tail tip of the aircraft was attempted and successful after approximately 6200 gallons of water were discharged into the rear of the aircraft and the forward and middle bilges were drained. As the weight shifted toward the rear, the sidewall bulge of the tires was visibly reduced. As the weight shifted away from the nose gear, the nose gear strut extended and more of the strut became visible.

Although weights and balances were not an issue during the cargo fire tests, ARFF personnel should still monitor the behavior of an aircraft during an incident to prevent a possible tail tip. A close watch on aircraft weight and balance is important to the safety of the firefighting operation and provides important lessons applicable to recommended tactics and strategies for freighter aircraft firefighting.

REFERENCES

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