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66-ZB-H200-ASI-18815

Mr. Timothy LeBaron
Investigator In Charge
National Transportation Safety Board
490 L'Enfant Plaza, SW
Washington DC 20594
via e-mail: [redacted]

BOEING

Subject: Boeing Submission for National Airlines (NAL) 747-400BCF N949CA Takeoff Accident Bagram AFB, Afghanistan – 29 April 2013

Reference: NTSB Tech Review Meeting on 7 January 2015

Dear Mr. LeBaron:

As requested during the reference technical review, please find the attached Boeing submission on the subject accident. Per your request we are sending this electronic version to your attention for distribution within the NTSB.

We would like to thank the NTSB for giving us the opportunity to make this submission. If you have any questions, please don't hesitate to contact us.

Best regards,

[redacted]

Paul R. Richter
Chief Engineer
Air Safety Investigation

Enclosure: Boeing Submission to the NTSB for the subject accident

Submission to the

National Transportation Safety Board

for the

National Air Cargo 747-400BCF N949CA Crash during Takeoff at Bagram Air Force Base 29 April 2013

The Boeing Company

18 March 2015

INTRODUCTION

On April 29, 2013, at about 1527 local time (1057Z), a Boeing 747-400, N949CA, operated as National Airlines flight 102, crashed shortly after takeoff from the Bagram Air Base (OAIX), Afghanistan. All 7 crewmembers onboard were fatally injured and the airplane was destroyed from impact forces and post-crash fire. The 14 Code of Federal Regulations (CFR), Part 121 Supplemental cargo flight was destined for Dubai World Central - Al Maktoum International Airport (OMDW), Dubai, United Arab Emirates (UAE). Visual meteorological conditions prevailed at the time.

Submission Abstract

- The Boeing Company, as the airplane's manufacturer, is an invited party to the investigation and provides technical and operational assistance to the National Transportation Safety Board (NTSB) in their investigation.
- The conclusions presented in this submission are based on factual information received from the NTSB, Boeing expertise, the use of analytical tools, and a methodical investigation process.
- At least one of the five MRAP's (the aft most MRAP) onboard N949CA broke loose from its restraints during takeoff and caused damage to systems on the airplane.
- At the very least, the FDR/CVR, Hydraulic System #1 and #2 and the aft pressure bulkhead were damaged by the loose MRAP.
- The combination of shifting weight and damaged airplane systems caused the airplane to pitch up to an extreme high angle and stall at a low altitude before impacting the ground.
- The 5 MRAP's were not loaded in accordance with the the guidance contained in the NAL Cargo Operations Manual and NAL Weight and Balance Manual (collectively, "NAL Guidance"), the Boeing and Telair Weight and Balance Manuals.
- The NAL Guidance instructions did not comply with Boeing and Telair Weight and Balance Manuals.

BOEING ASSISTANCE WITH THIS INVESTIGATION

The National Transportation Safety Board (NTSB) is conducting the investigation into this National Air Cargo 747-400 Boeing Converted Freighter (BCF) accident. Assisting the NTSB in their investigation are the Federal Aviation Administration (FAA), National Air Cargo Holdings, Inc. d/b/a National Airlines ("National Airlines"), Telair International, Boeing, and other designated parties.

As the manufacturer of the 747-400BCF airplane, Boeing's specific role in this investigation has been to provide technical information regarding the airplane design, manufacture and operation to assist the NTSB.

Furthermore, the NTSB requested that all parties submit proposed findings to be drawn from the factual information established during the course of the investigation. Boeing has responded to the NTSB request with this document, which:

- Provides an assessment of the factual information and other pertinent data.
- Identifies knowledge gained from the investigation.
- Identifies conclusions and recommendations supported by the knowledge gained from the investigation.

BOEING ASSESSMENT

The Boeing assessment of the accident is based upon the facts as documented in the NTSB's factual reports and investigation studies. These reports are observations of the airplane and accident site, post-accident examination of airplane systems and components, flight data recorder (FDR) data, flight simulation analysis, the cockpit voice recorder (CVR) transcript, operator and manufacturer manuals and procedures, operations and maintenance records and ground crew interview data.

THE AIRPORT

At the time of the accident, Bagram Airfield was the largest U.S. military base in Afghanistan and is located near the city of Bagram in the Parwan Province of Afghanistan. The base is primarily occupied by the U.S. Armed Forces, the International Security Assistance Force (ISAF) and minimally by the military of Afghanistan, and maintained by the Combined Joint Task Force 101st Airborne Division (CJTF-101). It is located at latitude/longitude of N 34° 56.88' /E 069° 15.9' with a field elevation of 4,895 feet above mean sea level. Runway 03/21 is 11,819 feet long and 151 feet wide.[1]

THE WEATHER

The weather reported at the time of the accident was moderate thunderstorms in the area with winds gusting to 17 knots. At the airport there were scattered clouds at 8,500 feet above mean sea level (MSL) and broken cloud layers at 14,000 and 20,000 feet MSL.[2] Based on weather observations, eye witness interviews and the security videos showing the accident, weather was not considered a factor in this accident.

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[1] NTSB Operations Factual Report dated 30 October 2014, Section 11.0

[2] NTSB Operations Factual Report dated 30 October 2014, Section 8.0

THE ACCIDENT AIRCRAFT

N949CA was a Boeing 747-400 passenger airplane that was modified in accordance with an FAA-approved Boeing Service Bulletin to operate in freighter configuration. As part of the freighter conversion, a Telair cargo loading and restraint system was installed by FAA-approved STC on the main deck. Testing and analysis conducted by the NTSB has determined that, prior to take-off, the airplane and all airplane systems were properly functioning and did not contribute to the accident. All of the fractured surfaces that were examined exhibited signs of overstress failures, with no evidence of fatigue or other material failure.[3]

HOSTILE ACTS

Immediately after the accident, when conditions permitted, U.S. Air Force personnel examined the wreckage at the accident site to determine if there were any indications of weapon effects. The Air Force conducted additional weapon effects inspections on the wreckage and the airplane parts found on the runway on May 11th and 12th. None of these inspections found signs of any weapon effects.[4] A military laboratory also examined two pieces of the airplane that were found on the runway (near rotation) for signs of explosives or other exploitable materials and none were detected.[5] In addition, no sounds of explosions or weapons effects were recorded on the CVR. Based on these findings, the Air Force concluded that hostile acts were not a factor in this accident. These findings were supported by the absence of any images of explosions or weapons effects (smoke, fire, etc.) in the three videos of the Accident that the NTSB's Vehicle Recorder Laboratory analyzed.

SEQUENCE OF EVENTS

On April 29th, at Camp Bastion, Afghanistan, National Airlines loaded 5 MRAP (Mine Resistant Ambush Protected) vehicles in the center position onto the cargo main deck of N949CA using straps as restraints. National Airlines was transporting the 5 MRAP's, consisting of (2) 12-ton M-ATV's and (3) 18-ton Cougars, from Camp Bastion to Dubai, UAE, with a fuel stop at Bagram Airfield. According to interviews, National Airlines had transported vehicles similar to the 12- ton M-ATV's onboard their B747-400 prior to the accident, but the Camp Bastion load was the first time National Airlines had ever attempted to load one or more 18-ton Cougar on a B747-400. It was also the first time National Airlines attempted to transport 18-ton Cougars on the B747-400.[6] The vehicles were loaded and then restrained on the main deck as follows; from front to back, (1) M-ATV, then (3) Cougars, then (1) M-ATV.

The MRAP's are too large and heavy to drive onto a 747-400 BCF, so they were placed on and secured to 8-foot by 20-foot aluminum pallets to help in the loading and distribution of weight. The main cargo deck on N949CA had a Telair loading system that contains a roller bearing system that allows the pallet-loaded MRAP's to be pushed into position by hand with assistance from electric drive wheels in the floor. The MRAP's were loaded in the center position (as opposed to left side or right side of the main deck), where they were restrained with standard 5,000 lb rated straps to the main deck floor tracks and Telair tie down locations. Because the MRAP's were loaded in the center position, the Telair floor locks could not be used. The straps

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[3] NTSB Structures Factual Report dated 30 January 2015, page 11-15; 26

[4] JCAT Email; Lt Col Chad Ryther, USAF to Tim LeBarron NTSB Investigator In Charge, dated May 12th 2013

[5] Military ACME Laboratory Results dated 11 May 2013

[6] NTSB Operations Factual Report dated 30 October 2014, Section 6.1, page 28

were the only means of restraint. Based on interviews of the National Airlines loaders at Camp Bastion, National Airlines used twenty-four 5,000 lb rated straps for restraining each of the two M-ATV's, and twenty-six 5,000 lb rated straps for each of the three Cougars.[7]

Several abnormal events occurred during the flight from Camp Bastion to Bagram. During the ground turn at Bagram Airfield, the cockpit area microphone recorded several conversations among the flight crew and cargo crew about these events. In one discussion, the flight crew discussed a brake over-temperature indication in the cockpit that occurred during landing. Consistent with that discussion, the FDR data showed that as the crew transitioned from auto braking to manual braking while landing at Bagram Airfield, a "BRAKE TEMP EICAS" message occurred.

Also during the ground turn, the crew discussed improper cargo movement that had occurred sometime during the flight to Bagram. The crew discussed a "busted" strap and the presence of a "knot." The crew further discussed a load movement of "a couple inches," and the fact that "all the [straps] that were keeping em from movin backwards were all loose." The accident Captain commented about heavy cargo not having a "lock". Another crewmember said, "I'm getting off this plane, I'm scared," to which the Captain responded "throw [the broken strap] out man, that's evidence. The loadmaster don't want that hangin around either." Based on the recorded conversation, the crew apparently addressed the cargo movement by replacing the broken item and "cinching them all down".[8]

After refueling and allowing additional time for the brakes to cool, N949CA took off on Runway 03. According to eyewitnesses and verified by video, N949CA pitched up nose high right after liftoff, climbed to less than 1,000 feet, rolled slightly to the left, and then rolled hard to the right and impacted at a slightly nose-down attitude just past the end of the runway threshold on the right side. This flight pattern supports the conclusion that the aircraft stalled immediately before it reached its maximum altitude. The forward 80-85 percent of the airplane wreckage was highly fragmented and consumed by fire. The aft 15-20 percent was outside the fire zone and much less fragmented.

LOOSE MRAP

Many pieces of evidence lead to the conclusion that at least the aft most MRAP (which will be referred to as MRAP #1) broke loose and penetrated the aft pressure bulkhead (APB), damaging airplane systems in the area. That evidence includes:

1. FDR/CVR paint transfer to MRAP #1
2. FDR/CVR recordings both stopping within seconds after liftoff
3. The MRAP #1 spare tire print on the aft pressure bulkhead (APB) liner
4. Airplane parts from the APB area of N949CA and a part from a M-ATV found along the runway starting at the takeoff rotation location
5. APB liner parts located in the back of MRAP #1
6. The loss of Hydraulic Systems #1 and #2 after takeoff (but prior to impact)
7. Damage to APB web
8. Horizontal Stabilizer Jackscrew

[7] NTSB Operations Factual Report dated 30 October 2014, section 6.4 page 39

[8] NTSB Cockpit Voice Recorder Factual Report dated Jan 4th 2015

1. FDR/CVR paint transfer to MRAP #1

The FDR and CVR are mounted in the E8 equipment rack, which is located aft of the L5 entry door and just forward of the APB. The FDR/CVR chassis is painted orange and is positioned at a height of approximately 100 inches above the main deck cargo floor. The orange paint transfer found on MRAP #1 was also located approximately 100 inches above floor level. The orange paint transfer was also located on the aft end, left (driver's) side of the MRAP #1.[9] This location on MRAP #1 is consistent with where the FDR/CVR would make contact if MRAP #1 moved aft and impacted the E8 equipment rack. Moreover, the lab testing of the orange paint transfer on the aft M-ATV concluded that it "shared similar peak patterns" with the orange paint on the FDR case.[10] As such, the composition, location and appearance of the paint marks on the aft M-ATV confirms it came from contacting the FDR/CVR cases prior to impact.[11]

2. FDR/CVR recordings both stopping within seconds after liftof

The FDR and CVR were damaged shortly after take-off. Valid data from the FDR ended approximately 2 seconds after liftoff with the airplane 33 feet in the air (radio altitude).[12] The CVR also stopped recording around the same time the FDR recording stopped. The last three statements recorded on the CVR were: 1) "Rotate", 2) "Positive climb, gear up", and 3) "Keep on that … (sounds like wing, weight, or wheel)."[13]

3. The MRAP #1 spare tire print on the aft pressure bulkhead (APB) liner

The APB cargo liner was found and inspected at the crash site. A black semi-circular tire imprint witness mark was visible on the APB liner. The tire imprint witness mark matches the 44-inch diameter spare tire on the MRAP #1. The height and orientation and tire lettering of the witness mark matches the height and orientation of the spare tire if the MRAP #1 moved aft and impacted directly in front of the APB.[14]

4. Airplane parts from the APB area of N949CA and a part from a M-ATV found along the runway starting at the takeoff rotation location

Twelve parts were recovered during a runway sweep that was performed immediately after the accident. The parts were recovered along a path that starts on or near Runway 03 in the vicinity of Taxiway C (near the point of liftoff) and continues on a path toward the crash site. Eleven of the parts were identified as airplane type parts, and of those, seven were positively identified as being from a 747-400 series airplane. All seven of the positively identified parts are from the area around the APB or E8 equipment rack. These seven parts were identified as: a section of hydraulic tubing from Hydraulic System #2; three sections of fuselage support structure; two pieces of exterior skin with blue paint (matching the color of N949CA); and a stiffener from the E8 equipment rack.[15] The 12th non-airplane part was identified as a capacitor from a M-ATV radio antennae base. The M-ATV antennae base is mounted at the

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[9] NTSB Structures Factual Report dated 30 January 2015, Figure 35

[10] NTSB Materials Laboratory Factual Report

[11]. NTSB Structures Factual Report dated 30 January 2015, p. 30; Figures 39- 41

[12] FDR Data Study dated 7 February 2014, page 3

[13] FDR Data Study dated 7 February 2014, page 4

[14] NTSB Structures Factual Report dated 30 January 2015, page 36

[15] NTSB Structures Factual Report dated 30 January 2015, page 31

same location where the orange paint transfer occurred on MRAP #1.[16] This antennae component was missing from MRAP #1 and could not be found at the crash site.

5. APB liner parts located in the back of MRAP #1

Several APB liner parts, including the interior liner between the APB and the airplane side of body interior lining and the lower APB cargo liner splice strap, were found on the right side of the aft-M-ATV trapped underneath the collapsed M-ATV structure.[17]

6. The loss of Hydraulic Systems #1 and #2 after takeoff (but prior to impact)

Hydraulic Systems #1 and #2 stopped functioning just after takeoff, but before ground impact. On the CVR, just before the end of the recording, the flight crew can be heard saying "Positive climb, gear up." This statement would imply that the gear handle is being moved to the retracted (gear up) position, retracting all landing gear. However, three videos that captured footage of the accident show that the nose landing gear and the two fuselage landing gears were still in the extended position at the time of impact. These landing gears are powered by Hydraulic System #1. The videos also show that two wing landing gears were retracted at the time of impact; these are powered by Hydraulic System #4.[18] Inspection of the actuators at the crash site corroborates these findings.

These observations, along with the Hydraulic System #2 tube found on the runway, leads to the conclusion that at the time of impact Hydraulic System #1 and #2 were not functioning, and Hydraulic System #4 was functioning. The evidence is inconclusive as to whether hydraulic system #3 was compromised before ground impact. To maintain systems separations requirements, Hydraulic System #1 and #2 are located on the left (port) side of the airplane as they pass through the APB; Hydraulic System #3 and #4 are located on the right (starboard) side. The damage to Hydraulic Systems #1 and #2, and the lack of damage to Hydraulic System #4, is consistent with the location of the orange paint transfer from the FDR and CVR onto the aft, left (driver's) side of MRAP #1.

7. Damage to APB web

Examination of the APB web found that a section of the web identified as APB-1 was separated from the rest of the APB web in a way consistent with being "punched out". The size of APB-1 would also be consistent with the size of MRAP #1 as the "punching" object. This would indicate that the M-ATV not only penetrated the APB, but went some distance beyond it to create this "punched out" section.

8. Damage to Horizontal Stabilizer Jackscrew

The distance between the APB web and the Horizontal Stabilizer Trim Drive Mechanism (HSTDM) is approximately 3.5 feet. The HSTDM rotates the leading edge of the Horizontal Stabilizer up or down to maintain pitch trim on the airplane by turning the Horizontal Stabilizer Ballscrew. At the accident site, the Horizontal Stabilizer Ballscrew (also known as a Jackscrew) was found severed. A subsequent examination found that the ballscrew had failed in bending due to a single overload event. A subsequent laboratory review could not

[16] NTSB Structures Factual Report dated 30 January 2015, page 36.

[17] NTSB Structures Factual Report dated 30 January 2015, page 33.

[18] NTSB Video Study dated 22 September 2014, page 5

conclusively establish when in the accident sequence this failure occurred. However, when this damage to the Horizontal Stabilizer Jackscrew is considered along with other evidence (including the "punched out" section of the APB web, the APB liner parts found on MRAP #1, and the observations from the airplane performance analysis (discussed immediately below), the most probable scenario is that after MRAP #1 "punched" through the APB liner, it continued moving aft and impacted the Horizontal Stabilizer Jackscrew, causing the damage to the Jackscrew and or the HSTDM attachments.

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The evidence discussed in this section demonstrates that, less than a few seconds after liftoff, at least one MRAP (MRAP #1) broke free from its restraints, moved aft, damaged the FDR/CVR, damaged Hydraulic Systems #1 and #2, penetrated the APB, and most probably damaged the Horizontal Stabilizer Trim Drive Mechanism or its attachments.

AIRPLANE PERFORMANCE ANALYSIS

Valid FDR data for the accident flight ends with the airplane at 33 feet radio altitude. At the NTSB's request, Boeing analyzed the FDR data to determine if there were any anomalies in airplane performance.

First, a baseline desktop simulation analysis was performed to see if the airplane performed as expected. This first simulation shows the airplane did perform as expected throughout the takeoff roll and rotation; however, during the last three seconds of the FDR recording, the airplane pitch, longitudinal acceleration and radio altitude started to deviate from the baseline simulation. Moving MRAP #1 aft past the APB to the HSTDM over the last three seconds improved the new simulation match over the baseline match during that timeframe.[19] This comparison supports the conclusion that the airplane was functioning as expected before lift off, but three seconds before the end of the FDR recording a center of gravity (CG) shift aft began to occur.

Further analysis was performed to simulate different combinations of CG shifts (to simulate various combinations of loose MRAP's) and hydraulic failures and what their impact would be on continued flight. A series of 20 scenarios were simulated. These simulations show that, with Hydraulic Systems #1 and #2 failed, and with only one MRAP shifted back to a position just in front of the HSTDM, the airplane is still controllable. The simulations further show that, with Hydraulic System #1 and #2 failed and with the Horizontal Stabilizer still fully functional, the airplane's pitch attitude and pitch rate will become uncontrollable if four MRAP's shift aft (still in an end-to-end orientation) to a position just in front of the HSTDM.[20]

An additional analysis was performed to account for a scenario where the HSTDM or its fuselage attachment may have been damaged, and to determine the effect that Horizontal Stabilizer movement would have on pitch attitude and control. This analysis was based on a failure of Hydraulic System #1 and #2, and one to three MRAPs shifting aft to the HSTDM. The analysis showed the following results:

- if one MRAP shifted aft and damaged the HSTDM or the Horizontal Stabilizer Jackscrew, the leading edge of the Horizontal Stabilizer would need to move down approximately 16 inches for the resulting nose-up pitching moment to no longer be controllable by the available flight control surfaces;

[19] FDR Data Study dated 7 February 2014, page 8

[20] FDR Data Study dated 7 February 2014, Figure 10

- if two MRAPs shifted aft (still in an end-to-end orientation) and damaged the HSTDM or the Horizontal Stabilizer Jackscrew, the leading edge of the Horizontal Stabilizer would need to move down approximately 10 inches for the resulting nose-up pitching moment to no longer be controllable by the available flight control surfaces;

- if three MRAPs shifted (still in an end-to-end orientation) and damaged the HSTDM or the Horizontal Stabilizer Jackscrew, the leading edge of the Horizontal Stabilizer would need to move down approximately 3 inches for the resulting nose-up pitching moment to no longer be controllable by the available flight control surfaces.

Each of these amounts of Horizontal Stabilizer movement (16 inches, 10 inches, or 3 inches) would be possible if the aft-most MRAP shifted aft and fractured the Horizontal Stabilizer Jackscrew or sheared the HSTDM from its fuselage attach point. Accordingly, if the Horizontal Stabilizer Jackscrew actuator had been liberated from its attach points on the fuselage, or if the MRAP fractured the Jackscrew, the horizontal stabilizer control system would most probably have been compromised to the point that continued safe flight and landing would not have been possible.

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Available FDR/CVR data and physical evidence (video, airplane component analysis and other data), with additional support from simulation analysis, lead to the conclusion that at least one MRAP (aft-most) broke loose of its restraints shortly after takeoff rotation, shifted aft and damaged the FDR/CVR, before penetrating the aft pressure bulkhead. The MRAP's aft movement compromised at least Hydraulic Systems #1 and #2, and most likely damaged the HSTDM. If only one MRAP broke free from its restraints and moved aft, the resulting center-of-gravity shift and damage to Hydraulic Systems #1 and #2, combined with a Horizontal Stabilizer movement of 16 inches (leading edge down) would have rendered the aircraft uncontrollable.[21] If two or three MRAPs broke free from their restraints and moved aft, the resulting center-of-gravity shift and damage to Hydraulic Systems #1 and #2, combined with a Horizontal Stabilizer movement of 10 inches or 3 inches (for two MRAPs or three MRAPs, respectively), would have rendered the aircraft uncontrollable. If four MRAPs broke free from their restraints and moved aft, the resulting center-of-gravity shift and damage to Hydraulic Systems #1 and #2 would have rendered the aircraft uncontrollable regardless of whether the HSTDM was also damaged. Based on this evidence, it is clear that the accident was caused by a combination of a rear shift in the aircraft's center of gravity and damage to the flight control systems caused by at least one MRAP breaking free from its restraints and moving aft.

NAL CARGO OPERATIONS MANUAL DEFICIENCIES

National Airlines' loading and restraining guidance did not comply with the guidance contained in the Boeing and Telair Weight and Balance Manuals (WBM). The N949CA Telair WBM is the authority for the Telair cargo restraint system on the airplane, and the Boeing WBM is the authority for the seat track tie-downs (these seat tracks remain from the original airplane configuration). These manuals cover not only the method and procedures for maintaining the

[21] FDR Data Study dated 7 February 2014, page 13.

airplane weight and center of gravity within approved limits, but also the methods and loads allowed at each tie-down location.

National Airlines developed its own procedures and guidance for loading and securing cargo; these are included in National Airlines' Cargo Operations Manual (COM). National Airlines stated that it developed its procedures based on the Boeing and Telair International WBM's, but the procedures and guidance developed and used by National Airlines were not in compliance with either the Boeing or Telair International manuals. Specifically, with regard to the Boeing WBM, the following are some of the more notable discrepancies:

- The NAL COM makes the assumption that the straps or attachments to the pallet are the limiting factors for the tie down allowable. In contrast, the Boeing WBM makes clear that the limiting factor can be the pallet or vehicle attachment point, the tie-down location, the strap limit, or the strap angle, and that all of these possibilities must be considered when determining tie-down allowables and restraint requirements.
- The NAL COM does not account for allowable reductions due to the aircraft tie down point limitations or the angle of the strap. In contrast, the Boeing WBM instructs that attach point limitations and strap angles must be considered in determining appropriate tie down requirements.
- The NAL COM provides no guidance about which seat tracks are approved as tie-down points. In contrast, the Boeing WBM provides specific guidance regarding which seat track positions are approved as attach points. Some tracks that the Boeing WBM does not approve as tie-down points were found at the accident site with straps attached.
- Chapter 2, sec 11 of the NAL COM states that "Allowable tie down track loads are 5,000 pounds in any direction at all points on the track". The Boeing WBM makes clear that specific attach points have specific tie-down restrictions, and that strap angles must be taken into account.
- The NAL COM guidance for meeting the aircraft running load limit does not work for centerline loaded pallet on the 747BCF as there is no pallet position defined. The NAL COM guidance in the Chapter 2, Sec 5.3 states "The aircraft floor's maximum running load, in lb/in (kg/m) measured parallel to the aircraft's centerline, is usually met by complying with the pallet position's maximum allowable gross weight". On the other hand, the Boeing WBM contains a chart showing the running load limit specific to centerline loading. These load limits take into account the width of the cargo and location on the main deck floor. These Boeing WBM floor running load limits, had National followed them, would have prohibited the loading and transporting of any Cougar vehicles in the center position due to their excessive weight.

The NAL COM loading instructions deviated or ignored Boeing WBM instructions.[22] Following the NAL COM instead of the Boeing WBM would have resulted in loading and securing MRAP's on N949CA in a way that did not comply with the Boeing WBM.

[22] Besides the NAL COM, National Airlines also published its own Weight and Balance Manual ("NAL WBM") that purports to contain procedures and guidance for loading and securing cargo. Heavily redacted excerpts of the NAL WBM are included as Attachment Five to the NTSB Structures Factual Report. Like the NAL COM, the NAL WBM may also contain deficient instructions that were not in compliance with either the Boeing or Telair International manuals. It is not clear how the NAL WBM and NAL COM are integrated together, if at all. Boeing, however, could not fully assess the NAL WBM or its interaction with the NAL COM because the NTSB only published very limited excerpts of the manual that were heavily redacted.

The Load on The Accident Aircraft Was Not Secured In Accordance With NAL's Own Deficient Guidance[23]

Based on its interviews with the loading crews at Camp Bastion, the NTSB determined that National Airlines restrained the 5 MRAP's using twenty-four 5,000 LB rated straps for each of the two M-ATV's, and twenty-six 5,000 LB rated straps for each of the three Cougars.[24] Importantly, even though a Cougar weighs six tons more than a M-ATV, NAL used only two additional straps to secure the heavier vehicles.

Within the first few days of the accident, the onsite NAL Chief Loadmaster provided his own calculations of how many straps would be required to restrain a M-ATV on N949CA. His calculations showed that 24 straps would be required for each M-ATV. During a subsequent meeting after the investigation team returned from Bagram, the NAL Chief Loadmaster revised the calculations for the accident load and determined that, using the guidance in the NAL COM, 32 straps would be required to secure a M-ATV and 44-46 straps were required to restrain a Cougar.[25] As such, the MRAP's on the Accident Aircraft were not restrained in accordance with the guidance in NAL's COM.

TIE DOWN ANALYSIS

At the NTSB's request, Boeing performed a tie-down analysis to determine how many MRAP's could be properly loaded and secured on a 747-400BCF using the guidelines in Boeing's WBM. Boeing's analysis determined that no Cougars could be loaded or transported because of structural limitations of the main deck cargo floor.[26] Boeing's analysis further determined that only one M-ATV could be installed on a 747-400BCF in accordance with the guidelines in Boeing's WBM. That single M-ATV would need a total of 60 straps, each of which would need to be secured to an approved tie-down location after taking into account appropriate strap angles, in order to comply with the guidelines in the Boeing WBM. In addition, even if a M-ATV was secured with an appropriate number of straps in one direction, failing to account for the tie-down angles, or securing the straps to unapproved tie-down locations, would violate the guidance in Boeing's WBM. Based on these considerations, only one M-ATV could have been properly secured on N949CA in accordance with Boeing's WBM.

KNOWLEDGE GAINED DURING THE INVESTIGATION (Findings)

The following knowledge gained is pertinent to drawing conclusions:

- Weather was not a factor in this accident
- Hostile acts were not a factor in this accident
- Sequence of Events
    - 5 MRAP's were loaded in the center position on to the cargo main deck of N949CA using straps as restraints. The 5 MRAP's, (2) 12-ton M-

[23] NTSB Structures Factual Report, dated 30 January 2015, page 18

[24] In addition, in chapter 6, sec 4.2 the NAL COM states that "If a double stud attachment or D-ring is used, the tie down is good for 5,000 lbs vertical, but only 4,000 lbs at any other angle". NAL appears to have ignored this 4,000 lb limit in the NAL COM.

[25] NTSB Structures Factual Report, dated 30 January 2015, page 59

[26] Boeing 747-400 BCF MRAP Tie Down Assessment for NTSB, page 3

ATV's and (3) 18-ton Cougars, were being transported from Camp Bastion, Afghanistan to Dubai, UAE with a fuel stop at Bagram AFB.

- National Air restrained the MRAP's using twenty-four 5,000 lb rated straps for each of the two M-ATV's, and twenty-six 5,000 lb rated straps for each of the three Cougars.
- Sometime during the Camp Bastion to Bagram AFB sector, at least one of the 5 MRAP's shifted. The straps were reported to be loose and one of the cargo restraints was also damaged or broken. This was reported by the onboard loadmaster to the flight crew before takeoff for Dubai. Although straps were tightened and the broken or damaged strap was apparently replaced before takeoff at Bagram, and the cockpit voice recording contains no indication that additional straps were used to secure the MRAP's.
- During the landing at Bagram AFB the brakes overheated.
- During takeoff from Bagram AFB, at least one MRAP, the aft most M-ATV, broke loose from its restraints and penetrated the aft pressure bulkhead (APB).
- On its way aft to the APB, the loose M-ATV impacted the FDR and CVR, rendering them both inoperable approximately 2 seconds after liftoff.
- After the loose M-ATV penetrated the APB, Hydraulic Systems #1 and #2 were compromised. Hydraulic System #4 continued to function at all times before ground impact. The evidence is inconclusive as to whether Hydraulic System #3 was compromised before ground impact.
- After the loose M-ATV penetrated the APB, performance and wreckage analysis shows it may have also impacted and damaged the horizontal stabilizer jackscrew.
- At less than 1,000 feet altitude, N949CA pitched up to an extreme high pitch attitude and stalled. The airplane rolled slightly left, then rolled hard to the right before impacting the ground at a wings level nose-down pitch attitude that resulted in a large explosion.

- Analysis
  - Prior to takeoff the airplane and all airplane systems were functioning as expected and did not contribute to the accident.
  - The methodology NAL used in loading and restraining the 5 MRAP's on N949CA violated NAL's own instructions for loading and restraining cargo on 747 aircraft. Had the accident aircraft been loaded in accordance with NAL's own instructions, 32 straps would have been used to restrain each M-ATV vehicle, and 44-46 straps would have been used to restrain each Cougar.
  - The fact that at least one MRAP shifted during the flight between Camp Bastion to Bagram confirms that the method that NAL used in loading and restraining the cargo was not sufficient.

- Even if the methodology NAL used to restrain the 5 MRAP's on N949CA had complied with NAL's own instructions for loading and restraining cargo on 747 aircraft, NAL's instructions did not comply with the guidance contained in the Boeing and Telair Weight and Balance Manuals.

- The methodology NAL used in loading and restraining the 5 MRAP's on N949CA also violated the Boeing and Telair Weight and Balance Manuals.

- A subsequent study shows that when following the Boeing and Telair Weight and Balance Manuals, only one M-ATV can be restrained on the cargo main deck, and that at least 60 straps would be needed to restrain that single M-ATV. The study also showed that zero Cougars could be carried due to floor loading weight limits.

- As a result of the improper loading and restraint of the 5 MRAP's on N949CA, at least one of the MRAP's broke free from its restraints, causing damage to the aircraft which impacted its ability to maintain controlled flight, and ultimately led to the extreme high pitch attitude and the subsequent unrecoverable stall.

CONCLUSIONS

Boeing believes that the evidence supports the following conclusions for the accident:

The accident occurred as a result of NAL loading, restraining, and attempting to transport the 5 MRAP's on N949CA in a manner that did not safely and appropriately secure them and in a way that violated the guidance contained in the Boeing and Telair Weight and Balance Manuals. As a result of the improper loading and restraint of the 5 MRAP's on N949CA, at least one of the MRAP's broke free from its restraints, causing a CG shift aft and severe damage to the aircraft. The combination of the aft CG shift and aircraft damage compromised the aircraft's ability to maintain controlled flight, and ultimately led to the extreme high pitch attitude and the subsequent unrecoverable stall.

RECOMMENDATIONS

Boeing makes the following recommendations based on the knowledge gained:

- The FAA should review whether to certify loadmasters.
- Cargo operators who have created their own supplemental loading documents should verify they are in compliance with the manufacturers' WBM's.

BOEING ACTIONS

As a result of this investigation, Boeing has taken the following actions:

- Enhancements are being made to the 747-400BCF and other 747 freighter model Boeing Weight and Balance Manuals to increase the number of seat tracks available for tie down. These changes are expected to be published starting in March 2015 and will be completed by the end of summer 2015.

- Boeing supported the National Air Carrier Association's 2013 and 2014 meetings relating to the carriage of ultra large cargo. These meetings were initiated by the Association in response to the NAL accident.
- Since the fall of 2013 Boeing enhanced its related training offerings including by increasing the number of Boeing Weight and Balance classes it teaches to meet the increased interest by operators.