In-Flight Separation of Vertical Stabilizer
American Airlines Flight 587
Airbus Industrie A300-605R, N14053
Belle Harbor, New York
November 12, 2001

Aircraft Accident Report

NTSB/AAR-04/04

**National
Transportation
Safety Board**

Washington, D.C.

Aircraft Accident Report

**In-Flight Separation of Vertical Stabilizer
American Airlines Flight 587
Airbus Industrie A300-605R, N14053
Belle Harbor, New York
November 12, 2001**

National Transportation Safety Board. 2004. *In-Flight Separation of Vertical Stabilizer, American Airlines Flight 587, Airbus Industrie A300-605R, N14053, Belle Harbor, New York, November 12, 2001.* Aircraft Accident Report NTSB/AAR-04/04. Washington, DC.

Abstract: This report explains the accident involving American Airlines flight 587, an Airbus Industrie A300-605R, N14053, which crashed into a residential area of Belle Harbor, New York, following the in-flight separation of the airplane's vertical stabilizer and rudder. The safety issues discussed in this report focus on characteristics of the A300-600 rudder control system design, A300-600 rudder pedal inputs at high airspeeds, aircraft-pilot coupling, flight operations at or below an airplane's design maneuvering speed, and upset recovery training programs. Safety recommendations concerning these issues are addressed to the Federal Aviation Administration and the Direction Général de l'Aviation Civile.

Contents

Figures

Abbreviations

AAMP	advanced aircraft maneuvering program
AC	advisory circular
AD	airworthiness directive
AFM	airplane flight manual
AFS	auto flight system
agl	above ground level
AOA	angle of attack
APC	aircraft-pilot coupling
APM	aircrew program manager
APU	auxiliary power unit
ASOS	automated surface observing system
ASR-9	airport surveillance radar-9
ASRS	aviation safety reporting system
ATC	air traffic control
ATCT	air traffic control tower
ATIS	automatic terminal information service
ATP	airline transport pilot
C	Celsius
CC	complementary conditions
CFD	computational fluid dynamics
CFIT	controlled flight into terrain
CFR	*Code of Federal Regulations*
CFRP	carbon fiber reinforced plastics
cg	center of gravity
CMO	certificate management office
CT	computed tomography

CVR	cockpit voice recorder
DGAC	Direction Général de l'Aviation Civile
EICAS	engine instrument crew alert system
FAA	Federal Aviation Administration
FARs	Federal Aviation Regulations
FBI	Federal Bureau of Investigation
FCOM	flight crew operating manual
FDAU	flight data acquisition unit
FDR	flight data recorder
FEA	finite element analysis
GFRP	glass fiber reinforced plastic
HBAT	handbook bulletin for air transportation
Hg	mercury
Hz	Hertz
JFK	John F. Kennedy International Airport
KCAS	knots calibrated airspeed
kN	kiloNewton
MAC	mean aerodynamic chord
METAR	meteorological aerodrome report
MIA	Miami International Airport
MPD	maintenance planning document
MRB	maintenance review board
msl	mean sea level
N	Newton
NASA	National Aeronautics and Space Administration
nm	nautical mile
Nm	Newton times meter(s)
NPRM	notice of proposed rulemaking
NRC	National Research Council

NSP	National Simulator Program
NWS	National Weather Service
PFA	progressive failure analyses
POI	principal operations inspector
S/N	serial number
SDAC	system data analog converter
SDR	service difficulty reports
SEM	scanning electron microscopy
SPECI	special weather observation
TAF	terminal aerodome forecasts
TRACON	terminal radar approach control
TWA	Trans World Airlines
UTC	coordinated universal time
V_A	design maneuvering speed
V_B	design gust speed
V_C	design cruise speed
V_D	design dive speed
V_{MC}	minimum control speed
VMS	vertical motion simulator
V_{SR}	reference stall speed
V_{SR1}	reference stall speed in a specific configuraton

Executive Summary

On November 12, 2001, about 0916:15 eastern standard time, American Airlines flight 587, an Airbus Industrie A300-605R, N14053, crashed into a residential area of Belle Harbor, New York, shortly after takeoff from John F. Kennedy International Airport, Jamaica, New York. Flight 587 was a regularly scheduled passenger flight to Las Americas International Airport, Santo Domingo, Dominican Republic, with 2 flight crewmembers, 7 flight attendants, and 251 passengers aboard the airplane. The airplane's vertical stabilizer and rudder separated in flight and were found in Jamaica Bay, about 1 mile north of the main wreckage site. The airplane's engines subsequently separated in flight and were found several blocks north and east of the main wreckage site. All 260 people aboard the airplane and 5 people on the ground were killed, and the airplane was destroyed by impact forces and a postcrash fire. Flight 587 was operating under the provisions of 14 *Code of Federal Regulations* Part 121 on an instrument flight rules flight plan. Visual meteorological conditions prevailed at the time of the accident.

The National Transportation Safety Board determines that the probable cause of this accident was the in-flight separation of the vertical stabilizer as a result of the loads beyond ultimate design that were created by the first officer's unnecessary and excessive rudder pedal inputs. Contributing to these rudder pedal inputs were characteristics of the Airbus A300-600 rudder system design and elements of the American Airlines Advanced Aircraft Maneuvering Program.

The safety issues discussed in this report focus on characteristics of the A300-600 rudder control system design, A300-600 rudder pedal inputs at high airspeeds, aircraft-pilot coupling, flight operations at or below an airplane's design maneuvering speed, and upset recovery training programs. Safety recommendations concerning these issues are addressed to the Federal Aviation Administration and the Direction Général de l'Aviation Civile.

1.   Factual Information

1.1   History of Flight

On November 12, 2001, about 0916:15 eastern standard time,[1] American Airlines flight 587, an Airbus Industrie A300-605R,[2] N14053, crashed into a residential area of Belle Harbor, New York, shortly after takeoff from John F. Kennedy International Airport (JFK), Jamaica, New York. Flight 587 was a regularly scheduled passenger flight to Las Americas International Airport, Santo Domingo, Dominican Republic, with 2 flight crewmembers, 7 flight attendants, and 251 passengers[3] aboard the airplane. The airplane's vertical stabilizer and rudder separated in flight and were found in Jamaica Bay, about 1 mile north of the main wreckage site.[4] The airplane's engines subsequently separated in flight and were found several blocks north and east of the main wreckage site.[5] All 260 people aboard the airplane and 5 people on the ground were killed, and the airplane was destroyed by impact forces and a postcrash fire. Flight 587 was operating under the provisions of 14 *Code of Federal Regulations* (CFR) Part 121 on an instrument flight rules flight plan. Visual meteorological conditions prevailed at the time of the accident.

The accident airplane arrived at JFK about 2231 on the night before the accident. The airplane had been flown from San Jose, Costa Rica, to JFK with an intermediate stop in Miami International Airport, Miami, Florida. During postaccident interviews, the pilots of the flight leg from MIA to JFK indicated that the flight was smooth and uneventful.

Flight 587 was the first leg of a 1-day roundtrip sequence for the flight crew. American Airlines records indicated that the captain checked in for the flight about 0614 and that the first officer checked in about 0630. The gate agent working the flight arrived at the departure gate about 0645. She stated that the flight attendants were already aboard the airplane at that time and that the captain and the first officer arrived at the gate about 0700.

---

[1] Unless otherwise indicated, all times in this report are eastern standard time based on a 24-hour clock.

[2] The A300-605R is one of several variants of the A300-600 series airplane. The "5" refers to the type of engine installed on the airplane (see section 1.6.3 for information), and the "R" refers to the airplane's ability to carry fuel in the horizontal stabilizer.

[3] Of the 251 passengers, 5 were lap children under 2 years of age.

[4] The vertical stabilizer is attached to the airplane's aft fuselage. The vertical stabilizer provides supporting structure for the rudder, which is an aerodynamic control surface that is used to make the airplane yaw, or rotate, about its vertical axis. An airplane cannot be flown without its vertical stabilizer.

[5] Section 1.12 provides additional information about the wreckage area.

About 0710, the airplane fueling process began.[6] The airplane fueler indicated that, during the fueling process, he saw one of the pilots perform an exterior inspection of the airplane. He finished the fueling process about 0745 and stated that he saw nothing unusual regarding the airplane.

Statements provided to the Port Authority of New York and New Jersey Police Department by American Airlines maintenance and avionics personnel indicated that, sometime between 0730 and 0800, the captain reported that the number 2 pitch trim and yaw damper system would not engage. Two avionics technicians were sent to the airplane to investigate the problem. They performed an auto flight system (AFS) check, which indicated a fault with the number 2 flight augmentation computer. The circuit breaker was then reset, another AFS check was performed, and no fault was detected. In addition, an autoland system check was performed, and that test also did not detect a fault. The avionics technicians estimated that they were in the cockpit for 5 to 7 minutes.

The cockpit voice recorder (CVR) recording began about 0845:35. The CVR indicated that, about 0859:58, the airplane was cleared to push back from the gate. About 0901:33, the ground controller provided the flight crew with taxi instructions to runway 31L, and the first officer acknowledged these instructions. About 0902:05, the captain told the first officer, "your leg, you check the rudders." (The first officer was the flying pilot, and the captain was the nonflying pilot.) Data from the flight data recorder (FDR) showed that, about 0902:07, the rudder pedal check began. The FDR data also showed that a maximum right rudder pedal deflection of about 3.7 inches was recorded about 0902:11 and that a maximum left rudder pedal deflection of 3.6 inches was recorded about 0902:19. About 0902:23, the first officer responded, "rudders check." The FDR data showed that the rudder pedals returned to their neutral position about 0902:25.

About 0906:53, the ground controller provided the pilots of Japan Air Lines flight 47, a Boeing 747-400, with taxi instructions to runway 31L. About 0908:01, the ground controller instructed the Japan Air Lines pilots to contact the local (tower) controller. About 0908:58, the ground controller instructed the flight 587 pilots to follow the Japan Air Lines airplane and to contact the local controller. The first officer acknowledged this instruction.

About 0911:08, the local controller cleared the Japan Air Lines airplane for takeoff. About 0911:36, the local controller cautioned the flight 587 pilots about wake turbulence and instructed the pilots to taxi into position and hold for runway 31L. The first officer acknowledged the instruction. About 0913:05, the local controller instructed the Japan Air Lines pilots to fly the bridge climb[7] and to contact the departure controller at the New York Terminal Radar Approach Control (TRACON). About 0913:21, the flight 587 captain said to the first officer, "you have the airplane."[8]

---

[6] The Port Authority of New York and New Jersey collected samples of fuel from the fuel truck that serviced the accident airplane and from the two tanks that supplied fuel to the truck. The fuel samples were sent to a New Jersey laboratory for analysis and were determined to conform to specifications.

[7] The bridge climb is one of several standard instrument departure routes from JFK.

[8] According to FDR data, the autopilot was not engaged at any time during the accident flight.

About 0913:28, the local controller cleared flight 587 for takeoff, and the captain acknowledged the clearance. About 0913:35, the first officer asked the captain, "you happy with that [separation] distance?"[9] About 3 seconds later, the captain replied, "we'll be all right once we get rollin'. He's supposed to be five miles by the time we're airborne, that's the idea." About 0913:46, the first officer said, "so you're happy."

The National Transportation Safety Board's airplane performance study for this accident[10] determined that flight 587 started its takeoff roll about 0913:51 and lifted off about 0914:29, which was about 1 minute 40 seconds after the Japan Air Lines airplane.[11] About 0914:43, the local controller instructed the flight 587 pilots to turn left, fly the bridge climb, and contact the New York TRACON departure controller. About 5 seconds later, the captain acknowledged this instruction. Radar data indicated that the airplane climbed to 500 feet above mean sea level (msl) and then entered a climbing left turn to a heading of 220°. About 0915:00, the captain made initial contact with the departure controller, informing him that the airplane was at 1,300 feet msl and climbing to 5,000 feet msl. About 0915:05, the departure controller instructed flight 587 to climb to and maintain 13,000 feet msl, and the captain acknowledged this instruction about 5 seconds later. About 0915:29, the CVR recorded the captain's statement "clean machine," indicating that the gear, flaps, and slats had all been retracted.

About 0915:35, flight 587 was climbing through 1,700 feet msl with its wings approximately level. About 1 second later, the departure controller instructed flight 587 to turn left and proceed direct to the WAVEY navigation intersection (located about 30 miles southeast of JFK). About 0915:41, the captain acknowledged the instruction. The controller did not receive any further transmissions from flight 587.

FDR data indicated that, about 0915:36, the airplane experienced a 0.04 G drop in longitudinal load factor, a 0.07 G shift to the left in lateral load factor, and about a 0.3 G drop in normal (vertical) load factor.[12] The airplane performance study found that these excursions were consistent with a wake turbulence encounter. Between 0915:36 and 0915:41, the FDR recorded movement of the control column, control wheel, and rudder pedals. Specifically, the control column moved from approximately 0° (neutral) to 2° nose up, 2° nose down, and back to 0°; the control wheel moved a total of seven times, with peaks at 18° right, 30° left, 37° right, 34° left, 5° left, 21° left, and 23° right, before moving to between 5° and 6° left;[13] and the rudder pedals moved from about 0.1 inch left (the starting point for the pedals) to about 0.1 inch right and 0.2 inch left before moving to

---

[9] Federal Aviation Administration (FAA) Order 7110.65, "Air Traffic Control Handbook," paragraphs 3-9-6, "Same Runway Separation," and 5-5-4, "Minima," indicate that the separation for a heavy airplane behind another heavy airplane is 2 minutes or 4 nautical miles (nm), respectively.

[10] See section 1.16.2 for detailed information from the airplane performance study.

[11] Japan Air Lines flight 47 and American Airlines flight 587 were separated at all times by at least 4.3 nm horizontally and 3,800 feet vertically.

[12] G is a unit of measurement that is equivalent to the acceleration caused by the earth's gravity (32.174 feet/second^2).

[13] The control wheel can be moved to a maximum of 78° either left or right.

0.1 inch left. The airplane performance study indicated that, during this time, the rudder moved from 0º (neutral) to about 2º left, about 0.6º right, and back to 0º.[14]

During the wake turbulence encounter, the airplane's pitch angle increased from 9º to 11.5º, decreased to about 10º, and increased again to 11º. The airplane's bank angle moved from 0º (wings level) to 17º left wing down, which was consistent with the turn to the WAVEY navigation intersection.

At 0915:44.7, the captain stated, "little wake turbulence, huh?" to which the first officer replied, at 0915:45.6, "yeah." At 0915:48.2, the first officer indicated that he wanted the airspeed set to 250 knots, which was the maximum speed for flight below 10,000 feet msl. At that point, the airplane was at an altitude of about 2,300 feet msl.

FDR data indicated that, about 0915:51, the load factors began excursions that were similar to those that occurred about 0915:36: the longitudinal load factor dropped from 0.20 to 0.14 G, the lateral load factor shifted 0.05 G to the left, and the normal load factor dropped from 1.0 to 0.6 G. The airplane performance study found that these excursions were also consistent with a wake turbulence encounter. According to the FDR, the airplane's bank angle moved from 23º to 25º left wing down at 0915:51.5, the control wheel moved to 64º right at 0915:51.5, and the rudder pedals moved to 1.7 inches right at 0915:51.9.

At 0915:51.8, 0915:52.3, and 0915:52.9, the CVR recorded the sound of a thump, a click, and two thumps, respectively. At 0915:54.2, the first officer stated, in a strained voice, "max power."[15] At that point, the airplane was traveling at 240 knots. About 0915:55, the captain asked, "you all right?" to which the first officer replied, "yeah, I'm fine." One second later, the captain stated, "hang onto it. Hang onto it." The CVR recorded the sound of a snap at 0915:56.6, the first officer's statement "let's go for power please" at 0915:57.5, and the sound of a loud thump at 0915:57.7. According to the airplane performance study, the vertical stabilizer's right rear main attachment fitting fractured at 0915:58.4,[16] and the vertical stabilizer separated from the airplane immediately afterward. At 0915:58.5, the CVR recorded the sound of a loud bang.[17] At that time, the airplane was traveling at an airspeed of about 251 knots.

---

[14] These rudder movements are within the authority of the yaw damper, which can move the rudder without a pilot or autopilot input. (Section 1.6.2 provides information about the A300-600's rudder control system, including the yaw damper.) Between 0915:41 and 0915:48, the rudder oscillated twice between 0º and 1º left and then moved to 0.5º left until 09:15:51. These rudder movements are also within the authority of the yaw damper.

[15] The FDR indicated that the captain did not subsequently change the airplane's power setting.

[16] For information about the vertical stabilizer's attachment fittings, see section 1.6.1. For information about the fracture of the right rear main attachment fitting, see sections 1.16.2.3 and 1.16.4.

[17] It took 0.14 second for the sound of the vertical stabilizer separation to travel from the back of the airplane to the front to be recorded on the CVR.

According to the FDR, the rudder pedals moved from 1.7 inches right to 1.7 inches left, 1.7 inches right, 2.0 inches right, 2.4 inches left, and 1.3 inches right between 0915:52 and 0915:58.5.[18] Also, the FDR showed that the control wheel moved 64º to the right at 0915:51.5, 78º (full) to the left at 0915:53.5, 64º to the right at 0915:55.5, and 78º to the left at 0915:56.5.[19] Figure 1 shows these cockpit control movements.

The airplane performance study estimated that, at 0915:53.2, the rudder was deflected 11º to the left,[20] and the sideslip angle at the airplane's center of gravity (cg) was about 4º to the left (after peaking temporarily at 5º to the left).[21] At 0915:56.8, the rudder was deflected 10.2º to the left, and the sideslip angle was about 7º to the left. At 0915:58.4 (the time that the right rear main attachment fitting fractured), the rudder was deflected between 10º and 11º to the right, the sideslip angle was between 11º and 12º to the right,[22] and the airplane experienced a 0.2 G shift to the right in lateral load factor.

The CVR recorded, at 0916:00.0, a sound similar to a grunt and, 1 second later, the first officer's statement, "holy [expletive]." At 0916:04.4, the CVR recorded a sound similar to a stall warning repetitive chime, which lasted for 1.9 seconds. At 0916:07.5, the first officer stated, "what the hell are we into…we're stuck in it." At 0916:12.8, the captain stated, "get out of it, get out of it." The CVR recording ended 2 seconds later. The airplane was located at 40º 34' 37.59" north latitude and 73º 51' 01.31" west longitude. The accident occurred during the hours of daylight.

Figures 2 and 3 show flight 587's radar track based on JFK Airport Surveillance Radar-9 (ASR-9) information. Figure 2 shows flight 587's flightpath, from takeoff to impact, in relation to the flightpath for Japan Air Lines flight 47, and figure 3 shows flight 587's flightpath overlaid on a topographical map, along with key events.

---

[18] After 0915:58.5, the rudder pedals moved briefly to 0.7 inch right and then to 3.9 inches right, where they remained for the remainder of the FDR recording. (The FDR stopped recording 13.6 seconds before impact.)

[19] The directional movements of the control wheel between 0915:51.5 and 0915:58.5 mostly paralleled those of the rudder pedals. The only control wheel movements with directions that did not parallel those of the rudder pedals occurred between 0915:53.5 and 0915:56.0, when the pedals moved to 1.7 inches right and then 2.0 inches right; the control wheel showed a right-to-left movement between 0915:53.5 and 0915:54.5 and a left-to-right movement between 0915:54.5 and 0915:55.5. Also, between 0915:51 and 0915:53.5, the rudder pedal movements lagged behind the control wheel movements by about 0.2 second; after 0915:55.5, the pedal movements lagged behind the wheel movements by 0.5 second.

[20] The rudder angle data detected by the rudder position sensor at the vertical stabilizer were filtered before they were recorded on the FDR. As a result, the rudder angles during the second set of load factor excursions had to be reconstructed using the recorded FDR data, the characteristics of the filter (as determined from a test performed during this investigation), and constraints imposed by the rudder control system and the recorded motion of the airplane. See section 1.11.2 for information about the data filter and section 1.16.2 for information about the reconstruction of rudder angles.

[21] Sideslip is the angle between the longitudinal stability axis of the airplane and the direction of motion that produces an airspeed component along the airplane's lateral axis; simply stated, sideslip is a measure of the "sideways" motion of the airplane through the air. The sideslip angle was not recorded on the FDR but was calculated using FDR parameters, including heading, roll, and pitch angles and longitudinal, lateral, and normal load factors. See section 1.16.2 for more information.

[22] Afterward, the sideslip angle continued to increase and reached 31º at the end of the FDR recording.
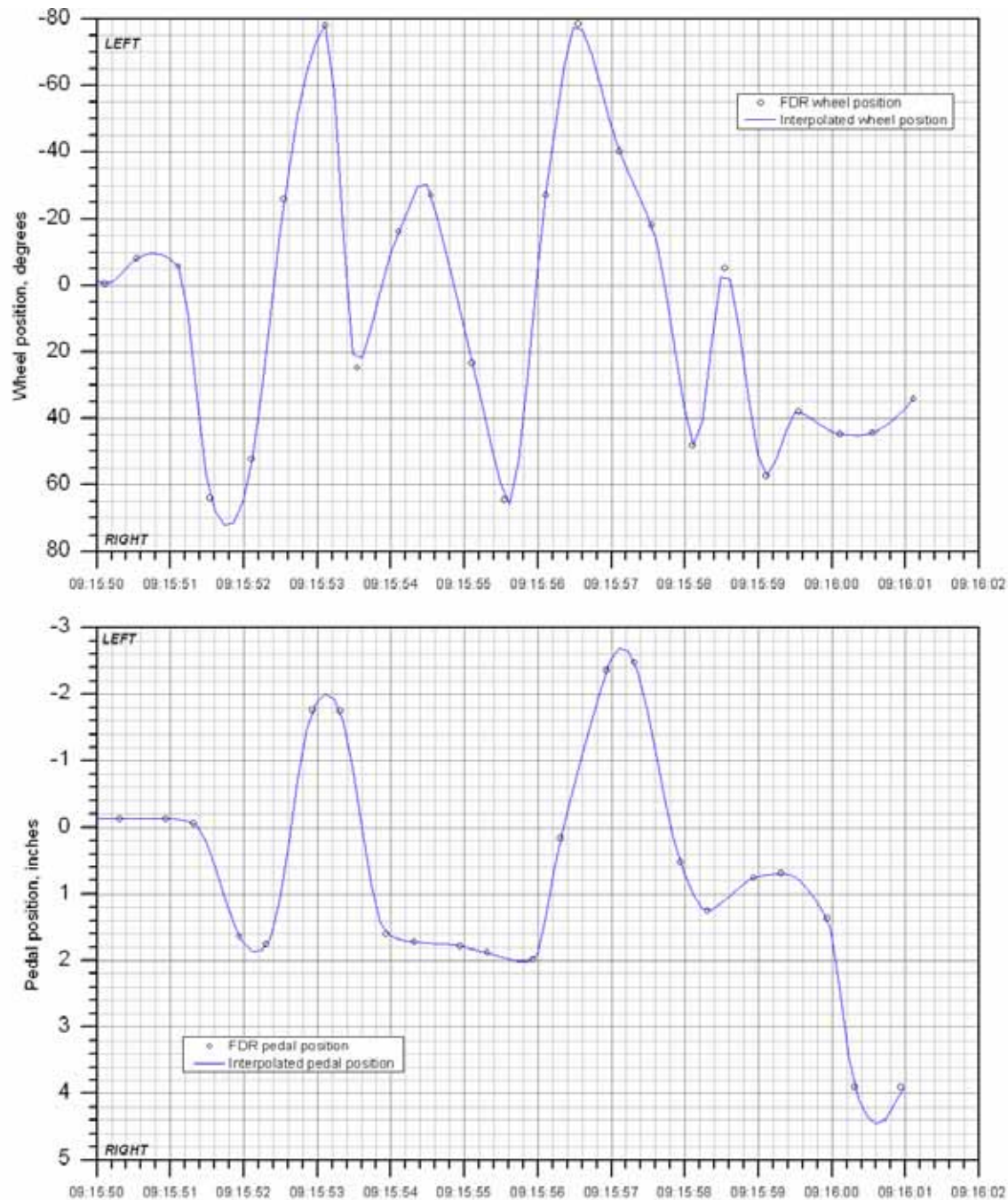
Figure 1. Control Wheel and Rudder Pedal Movements During the Second Wake Encounter

Figure 2. American Airlines Flight 587 and Japan Air Lines Flight 47 Flightpaths
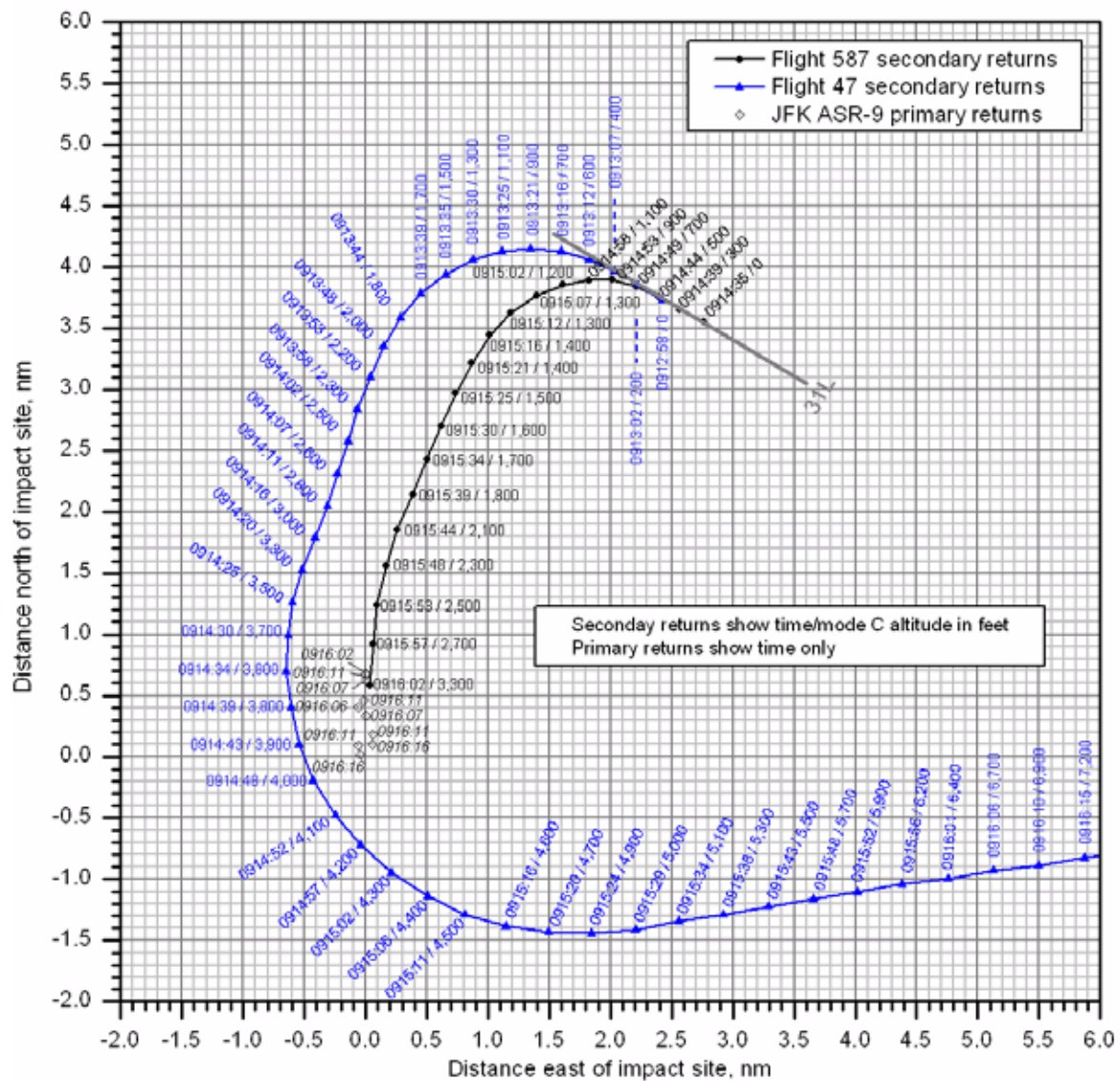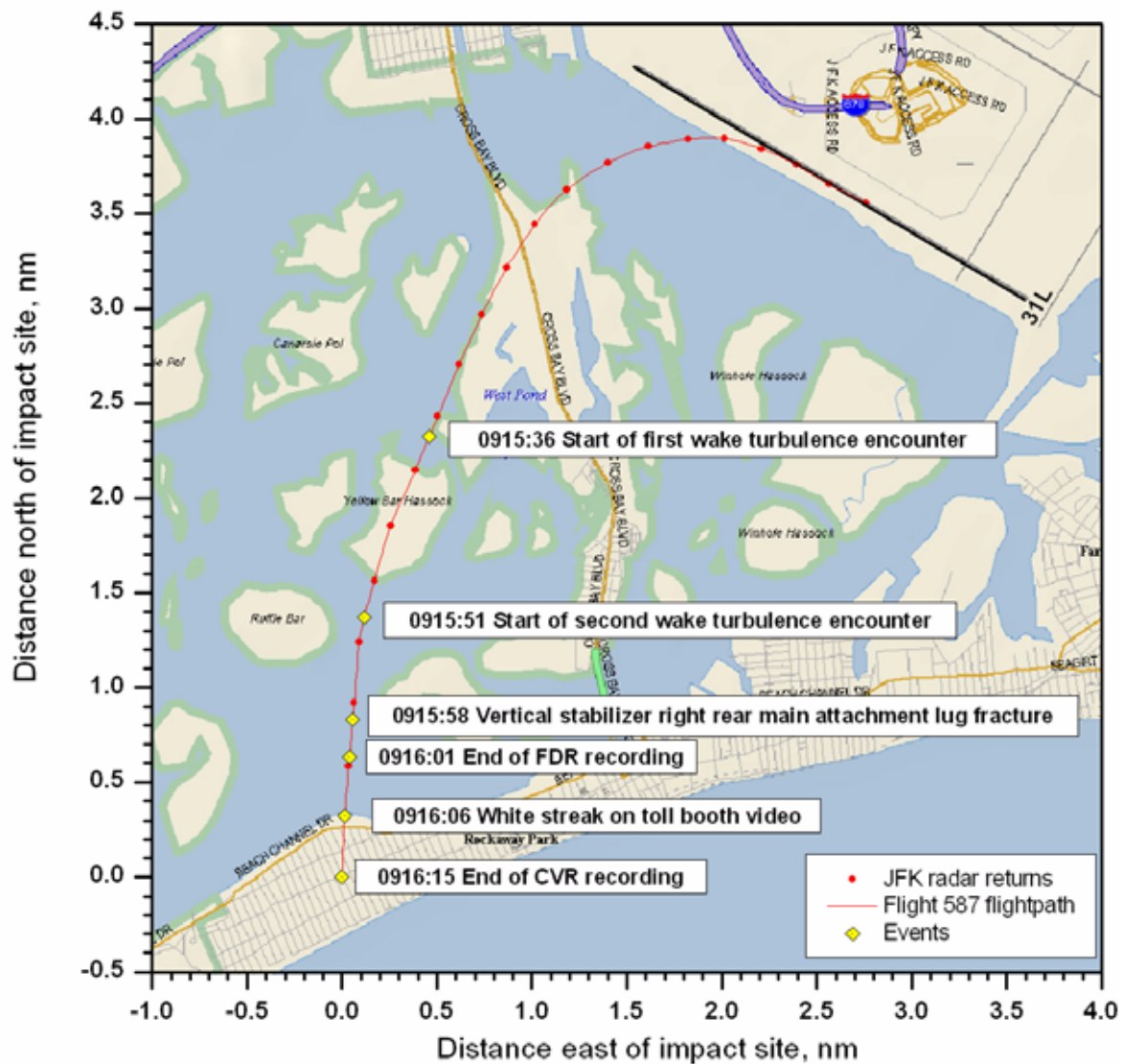
Note: The toll booth video and the white streak that appears on it are explained in section 1.16.1 of this report.

Figure 3. Flight 587's Flightpath and Key Events

1.2 Injuries to Persons

Table 1. Injury chart

Injuries	Flight Crew	Cabin Crew	Passengers	Other	Total
Fatal	2	7	251	5	265
Serious	0	0	0	0	0
Minor	0	0	0	0	0
None	0	0	0	-	0
Total	2	7	251	5	265

Note: Five fatalities occurred on the ground.

1.3 Damage to Airplane

The airplane was destroyed by impact forces and a postcrash fire.

1.4 Other Damage

In the immediate vicinity of the impact area, four homes were destroyed, three homes received substantial damage, and three homes received minor damage. In addition, the in-flight separation of the engines resulted in property damage where the engines came to rest. A gas station received minor damage as a result of the impact of the left engine, and a home and a boat (parked in the driveway) received severe damage as a result of the impact of the right engine.

1.5 Personnel Information

1.5.1 The Captain

The captain, age 42, was hired by American Airlines in July 1985. He held an airline transport pilot (ATP) certificate and a Federal Aviation Administration (FAA) first-class medical certificate dated June 5, 2001, with no limitations. The captain received a type rating on the A300[23] in September 1988 while serving as a first officer[24] and

---

[23] The A300 is designated as the A310 on pilot certificates.

[24] Title 14 CFR Section 121.543, "Flight crewmembers at controls," (b) (3) (i), states, in part, that a second-in-command can act as a pilot-in-command during the en route portion of the flight if the pilot holds an ATP certificate and an appropriate type rating, is currently qualified as pilot-in-command or second-in-command, and is qualified as pilot-in-command of that aircraft during the en route cruise portion of the flight.

received a type rating on the Boeing 727 in December 1991. He completed initial operating experience as an A300 captain in August 1998.

According to American Airlines records, the captain joined the U.S. Air Force Reserves in June 1982. He flew T-37, T-38, and C-141 airplanes while on duty and received an honorable discharge in 1992. He had accumulated 1,922 hours total flying time in military and general aviation before his employment with American Airlines.

American Airlines records also indicated that the captain had accumulated 8,050 hours total flying time,[25] including 3,448 hours as pilot-in-command and 1,723 hours as an A300 pilot-in-command. He had flown approximately 146 and 52 hours in the 90 and 30 days, respectively, before the accident. The captain's last recurrent training occurred from June 18 to 22, 2001; his last recurrent proficiency check was on June 21, 2001; and his last pilot-in-command line check occurred on July 31, 2001. FAA records indicated no accident or incident history or enforcement action, and a search of the National Driver Register database indicated no record of driver's license suspension or revocation.

According to American Airlines records, the captain had a scheduled day off on November 8, 2001. He flew a trip that started on the morning of November 9 and ended on the night of November 10. The captain had a day off on November 11. According to his wife, the captain's activities on November 11 included going to church in the morning and watching television and attending a Cub Scouts committee meeting in the afternoon. He went to sleep about 2200. On November 12, the captain awoke about 0416 and left his residence about 0500 to check in for the flight.

The captain's wife said that he was in good health and that he exercised regularly. She indicated that he consumed alcohol occasionally but abstained from alcohol within the required period before reporting for duty. The captain's wife also stated that he did not smoke, use tobacco products, or suffer from any sleep disorders. In addition, she indicated that no changes had occurred in the captain's eating or sleeping habits, off-duty activities, or financial situation in the year before the accident.

American Airlines records indicated that the captain and the first officer had flown together on 36 flight segments before the accident. The captain's wife stated that he and the first officer "got along well."

1.5.1.1 Pilot Interviews Regarding the Captain

The first officer who flew with the captain on November 9 and 10, 2001, described the captain's management style as "ideal." The first officer stated that the captain would let him fly the airplane but would not hesitate to make suggestions or offer an opinion. Another first officer who flew recently with the captain stated that he was "confident,

---

[25] This figure includes time as a captain and a first officer. The captain received a flight engineer certificate in August 1985, but American Airlines' records did not reflect the captain's flight times as a flight engineer.

respected, and able to get a point across in a nice way." A first officer who indicated that he had often flown with the captain on the 727 stated that the captain was an "extremely good pilot" who was "very relaxed and competent." This first officer also stated that he "couldn't imagine him [the captain] panicking."

1.5.2 The First Officer

The first officer, age 34, was hired by American Airlines in March 1991. He held an ATP certificate and an FAA first-class medical certificate dated October 18, 2001, with a limitation that required him to wear correcting lenses while exercising the privileges of the certificate. The first officer received a type rating on the A300 in November 1998.

According to American Airlines records, the first officer had flown Shorts 360, Beechcraft 99, and DeHavilland DHC-6 airplanes in commuter and regional operations under 14 CFR Parts 121 and 135. He had accumulated 3,220 hours total flying time in commercial and general aviation before his employment with American Airlines.

American Airlines records also indicated that the first officer had accumulated 4,403 hours total flying time,[26] including 1,835 hours as an A300 second-in-command. He had flown approximately 135 and 52 hours in the 90 and 30 days before the accident. The first officer's second-in-command qualification line check occurred on December 12, 1998; his last recurrent training occurred from December 17 to 21, 2000, and on January 5, 2001; and his last recurrent proficiency check was on December 23, 2000.[27] FAA records indicated no accident or incident history or enforcement action, and a search of the National Driver Register database indicated no record of driver's license suspension or revocation.

American Airlines records indicated that the first officer flew 1-day trip sequences on November 8 and 9 and was off duty on November 9 at 2209. He then had a 48-hour crew rest period on November 10 and 11. According to his father, the first officer's activities on November 11 included helping a friend prepare her sailboat for the winter and then going out to lunch, having friends over to his home for dinner, and speaking by telephone with his parents about 2230. A friend of the first officer's (an American Airlines flight attendant), who spoke with him by telephone earlier in the evening of November 11, indicated that he planned to go to bed between 2200 and 2300. The friend also indicated that the first officer was excited about his trip the next day because he liked the captain and enjoyed working with him. The first officer's father indicated that his son's alarm clock had been set for 0530 on the morning of the flight.

---

[26] The first officer received a flight engineer certificate in April 1990, but American Airlines' records did not reflect the first officer's flight times as a flight engineer.

[27] The first officer completed the ground school portion of the training on January 5, 2001, because the classroom presentation for human factors had been canceled (for unknown reasons) during the December 17 through 21, 2000, time period. Also, the first officer's proficiency check was not accomplished until December 23, 2000, because of mechanical problems with the simulator during the December 17 through 21, 2000, time period.

The first officer's father indicated that his son was in good health and was "very health conscious" and that no recent changes had occurred in his son's health. The first officer's father also stated that his son consumed alcohol occasionally and never used illicit drugs or tobacco products. The first officer's friend indicated that he enjoyed his flying schedule because he liked getting up early for trips and returning home the same day.

1.5.2.1 Pilot Interviews Regarding the First Officer

An American Airlines captain who flew several times with the first officer on the 727 (when they were a junior captain and junior first officer, respectively) told Safety Board investigators that, during one flight sometime in 1997,[28] the first officer had been "very aggressive" on the rudder pedals after a wake turbulence encounter. Specifically, the captain indicated that, when the airplane was at an altitude of between 1,000 and 1,500 feet, the first officer "stroked the rudder pedals 1-2-3, about that fast." The captain thought that the airplane had lost an engine and was thus focused on the engine instruments. The captain stated that he then asked the first officer what he was doing and that the first officer replied that he was "leveling the wings due to wake turbulence." The captain, who had his feet on the rudder pedals, thought that the first officer had pushed the rudder to its full stops.

The captain did not recall what type of airplane the 727 was following. He thought that the wake turbulence encounter required only aileron[29] inputs to level the wings but did not think that the first officer had made any such inputs during the encounter. The captain recalled being startled by the first officer's rudder inputs and indicated that they did not level the wings but created left and right yawing moments and heavy side loads[30] on the airplane. He further indicated that the first officer did not need to be so aggressive because the 727 was "a very stable airplane."

According to the captain, he and the first officer discussed this event later in the flight. The captain pointed out to the first officer that his use of the rudder pedals was "quite aggressive," but the first officer insisted that the American Airlines Advanced Aircraft Maneuvering Program (AAMP)[31] directed him to use the rudder pedals in that manner. The captain disagreed with the first officer and told him that the AAMP directed that the rudder was to be used at lower airspeeds. The captain told the first officer to review the AAMP when he returned home and to be less aggressive on the rudder pedals when they flew together. The captain indicated that, during a wake turbulence encounter

---

[28] American Airlines records indicated that the flight occurred during a 3-day trip sequence from August 31 to September 2, 1997.

[29] An aileron is an aerodynamic control surface that is attached to the trailing edges of each wing. The ailerons, when commanded, rotate up or down in opposite directions.

[30] Sideload is an effect of lateral acceleration that is typically the result of sideslip or yaw acceleration.

[31] According to American Airlines, AAMP is "advanced training for experienced aviators involving upsets in aircraft attitude." AAMP consists of ground school and simulator flight training. At the time of the 1997 flight, the first officer had attended AAMP ground school but had not yet attended AAMP simulator training. For more information about AAMP, see section 1.17.1.2.

on a subsequent flight, the first officer modified his wake turbulence maneuver; specifically, the first officer used the rudder during the encounter but did not push the rudder to its full stop. The captain added that the first officer was still "very quick" on the rudder.

The captain stated that he did not document or report this event at the time that it occurred. The captain further stated that he remembered the event with such clarity because he had never seen any pilot other than the first officer perform this maneuver.

The flight engineer who flew with the captain and the first officer during the 1997 trip sequence recalled that the captain and the first officer had a discussion regarding piloting skills but added that he was not part of that conversation. The flight engineer indicated that he did not recall anything remarkable (such as a yawing event associated with wake turbulence) that would have provoked the discussion. The flight engineer also indicated that the first officer did not discuss the incident with him but that the captain made a "passing comment" to him about the incident after the flight.

The flight engineer did remember a different event involving the first officer that he thought also occurred sometime in 1997. Specifically, the flight engineer and the first officer (the flying pilot) were on final approach (about 7 miles from the runway) in instrument meteorological conditions to LaGuardia International Airport, New York, when a Boeing 737 ahead of their 727 performed a go-around. The 727 encountered the wake from the 737. The flight engineer thought that the airplane rolled as a result of the wake encounter but that the bank angle did not exceed 30º. The flight engineer stated that the first officer made a "fast" decision to go around because of the wake. The first officer called for maximum power without "discussion or hesitation." The flight engineer explained that the airplane's tail went down as the nose of the airplane pitched up. The flight engineer stated that the go-around felt "weird" but that the first officer "flew the airplane to do what was necessary to keep the airplane under control." The flight engineer also stated that the event happened when the airplane was at an altitude of between 3,000 and 5,000 feet above ground level (agl) and that the airplane was not in immediate danger of ground contact. In addition, the flight engineer stated that the event was one of the more memorable ones of his career.

The captain indicated that the first officer's aggressive response to wake turbulence was out of character. Specifically, the captain described the first officer's overall flying skills as "excellent" and did not recall aggressive movements or abnormal rudder inputs during other trips with him. Also, the flight engineer stated that the first officer flew airplanes "smoothly and accurately." In addition, the Safety Board interviewed other pilots who provided similar information about the first officer's flying abilities. For example, one captain who flew with the first officer on the 727 stated that he was an "excellent" pilot who was "well above the norm." This captain also stated that he never had to question the first officer's flying ability and that he never saw the first officer fly the airplane aggressively.

1.6   Airplane Information

Airbus Industrie,[32] the manufacturer of the A300-600 airplane, is headquartered in Toulouse, France. The airplane is type-certificated for operation in the United States under 14 CFR 21.29 and a bilateral airworthiness agreement between the U.S. and French governments. (See section 1.6.4 for A300-600 certification information.)

The development of the A300 airplane began in May 1969, and the first flight of an A300 occurred in October 1972. The A300B2 and A300B4 models entered service in May 1974 and June 1975, respectively. The development of the A300-600 series airplane (a derivative of the A300B2/B4) began in December 1980, the first flight of an A300-600 occurred in July 1983, and the airplane was certificated in March 1984. Before the accident, 242 A300-600 series airplanes were in service worldwide.

The accident airplane's official designation was A300B4-605R. A review of the American Airlines air carrier certificate, which included the standards, terms, conditions, and limitations contained in the FAA-approved operations specifications, revealed no discrepancies regarding the company's operation of the A300B4-605R airplane. A review of the FAA's type certificate data sheet for the A300B4-605 airplane, which prescribes the conditions and limitations under which the airplane meets airworthiness requirements, revealed no discrepancies.

The accident airplane, N14053, serial number (S/N) 420, was delivered new to American Airlines on July 12, 1988.[33] At the time of the accident, the airplane had accumulated 37,550 flight hours and 14,934 cycles.[34] All applicable FAA airworthiness directives (AD) were accomplished on the airplane.

The airplane's weight and balance on the day of the accident were calculated according to the American Airlines takeoff performance system and the procedures in the Airbus A300-600 Flight Crew Operating Manual (FCOM). Both computations determined that the airplane's weight and balance were within limitations. The airplane departed JFK with a takeoff weight of 349,370 pounds, which was below the maximum takeoff weight limitation of 353,500 pounds, and the corresponding cg was 29.1 percent mean aerodynamic chord (MAC). The airplane had a forward limit of 20.3 percent MAC and an aft limit of 34.3 percent MAC.

---

[32] Airbus Industrie is a consortium of aerospace companies located in countries throughout Europe, including France, Germany, Great Britain, and Spain. A300-600 parts are manufactured in Airbus facilities throughout Europe, but the final assembly of the A300-600 occurs at company headquarters in Toulouse.

[33] In a final commitment letter dated July 12, 1988, Airbus indicated that "delamination and bonding failure have been found in the aircraft fin central fittings." (The terms "fin" and "vertical stabilizer" are synonymous.) A repair was performed that reinforced the defect area with additional fabric layers attached by rivets. The final commitment letter also stated, "further to the several actions and repairs accomplished, there are no further aircraft limitations."

[34] An airplane cycle is one complete takeoff and landing sequence.

1.6.1 Vertical Stabilizer and Rudder

The A300-600 vertical stabilizer and rudder were constructed with composite materials, that is, mixtures that contain two or more distinct materials that are unified into one combined material. The composite materials used in the vertical stabilizer and the rudder consisted primarily of long fibers of carbon or glass held together by an epoxy polymer. These materials are identified as carbon fiber reinforced plastics (CFRP) or glass fiber reinforced plastics (GFRP). The materials are manufactured as plies (or sheets) of fibers that are premixed with an uncured, flexible epoxy. The plies in the sheets are either oriented in one direction or are woven with fibers oriented at right angles. The plies are shaped and stacked in a mold and are then cured under heat and pressure to form a solid structure. The stiffness and strength of a structure made of composite materials depend on the number of plies and the orientation of the fibers in the plies.

The vertical stabilizer consists of a torque box, a leading edge and tip, and a trailing edge. The torque box is the main structural component. It is made from a CFRP material and has a front, center, and rear spar; left and right skin panels; 18 ribs (including top and bottom closure ribs);[35] and 24 stringers on each skin panel. The leading edge and tip are curved panels made from a GFRP material with a honeycomb core and are mechanically fastened to (but removable from) the torque box. The trailing edge panels are made from a GFRP material with a honeycomb core and are mechanically fastened to (but removable from) the trailing edge support structure, which is made of a light alloy framework that is mechanically fastened to the torque box.

The vertical stabilizer is attached to the aft fuselage by three pairs of main attachment fittings and three pairs of transverse load fittings, as shown in figure 4. All of the fittings are made from a CFRP material. The main attachment fitting pairs, which are up to 1.6 to 2.5 inches thick, are located at the bottom of the front, center, and rear spars and are integrated in the skin panels. The transverse load fittings pairs, which are up to 0.5 inch thick, are integrated in the front, center, and rear spars. Each main attachment fitting (left forward, left center, left rear, right forward, right center, right rear) has its own assembly that consists of inboard and outboard fitting halves that are bonded to the skin panels during the curing process. The fitting assemblies and skin panels have lug portions,[36] which extend below rib 1. Figure 5 shows a main attachment lug in detail.

---

[35] The ribs are numbered sequentially from bottom to top; thus, rib number 1 is the bottom closure rib, and rib number 18 is the top closure rib.

[36] The part of a fitting through which a pin passes to fasten mating parts is the lughole, and the area that immediately surrounds the lughole is the lug portion of the fitting.
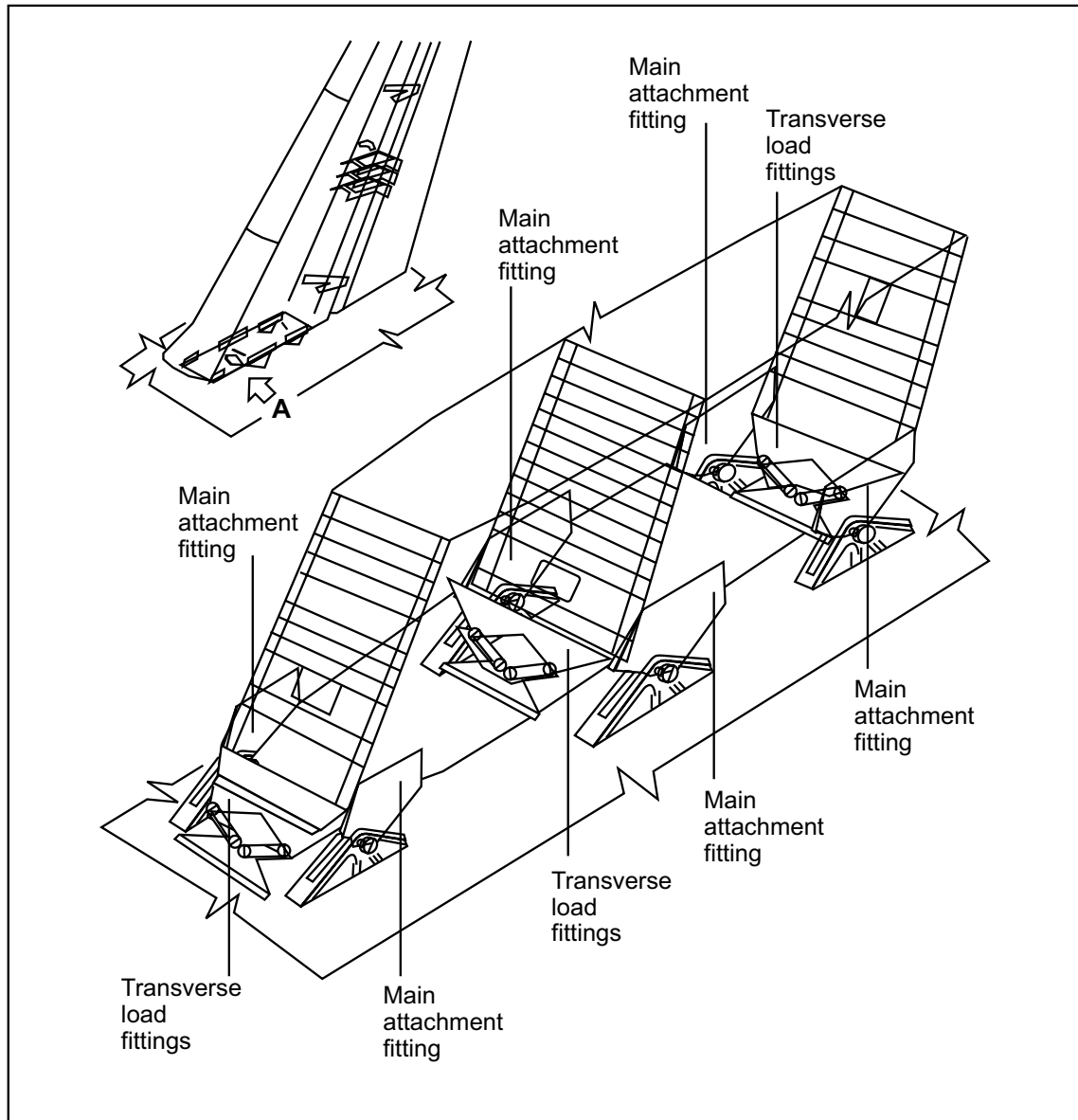
Source: Airbus

Note: Letter A in the left corner shows the location of a main attachment lug (which is shown in detail in figure 5).

Figure 4. Vertical Stabilizer-to-Aft Fuselage Attachment Points
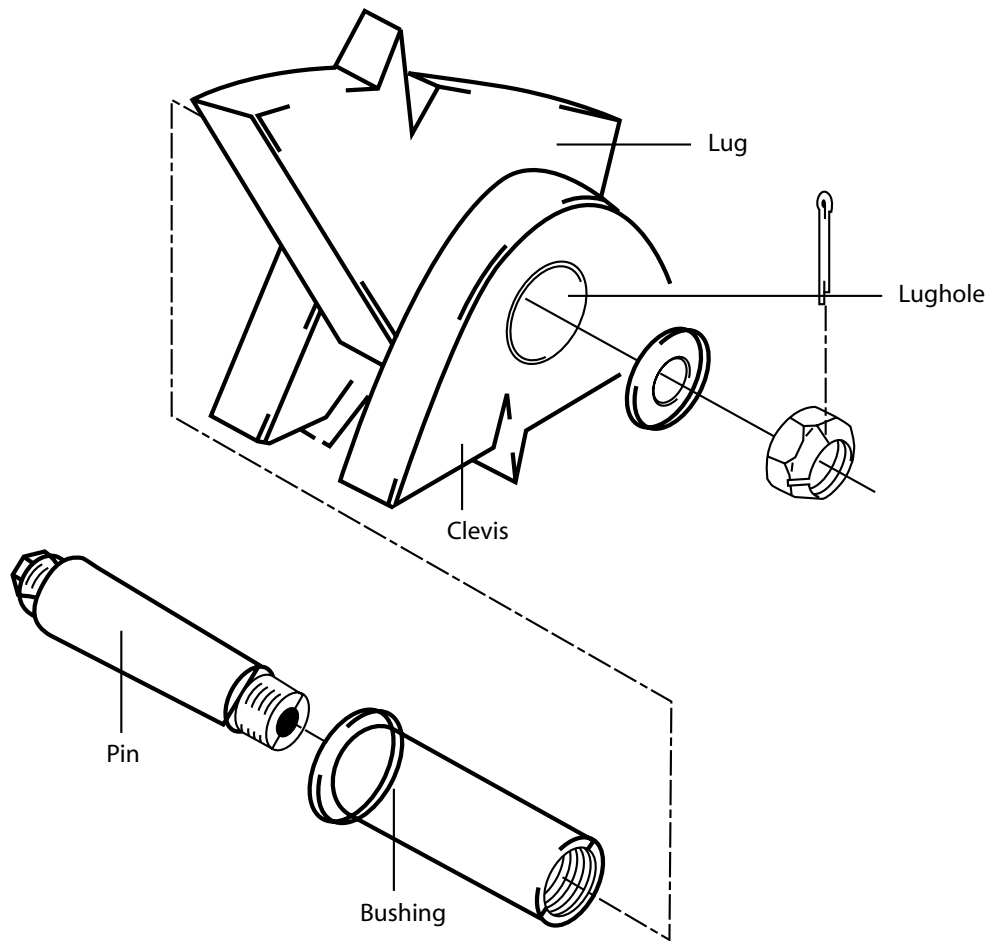
Source: Airbus

Figure 5. Main Attachment Lug

The rudder is attached to the aft portion of the vertical stabilizer and is used for controlling engine-out situations and aligning the airplane with the runway during crosswind landings. The rudder consists of the rudder torque box and rudder leading edge and tip. These parts are made from a CFRP and GFRP material over a honeycomb core. The rudder torque box, which is assembled from the left and right skin panels and the spar web, is the main structural component and has a front spar and top and bottom closure ribs. The rudder leading edge and tip are mechanically fastened to (but removable from) the rudder torque box. Three mechanically controlled hydraulic actuators, referred to as servo controls, operate the rudder. Information about the rudder control system is discussed in section 1.6.2.

The rudder is attached to the vertical stabilizer rear spar by seven hinge arm assemblies. These assemblies consist of a hinge arm, a hinge attachment fitting on the vertical stabilizer skin panels and rear spar, and a hinge attachment fitting on the rudder

skin panels and rudder front spar. Hinge arm numbers 1, 5, 6, and 7 are made from aluminum alloy, and hinge arm numbers 2, 3, and 4 are made from tubular steel. Each hinge arm has three self-aligning bearings that allow the rudder to rotate about the hinge line (that is, the axis about which the rudder rotates).[37] The vertical stabilizer hinge attachment fittings are made from a CFRP material, and the rudder hinge attachment fittings are made from aluminum. The three rudder servo controls are part of hinge arm assembly numbers 2, 3, and 4 (one per assembly) and are attached with fittings to the vertical stabilizer rear spar and the rudder front spar.

The rudder is also attached to the vertical stabilizer rear spar by a support strut assembly, which maintains vertical alignment of the rudder. This assembly consists of a support strut and a support strut attachment fitting on the vertical stabilizer skin panels and rear spar. The support strut and its attachment fitting are made of an aluminum alloy. The support strut assembly is installed above and attached to hinge arm assembly number 4.

1.6.2 Rudder Control System

The rudder control system includes (1) the rudder pedals, the rudder trim actuator, the yaw damper actuator, and the yaw autopilot actuator, which command the rudder to move; (2) pushrods, bellcranks, a tension regulator, and cables (also referred to as linkages), which transmit rudder commands; (3) three servo controls (upper, middle, and lower), which operate the rudder; (4) a rudder travel limiter system, which provides a variable stop that limits rudder pedal travel with increasing airspeeds; and (5) a differential unit, which is a mechanical device that sends the rudder servo controls a command that is the sum of a pilot or an autopilot input and a yaw damper input. The maximum rudder deflection is 30° either left or right, the maximum rate of rudder movement (with no loads) is 60° ±5° per second, and the maximum rudder pedal displacement is 4 inches.[38] The rudder control system is shown in figure 6.

Each pilot position has a pair of rudder pedals (left and right).[39] The rudder pedals are connected through pushrods and bellcranks to a cable tension regulator under the cockpit. The cable tension regulator maintains constant cable tension and transmits rod motion to two cables that run the length of the fuselage to a rudder control quadrant located aft of the pressure bulkhead and below the vertical stabilizer. The rudder control quadrant converts cable motion to bellcrank and rod movements that travel along the rear spar of the vertical stabilizer to the rudder servo controls. The rudder pedals have a 22-pound breakout force,[40] that is, the rudder pedal does not begin to move until 22 pounds of pedal force has been applied.

---

[37] The rudder hinge line lies on the 70 percent chord of the vertical stabilizer and rudder assembly and is swept back 30°.

[38] The rudder deflection limits and the rudder pedal limits decrease with increasing airspeed, as discussed later in this section.

[39] A pushrod provides a rigid connection between the pedals at one pilot position and the pedals at the other pilot position. As a result, rudder motion can only occur if one pilot solely operates the pedals or if both pilots move their pedals in the same direction.

[40] The purpose of the breakout force is to prevent any inadvertent rudder pedal input.
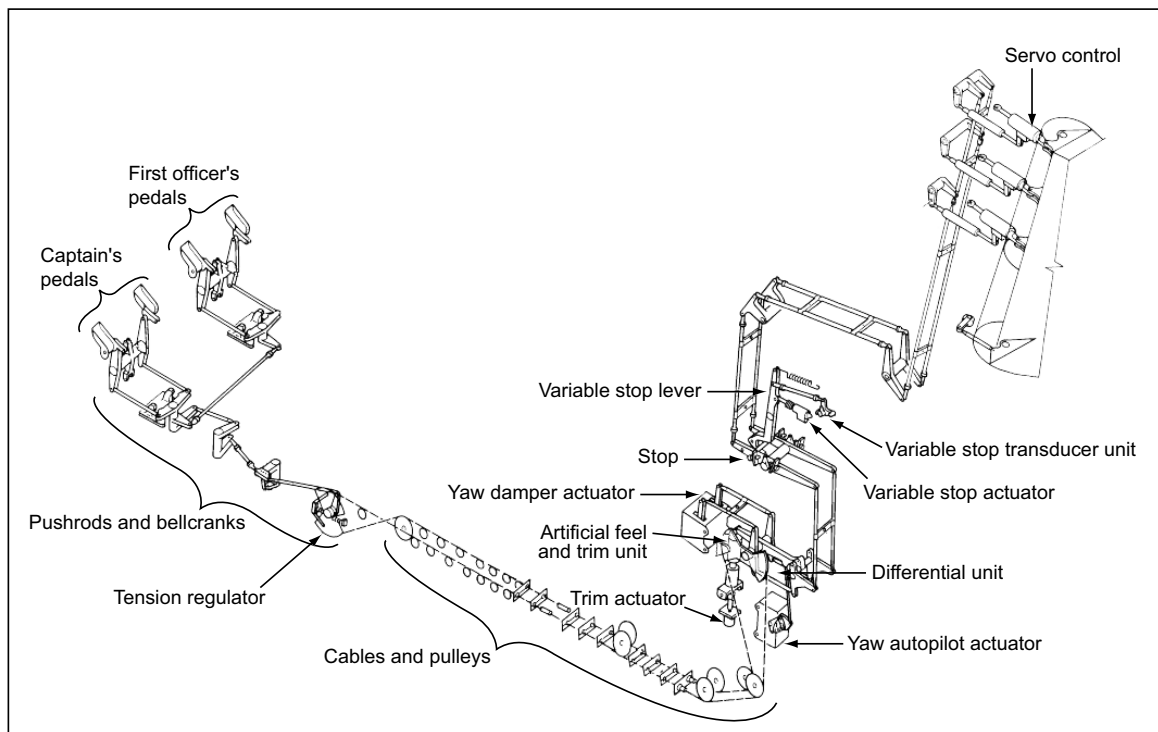
Source: Airbus

Figure 6. Rudder Control System

The rudder trim actuator implements rudder trim by adjusting the length of the artificial feel and trim unit through an internal jackscrew. The artificial feel and trim unit, which is connected through a bellcrank to the rudder control quadrant, also provides rudder pedal feel and centering forces. The artificial feel and trim unit provides force feedback to the pilot during a pedal input and a one-to-one correspondence between pedal position and pedal force. The springs in the artificial feel and trim unit provide rudder pedal force feel loads that are proportional to the rudder pedal input. The artificial feel and trim unit brings the rudder pedals and rudder deflection back to zero (assuming no trim is commanded) when all forces are released from the rudder pedals. If trim is commanded, the artificial feel and trim unit brings the pedals and rudder back to the trim position.

The yaw damper actuator is an electrohydraulic mechanism that operates the yaw damper system.[41] The yaw damper actuator has two cylinders, each of which is controlled by a flight augmentation computer. The two yaw damper cylinders have a common output axis that is connected to two output levers that lead to the differential unit. One of the yaw damper cylinders is referred to as the driving cylinder, and the other yaw damper cylinder

---

[41] The three functions of the yaw damper system are Dutch roll damping (that is, overcoming the yawing and rolling oscillations that are inherent in swept-wing airplanes), turn coordination, and engine failure compensation. Dutch roll damping is active throughout the flight envelope. Turn coordination is not active if the autopilot is engaged. Engine failure compensation is active only if the autopilot is engaged.

is referred to as the driven cylinder. The yaw damper system commands small rudder position changes to minimize the effects of yaw rate. For example, if the airplane were yawing to the left, small right rudder deflections, as commanded by the yaw damper, would tend to slow the yaw rate and minimize the yaw angle that would develop.

Yaw damper commands are limited by software in the flight augmentation computers to a maximum of 39º of rudder per second. The maximum allowable displacement of the rudder by the yaw damper for airspeeds up to 165 knots is 10º, and the maximum allowable displacement for airspeeds greater than 165 knots is determined by the formula 10 x (165/knots indicated airspeed)². The maximum displacement of the rudder by the yaw damper at an airspeed of 250 knots (the approximate airspeed of the flight 587 airplane at the time of the accident) is 4.4º. The yaw damper and the rudder pedals are not linked, so yaw damper inputs do not result in pedal motion (because such inputs can be transmitted independent of the main bellcrank).

Rudder position is determined by the sum of the rudder pedal input and the yaw damper command. However, a rudder pedal input can negate the effect of the yaw damper. Specifically, the rudder position can be held at its limit (shown in table 2 later in this section) by a continuous push of the pedal, regardless of the yaw damper command. For example, if the pedal commanded a rudder position at the limit, a yaw damper command could allow the rudder position to decrease from that limit, but pushing the pedal farther forward would cause the rudder position to again achieve the limit. Conversely, if a yaw damper command resulted in a rudder position that was greater than the limit, the system would push the pedal aft while the rudder position remained at the limit. In either case, the rudder would remain at the limit while the yaw damper commanded a left or right input and the pedals moved in the opposite direction.

The yaw autopilot actuator, which produces yaw autopilot commands,[42] is a single unit that houses two electrohydraulic actuators, each of which is controlled by a flight control computer.   The yaw autopilot actuator has an output lever that is connected through a torque limiter to the main bellcrank. The torque limiter allows a pilot to override an autopilot output as long as the pilot applies about 143 pounds more than the rudder pedal feel forces. Yaw autopilot commands are limited by software in the flight control computers to a maximum of 34º of rudder per second. The yaw autopilot actuator and the rudder pedals are rigidly linked, so a yaw autopilot input (through the main bellcrank) results in pedal motion.

The rudder travel limiter system reduces the maximum allowable rudder deflection as airspeed increases. Specifically, the system reduces the maximum rudder deflections from ±30º at speeds at and below 165 knots to ±3.5º at speeds of 395 knots and above, as shown in table 2. Rudder pedal and yaw damper commands are restricted to the limits imposed by the rudder travel limiter system.

---

[42] The yaw autopilot is active only if the slats are extended and the autopilot is engaged.

Table 2. Rudder Limits at Various Airspeeds

Airspeed (knots)	Rudder limit (degrees)
0 to 165	30
220	14.5
250	9.3
270	7
310	5
350	4
395 and above	3.5

The rudder travel limiter system is controlled by two feel and limitations computers. Each feel and limitations computer receives indicated airspeed data from two air data systems and uses the data from the system with the higher values to determine the appropriate rudder limit.[43] Feel and limitations computer number 1 is normally the active computer, and feel and limitations computer number 2 is normally the backup computer. Both feel and limitations computers are powered by a.c. electricity, but computer number 1 receives a.c. electrical power from the airplane's emergency bus. Each feel and limitations computer operates one of the motors of the variable stop actuator. Figure 7 shows the rudder travel limiter system along with the maximum rudder deflections shown in table 2.

The variable stop actuator motors are rigidly connected and are powered by a.c. electricity. The motors drive a jackscrew through a reduction gear and torque limiter to adjust the position of a variable stop lever, which limits the travel of the bellcrank that is located above the differential unit. Two transducers (one for each feel and limitations computer) indicate the position of the variable stop actuator. The transducers are connected to the variable stop lever by a pushrod. In the event that a.c. electrical power is lost, the feel and limitations computers would drive the variable stop actuator to provide full authority (that is, 30° either side of neutral) to the rudder control system.

---

[43] If one of the air data systems were to fail, then both feel and limitations computers would use indicated airspeed data from the operating air data system.
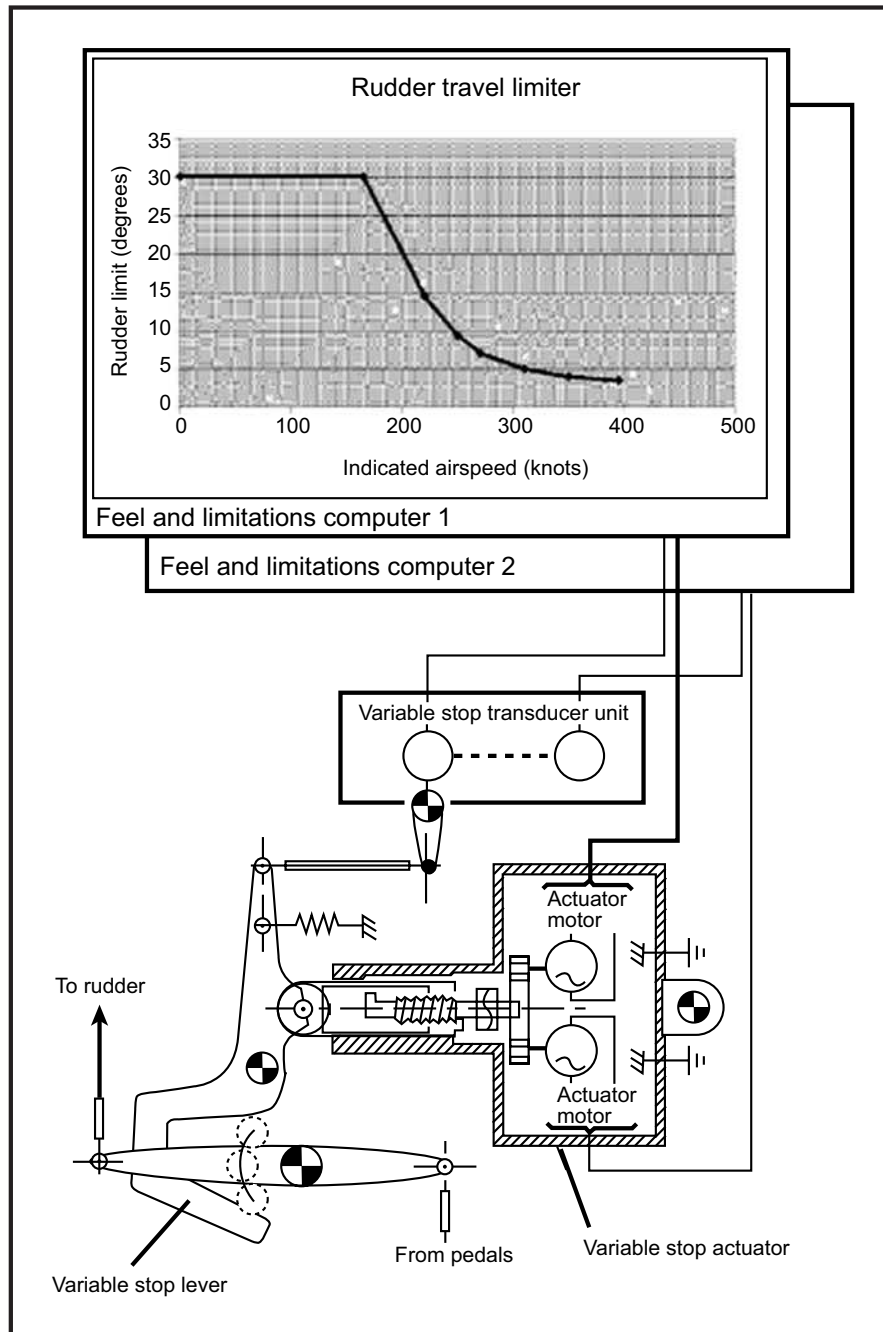
Source: Airbus

Figure 7. Rudder Travel Limiter System

The variable stop limits the rudder pedal travel as airspeed increases over 165 knots. As the pedal travel limit is reduced, the pedal force required to reach the new travel limit is also reduced. Table 3 shows the pedal force and pedal travel required to achieve the maximum deflection of the A300-600 rudder at a low airspeed (135 knots

calibrated airspeed [KCAS]) and at the approximate airspeed that the flight 587 airplane was traveling at the time of the accident (250 KCAS).

Table 3. Rudder Pedal Force Required for Full Rudder Deflection

Airspeed (KCAS)	Pedal force (pounds)	Pedal travel (inches)	Full rudder deflection (degrees)
135	65	4	30
250	32	1.2[a]	9.3

[a] This amount of pedal travel may change slightly because of the response of the yaw damper.

1.6.2.1 Public Hearing Testimony on the A300-600 Rudder Control System

At the public hearing for this accident,[44] the vice president of Airbus' flight control and hydraulic department stated that the rudder was not normally used during cruise flight to control roll.[45] The vice president of training for Airbus North America customer services stated that the ailerons and spoilers were used to control roll.[46] This Airbus vice president also stated that the rudder was used to control yaw and sideslip and that the rudder "is not a primary flight control to induce roll under any circumstances unless normal roll control is not functional." He further stated that, if pilots were to experience a roll for any reason, "they will intuitively try and counter the roll with their normal roll control. If they exhaust their normal roll control, they will then go to rudder to try and induce a roll." He added that it would be "a long path to get down to that level of degradation to where a pilot would be exposed to using rudder."

Regarding the rudder travel limiter system, American Airlines' A300 fleet standards manager[47] stated that, before the flight 587 accident, he thought that pilots knew "quite a bit" about the rudder limiter system but that, after the accident, it became apparent that pilots, as well as the aviation industry as a whole, "didn't know much about rudder

---

[44] The Safety Board held a public hearing for this accident from October 29 to November 1, 2002, in Washington, D.C. (see appendix A). The Board may hold a public hearing as part of its investigation into an accident to supplement the factual record of the investigation. The Board calls technical experts as witnesses to testify, and Board investigative staff and designated representatives from the parties to the investigation ask questions to obtain additional factual information. The hearing is not intended to analyze factual information for cause.

[45] Roll is the rotation of an airplane about its longitudinal axis.

[46] A spoiler is a device located on a wing's upper surface that, when commanded, provides increased drag and decreased lift. The A300-600 has one aileron and five spoilers on each wing.

[47] The A300 fleet standards manager has been in that position since July 2002. At the time of the accident, he was the Fokker F.100 and A300 fleet training manager.

limiter systems and in fact possibly had wrong perceptions." The A300 fleet standards manager also stated the following:

> Most pilots think that a limiter on some system will protect…the pilot from exceeding whatever parameter that limiter is limiting. And in this case…and it's not unique to Airbus aircraft…the pilots think that the rudder limiter will protect the aircraft structurally, and if it can't…they think…that there would be a limitation or a warning or caution or a note that would indicate…that the rudder limiter couldn't protect [the aircraft] structurally.

Regarding the rudder pedals, the A300 fleet standards manager stated that, before the flight 587 accident, American Airlines did not teach its pilots during training that rudder pedal movement would become restricted as airspeed increased. The fleet standards manager also stated that he did not know that the rudder pedal movement would become restricted because the pedals are not normally pushed to the stop in flight. In addition, the fleet standards manager stated that, before the flight 587 accident, he did not think that any pilot would have thought that full rudder could be gained from about 1 1/4 inch of pedal movement and 10 pounds of pressure (above the breakout force) at an airspeed of 250 knots.

1.6.2.2 Airbus Changes to the A300-600 Rudder Control System Design

In designing the A300-600 rudder control system, Airbus made two changes to the rudder control system that was used on the airplane's predecessors, the A300B2 and A300B4. First, Airbus decreased the forces required to depress the rudder pedals on the A300-600. At the public hearing, the vice president of Airbus' flight control and hydraulic department stated that pilots suggested that roll control (aileron) forces be reduced to allow for more precise piloting. As a result, Airbus decided to reduce control wheel forces by about 30 percent and to reduce rudder pedal forces to maintain consistency with control wheel forces. According to an Airbus flight control systems engineer, the reduced pedal force was achieved because (1) the springs in the A300-600 artificial feel and trim unit were different than those in the A300B2/B4 artificial feel and trim unit; (2) the A300-600's design included a variable stop actuator, whereas the A300B2/B4's design included a variable lever arm; and (3) the ratio between the pedals and the artificial feel and trim unit in the A300-600 was different than that in the A300B2/B4.

Second, Airbus changed the rudder travel limiter system on the A300-600 from a variable ratio design,[48] which was used on the A300B2/B4, to a variable stop design. Airbus indicated that the variable stop design was chosen for the A300-600 over the variable ratio design because it was less complex and had less severe failure modes.

The two changes to the A300-600's rudder control system resulted in a substantial increase in the airplane's response to a given amount of force above the pedal breakout

---

[48] The variable ratio design allows a constant range of pedal travel but reduces the amount of commanded control surface movement at higher airspeeds through an internal limiter.

force at higher airspeeds. The magnitude of the airplane's response to forces applied on the controls is a measure of the sensitivity of those controls. A more sensitive control requires less pilot force on, and less displacement of, the control to obtain a given airplane response than a less sensitive control. The sensitivity of the controls has an important influence on the handling qualities of the airplane, and a pilot's feel for the airplane is largely a matter of familiarity with the sensitivity of the controls.

The sensitivity of an airplane's pitch axis control (that is, the control column) is carefully engineered during design and is affected by certification requirements, such as the speed stability requirement contained in 14 CFR 25.173(c), which regulates the "stick force per knot" gradient required to deviate from the trim airspeed using the column. Military specifications for fighter and transport aircraft (MIL-STD-1797A, appendix A) further regulate the sensitivity of the pitch axis through specifications for "stick force per G" characteristics, which measure the amount of column force required to hold the airplane in a steady pull-up or a steady level turn at a given normal load factor. As a result of these requirements, the sensitivity of the pitch controls do not change substantially as airspeed increases.

No Federal Aviation Regulations (FAR) or military specifications are analogous to the pitch control sensitivity requirements governing the sensitivity of the pedal controls, except for the requirement in 14 CFR 25.177 that the angle of sideslip must be "substantially proportional" to the rudder angle (see section 1.6.4.4). As a result, the sensitivity of the pedals can be either relatively constant with airspeed (as it is for variable ratio systems), or it can increase significantly with airspeed (as it does for variable stop systems).

There is also no industry standard measure of rudder pedal sensitivity that is analogous to the stick-force-per-knot or stick-force-per-G measures of sensitivity in the pitch axis. Developing such an analogous measure for pedal sensitivity is difficult because the airplane response to a pedal input can quickly become very complicated, involving motion about all three axes of the airplane as the sideslip angle resulting from the initial yawing motion produces a roll, and the roll is followed by a drop in pitch and an increase in airspeed. However, if a pedal input were initiated from steady, level flight, the initial response of the airplane would be a yaw acceleration in the direction of the pedal input. This yaw acceleration would produce a lateral acceleration at the cockpit, and the more sensitive the pedals, the larger the lateral acceleration will be for a given input. Thus, a measure of pedal sensitivity that is similar to the stick-force-per-G measure of pitch sensitivity is the amount of initial lateral acceleration produced in the cockpit per pound of pedal force above the breakout force.

The sensitivity of the rudder pedals, measured in this way, is proportional to the square of the airplane's airspeed, the amount of rudder deflection per pedal deflection, and the amount of pedal deflection per pedal force. With either variable ratio or variable stop rudder control systems, the amount of pedal deflection per pedal force remains constant. For airplanes with variable ratio systems, as airspeed increases, the amount of rudder deflection per pedal deflection decreases, which offsets the effect of increasing airspeed and keeps the pedal sensitivity relatively constant. For airplanes with variable stop

systems (such as the A300-600), the rudder deflection per pedal deflection remains constant, so the sensitivity of the pedals increases with the square of the airspeed. These characteristics are illustrated in figure 8, which compares the A300-600 and A300B2/B4 rudder pedal sensitivities as a function of airspeed and shows that the A300-600 is twice as responsive to a pedal displacement at 250 knots KCAS than at 165 KCAS.
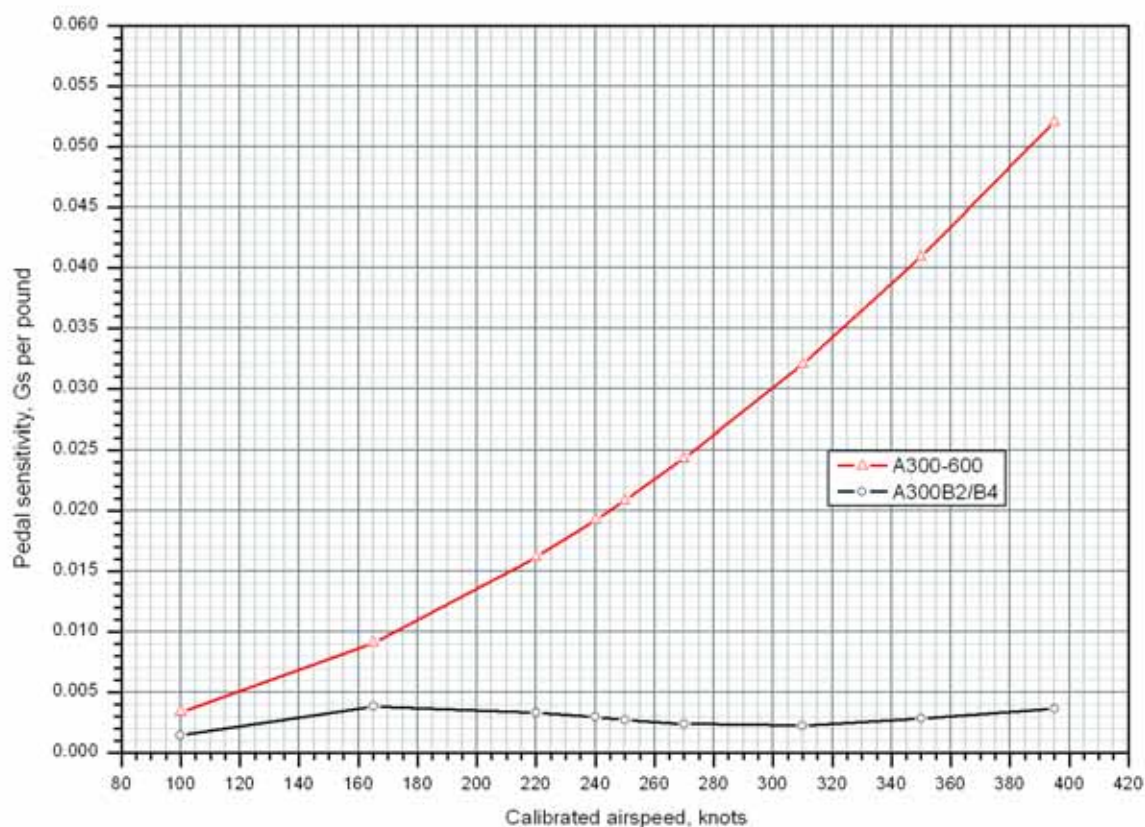
Figure 8. A300-600 and A300B2/B4 Rudder Pedal Sensitivities

1.6.2.3 A300-600 Rudder Control System Design Compared With Other Airplanes

The Safety Board compared the rudder control system design characteristics of the A300-600 with the A300B2/B4, other Airbus airplanes, and Boeing- and McDonnell Douglas-designed airplanes, as shown in table 4. Also, the Board used four metrics to quantify aspects of pedal sensitivity at 250 knots for the same airplane models, as shown in table 5. These four metrics were (1) the ratio of maximum force to breakout force, (2) the degrees of rudder commanded per pound of force above the breakout force, (3) the

pedal displacement as a percent of total displacement at low airspeed, and (4) the work involved in pushing the pedal to maximum. For the second metric (degrees of rudder commanded per pound of force above the breakout force), a higher value suggests a more sensitive rudder pedal design; for the other three metrics, a lower value suggests a more sensitive pedal design.

Table 4. A300-600 Rudder Control System Design Characteristics Compared With Those of Other Airplanes

Airplane	Breakout force (pounds)	135 knots			250 knots		
		Pedal force (pounds)	Pedal travel (inches)	Rudder deflection (degrees)	Pedal force (pounds)	Pedal travel (inches)	Rudder deflection (degrees)
Airbus-designed airplanes							
A300B2/B4	22.0	125.0	4.0	30.0	125.0	4.0	9.3
A310	22.0	65.0	4.0	30.0	32.0	1.2	9.3
A300-600	22.0	65.0	4.0	30.0	32.0	1.2	9.3
A320	21.3	80.0	4.0	30.0	36.0	1.1	8.3
A330-300	32.0	80.5	4.0	30.0	45.0	1.2	9.5
A340-300	32.0	80.5	4.0	30.0	45.0	1.2	9.5
Boeing-designed airplanes							
707	[a]	70.0	2.3	24.0	100.0	1.3	9.0
727	17.0	80.0	3.0	18.0	50.0	1.3	7.0
737	15.0	70.0	2.8	18.0	50.0	1.0	4.0
747	19.0	80.0	4.0	30.0	80.0	4.0	12.0
757	16.0	80.0	4.0	26.0	80.0	4.0	6.0
767	17.0	80.0	3.6	26.0	80.0	3.6	8.0
777	18.0	60.0	2.9	27.0	60.0	2.9	9.0
McDonnell Douglas-designed airplanes							
DC-8	[a]	85.0	3.6	32.0	65.0	1.5	13.0
DC-9	16.0	75.0	2.6	22.0	60.0	1.1	8.0
MD-80	15.0	75.0	2.6	22.0	60.0	1.1	8.0
MD-90	20.0	75.0	3.3	29.0	65.0	1.6	13.0
DC-10	10.0	80.0	3.8	23.0	65.0	2.0	14.0

Airplane	Breakout force (pounds)	135 knots			250 knots		
		Pedal force (pounds)	Pedal travel (inches)	Rudder deflection (degrees)	Pedal force (pounds)	Pedal travel (inches)	Rudder deflection (degrees)
McDonnell Douglas-designed airplanes							
MD-11	10.0	80.0	3.8	23.0	65.0	2.2	15.0
717	20.0	75.0	3.3	29.0	65.0	1.6	13.0

[a] These data were not supplied to the Safety Board.

Table 5. Metrics Used to Compare Rudder Pedal Sensitivity at 250 Knots

Airplane	System	Metric of rudder pedal sensitivity			
		Ratio of maximum force to breakout force[a]	Rudder commanded (degrees) per pound of force above the breakout force	Pedal displacement as a percent of total displacement	Work involved (pound inches) in pushing the pedal to maximum
Airbus-designed airplanes					
A300B2/B4	Variable ratio	4.68	0.09	100	294
A310	Variable stop	1.45	0.93	30	32
A300-600	Variable stop	1.45	0.93	30	32
A320	Variable stop	1.69	0.56	28	32
A330	Variable stop	1.41	0.73	31	48
A340	Variable stop	1.41	0.73	31	48
Boeing-designed airplanes					
707	Force limit[b]	[c]	[c]	57	[c]
727	Force limit	2.94	0.21	43	44
737	Force limit	3.33	0.11	36	33
747	Variable ratio	4.21	0.20	100	198
757	Variable ratio	5.00	0.09	100	192
767	Variable ratio	4.71	0.13	100	175
777	Variable ratio	3.33	0.21	100	113

		Metric of rudder pedal sensitivity			
Airplane	**System**	**Ratio of maximum force to breakout force**[a]	**Rudder commanded (degrees) per pound of force above the breakout force**	**Pedal displacement as a percent of total displacement**	**Work involved (pound inches) in pushing the pedal to maximum**
McDonnell Douglas-designed airplanes					
DC-8	Force limit	c	c	42	c
DC-9	Variable stop	3.75	0.18	42	42
MD-80	Variable stop	4.00	0.18	42	41
MD-90	Variable stop	3.25	0.29	48	68
DC-10	Force limit	6.50	0.26	53	75
MD-11	Force limit	6.50	0.27	58	83
717	Variable stop	3.25	0.29	48	68

Note: These metrics are not provided for the 135-knot airspeed (which was shown in table 4) because rudder control characteristics at that airspeed are relatively similar among all transport-category airplanes.

[a] This number was achieved by dividing the maximum pedal force by the breakout force.

[b] In the force limit design (also referred to as a blowdown limited design), the pedal displacement reduces with airspeed, but the hydraulic power available to move the rudder is limited and cannot overcome high vertical stabilizer aerodynamic loads, even with a pilot-commanded rudder input. Because this design adds an extra safety feature to prevent high vertical stabilizer loads, the pedal sensitivity measures may not be directly comparable with the other two rudder pedal designs.

[c] Because the Safety Board did not receive breakout force data for these airplanes, the Board was unable to make these computations.

1.6.3 Powerplants

The accident airplane was equipped with two General Electric CF6-80C2A5 engines. The left (number 1) engine, S/N 695-211, was installed on the accident airplane on August 13, 2001, and had accumulated 31,112 hours and 12,282 cycles since new, 2,887 hours and 1,072 cycles since overhaul, and 694 hours and 264 cycles since installation. The right (number 2) engine, S/N 690-280, was installed on the accident airplane on July 30, 1998, and had accumulated 25,131 hours and 13,216 cycles since new, 11,658 hours and 5,421 cycles since overhaul, and 2,618 hours and 1,229 cycles since installation.

The engine condition monitoring data from October 31 to November 11, 2001, for both engines showed no abnormal shifts in N1 and N2 rpm,[49] exhaust gas temperature, fuel flow, vibration, oil temperature, and oil pressure. The engine takeoff performance data for the accident flight and for the nine previous flights showed that neither engine exceeded any of the operating limits for N1 and N2 rpm, exhaust gas temperature, fuel

---

[49] N1 is the low pressure rotor speed; N2 is the high pressure rotor speed.

flow, N1 and N2 vibration, oil temperature, and oil pressure. Also, the engine performance data for the flight that preceded flight 587 in the accident airplane indicated that the takeoff was at maximum engine power.[50]

The accident airplane was also equipped with an AlliedSignal (Honeywell) GTCP331-250H auxiliary power unit (APU), S/N P-1077. The APU is mounted in the aft fuselage and consists of three main components: the power section, the load compressor, and the accessory gearbox. The power section has a two-stage centrifugal compressor driven by a three-stage axial flow turbine that is governed by a fuel control unit and an electronic control box. The load compressor has a single-stage centrifugal compressor that is directly driven by the power section and provides bleed air to the airplane's pneumatic system. The accessory gearbox is directly driven by the power section and carries the fuel control unit, a.c. generator, cooling air fan, and starter motor. The accident APU was installed in the accident airplane on September 20, 2001, and had accumulated 19,723 hours and 12,104 cycles since new and 426 hours and 215 cycles since installation.

1.6.4 Airplane Certification

As previously stated, the A300-600 is type certificated for operation in the United States under 14 CFR 21.29 and a bilateral airworthiness agreement between the U.S. and French governments. According to the FAA, a bilateral agreement is reached after a foreign authority establishes a demonstrated level of competency and the ability to interpret and comply with U.S. airworthiness regulations. To achieve this agreement, the foreign authority first submits an application and information on the airplane to the FAA, which then determines whether the airplane has any unique features or unusual characteristics. Afterward, the FAA determines the extent that it wants to participate in the foreign certification. For airplanes that are a model change from an airplane that has already been evaluated and has a satisfactory service history, and for which the foreign certification authority is believed to be capable of evaluating the airplane according to U.S. regulations, the FAA accepts the foreign certification authority's findings of compliance.

At the public hearing, an FAA airframe engineer stated that the FAA did not make findings of compliance for the A300-600 because it was a derivative of the A310 airplane but that the FAA made findings of compliance for several areas on the A310.[51] For example, the FAA made findings of compliance on the design and strength of the A310 vertical stabilizer, which is structurally identical to the A300-600 vertical stabilizer. The FAA also worked closely with Airbus and European airworthiness agencies to establish certification and test programs for the A310 vertical stabilizer.

---

[50] Depending on airplane weight, runway length, and weather conditions, an airplane may take off with less than maximum engine power. The use of reduced engine power for takeoff decreases the deterioration of an engine, thus permitting it to remain in service longer. An airplane must make a maximum engine power takeoff within a specified number of days to demonstrate that its engines are capable of attaining maximum engine power.

[51] A310 development began in July 1978, and the A310's first test flight was in April 1982.

The loads certification for the A300-600 vertical stabilizer is discussed in section 1.6.4.1. The design loads for the vertical stabilizer are discussed in section 1.6.4.2. For information on the structures certification basis of the vertical stabilizer, see the public docket for this accident.

1.6.4.1 Loads Certification for the Vertical Stabilizer

1.6.4.1.1 Federal Aviation Regulations

Airbus airplanes are designed and certificated according to the requirements of 14 CFR Part 25, "Airworthiness Standards: Transport-Category Airplanes." The loads and structures certification basis for the A300-600 vertical stabilizer were Subpart C, "Structure," and Subpart D, "Design and Construction," Amendments 1 through 44, in Part 25.[52]

Section 25.301, "Loads," was at amendment level 23 (enacted in May 1970) at the time that the A300-600 was certificated (March 1984). However, Airbus asked (and the European certification authorities agreed) to apply the original 1965 version of this regulation, which was in effect at the time of the original A300B2 type certificate application date. The FAA accepted the regulation's original 1965 language as part of the A300-600's certification basis; thus, Airbus was not required to comply with amendment level 23 for the regulation.

The original 1965 Section 25.301 language stated the following:

(a) Strength requirements are specified in terms of limit loads (the maximum loads to be expected in service) and ultimate loads (limit loads multiplied by prescribed factors of safety).[53] Unless otherwise provided, prescribed loads are limit loads.

(b) Unless otherwise provided, the specified air, ground, and water loads must be placed in equilibrium with inertia forces, considering each item of mass in the airplane. These loads must be distributed to conservatively approximate or closely represent actual conditions.

(c) If deflections under load would significantly change the distribution of external or internal loads, this redistribution must be taken into account.

Amendment 23 added the following sentence to Section 25.301(b): "Methods used to determine load intensities and distribution must be validated by flight load

---

[52] The applicable FARs appear in an Airbus document titled *A310, A300-600, A300-600R airworthiness requirements* (AI/V-C 600/78, Issue 9, November 1994), which can be found in the public docket for this accident.

[53] In public hearing testimony, the FAA airframe engineer stated that an airplane was expected to experience limit load once in its lifetime and that an airplane was never expected to experience ultimate load.

measurement unless the methods used for determining those loading conditions are shown to be reliable."

Section 25.303, "Factor of safety," was at amendment level 44 (enacted in December 1978) at the time that the A300-600 was certified. This section stated the following:

> Unless otherwise specified, a factor of safety of 1.5 must be applied to the prescribed limit load which are considered external loads on the structure. When a loading condition is prescribed in terms of ultimate loads, a factor of safety need not be applied unless otherwise specified.

Section 25.305, "Strength and deformation," was at amendment level 23 at the time that the A300-600 was certified. However, Airbus asked (and the European certification authorities agreed) to apply the original 1965 version of this regulation, which stated the following:

> (a) The structure must be able to support limit loads without detrimental permanent deformation. At any load up to limit loads, the deformation may not interfere with safe operation.

> (b) The structure must be able to support ultimate loads without failure for at least 3 seconds. However, when proof of strength is shown by dynamic tests simulating actual load conditions, the 3-second limit does not apply. Static tests conducted to ultimate load must include the ultimate deflections and ultimate deformation induced by the loading. When analytical methods are used to show compliance with the ultimate load strength requirements, it must be shown that—

> (1) The effects of deformation are not significant;

> (2) The deformations involved are fully accounted for in the analysis; or

> (3) The methods and assumptions used are sufficient to cover the effects of these deformations.

> (c) Where structural flexibility is such that any rate of load application likely to occur in the operating conditions might produce transient stresses appreciably higher than those corresponding to static loads, the effects of this rate of application must be considered.

Amendment 23 added Section 25.305(d), which stated, "the dynamic response of the airplane to vertical and lateral continuous turbulence must be taken into account."

Section 25.351, "Yawing Conditions," was at amendment level 44 at the time that the A300-600 was certified. This section stated the following:

> The airplane must be designed for loads resulting from the conditions specified in paragraphs (a) and (b) of this section. Unbalanced aerodynamic moments about

the center of gravity must be reacted in a rational or conservative manner considering the principal masses furnishing the reacting inertia forces:

    (a) *Maneuvering*. At speeds from V_{MC} [minimum control speed] to V_A [design maneuvering speed], the following maneuvers must be considered. In computing the tail loads,[54] the yawing velocity may be assumed to be zero:

        (1) With the airplane in unaccelerated flight at zero yaw, it is assumed that the rudder control is suddenly displaced to the maximum deflection, as limited by the control stops, or by a 300 lb. rudder pedal force, whichever is less.

        (2) With the rudder deflected as specified in subparagraph (1) of this paragraph, it is assumed that the airplane yaws to the resulting sideslip angle.

        (3) With the airplane yawed to the static sideslip angle corresponding to the rudder deflection specified in subparagraph (1) of this paragraph, it is assumed that the rudder is returned to neutral.

    (b) *Lateral gusts*. The airplane is assumed to encounter derived gusts normal to the plane of symmetry while in unaccelerated flight. The derived gusts and airplane speeds corresponding to conditions B' through J' (in § 25.333(c)) (as determined by §§ 25.341 and 25.345 (a)(2) or 25.345 (c)(2)) must be investigated. The shape of the gust must be as specified in § 25.341. In the absence of a rational investigation of the airplane's response to a gust, the gust loading on the vertical tail surface must be computed [according to a specific equation].[55]

Section 25.351(a) does not require a return of the rudder from the overswing sideslip angle to neutral or a full rudder movement in one direction followed by a movement in the opposite direction.

At the public hearing on this accident, an Airbus senior specialist in composites testified that the design of the A300-600 vertical stabilizer met or exceeded all U.S. certification standards. He also stated that the certification of the composite structure has been validated by more than 40 million flight hours by Airbus airplanes.

1.6.4.1.2 Public Hearing Testimony on Section 25.351

The FAA's chief scientific and technical advisor for loads and aeroelasticity explained that Section 25.351(a) defines a single maneuver that encompasses a few points that are of special interest to loads. The maneuver is performed at wings level and is not coupled with roll, although some sideways motion of the airplane will occur. He stated that the maneuver is performed as follows: A pilot makes and holds a rapid, sudden, full

---

[54] The terms "vertical tail" and "vertical stabilizer" are synonymous.

[55] For details on the FAR sections and the specific equation for computing the gust loading on the vertical stabilizer surface, see Airbus' document, *A310, A300-600, A300-600R airworthiness requirements*, in the public docket for this accident.

rudder control input up to a maximum of 300 pounds at any speed between V_{MC} and V_A.[56] The airplane yaws sideways; the rolling motion is held by the ailerons, and, as the rudder is held, the sideslip builds dynamically to a peak value before settling down to a final steady-state value. Afterward, the pilot suddenly returns the rudder to neutral. The peak sideslip value, referred to as the overswing sideslip value, is typically about 1.5 to 1.6 times the steady-state value.

The loads and dynamics manager at Airbus stated that Airbus analyzed the yawing maneuver in accordance with Section 25.351(a). He indicated that, at overswing sideslip, the loads on the vertical stabilizer induced by the rudder are opposite from those induced by the sideslip. He also indicated that, when the rudder is returned from steady sideslip to neutral, the loads on the vertical stabilizer are only those induced by sideslip.

The FAA's chief scientific and technical advisor for loads and aeroelasticity stated that, if the rudder were returned to its neutral position at the point of overswing sideslip, the aerodynamic loading on the vertical stabilizer would increase. The local domain manager for loads and aeroelasticity at Airbus indicated that a return of the rudder from the overswing sideslip angle to neutral or a full rudder movement in one direction followed by a movement in the opposite direction would result in external loads that were "a little bit higher" than those that were developed using the current regulation.

The FAA airframe engineer stated that, since the 1953 implementation of Civil Aeronautics Regulation 4B (the predecessor to the FAR that described the maneuvering conditions for the design of the vertical stabilizer), no historical evidence would lead the FAA to believe that the design loads envelope for the vertical stabilizer was inadequate. The airframe engineer stated that a maneuver with alternating rudder inputs was an extreme maneuver and that, if the maneuver were performed, loads would build that would exceed the current requirements. He further stated that, if two sets of alternating rudder inputs were performed, a series of dynamic maneuvers would start that could be benign or "could lead the airplane into a severe dynamic situation where, at the proper frequency, this continued application of this surface would allow the motion of the airplane to build up to the point where the sideslip would become excessive and overload the airplane."

According to the FAA's chief scientific and technical advisor for loads and aeroelasticity, the gust event in FAR 25.351(b) is not an instantaneous condition. He stated that the airplane traverses a gust and that the gust intensity builds initially from zero to a maximum in the time it takes the airplane to travel a distance equal to 12.5 mean geometric chord lengths of the wing. Afterward, the gust velocity decreases back to zero as the airplane again travels a distance equal to 12.5 mean geometric chord lengths of the wing. The equation in Section 25.351(b) provides a means for estimating the peak load occurring during this event. The peak gust loads are examined at V_C, the design cruising speed (the nominal case); V_B, the design speed for maximum gust intensity (a lower speed

---

[56] Even though Section 25.351(a) states that yaw maneuvers must be analyzed for all speeds between V_{MC} and V_A, an additional requirement (discussed in section 1.6.4.1.3), states that yaw maneuvers must be analyzed for all speeds up to V_D, the design diving speed.

than V_C, but a higher gust velocity is assumed); and V_D, the design diving speed (a speed that is outside the normal operating envelope, but a reduced gust velocity is assumed).

1.6.4.1.3 Complementary Conditions

The French and the German civil aviation authorities—the Direction Général de l'Aviation Civile (DGAC) and the Luftfahrt-Bundesamt (commonly referred to as the LBA), respectively—established complementary conditions (CC) to be addressed during airplane design and certification. These conditions are requirements in addition to those in the FARs.

CC5-1, "Design Manoeuvre Condition, A—General," requires the following in addition to Section 25.331(a):

> The manufacturer will carry out a rational analysis of the specified manoeuvres taking into account the effects of flexibility. Under no circumstances is it necessary for the speed of deflection of the control surfaces to exceed the maximum speed permitted by the servo controls, with control surfaces under appropriate aerodynamic load.

CC5-1, "Design Manoeuvre Condition, C—Yaw Manoeuvre," requires the following in addition to Section 25.351(a):

> The deflection of the control surfaces should correspond to the smallest angle corresponding to
>
> Maximum travel compatible with the stops
>
> Maximum power of the servo controls
>
> Maximum pilot effort of 300 lbs
>
> Yaw manoeuvres must be analysed for all speeds between V_{MC} and V_D

CC6, "Design Gust Condition," requires the following in addition to Section 25.341(a): "the values for gust speeds…also apply for the recommended speed in turbulent air shown in the flight manual." Also, CC6 requires the following in addition to Section 25.341(c) and 25.351:

> the following method [for calculating the gust loading on the vertical stabilizer surfaces] may be applied at the request of the certification authorities: taking into account the aeroelastic and dynamic effects of flexibility, the most unfavourable response of the flexible aircraft will be calculated for an isolated gust.[57]

---

[57] The equation for making this calculation is included in the public docket for this accident.

Last, CC6 requires the following in addition to Section 25.305: "a study of the behaviour of the aircraft in continuous turbulence should be made."

At the time of the A300-600 certification, the European airworthiness authorities, especially the British Civil Aviation Authority, asked for a "tuning" of the discrete gust event described in Section 25.351(b), that is, a variation of gust length, with a fully flexible airplane (which deforms dynamically). At the public hearing for this accident, the FAA's chief scientific and technical advisor for loads and aeroelasticity testified that, even though CC6 was not in effect at the time that the A300-600 was certificated, Airbus elected to use a "discrete tuned gust model" to show compliance with the conditions described in CC6.

Airbus' discrete tuned gust model was based on the discrete gust model described in Section 25.351(b), which had a fixed gust gradient of 12.5 times the mean geometrical chord. According to the FAA's chief scientific and technical advisor for loads and aeroelasticity, the discrete tuned gust model employed a calculation procedure that determined the actual loads at all times during the gust event, from which the peak load could be extracted. Such a model was necessary to fully account for the aeroelasticity and the dynamic effect of flexibility. The gust to be considered had the same profile as that defined in Section 25.351(b), but, instead of being limited to a fixed gust gradient of 12.5 times the mean geometrical chord, it was allowed to vary within a specified range. For A300-600 series airplanes, the gust gradient varied between 7 and 18 times the mean geometric chord using the same gust velocities prescribed in Section 25.341.

The FAA's chief scientific and technical advisor for loads and aeroelasticity and the FAA airframe engineer testified that CC5-1 and CC6 exceeded the FAA requirements in place at the time that the A300-600 was certificated.

1.6.4.2 Design Loads for the Vertical Stabilizer

Airbus established vertical stabilizer loads for specific conditions, as defined by the applicable airworthiness requirements in 14 CFR Part 25. These conditions were the yawing maneuver that results from rudder displacement conditions; an engine failure (the loss of thrust) and the associated pilot corrective action; potential systems failures, in particular, flight control systems; and atmospheric anomalies (for example, a lateral gust).

Airbus performed a loads assessment of the A300-600 using a theoretical model that involved aerodynamic, mass, structural stiffness, engine, and systems data. The model was validated by data generated during ground and flight tests. With the use of this model, airplane movements resulting from yawing maneuvers, gusts, and engine failures were simulated, and the associated internal forces induced by the external aerodynamic and mass inertial loadings (the net external loading) on the vertical stabilizer were calculated. These internal forces are transmitted to the fuselage through the six main attachment fittings and the six transverse load fittings. The internal forces within each lug are characterized by the local stress (force per unit area of material), which can be compared directly with measured material strength values.

The external aerodynamic and mass inertial loadings on the vertical stabilizer can also be quantified as a net shear (a side load), a net bending (a moment about the longitudinal axis), and a net torsion (a moment about the vertical axis), as shown in figure 9. The correlated shear force diagram, which is used to define the limit and the ultimate load design envelopes, consists of one diagram plotting net shear versus net torsion and, as shown in figure 10, one diagram plotting net torsion versus net bending.[58]
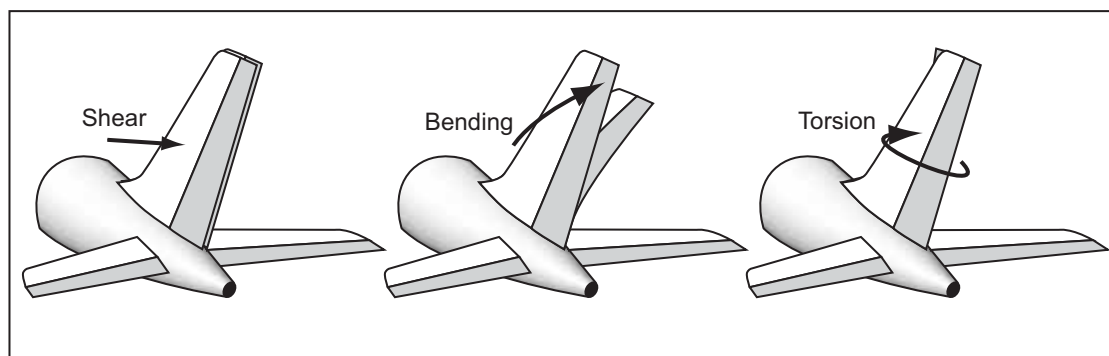
Figure 9. Shear, Bending, and Torsion
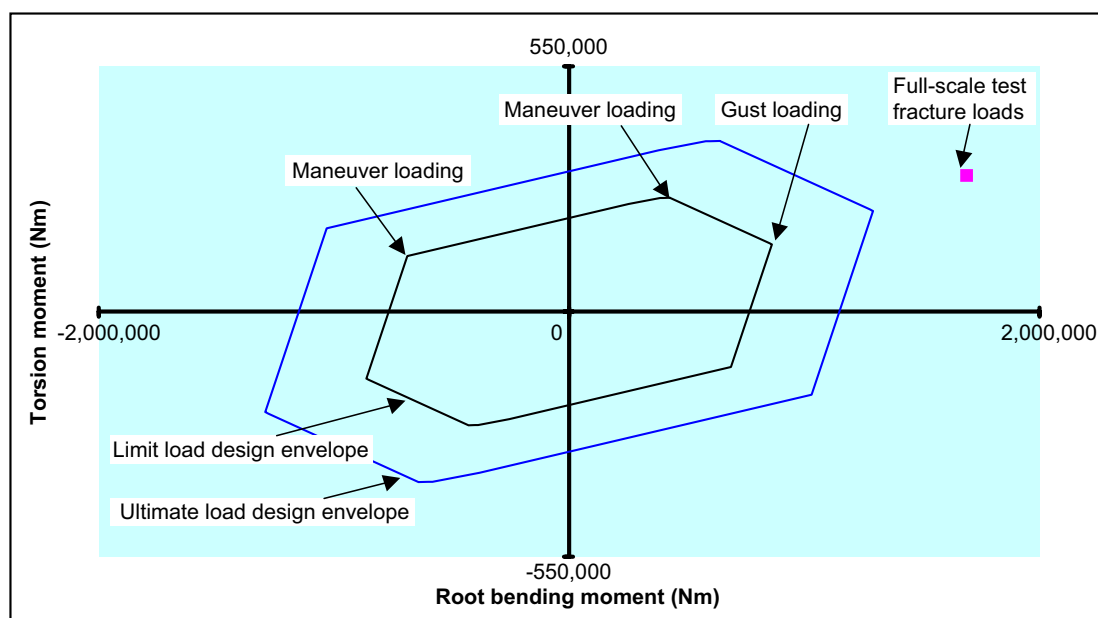
Figure 10. Net Torsion Versus Net Bending

---

[58] Any design condition can be located as a point on the correlated shear force diagram.

During the design and certification process, Airbus considered all of the critical loading conditions that formed the vertical stabilizer's design load envelope. The lateral gust condition produced the largest bending moment at the root (the location where the vertical stabilizer attaches to the aft fuselage) compared with the other critical loading conditions and produced the critical margins of safety[59] for the rear main attachment fittings; as a result, the rear main attachment fittings were designed by the lateral gust condition. The gust condition also produced the critical margins of safety for portions of the skin panels and several internal ribs. (Other parts of the vertical stabilizer had their lowest margins of safety produced by different conditions.) Airbus conducted a full-scale structural test during certification to demonstrate that the vertical stabilizer could withstand limit and ultimate loads and to validate the analysis tools and methodology that were used in designing the vertical stabilizer. Section 1.6.4.3 provides details about this test.

1.6.4.3 Vertical Stabilizer Certification Tests

In 1986, Airbus performed a full-scale static structural test of the entire A310-300 vertical stabilizer. (As stated previously, the A310 vertical stabilizer is structurally identical to that of the A300-600, but the A310-300 vertical stabilizer has higher design loads.) The test was performed with the vertical stabilizer attached to a laboratory fixture and not an airplane fuselage. The aerodynamic loading for the lateral gust and yaw maneuver conditions was simulated by applying loads to the left side of the vertical stabilizer and to the fuselage clevises. The tests were conducted in hot and wet conditions to capture environmental effects that could degrade the performance of composite materials.[60]

Airbus certification documents showed that, for the lateral gust and yaw maneuver conditions, the A310-300 vertical stabilizer withstood loads up to limit load without permanent deformation and loads up to ultimate load for 3 seconds. The documents also showed that the vertical stabilizer was loaded to about two times the design limit load for the lateral gust condition, as shown in table 6, before the left rear main attachment lug

---

[59] Airbus used the stresses calculated for limit and ultimate loads, along with measured material strength values, to compute the margins of safety for the vertical stabilizer structure.

[60] The test structure was conditioned in an environmental chamber (which controlled heat and humidity) for 3 weeks until the structure reached an average temperature of about 70º C and increased in weight by about 1.2 percent as a result of moisture absorption.

fractured.   The loads in table 6 are presented in Newtons[61] for consistency with the certification documents.

Table 6. A300-600 Design Limit Loads for the A300-600 and A310-300 and the 1986 Full-Scale Certification Test Loads

Load type	A300-600 design limit loads	A310-300 design limit loads	A310-300 full-scale certification test loads
Shear (in N)	-215,800	-223,390	-424,440
Bending moment in Nm)	861,650	883,300	1,677,700
Torsion (in Nm)	152,680	161,000	340,720

The full-scale test revealed that the left rear main attachment lug fractured because of a tensile static overload. The test further revealed that the lug fractured with a resultant lug force of about 905 kN, which is about twice the resultant lug forces at limit load for the A300-600 and A310-300 lateral gust conditions (454 and 466 kN, respectively, when calculated using hot and wet conditions).[62]

In 1985, Airbus performed static tests on two right rear main attachment fittings at room temperature ambient conditions (20º C). The first fitting was tested for strength in compression and tension,[63] and the second fitting was tested for strength in tension. The first fitting experienced a compression failure of the skin and stringers away from the lug at a load of 1,003 kN. The second fitting experienced a cleavage-tension failure[64] at the lughole at a load of 1,036 kN.   Both tests were conducted using in-plane loads only and did not account for the lateral component of load at the lug. The exclusion of this loading component caused a reduction in the local lug bending moment and the transverse shear; thus, the lug fractured at a larger resultant force than that experienced during the full-scale test.

1.6.4.3.1 Validity of the Full-Scale Vertical Stabilizer Certification Test

The Safety Board asked the National Aeronautics and Space Administration's (NASA) Langley Research Center in Hampton, Virginia (NASA-Langley), to review and

---

[61] A Newton is a unit of force that is equal to 0.2248 pounds. In this report, loads are presented as Newtons (N) and kiloNewtons (kN). One kN equals 1,000 N. Bending and torsion moments are presented in this report in Newton-meters, or Newtons times meters (Nm).

[62] The resultant lug forces are 475 kN for the A300-600 and 487 kN for the A310-300 when calculated using room temperature ambient conditions (20° C).

[63] Compression refers to loading in which two ends are pushed in directions toward each other, and tension refers to loading in which two ends are pulled in directions away from each other.

[64] According to the ASM Handbook, volume 21, "Composites," a cleavage-tension failure is one of several failure modes for mechanically fastened composite joints. This failure mode typically initiates by a translaminar fracture (that is, a fracture that occurs across composite layers, or plies) in a plane parallel to the load direction between the fastener hole and the end of the piece (lug).   Susceptibility to cleavage-tension failures over other failure modes generally increases as the fastener is located closer to the end of the specimen.

assess Airbus' 1986 full-scale vertical stabilizer certification test. One concern with the full-scale test was that, because the vertical stabilizer was tested off the airplane, the loads applied at the main attachment fittings might not have represented the condition with the vertical stabilizer attached to the airplane. During the Airbus certification test, the loads applied to the fittings were prescribed exactly from Airbus' global finite element analysis (FEA) of the vertical stabilizer, rudder, and aft fuselage. As a result, the validity of the vertical stabilizer loading during the full-scale certification test depended on the validity of the global FEA.

Under the direction of Safety Board investigators, NASA-Langley conducted test and analysis correlations and stiffness sensitivity studies on the fuselage and vertical stabilizer to determine the validity of Airbus' global FEA. NASA-Langley's work confirmed that the applied forces in Airbus' full-scale test represented the condition with the vertical stabilizer attached to the airplane. The insensitivity of attachment lug forces to stiffness variations demonstrated that the attachment lug forces were primarily the result of the aerodynamic load distribution and the overall geometry of the structure rather than the local stiffness representation of the attachment lug itself.

1.6.4.3.2 Validity of the Attachment Fitting Certification Tests

The Safety Board requested that NASA-Langley conduct a detailed strength analysis of the vertical stabilizer main attachment fittings to determine whether Airbus' 1985 certification tests on two right rear main attachment fittings were valid. Under the direction of Board investigators, NASA-Langley performed FEA and progressive failure analyses (PFA) to assess Airbus' certification tests.

According to NASA-Langley, the lug allowable strength (force) applied by Airbus during design and certification was expressed in terms of a resultant force and did not explicitly represent the effect of local bending moments on the strength of the fittings. The local lug bending moment of concern was the moment about the airplane's longitudinal axis. NASA-Langley conducted a detailed strength analysis that showed that the bending moment at the rear lug influenced the failure strength of the lug.

NASA-Langley found that Airbus' allowable strength for the fittings was based on a "building block" test sequence[65] that ultimately incorporated local bending moment effects. This bending moment was primarily the result of (1) the eccentricity in the skin-panel-to-lug transition region of the vertical stabilizer structure coupled with large in-plane loads in the vertical stabilizer skin and (2) the lateral loads on the lug. Thus, the bending moment at the lug was directly related to the forces on the lug.

During the full-scale test, the loads introduced into the fittings resulted in forces and moments that were representative of those that would be experienced by the airplane during flight. The full-scale test generated a representative local bending moment in response to the applied forces to the fittings; thus, the right rear main attachment lug

---

[65] The building block test sequence involved coupons first followed by subcomponent tests and then full-scale tests.

fractured at a lower resultant force than that experienced during the tests on the fittings. According to NASA-Langley, when Airbus reduced the allowable attachment fitting strength, the effect of a representative bending moment on the fitting strength was captured, even though the magnitude of the bending moment was not computed or measured.

1.6.4.4 Yaw Axis Certification Requirements

Section 25.143, "Controllability and Maneuverability—General," paragraph (b), states that it must be possible for the airplane to make a smooth transition from one flight condition to another without exceptional piloting skill, alertness, or strength and without danger of exceeding the airplane limit load factor under any probable operating conditions, including the sudden failure of the critical engine. Paragraph (c) includes a table that prescribes the maximum control forces permitted during the testing required by this section. The table indicates that, for short-term application of yaw control, 150 pounds of force can be applied to the rudder pedals and that, for long-term application of yaw control, 20 pounds of force can be applied to the rudder pedals. Paragraph (f) describes qualitative limits on pitch force sensitivity to prevent overstress and overcontrol,[66] but no such paragraph exists for roll or yaw force sensitivity.[67]

Section 25.147, "Directional and Lateral Control," paragraph (a), states that it must be possible for the airplane, with its wings level, to yaw into the operative engine and, at 1.3 V_{SR1} (the reference stall speed in a specific configuration), to safely make a reasonably sudden change in heading of up to 15° in the direction of the critical inoperative engine.

Section 25.149, "Minimum Control Speed," paragraph (b), states that, when the critical engine is suddenly made inoperative, it must be possible to maintain control of the airplane with that engine still inoperative and to maintain straight flight with a bank angle of no more than 5°. Paragraph (d) states that the rudder forces required to maintain control at V_{MC} cannot exceed 150 pounds.

Section 25.177, "Static Directional and Lateral Stability, paragraph (c), states that, in straight, steady sideslips, aileron and rudder control movements and forces must be

---

[66] Paragraph (f) states the following: "When maneuvering at a constant airspeed or Mach number (up to V_{FC}/M_{FC} [the maximum speed for stability characteristics]), the stick forces and the gradient of the stick force versus maneuvering load factor must lie within satisfactory limits. The stick forces must not be so great as to make excessive demands on the pilot's strength when maneuvering the airplane, and must not be so low that the airplane can easily be overstressed inadvertently. Changes of gradient that occur with changes of load factor must not cause undue difficulty in maintaining control of the airplane, and local gradients must not be so low as to result in a danger of overcontrolling."

[67] Section 25.177 (discussed later in this section) places qualitative requirements on the proportionality between the rudder control movements and forces and the sideslip angle in steady sideslips, which affects the sensitivity of the rudder control system.

substantially proportional to the angle of sideslip and that the factor of proportionality must lie between limits found necessary for safe operation.[68]

Section 25.181, "Dynamic Stability, paragraph (b), states that any combined lateral/directional oscillations (that is, Dutch roll) occurring between 1.13 V_{SR} (the reference stall speed) and the maximum allowable speed appropriate to the configuration of the airplane must be positively damped with the controls free and must be controllable with normal use of the primary controls and without exceptional pilot skill.

1.6.4.5 Design Maneuvering Speed Information

V_A is an important airspeed related to load factors. Section 25.1583, "Operating Limitations," requires that transport-category airplane pilots be provided with information on the airplane's V_A airspeed. Section 25.1583 also requires that the pilots receive "a statement that full application of rudder and aileron controls, as well as maneuvers that involve angles of attack near the stall, should be confined to speeds below this value."

FAA Advisory Circular (AC) 61-23C, "Pilot's Handbook of Aeronautical Knowledge," states that "any combination of flight control usage, including full deflection of the controls, or gust loads created by turbulence should not create an excessive air load if the airplane is operated below [design] maneuvering speed."

In a postaccident interview, American Airlines' managing director of flight operations technical stated that the rudder should be able to be fully displaced and stay within its structural limit as long as the rudder travel limiter were working properly and the airplane were traveling below V_A. Also, he thought that the rudder travel limiter would protect the airplane with a full deflection of the rudder followed by a deflection in the opposite direction as long as the airplane was traveling below V_A. He further stated that most of the company pilots believed that, if the pilot made right, left, and right rudder inputs, the airplane would be protected as long as it was traveling below V_A.

At the public hearing, American Airlines' A300 fleet standards manager stated that, before the flight 587 accident, he thought that the rudder could be exercised to its full authority in alternating sideslips on airplanes that were traveling below V_A. He also thought that the rudder travel limiter would preclude any risk of damaging the airplane.

---

[68] At the public hearing, an FAA flight test pilot stated that the FAA's steady heading sideslip tests were accomplished in "a very slow, methodical way." He further stated that, during the tests, pilots applied force to the rudder pedals "very carefully and slowly" to generate sideslip.

1.6.5 Maintenance Records

American Airlines developed its maintenance program for its fleet of A300-600 airplanes using the FAA's A300-600 Maintenance Review Board (MRB) report[69] and Airbus' A300-600 Maintenance Planning Document (MPD).[70] The required maintenance tasks for the A300-600 were included in American's engineering specification maintenance document, and the specific work to be accomplished was found within American's Maintenance Check Manual work cards or the applicable engineering specification orders.

American's engineering specification maintenance intervals for A300-600 airplanes included "periodic service;" "A," "B," and "C" checks (the C checks were divided into "1C," "2C," "3C," "4C," "5C," "6C," and "8C" checks); and "main base visit" checks. Periodic service checks are to be accomplished at a maximum of 2 flying days from the last periodic service or higher check. A and B checks are to be accomplished every 65 and 500 flight hours, respectively.[71] All but one of the C checks are performed every 15 months.[72] The main base visit check is to be accomplished at a maximum of every 30 months.

The accident airplane's last periodic service check occurred on November 11, 2001; the last A check occurred on November 9, 2001; and the last B check was performed on October 3, 2001. (All of these checks were performed at JFK.) The last C and main base visit checks occurred on December 9, 1999, at American Airlines' Maintenance and Engineering Center in Tulsa, Oklahoma. As part of the last main base visit check, a detailed visual inspection of the vertical stabilizer attachment was performed. (American Airlines conducts this inspection once every 5 years—every other Main Base Visit—in accordance with the requirements of the A300-600 MRB report.)

---

[69] The FAA's A300-600 MRB report, dated March 2000, outlined the initial minimum maintenance and inspection requirements to be used in developing an approved continuous airworthiness total maintenance program for A300-600 airplanes. The requirements in the report were developed using the task-oriented Maintenance Steering Group 3 risk analysis methodology, dated September 1993. (The Maintenance Steering Group 2 risk analysis methodology, dated March 1988, was in effect between the time that the accident airplane entered American's fleet and the time that the Maintenance Steering Group 3 risk analysis methodology was issued.) The MRB report was based on an airplane utilization of between 2,500 and 5,000 hours and 2,500 flight cycles in 15 months. The report indicated that the basic check intervals were 400 flight hours for an "A" check and 15 months for a "C" check. The maintenance tasks and intervals with which to perform these tasks were defined in the "Systems and Powerplant Program," the "Structures Program," and the "Zonal Inspection Program."

[70] Airbus' A300-600 MPD provided scheduled maintenance recommendations and information to assist operators in establishing their own maintenance program. The MPD included task numbers, task description/preparation data/access requirements, and maintenance intervals/thresholds. The MPD assumed that the 2,500-flight hour C check would be accomplished about every 12 to 15 months. The version of the MPD that was current at the time of the accident was dated April 30, 2001.

[71] The MRB weekly check became the American Airlines A check. The MRB A check became the American Airlines B check.

[72] The 1C, 2C, 3C, 4C, 5C, 6C, and 8C checks are to be accomplished every 15, 30, 45, 60, 75, 90, and 120 months, respectively.

The airplane maintenance logbook for N14053 was recovered after the accident. The last entry for November 11, 2001, indicated, "no items." The only entry for November 12, 2001, was an informational note to the crew that the first flight security check had been completed at 0130. No minimum equipment list (deferred maintenance) items were found in the logbook. Also, American's field maintenance reliability report (a computerized report that indicates the maintenance status of an airplane and includes data fields not found on logbook discrepancy forms) for N14053 between January 1 and November 12, 2001, did not note any minimum equipment list items.

The aircraft damage log for N14053 (a computerized program that contains a record of external damage to the airplane structure that was not permanently repaired at the time the damage was noted) was reviewed for events between February 22, 1991, and August 17, 2001 (the date of the last entry). No damage involving the vertical stabilizer was recorded.

According to the FAA's incident data system, the accident airplane was involved in a turbulence incident on November 28, 1994. Specifically, American Airlines flight 1218 was en route from Bridgetown, Barbados, to San Juan, Puerto Rico, when the airplane encountered severe clear air turbulence while in normal cruise flight. After the turbulence encounter, the airplane landed at San Juan without further incident. Of the 221 people aboard the airplane, 47 were injured.

After the incident, American Airlines performed a special inspection of the airplane because of the excessive turbulence that the flight encountered. Records on the completed inspection were not available (the records were required to be retained only for 1 year), but the work cards that were used during this special inspection were available. The work cards indicated that the vertical stabilizer torque box was to be inspected externally for distortion, cracks, pulled or torn fasteners, or damaged paint work. If damage was found, the work cards instructed that the attachment fittings and front and rear spar webs be inspected for distortion, cracks, pulled or torn fasteners, or damaged paint work and that, on the rear spar, the hydraulic lines, mechanical linkages, electrical looms, and their mounts be inspected for distortion, cracks, rupture, and fluid leakage.

FAA accident and incident data indicated that American Airlines' Airbus airplanes were involved in 16 maintenance-related events from January 1, 1996, to November 29, 2001. None of these events involved N14053.

FAA service difficulty reports (SDR) between January 1995 and November 2001 were reviewed for A300 maintenance-related "vibration" involving the airplane's flight controls, fuselage, stabilizers, and wings; "flutter;" "group control flight system;" and "group empennage structure." Regarding the A300 vibration category, 19 SDRs were submitted. Regarding the A300 flutter category, one SDR was submitted. Regarding the group control flight system category, 54 SDRs were submitted. Regarding the "group empennage structure" category, 12 SDRs were submitted. All of the SDRs were cleared by maintenance actions; no maintenance trends were found.

In addition, 62 SDRs were submitted for N14053 from January 1, 1995, to the accident date. No significant findings related to the circumstances of the flight 587 accident were identified.

1.7 Meteorological Information

Weather observations at JFK are made by an automated surface observing system (ASOS), which is maintained by the National Weather Service (NWS). The ASOS records continuous information on wind speed and direction, cloud cover, temperature, precipitation, and visibility.[73] The ASOS transmits an official meteorological aerodrome report (known as a METAR) each hour and a special weather observation (known as a SPECI) as conditions warrant; such conditions include a wind shift, change in visibility, and change in ceiling (cloud cover or height). ASOS observations at JFK are augmented and edited by certified weather observers under contract with the FAA.

Weather observations are transmitted in coordinated universal time (UTC). (Eastern standard time is 5 hours behind UTC time.) The 1351Z METAR[74] (0851 local time) on the day of the accident indicated the following: winds 310° at 11 knots, visibility 10 miles, few clouds at 4,300 feet, temperature 6° C (about 42° F), dew point -6° C, and altimeter setting 30.44 inches of mercury (Hg). At 1425 (0925 local time), a SPECI was issued because of the accident (which had occurred about 9 minutes earlier). The SPECI indicated the following: winds 270° at 8 knots, visibility 10 miles, few clouds at 4,800 feet, temperature 6° C, dew point -6° C, altimeter setting 30.44 inches of Hg, aircraft mishap,[75] smoke plume south.

Automatic terminal information service (ATIS) information is based on ASOS observations. ATIS information Delta, which the flight crew was using,[76] was based on the 1251Z METAR (0751 local time). ATIS information Echo, which was in effect at the time that the airplane departed JFK,[77] was based on the 1351Z METAR.

American Airlines' flight release for flight 587 contained, among other items, METARs for JFK, Santo Domingo, and the alternate airport (San Juan) and terminal aerodrome forecasts[78] (TAF) for the three airports. American Airlines Weather Services provided the following TAF information for JFK, which was valid from 1300Z to 2300Z

---

[73] Cloud cover is expressed in feet agl. Visibility is expressed in statute miles.

[74] The "Z" designation that follows the time in a weather observation stands for Zulu, which indicates UTC time.

[75] This remark was only transmitted locally.

[76] About 0901:24, the first officer contacted the ground controller and informed him that he had received ATIS information Delta, which stated the wind was 330° at 11 knots, visibility was 10 miles, a few clouds were at 3,400 feet, temperature was 4° C, dew point was -6° C, and altimeter was 30.42 inches of Hg.

[77] The CVR and air traffic control (ATC) transcripts do not indicate that the flight crew had received ATIS information Echo.

[78] TAFs are prepared by the NWS and are normally issued every 6 hours with amendments issued as conditions warrant.

(0800 to 1800 local time) on the day of the accident: winds 310º at 12 knots, gusting to 22 knots; visibility greater than 6 miles; few clouds at 5,000 feet; temporary clouds scattered at 5,000 feet.

1.8 Aids to Navigation

No problems with any navigational aids were reported.

1.9 Communications

No communications problems were reported between the pilots and any of the air traffic controllers who handled the flight.

1.10 Airport Information

JFK is located 1/2 mile southeast of the city of New York limits and has an elevation of 13 feet msl. The airport has four runways: runway 13L/31R is 10,000 feet long and 150 feet wide; runway 13R/31L (the accident airplane departed from runway 31L) is 14,572 feet long and 150 feet wide; runway 4L/22R is 11,351 feet long and 150 feet wide; and runway 4R/22L is 8,400 feet long and 150 feet wide. Runway 31L has an elevation of 12 feet msl.

The Port Authority of New York and New Jersey Police Department stated that, after the crash of flight 587 had been confirmed, a Port Authority employee conducted a visual inspection of the full length of runway 31L and the taxiways used by the accident airplane. No debris was found on the runway or the taxiways.

1.10.1 Air Traffic Control Information

ATC radar coverage for the JFK area is provided by an ASR-9 radar located on the airport. The ASR-9 is a short-range (60 nm) radar that provides position and track information to controllers at the New York TRACON and the JFK air traffic control tower (ATCT) for aircraft operating within terminal airspace. ASR-9 antennas rotate about 13 times per minute, resulting in a radar return about every 4.6 seconds.

Flight 587 was handled by three air traffic controllers on the day of the accident: a ground controller and a local controller at the JFK ATCT and a departure controller at the New York TRACON. A controller-in-charge was also present at the JFK ATCT at the time of the accident.[79]

---

[79] The controller-in-charge was performing duties in the absence of the tower supervisor. He was not monitoring any particular controller position and did not see flight 587 during taxi, takeoff, or departure.

The ground controller first became aware of flight 587 when the flight crew called for taxi clearance. He instructed the flight crew to taxi out of the ramp area to a taxiway for sequencing into the departure queue. When the airplane arrived at the taxiway, the ground controller instructed the flight crew to follow the Japan Air Lines 747 into the queue, and the crew followed this instruction.[80] The departure controller indicated that he had "a good look" at the accident airplane during its taxi and did not notice anything unusual.

The local controller first became aware of flight 587 when she cleared the airplane to taxi into position and hold on the runway. She then issued a wake turbulence advisory because the Japan Air Lines 747 was a heavy jet. The local controller also indicated that she added extra radar separation between the Japan Air Lines 747 and the flight 587 airplane because 747s are often "slow climbers." Once the separation was established, the local controller issued the current wind and cleared flight 587 for takeoff. She watched the airplane during its takeoff roll and did not see anything unusual.

The last time the local controller saw the accident airplane was when it made the left turn needed to follow the bridge climb. She then instructed the flight crew to contact departure control. The local controller first became aware of the accident when she heard an unidentified pilot stating, over radio frequency, that an airplane was crashing south of the airport. She reported that she said this information out loud and that everyone in the tower turned to look for the accident. The local controller reported that she then saw a black plume of smoke.

The controller-in-charge first became aware of the accident from the local controller and an outside telephone call. The controller-in-charge then called the New York TRACON to see if it had lost an airplane. The flight data controller at the TRACON answered the telephone and indicated that flight 587 was missing. When the controller-in-charge went to get the flight strip for flight 587, he noticed a large plume of smoke outside. The controller-in-charge stated that he notified the Port Authority Police Department of the accident and that the tower supervisor had returned almost immediately to the ATCT after the accident occurred.

The departure controller first became aware of flight 587 when the flight crew reported on frequency. At that point, the airplane was climbing through 1,300 feet msl. The departure controller's radar identified the airplane, and he issued an instruction for the airplane to climb to 13,000 feet msl. The departure controller subsequently issued an instruction for the airplane to turn left and proceed direct to the WAVEY intersection. Soon afterward, he noticed that the airplane's radar target had disappeared and that its data block was no longer showing airspeed or altitude. One of the pilots of American Airlines flight 686, which departed JFK after American Airlines flight 587, reported seeing fire and smoke south of Long Island, New York. When the JFK ATCT called to see if the TRACON had lost any airplanes, the departure controller informed the TRACON's flight data controller that flight 587 was lost.

---

[80] The departure controller indicated that the sequencing of flights in the queue was decided by airplane type and departure fix. He estimated that between 8 and 10 airplanes were waiting in the queue to take off.

The departure controller stated that nothing was unusual on the day of the accident about the spacing between airplanes coming from JFK to the TRACON. The departure controller thought that the Japan Air Lines 747 was about 7 miles ahead of flight 587 and that the 747's flight track was normal. The departure controller also stated that he had not received any turbulence reports from other airplanes in the area.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The accident airplane was equipped with a Fairchild model A-100A CVR (S/N unknown). According to Airbus documents, the CVR was operating off the emergency bus, which allowed the CVR to continue recording after the engines separated from the airplane.

The exterior of the CVR showed evidence of significant structural damage. The front panel, including the underwater locator beacon, was missing. The outer metal enclosure was heavily covered with soot and was dented, and it had to be cut to gain access to the tape reel. The exterior of the crash case was not damaged. The tape did not show evidence of heat damage, but several inner windings were crinkled.[81]

The CVR was sent to the Safety Board's audio laboratory in Washington, D.C., for readout and evaluation. The CVR data started at 0845:35 and continued uninterrupted until 0916:14.8. The recording consisted of four channels of audio information, three of which were excellent quality and one of which was poor quality.[82] The three channels that contained the excellent quality information were the cockpit area microphone, the captain's audio panel, and the first officer's audio panel. The fourth channel contained a high-frequency squeal and was mostly unreadable.[83] A transcript was prepared of the entire 30-minute 39-second recording (see appendix B).

1.11.2 Flight Data Recorder

The accident airplane was equipped with a Fairchild model FA2100 FDR, S/N 1186, that was manufactured by L-3 Communications. The FDR used solid-state flash memory, stored in a crash-survivable memory unit, as the recording medium. The FDR was sent to the Safety Board's laboratory for readout and evaluation.

---

[81] This portion of the recording contained the oldest data, which recorded the events before flight 587 left the gate.

[82] The Safety Board rates the quality of CVR recordings according to a five-category scale: excellent, good, fair, poor, and unusable. See appendix B for a description of these ratings.

[83] The fourth channel is used to record a third crewmember's audio information if the CVR is installed into a three-crewmember airplane. The fourth channel is usually not used on a two-crewmember airplane.

The FDR showed extensive fire and impact damage. The memory module inside the memory unit did not show any damage, but the memory cable needed to be replaced before the data could be read out.

The FDR contained more than 81 hours of recorded data, and American Airlines provided conversion formulas for the data.[84] The FDR recorded about 1 minute 33 seconds of flight data for the accident airplane, beginning at 0914:28.45 (the time that the right main landing gear squat switch changed from ground to air) and ending at 0916:01.23 (before airplane impact).

The analog signals from the rudder position, aileron right position, aileron left position, elevator position, and horizontal stabilizer position were processed through the airplane's system data analog converter (SDAC)[85] computer before they were sent to the flight data acquisition unit (FDAU)[86] as a digital signal. The SDAC computer applied a filter to the data,[87] and the FDR recorded the filtered digital value. (Uncertainties in the FDR data associated with data filtering are discussed in section 1.16.2.)

An SDAC bench test was conducted on February 4 and 5, 2002, at Airbus' facility in Toulouse. One purpose of the test was to define the filtering function and the associated processing delay of the SDAC. The Safety Board and Airbus independently analyzed the results of the test and concluded that the SDAC applied a first-order lag filter with a 0.434-second time constant.

Another purpose of the test was to input data into the SDAC and compare the SDAC output data to the calculated filtered output data. The input data were Airbus' first estimation of the accident airplane's flight control surface movements. The calculated filtered output data were computed by applying a filter to the input data. These results supported the conclusion that the SDAC filter was a first-order lag filter with a 0.434-second time constant.

---

[84] During the initial readout of the FDR, the conversion equation for the rudder pedal parameter was found to be incorrect. Thus, the FDR data had to be examined to obtain reference data to establish the proper equation for the rudder pedal position parameter. In addition, revised equations for the control wheel and control column positions were established based on the FDR data. (The airplane was not initially configured with the rudder pedal position, control wheel position, and control column position parameters because they were not mandatory when the airplane was manufactured.) American Airlines added flight control input sensors and the associated hardware to the airplane to comply with 14 CFR 121.344, which required that, no later than August 20, 2001, all transport-category airplanes be equipped with FDRs that record control input positions.

[85] In some Airbus documents, the SDAC is also referred to as the system data acquisition concentrator.

[86] The FDAU converts and conditions Aeronautical Radio, Inc. (better known as ARINC), data into a serial data stream, which the FDR records in a digital format.

[87] See sections 1.18.7.1 and 1.18.7.3 for information regarding the Safety Board's recommendations to the FAA regarding the filtering of flight control position data.

1.12 Wreckage and Impact Information

1.12.1 General Wreckage Description

The main wreckage area was located about 4 miles southwest of runway 31 at the intersection of Newport Avenue and Beach 131st Street. The main wreckage was confined to an area of about 500 by 300 feet and was oriented on a magnetic heading of about 040º. The vertical stabilizer and the rudder separated from the airplane in flight and were recovered from Jamaica Bay, which was about 3/4 mile north of the main wreckage area. Figure 11 shows the vertical stabilizer after it was recovered from Jamaica Bay. The left and right engines also separated from the airplane in flight. The left engine was recovered at 441 Beach 129th Street, which was about 800 feet north-northeast from the main wreckage area. The right engine was recovered at 414 Beach 128th Street, which was about 800 feet northeast of the main wreckage area.

The largest piece of airplane structure recovered on land away from the main wreckage area and the engines was the left wing tip, which was recovered at the intersection of Beach 125th Street and Cronston Avenue. Smaller pieces of airplane debris were found from Beach 116th Street to the accident site (between Jamaica Bay and the Atlantic Ocean) and in Jamaica Bay. All major sections of the airplane were accounted for in the wreckage. Most of the airframe and its associated systems showed severe impact and fire damage.

Figure 11. Vertical Stabilizer After Recovery From Jamaica Bay

1.12.2 Vertical Stabilizer and Rudder

The vertical stabilizer was mostly intact. The left and right skin panels did not exhibit any significant damage, but the six main attachment fittings and the three pairs of transverse load fittings were fractured.

The right rear main attachment fitting fractured at the lughole (see figure 12). The right center main attachment fitting remained attached to the aft fuselage but separated from the vertical stabilizer when it fractured just above ribs 1 and 4 and the skin/stringer interface. The right forward main attachment fitting fractured at the lughole. The left rear main attachment fitting assembly (that is, the inboard and outboard fitting assembly halves and the lug portion of the skin laminate) fractured from the vertical stabilizer but remained attached to the aft fuselage. The left center main attachment fitting separated from the vertical stabilizer at the fastener line along the rib 1 attach angle. The left forward main attachment fitting fractured at the lughole, but the lower part of the fitting remained attached to the aft fuselage. [88]

Figure 12. Right Rear Main Attachment Fitting

The transverse load fittings at the rear and center spars fractured at the location where the spars and aft fuselage interfaced. The transverse load fittings at the front spar fractured from the vertical stabilizer along with part of the front spar web, which remained attached to the forward main attachment and transverse load fittings.

---

[88] For information on the damage to the main attachment fittings, see section 1.16.3.3.

The entire rudder separated from the vertical stabilizer, except for portions of the rudder spar structure that remained attached to hinge arm assembly numbers 2, 3, 4, 5, and 7. The rudder had numerous fractures and broke into a section including and above hinge arm assembly number 7, a section between hinge arm assembly numbers 4 and 7, and many pieces below hinge arm assembly number 4. For additional information on the damage to the vertical stabilizer and rudder, see Materials Laboratory Factual Report number 02-077 in the public docket for this accident. For information on tests performed on the vertical stabilizer and rudder, see section 1.16.3.

1.12.3   Rudder Control System

The three rudder servo controls remained attached to the vertical stabilizer. The fittings that attached the servo controls to the rudder fractured at the rudder attachment locations, and the bulk of the fittings and small pieces of rudder structure remained attached to the servo controls.

The rudder frame assembly[89] components detached from the empennage. The artificial feel and trim unit, rudder trim actuator, yaw damper actuator, yaw autopilot actuator, and variable stop actuator were located; all had suffered heat damage. Most of the linkages (that is, pushrods and bellcranks), the rudder control quadrant, and the rudder travel limiter were fractured and melted. No rudder control system components forward of the rudder frame assembly were identified in the wreckage. For information on tests performed on rudder control system components, see section 1.16.5.

1.12.4 Powerplants

Neither the left engine nor the right engine had any indications of an uncontainment, case rupture, in-flight fire, preimpact malfunction, or bird strike. The thrust reversers were found in the stowed position.

Between November 28 and December 4, 2001, the engines were disassembled and examined at American Airlines' Maintenance and Engineering Center in Tulsa. The examination revealed that the high pressure compressor and turbine rotors' blades were bent opposite of the direction of rotation and that the fan and low pressure turbine rotors' blades were bent or broken only where they were crushed by the engines' case.

The APU was found in the airplane's aft fuselage, which was recovered at the corner of Beach 131st Street and Newport Avenue. The APU had broken loose from its supports and was found slightly forward of its normal position. The APU showed no indications of an uncontainment, case rupture, or in-flight fire.

---

[89] The rudder frame assembly houses the rudder control quadrant, artificial feel and trim unit, rudder trim actuator, yaw damper actuator, yaw autopilot actuator, main bellcrank, differential unit, variable stop actuator, and variable stop lever.

On December 13, 2001, the APU was disassembled and examined at Honeywell's engine teardown facility in Phoenix, Arizona. The APU showed no evidence of any rotational damage to the compressor impellers and turbine rotors. The APU also showed no evidence of an in-flight fire, case rupture, uncontainment, or hot air leak across a case flange.

1.13 Medical and Pathological Information

Tissue specimens from the captain and the first officer were sent to the FAA's Civil Aerospace Medical Institute in Oklahoma City, Oklahoma, for toxicological analysis. The captain's specimens tested negative for major drugs of abuse and for prescription and over-the-counter medications but tested positive for ethanol.[90] The first officer's specimens tested negative for major drugs of abuse and ethanol but tested positive for ephedrine and pseudoephedrine.[91]

1.14 Fire

A postcrash fire developed after airplane impact. The parts of the vertical stabilizer and rudder that separated in flight showed no evidence of fire damage.

1.15 Survival Aspects

The accident was not survivable for any of the airplane occupants.

1.16 Tests and Research

1.16.1 Video Study

Two security cameras from the Metropolitan Triborough Bridge and Tunnel Authority of New York captured a portion of the accident flight. These cameras, which shared a common time base, were located in two lanes (1 and 5) at the Gil Hodges Marine Parkway Bridge toll plaza. The video from the camera in lane 1 showed the airplane as a small black dot moving from left to right across the sky. The dot then became obscured by a building. At that point, the video from the camera in lane 5 showed a small black dot emerging from behind another obstruction (part of a toll booth). The dot continued initially to move left to right but then started to descend. During the descent, a white

---

[90] Ethanol in specimens can be the result of the postmortem production of ethanol.

[91] These substances are present in many over-the-counter medications used to treat upper respiratory symptoms. The first officer had reported, on his FAA medical certificate application, a history of mild seasonal allergies. The substances were also found in nutritional supplements marketed for various purposes. These substances do not usually result in impairment.

"streak" was briefly seen trailing behind the dot before it became obscured by the building.[92] About 40 seconds later, black smoke was seen rising in the background.[93] Detailed examination of the video in the Safety Board's laboratory revealed no images of an object or objects falling off the airplane.

The Safety Board conducted a video study to accomplish three objectives. First, the study was to compare the elapsed time information from the video recordings with that of the radar/CVR/FDR data. Second, the study was to determine the time and location of the white streak. Third, the study was to calculate the position of the airplane after the loss of FDR and radar data.

The study estimated that the first indication of the white streak occurred when the alignment of the airplane was directly above column 3 of the building seen in the video from lane 5. On the basis of the elapsed time between the last recorded radar return and the end of the CVR recording, the white streak was calculated to have begun at 0916:06.14, or about 4.3 seconds after the last recorded radar return.

In addition, the study determined the airplane's position at several points after the loss of FDR and radar data. The airplane's altitudes were calculated using data from the site survey, still images from the video recordings, and an architectural drawing of the building in the cameras' view. The alignment of the airplane was over the roof midpoint (lane 1) at 0916:02.26 and at an altitude of 2,398 feet msl.[94] The airplane's alignment was over column 3 (lane 5) at 0916:06.14 (the same time as the white streak appeared) and at an altitude of 2,428 msl. The airplane's alignment was over column 4 (lane 5) at 0916:09.38 and at an altitude of 2,012 feet msl. The airplane's alignment was over the roofline at column 5 (lane 5) at 0916:12.08 (the end of the period that the airplane is visible in the video) and at an altitude of 1,470 feet msl.

1.16.2 Airplane Performance Study

The Safety Board conducted an airplane performance study to describe the motion of the accident airplane, identify the causes of the motion, and calculate the resulting aerodynamic loads on the vertical stabilizer. The data used to determine the airplane's motion and the resulting loads included ATC radar, CVR, and FDR data; wreckage location and condition; ground scars, markings, and damage to surface structures; weather information; and outputs from computer programs and simulations.

---

[92] The video recorded by the camera in lane 1 included the midpoint of the building's roof. The video recorded by the camera in lane 5 included columns 3 through 7 of the building.

[93] The Safety Board received another videotape that captured the accident flight. The video was reportedly taken by a construction crew working near runway 4R at JFK on the day of the accident. The video showed the departures of both Japan Air Lines flight 47 and American Airlines flight 587. The video depicted the accident airplane as it taxied into position for takeoff, began its takeoff roll, lifted off the runway, and began a left turn. The video then panned away from the airplane, and the camera was turned off for a short time. The next image on the video was smoke rising from the ground in the distance. (This video was not part of the video study.)

[94] All altitudes derived from the video study are estimated to be accurate within 65 feet.

The computational tools used in the airplane performance study included an engineering flight simulation of the A300-600 to compute the airplane's dynamic response to control inputs and a computational fluid dynamics (CFD) code to compute the aerodynamic loads over both rigid and flexible models of the vertical stabilizer. The Safety Board developed its A300-600 engineering simulation using data from Airbus' A300-600 engineering simulator. The CFD computations were performed by Airbus at the direction of, and in cooperation with, Board investigators.

Many performance parameters required to define the motion of the airplane were recorded directly by the FDR. Other parameters required to define the airplane motion were not recorded by the FDR and had to be derived from the available FDR parameters and/or supplemented with information obtained from simulator studies and other computations. The performance parameters of most interest to this investigation were those required to determine the aerodynamic loads on the vertical stabilizer; the most significant of these parameters included the dynamic pressure of the air flowing past the airplane, the sideslip angle, and the rudder angle. None of these parameters were recorded directly on the FDR.

Even though the FDR did not directly record rudder angle data, the FDR did record a filtered rudder signal that could be used to check whether an estimate of rudder position, obtained by other means, was viable. The dynamic pressure and sideslip angle could be computed from other FDR parameters.[95] However, because of uncertainties in the FDR data—including data latencies (that is, delays), data filtering, and sampling rate effects—the rudder and sideslip angles at the time that the vertical stabilizer separated from the airplane were determined within a narrow range—10° to 11° for the rudder angle and 10° to 12.5° for the sideslip angle.

1.16.2.1 Wake Vortex Investigation

As part of the airplane performance study, the Safety Board requested that NASA-Langley conduct a wake vortex investigation. Specifically, the Board asked NASA-Langley to investigate whether flight 587 could have encountered the wake vortexes of Japan Air Lines flight 47. Such an encounter could explain the two sets of load factor excursions—the first occurring about 0915:35 at an altitude of 1,750 feet agl and the second occurring about 0915:51 at an altitude of 2,430 feet agl—that were recorded on flight 587's FDR.

NASA-Langley used flightpath and wind information for American Airlines flight 587 and Japan Air Lines flight 47 provided by the Safety Board, as well as atmospheric data for the day of the accident, as inputs to four wake prediction models.[96] In a report on its investigation,[97] NASA-Langley stated the following: A wake vortex

---

[95] These calculations are outlined in "Aircraft Performance Group Chairman's Aircraft Performance Study" in the public docket for this accident.

[96] These models are described, and their individual results are presented, in appendix B of "Aircraft Performance Group Chairman's Aircraft Performance Study."

[97] National Aeronautics and Space Administration, *AA 587 Wake Vortex Investigation, Modeling and Analysis by NASA Langley Research Center* (Hampton, VA: NASA, 2002).

from Japan Air Lines flight 47 was likely transported into the flightpath of flight 587. The atmospheric conditions aloft were favorable for a slow rate of vortex decay. The wake vortex from Japan Air Lines flight 47 would have had an age of about 100 seconds, and flight 587 would have encountered the wake vortex at a time before vortex linking and rapid vortex decay. The predicted circulation of the wake vortex at the times of the apparent encounters would have been between 63 and 80 percent of the vortex's initial strength.

In testimony at the public hearing, the main author of the wake vortex investigation report stated that, even though his work supported a wake encounter, the wake was "nothing extraordinary."

1.16.2.2 Flight 587 Simulation

The Safety Board developed a desktop computer simulation of flight 587 using A300-600 simulator model data provided by Airbus. The Board developed the desktop computer simulation to independently compute the response of the A300-600 to the thrust levels and flight control inputs recorded on the FDR and to compare the expected behavior of the airplane, as predicted by the simulator, with the actual behavior recorded by the FDR. This comparison could help determine whether external forces or moments (such as those from an atmospheric disturbance) were required to produce the motion of the airplane or whether the motion could be completely accounted for by the forces and moments produced by the engine thrust and control surface positions.

The load factor and engine N1 data fluctuations recorded on the FDR suggested that flight 587 encountered the wake of Japan Air Lines flight 47 for the second time between about 0915:50 and 0915:54 and that the motion of the airplane was affected by the wake vortex during this time. To account for the effects of the wake vortex during this 4-second period, the Safety Board's simulation incorporated external pitching, rolling, and yawing moments and vertical and horizontal wind gusts designed to make the simulator motion closely match the motion recorded on the FDR. After the 4-second period, the airplane was assumed to be free of the wake, so the external moments and wind gusts were removed. The external moments and wind gusts fully accounted for the effect that the wake turbulence had on the airplane, as recorded by the FDR. Any additional effects of the wake turbulence that were not recorded on the FDR (because of limited sampling rates, for example) would have had a negligible impact on the airplane motion. Throughout the simulation, the simulator cockpit control positions and aerodynamic surface positions were driven to match the positions recorded on the FDR as closely as possible without sacrificing the match of the motion recorded by the FDR.

To evaluate the magnitude of the effects of the wake vortex-induced external moments and vertical and horizontal wind gusts required to match the motion recorded on the FDR, the desktop computer simulation was run without any cockpit control or control surface movements. The simulator computed the response of the airplane solely to the forces and moments induced by the wake encounter.

The simulation indicated that, although external winds and moments, which were assumed to be attributable to the wake encounter, were required to match the airplane motion recorded on the FDR, the large roll and yaw oscillations, lateral load factors, and sideslip angles achieved during the accident sequence were the result of control wheel and rudder pedal inputs. The external winds and moments, by themselves, produced only an initial 10° deviation in bank angle (from the existing 23° bank angle) and only subtle changes in heading, resulting in sideslip angles of less than 2.5°.

Another simulation incorporated an alternative yaw damper design in which the yaw damper inputs could not be overridden by pilot pedal deflections at the rudder limits. The Safety Board evaluated the effects that this yaw damper design would have on the rudder pedal inputs made during the accident sequence. The results of this simulation indicated that such a system allowed the yaw damper to attenuate (but not prevent) the development of the sideslip angle resulting from alternating full rudder pedal inputs.

1.16.2.3 Loads on the Vertical Stabilizer

At any given altitude and airspeed, many parameters affect the loads on the vertical stabilizer;[98] the most significant of these parameters are sideslip angle and rudder angle. During the design of the A300-600, Airbus developed a model of the loads on the vertical stabilizer based on linearized wind tunnel data that described the effects of sideslip angle and rudder angle on the vertical stabilizer structural loads. With the use of this linear loads model, the Safety Board calculated the shear, bending, and torsion loads on the vertical stabilizer during the final seconds of flight 587's recorded FDR data (before the sound of the loud bang at 0915:58.5). Figure 13 shows the calculated bending moment about the root chord in the vertical stabilizer axis system.[99]

---

[98] Aerodynamic loads on the vertical stabilizer are produced by the pressure distribution over its surface. Inertial loads on the vertical stabilizer result from the acceleration of its mass. During the accident sequence, the inertial loads on the vertical stabilizer were extremely small compared with the aerodynamic loads.

[99] For structural analysis purposes, loads on the vertical stabilizer are expressed in terms of their components in the vertical stabilizer axis system, which is rotated about the pitch axis relative to the airplane body axis system. The airplane body axis system is coincident with the longitudinal, lateral, and vertical axes of the airplane.
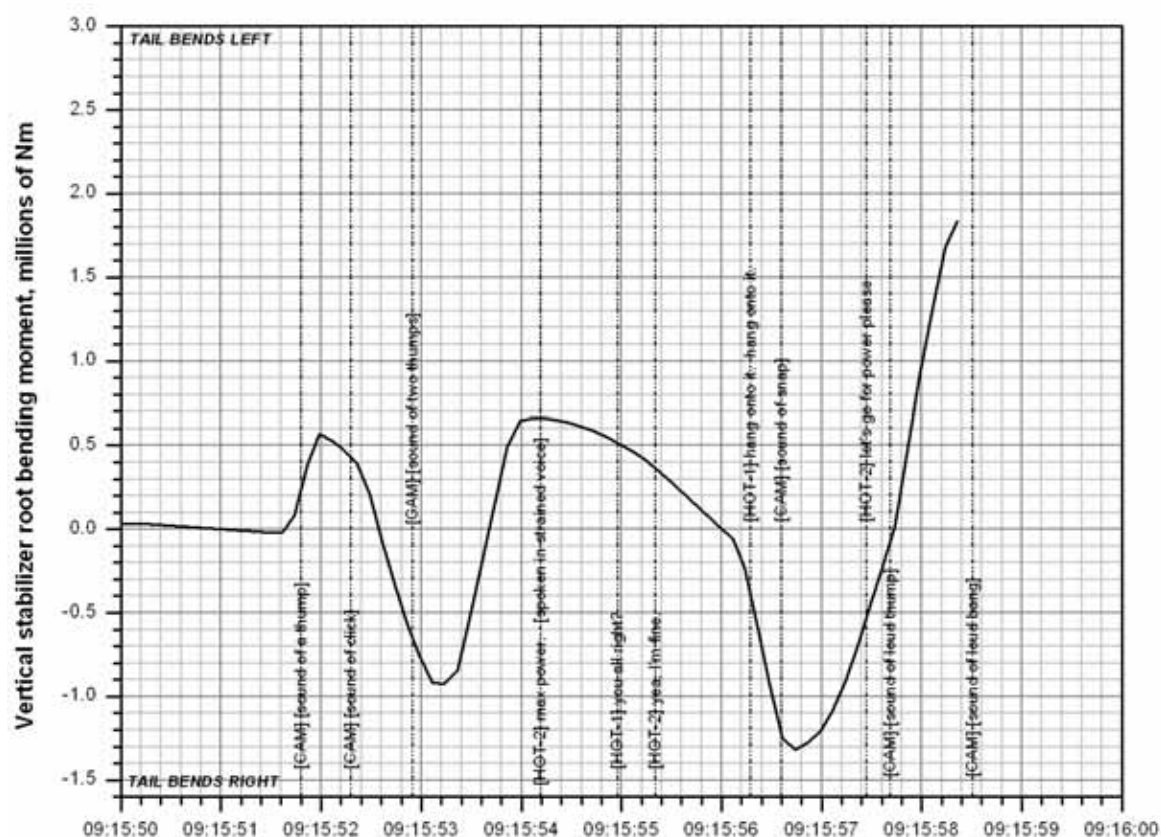
Figure 13. Bending Moment About the Root Chord in the Vertical Stabilizer Axis System

The Safety Board was especially interested in determining the loads when the right rear main attachment lug fractured (0915:58.4). This time was established by the following:

- The sideslip and heading angles in the Safety Board's simulations of the accident flight diverged from those based on the FDR data about the time of the loud bang recorded on the CVR (0915:58.5), indicating that the accident airplane's directional stability was reduced about this time (which is consistent with the loss of the vertical stabilizer).

- A momentary change in the trend in lateral acceleration (from decreasing to increasing) occurred at 0915:58.4. This momentary change was associated with a 0.2 G jump in lateral acceleration recorded about this time. Such a jump is consistent with the sudden inability of the vertical stabilizer to transfer side force loads into the fuselage.

- If the loud bang recorded on the CVR was associated with the fracture of the right rear lug, then the sound would have had to originate at 0915:58.4 because of the time that it would take for the sound to travel from the vertical stabilizer to the CVR microphone. This time is consistent with that of the change in the trend of the lateral acceleration.

The rudder and sideslip angles about the time of the lug fracture were large enough that portions of the vertical stabilizer began to exhibit aerodynamic stall behavior, that is, regions of separated flow. This separated flow affected the loads such that the linear loads model (which does not account for flow separation) could overestimate the loads in those conditions (high sideslip and rudder angles) in which separated flow is present. As a result, a CFD analysis was performed to calculate directly the effects of the separated flow at the high sideslip and rudder angles of interest. Specifically, the Safety Board asked Airbus to perform a CFD analysis of the flowfield about the entire A300-600 airplane and to provide the aerodynamic pressure loads over portions of the vertical stabilizer. The conditions at which these calculations were made reflected the flight conditions and airplane orientation at the time that the vertical stabilizer separated from the aft fuselage. Because of uncertainties in the sideslip angle, rudder angle,[100] and the absolute load values computed by CFD, the final estimate of loads at the time of the lug fracture were expressed as a range of values. At the time that the vertical stabilizer separated from the airplane, the range of the shear, bending, and torsion loads on the vertical stabilizer were as follows:

- shear force: 353,000 to 436,000 N ±5 percent

- bending moment: 1,580,000 to 1,840,000 Nm ±5 percent (see figure 14)

- torsion moment: 18,600 to 48,100 Nm ±5 percent

The bending moment load ranges shown in figure 14 are presented along with the "effective sideslip angle" range[101] and the rudder range at the time that the vertical stabilizer separated from the airplane. Figure 15 compares the estimated aerodynamic loads with the A300-600 design envelopes (as defined by the torsion versus bending correlated shear force diagram).

---

[100] Even though Safety Board investigators were eventually able to derive a meaningful time history of the rudder angle after the second wake encounter, the filtering of the rudder sensor data before they were recorded on the FDR and the low, 2-Hertz (Hz) sample rate of those data hindered and delayed Board investigators' knowledge of this parameter.

[101] The effective sideslip angle at the vertical stabilizer differed from the sideslip angle at the cg because of yaw rate effects. The left yaw rate at the time of vertical stabilizer separation increased the sideslip angle at the vertical stabilizer relative to the sideslip angle at the cg.
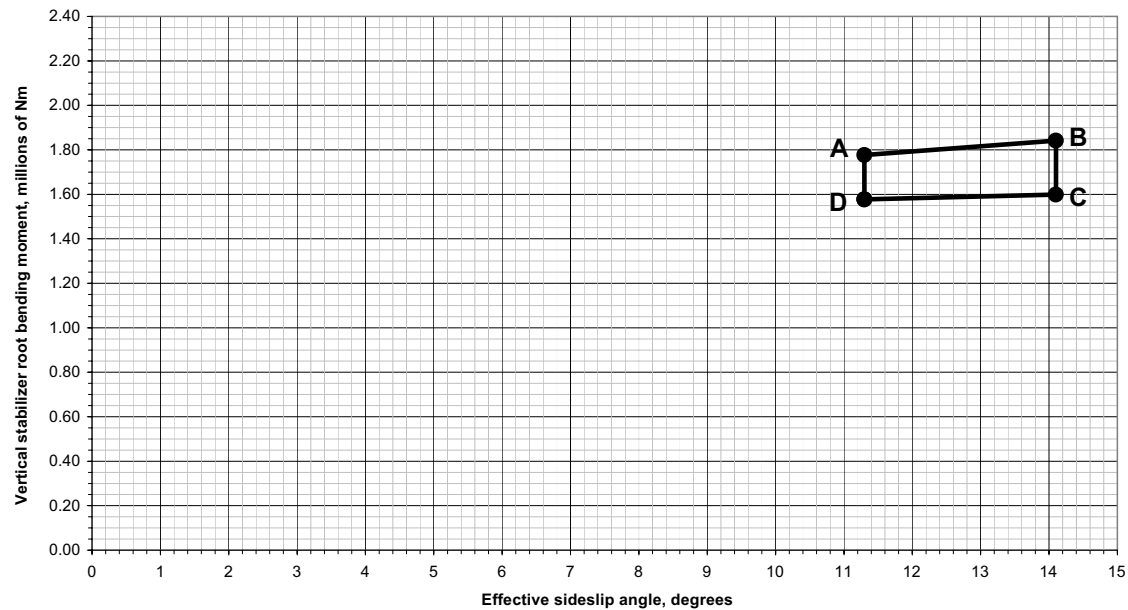
Note: The calculated range of the root bending moment is defined by points A through D, which are described in addendum 2 to the airplane performance study. See the public docket for this accident for more information.

Figure 14. Bending Moment Load Range at the Time of Vertical Stabilizer Separation
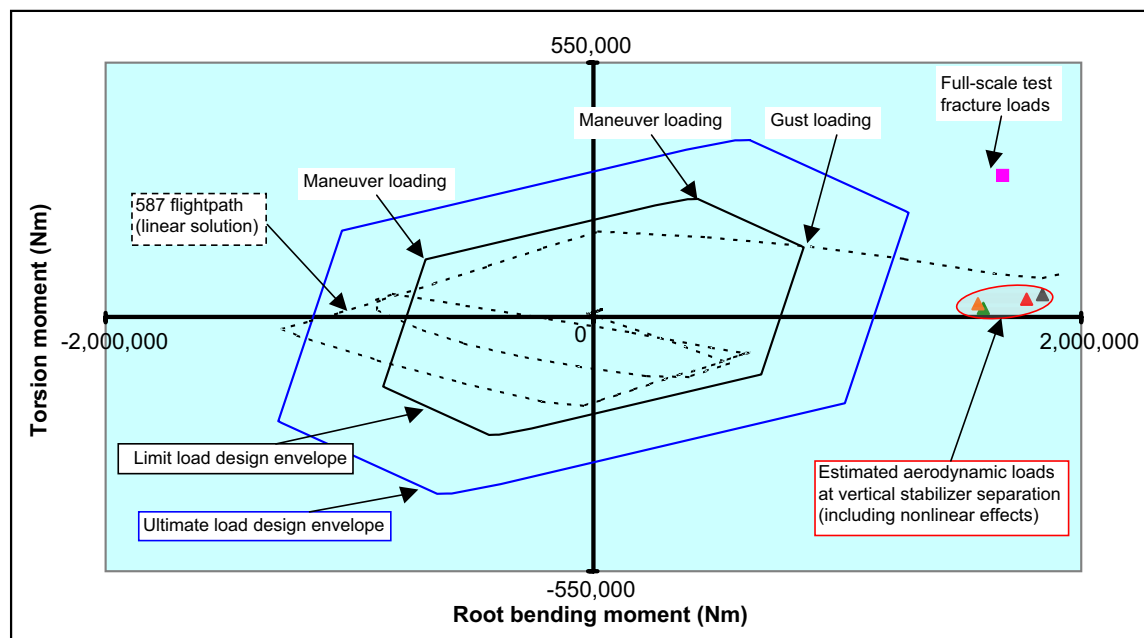
Note: The four triangles correspond to the four points in figure 14. Specifically, the red triangle is point A, the gray triangle is point B, the green triangle is point C, and the orange triangle is point D.

Figure 15. Estimated Aerodynamic Loads in Relation to the Torsion Versus Bending Correlated Shear Force Diagram

1.16.3 Examinations of the Flight 587 Vertical Stabilizer and Rudder

1.16.3.1 Nondestructive Inspections

Pieces of the flight 587 vertical stabilizer and rudder underwent several nondestructive inspections after the accident. The vertical stabilizer was inspected using ultrasonic inspection, Lamb wave imaging, and x-ray computed tomography (CT) scanning, and the rudder was inspected using x-ray radiography, Lamb wave imaging, thermography, ultrasonic inspection, and computer-aided tap testing.[102]

NASA-Langley conducted an ultrasonic inspection and Lamb wave imaging of the vertical stabilizer's left and right skin panels. The ultrasonic inspection detected two notable delaminations (that is, fractures between the composite layers) near the front and rear spars on the left skin panel that extended upward from the lower end up to 43 inches at the front and up to 37 inches at the rear. The ultrasonic inspection detected no notable delaminations on the right skin panel, except for an area within about 4 inches of the right center lug. The Lamb wave imaging found no apparent evidence of any change in stiffness on the left and right skin panels of the vertical stabilizer, except for stiffness changes associated with thickness variations.

The U.S. Army Research Laboratory, Aberdeen, Maryland, and the Ford Motor Company's Nondestructive Evaluation Laboratory, Livonia, Michigan, conducted CT scanning of selected fractured pieces and cut sections from the vertical stabilizer lug areas (specifically, those in which delaminations had been identified during the ultrasonic inspections). The scanning produced two-dimensional slice images, and a visualization software program produced three-dimensional images from these two-dimensional slice images, as shown in Materials Laboratory Factual Report 03-033. Delaminations were observed, and multiple delaminations through the thickness were visible in some areas.

Airbus conducted a hand-held ultrasonic inspection of the vertical stabilizer at the main attachment and transverse load lug areas, the lower ends of the spars, rib number 1, and the hinge attachment fittings. Airbus also conducted a hand-held ultrasonic inspection of the rudder hinge attachment fittings and ultrasonic imaging of the vertical stabilizer skin panels at the stringer locations. An Airbus Inspection Protocol document dated March 4, 2002, indicated that Airbus found debondings, delaminations, and damages at

---

[102] Ultrasonic inspection is a contact technique that uses a transducer on the surface to measure the ultrasonic response of the structure. Lamb wave (also known as guided acoustic wave) imaging is a method for inspecting the stiffness and thickness of composites. CT scanning measures the transmitted x-ray intensity of a part that has been rotated and translated through an x-ray beam. Computers then use the data to reconstruct two- or three-dimensional renderings of the part. X-ray radiography is a quick, noncontact method for imaging subsurface features using x-rays and is commonly used to detect entrapped water in honeycomb structures. Thermography is a quick, noncontact technique for imaging subsurface features by measuring surface temperature changes. Computer-aided tap testing involves striking an impactor on the surface of a composite part and measuring the time of contact of the impactor, which is related to the local stiffness of the part. The data are collected and mapped into a color image in which each color is related to a range of stiffness values. For more information on these nondestructive inspection techniques, see Materials Laboratory Factual Reports 02-078 and 03-033 in the public docket for this accident.

the lower part of the vertical stabilizer in the lug areas, the spar areas, and rib number 1 area but not in the hinge attachment fitting areas.[103] The document also indicated that Airbus found debondings, delaminations, and damages in and at the rudder hinge attachment fitting areas.

NASA-Langley conducted x-ray radiography, Lamb wave imaging, and thermography of a portion of the rudder (from hinge attachment fitting 7 down to between hinge attachment fitting numbers 5 and 4). Entrapped water was detected at the lower portion of the rudder section by x-ray radiography and thermography.[104] The Lamb wave imaging determined that the facesheet had fractured from the honeycomb in areas at the lower portion of the rudder section. According to testimony at the public hearing from the NASA-Langley official who conducted the nondestructive examination research, the locations of the water found during the nondestructive examinations seemed to correspond with areas that showed visible damage and with facesheets fractured from the honeycomb. He also testified that the water most likely got into the rudder while it was in Jamaica Bay.

Representatives from the Center for Aviation Systems Reliability at Iowa State University, Ames, Iowa, conducted computer-aided tap testing of the rudder. During tap testing at Floyd Bennett Field on November 28 and 29, 2001, images of the left and right skin panels showed that areas of low stiffness were most likely caused by the debonding of the rudder skin from the honeycomb core structure along a number of buckling failures and that areas of high stiffness could be caused by manufacturing features such as core splices, core potting, and ply overlap.[105]

During tap testing at NASA-Langley from March 6 to 8, 2002, images of the left and right skin panels showed a high degree of consistency between the inside and outside surfaces of the rudder skin. The images also showed symmetrical areas of higher stiffness on the inside and outside surfaces. In addition, the images showed that the patterns for the large buckle failure near hinge attachment fitting number 5 were different between the left

---

[103] Personnel from Sandia National Laboratory, Albuquerque, New Mexico, manually inspected the lower end of the vertical stabilizer skin panels and the attachment lugs when the vertical stabilizer was at Floyd Bennett Field in Brooklyn, New York (before the vertical stabilizer and the rudder were shipped to NASA-Langley). The results of the inspection were difficult to interpret because of the complex geometry of the structure in those areas. Those results for which interpretation was possible corresponded well with the results reported by Airbus and NASA-Langley.

[104] Wayne State University in Detroit, Michigan, made several thermographic images of the rudder while it was at Floyd Bennett Field. The results were similar to those of NASA.

[105] In addition, personnel from Sandia National Laboratory performed tap testing and ultrasonic mechanical impedance analysis when the rudder was at Floyd Bennett Field. Tap testing was completed using an instrument similar to the one used during computer-aided tap testing (a digital readout but no computer interface). The ultrasonic mechanical impedance analysis method evaluated the object's vibrational response to an ultrasonic signal, and the response is related to local stiffness. The locations of stiffness changes detected by these techniques corresponded well with those detected by the computer-aided tap testing that was done at Floyd Bennett Field and at NASA-Langley.

and right skin panels.[106] On the right skin panel, the buckle failure was located aft of hinge attachment fitting number 5 at almost 90º to the spar with a 45º branch angled upward and, at the aft half of the chord, a 45º branch angled downward. The left skin panel buckle failure was angled mostly in a downward 45º direction aft of hinge attachment fitting number 5, although a branch was also present upward along the leading edge spar.

1.16.3.2 Materials Testing and Microstructural Examination

At the Safety Board's request, NASA-Langley conducted materials testing and microstructural examination of the vertical stabilizer and rudder.[107] Samples were selected from multiple locations on the vertical stabilizer and rudder to determine chemical composition, extent of cure, glass transition temperature, fiber and void volume fractions, and ply stacking sequence (layup).

The chemical composition of each sample from the vertical stabilizer was assessed using infrared spectroscopy, which measured the total attenuated reflectance through a microscope. The results were typical for CFRP material with no significant variances in the spectrums for each specimen.

The extent of cure and the glass transition temperature of one area from the upper end of the right skin panel were analyzed using modulated differential scanning calorimetry, dynamic mechanical analysis, and differential scanning calorimetry in both the as-received condition and in the dry condition.[108] The moisture content for the as-received condition was approximately 0.58 percent. The modulated differential scanning calorimetry results corresponded to an extent of cure greater than 97 percent. The dynamic mechanical analysis results showed that, in the as-received condition, the onset glass transition temperature measured 134° C, which was between the qualification values of 144° C for the dry condition and 122° C for the 50 percent relative humidity (0.7 percent moisture content) condition. The portion of the sample that was tested in the dry condition had an onset glass transition temperature of 149° C. The differential scanning calorimetry results showed no significant variance among the extent of cure and the glass transition temperature of all samples, and the results indicated that the extent of cure was sufficient.

---

[106] The most severe damage to the rudder occurred near hinge attachment fitting numbers 2 through 4, but the skin panels near these fittings were difficult to image. The most prominent facesheet-to-honeycomb fracture damage to the upper two-thirds of the rudder was the large buckles near hinge attachment fitting number 5.

[107] Some testing and microscopy were completed at Airbus' composites technology division in Bremen, Germany.

[108] The curing temperature for the vertical stabilizer CFRP material is specified to be 250° F. According to Airbus materials qualification data, the onset glass transition temperature should be 144° C in the dry condition and 122° C after exposure to a climate of 50 percent relative humidity (corresponding to a moisture content of 0.7 percent weight).

Samples of the vertical stabilizer material were cut, mounted, and polished for microscopic observation and quantitative analysis. Results indicated that the materials were prepared to the desired fiber volume fractions with acceptable void content.[109] No evidence of microcracking was observed. The observed layup in each sample was compared with the engineering drawing, and only the sample from the right forward lug showed layup discrepancies. The observed layup in each sample was compared with the engineering drawings, and only the sample from the right forward lug showed layup discrepancies. Among the 124 layers in this sample, 2 layers had orientations that were different from the drawing. Also, two layers appeared to be missing from one position through the thickness, but two additional layers were present in another position. The total number of layers of each orientation in this sample was correct, and the discrepancies represented a small fraction of the total number of layers.

For the rudder, the extent of cure and the glass transition temperature of a sample from the right skin panel were analyzed using modulated differential scanning calorimetry and dynamic mechanical analysis.[110] Portions of the sample were tested in the as-received condition and in the dry condition. The moisture content for the as-received condition was approximately 0.81 percent. The modulated differential scanning calorimetry results corresponded to an extent of cure of 100 percent. The dynamic mechanical analysis results showed that, in the as-received condition, the onset glass transition temperature measured 82.9° C, which was between the qualification values of 102° C for the dry condition and 75° C for the 70 percent relative humidity/70° C (0.75 to 0.90 percent moisture content) condition. The portion of the right skin sample that was tested in the dry condition had an onset glass transition temperature of 102.5° C.

Additional details of the testing discussed in this section appear in Materials Laboratory Factual Report 02-082.

1.16.3.3 Fractographic Examination of the Main Attachment Lugs

The Safety Board conducted a fractographic examination of the vertical stabilizer main attachment lugs. The fracture features were initially examined visually and then were examined using an optical stereoscope and scanning electron microscopy (SEM), which magnified the features. Fractures observed in the vertical stabilizer consisted primarily of translaminar fractures and delaminations. (Translaminar fractures require the breaking of fibers, the main load-bearing component of the composite. Delaminations do not require fiber breakage.) No evidence of fatigue was observed on any fracture surface.

The right rear lug had translaminar fractures intersecting the lughole. The translaminar fracture surfaces had a rough appearance consistent with fracture primarily under tensile loading. When examined using SEM, fibers that were generally

---

[109] According to Airbus engineering drawings, the fiber volume fraction for the vertical stabilizer CFRP material is 60 percent ± 4 percent. The maximum porosity permitted in the cross-section is 2.5 percent. The layup consists of fabric and tape layers, with the fabric layers oriented at ±45° and at 0/90° relative to the 0° fiber direction and the tape layers with fibers all oriented parallel to the 0° fiber direction.

[110] Other samples were selected from the rudder for peel tests and flatwise tensile tests.

perpendicular to the fracture plane showed radial fracture patterns consistent with overstress fracture under tensile loading. The right rear lug also had delaminations within the lug. Examination of a delamination surface using SEM showed evidence of hackles[111] associated with shearing at the fracture surface and did not show any evidence of fatigue. At the outboard side of the lug, the translaminar fractures were in locations and orientations that were consistent with a cleavage-tension failure mode.

The right center lug area was fractured in the vertical stabilizer structure above the lughole. The translaminar fracture surfaces had a rough appearance consistent with fracture under tensile loading. Also, the lugs had delaminations that were limited to within the lug or within 4 inches of a translaminar fracture.

The right forward lug had translaminar fractures that intersected the lughole. The translaminar fracture features were generally rough and were consistent with fracture under tensile loading. Also, the lug had delaminations that did not extend into the main portion of the vertical stabilizer beyond the lug.

The left rear lug had a translaminar fracture in the vertical stabilizer structure above the lughole. The translaminar fracture features near the inboard side of the fracture were generally rough and were consistent with overstress fracture under tensile loading. Most of the translaminar fracture surface at the outboard side appeared smooth and had yellow-colored fibers, which were consistent with postfracture damage. The left aft lug had delaminations extending up to 37 inches from the lower end. Fracture features on the left aft delamination indicated a shear direction that was consistent with the lower pieces moving downward relative to the remaining structure.

The left center lug area had a translaminar fracture through the vertical stabilizer structure at the rib 1 fastener location. Most of the translaminar fracture surface had a rough appearance that was consistent with overstress fracture under tensile loading, but fracture features that were consistent with compression loading were observed at the outboard edge, indicating bending to the left.

The left forward lug had translaminar fractures intersecting the lughole with rough fracture features that were consistent with overstress fracture primarily under tensile loading. Multiple delaminations within the lug and a bearing indentation on the outboard side were consistent with bending to the left. Also, the left forward lug area had a delamination extending upward into the structure up to 43 inches from the lower end. Fracture features on the left forward delamination indicated a shear direction that was consistent with fracture under tensile loading and/or bending to the left.

For detailed information on the fractographic examination of the vertical stabilizer main attachment lugs, see Materials Laboratory Factual Report 02-083 in the public docket for this accident.

---

[111] Hackles are matrix fracture features that indicate a significant component of shear across the fracture surface. Hackles are formed when matrix microcracks that are spaced fairly regularly along planes of maximum tension join together.

1.16.4 Structural Analyses and Tests

1.16.4.1 Finite Element Analysis and Progressive Failure Analysis

At the Safety Board's request, NASA-Langley and Airbus independently conducted an FEA to assess flight 587's most likely failure scenarios. The following failure scenarios were assessed: (1) fracture of the right rear main attachment lug; (2) buckling of portions of the vertical stabilizer skin panels, resulting in fracture of the right rear main attachment lug, rudder hinge line failure, or rudder fracture; (3) rudder skin fracture; (4) actuation of a bent rudder hinge line, resulting in rudder fracture or rudder hinge line failure; and (5) flutter of the vertical stabilizer resulting from delamination of the rudder skin sandwich panel.

NASA-Langley's and Airbus' analyses determined that the fracture of the right rear main attachment lug was the most probable initial failure. The analyses indicated that, after the right rear main attachment lug fractured, all of the remaining attachment fittings would fracture with no increase in external loading.

Under the direction of Safety Board investigators, NASA-Langley and Airbus evaluated the fracture of the right rear main attachment lug using global (entire vertical stabilizer) and local (lug area only) models. In the local model, the right rear main attachment lug was analyzed, including the neighboring skin and stringer region between ribs 1 and 5, the right half of ribs 1 through 5, and the right half of the rear spar. NASA and Airbus used detailed FEA models to determine lug contact areas, contact pressures, and the stress and strain profiles[112] under a loading representative of the accident condition (that is, the loading at the time that the vertical stabilizer separated from the aft fuselage) and Airbus' full-scale certification test (see section 1.6.4.3). The FEA results showed that the lug contact areas, contact pressures, and the stress and strain profiles for the accident condition were in agreement with those for the full-scale certification test.

NASA used a PFA model to determine the predicted failure load, failure mode, and location of failure initiation for the right rear main attachment lug for the accident condition and the full-scale certification test. The PFA results showed that, for the accident condition, the predicted failure load for the right rear main attachment lug was about two times its design limit load, as defined by the lateral gust condition. The PFA results also showed that the predicted failure load and location of failure initiation for the rear main attachment lugs during the full-scale certification test and for the accident condition were in agreement. In addition, the PFA results showed that the predicted failure mode of the rear main attachment lugs during the full-scale certification test and for the accident condition was consistent with a cleavage-tension failure.

---

[112] As stated in section 1.6.4.2, stress is the force per unit area of material. Strain is the deformation per unit length of material.

1.16.4.2 Postaccident Lug Tests

As indicated in section 1.16.4.1, NASA-Langley's and Airbus' FEA models showed that the stress and strain profiles of the right rear lug at the time of vertical stabilizer separation were equivalent to those of the full-scale certification test at failure, and NASA's PFA results showed that the failure load, failure mode, and location of failure initiation for the accident condition were equivalent to those of the full-scale certification test. However, no actual test data for the accident condition existed to validate the FEA and PFA results for the accident condition and to validate the most likely failure scenario for flight 587—fracture of the right rear main attachment lug. As a result, the Safety Board conducted three static lug tests at Airbus' production facility in Hamburg, Germany. The purpose of the tests was to demonstrate the behavior of the lugs under the flight 587 tensile load conditions, which were derived from FDR data and FEA models.

The FEA and PFA models indicated that lug strength was a function of the lug resultant force and the lug local lateral bending moment applied at the lug pin, which are primarily influenced by the root bending moment and net side load on the vertical stabilizer. The computed pin loading from the global and local analysis for the airplane model and accident condition was used to prescribe loading conditions for the static lug tests.

The first test was performed on August 13, 2003, using a left rear main attachment fitting from an A310 skin panel that was used as a manufacturing test article. During the test, the lateral load application control commanded a shutdown because of a change in the fitting's lateral stiffness. (As a result, the second and third static lug tests were conducted with displacement control instead of load control.) The load level achieved during this first test was 907 kN. Visible fiber cracks were observed on the outboard surface of the lug. The location of this damage was consistent with the initiation of failure in the cleavage-tension mode, as indicated by the PFA model results.

Delaminations within the test lug were similar to those observed within the flight 587 right rear main attachment lug. Also, the fracture initiation location was consistent with that predicted by the PFA model and was similar to the location observed in the accident fitting. Further, the measured strain values for the first test fitting compared well with the strain values predicted by the FEA models. In addition, the strain level comparison between the FEA models for the first static lug test and the FEA models for aircraft configuration indicated that this test represented the behavior of the flight 587 right rear main attachment lug during the accident sequence.

The second and third tests were conducted using fittings from the airplane used for American Airlines flight 903, which experienced an excursion outside the A300-600 certificated design envelope in 1997. (For more information about the flight 903 accident, see section 1.18.2.1.) The second test was performed on December 17, 2003, using the left rear main attachment fitting from the flight 903 airplane. The left rear main attachment fitting contained nonvisible damage that was not detected during a March 2002 nondestructive inspection (see section 1.18.2.1.1.) Loads were applied until the lug fractured at a load level of 893 kN. The type and location of the translaminar

fractures and delaminations were consistent with those observed during the first test and with the accident lug.

As with the first test, the fractures occurred at locations that were consistent with those predicted by the PFA model and similar to the locations observed in the accident lug. Also, the measured strain values for the second test fitting compared well with the strain values predicted by the FEA models. In addition, the strain level comparison between the FEA models for the second test and the FEA models for aircraft configuration indicated that this test represented the behavior of the flight 587 right rear main attachment lug during the accident sequence.

The third test was conducted on February 12, 2004, using the right rear main attachment fitting from the flight 903 airplane. The right rear main attachment fitting contained nonvisible damage that was greater than the damage that was detected during the March 2002 nondestructive inspection (see section 1.18.2.1.1). Loads were applied until a load level of 953 kN was reached; at that point, the maximum programmed load level had been achieved and maintained. The test was then stopped so that the load limitation could be removed. When the load application resumed, the test fitting fractured at a load level of 1,093 kN. Examination of the test data revealed that significant damage had occurred to the test fitting at a load level of 953 kN. This damage influenced the lug loading conditions during the subsequent loading.

Overall, the type and location of the fractures and delaminations in the third test lug were consistent with those observed during the first and second tests and with the accident lug. As with the first and second tests, the fractures occurred at locations that were consistent with those predicted by NASA's PFA model and was similar to the location observed in the accident lug. Also, the measured strain values for the third test fitting compared well with the strain values predicted by the FEA models up to 953 kN. In addition, the strain level comparison between the FEA models for the third test and the FEA models for aircraft configuration indicated that this test represented the behavior of the flight 587 right rear main attachment lug during the accident sequence.

In summary, the results of the three static lug tests produced failure load levels, a failure mode, and a failure initiation location that were consistent with the results of NASA-Langley's and Airbus' FEA models and NASA's PFA model. Also, the tested lugs had fracture features that were similar to those observed on the right rear main attachment lug from the accident airplane. In addition, even though the lugs used in the second and third test (from the flight 903 airplane) contained nonvisible damage, the tests indicated that the lugs performed to their design strength and that the nonvisible damage did not have a detrimental effect on the lugs' overall performance.

1.16.4.3 Summary of Structural Analyses and Tests

NASA's and Airbus' FEA models determined that failure of the right rear main attachment lug was the most probable initial failure. The FEA models and NASA's PFA model also determined that the failure initiated at the final observed maximum vertical stabilizer root bending condition during the accident flight, when the vertical stabilizer

was subjected to a global root bending moment of more than two times the value defined by the limit load design envelope. (As previously stated, for certification, the vertical stabilizer is only required to support loads of 1.5 times limit load without catastrophic failure.) The structural analyses showed that the large aerodynamic loading produced by the accident scenario would result in the right rear main attachment lug experiencing reaction forces and associated stresses that were equivalent to those that produced lug fractures in the Airbus full-scale certification test (lateral gust condition) and the Safety Board's static lug tests. Figure 16 compares the resultant lug forces at the time of fracture for the tests and analyses that were pertinent to the flight 587 investigation.

AA587 Lug Failure Load Comparison
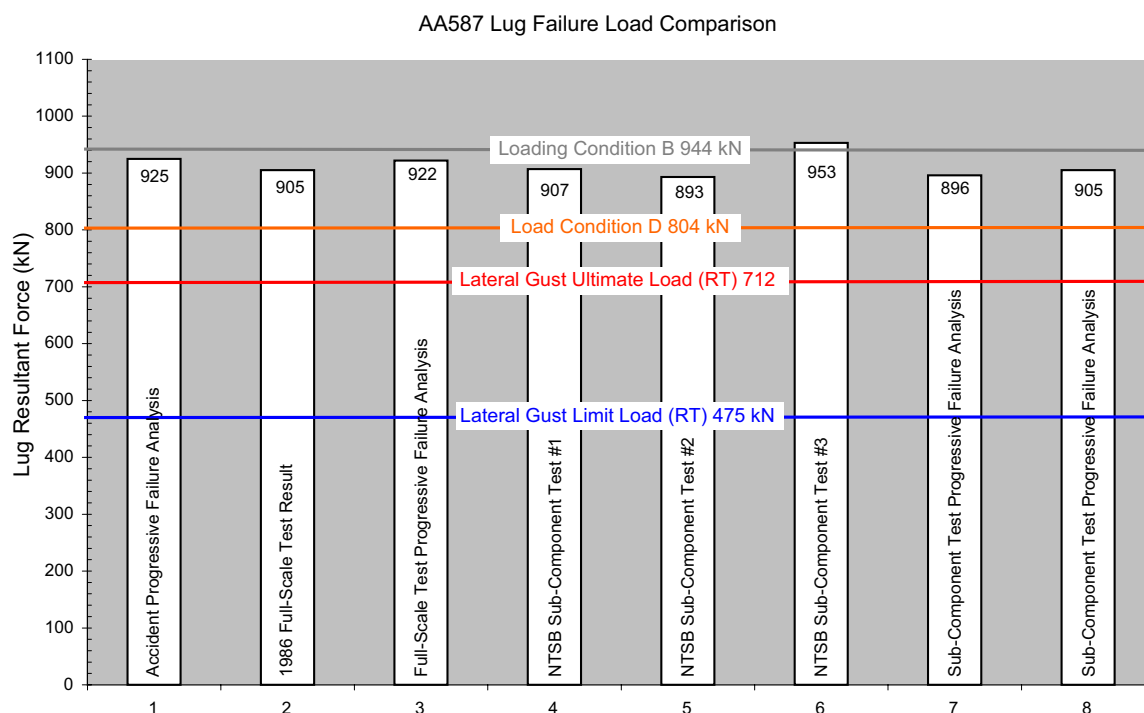
Note: The lug forces defined by the gray and orange lines correspond to the conditions defined by the gray and orange triangles shown in figure 15.

Figure 16. Comparison of Lug Forces at the Time of Fracture

The stresses developed exceeded the strength values for the CFRP material used in the manufacturing of the lugs; thus, the accident lug and the tested lugs fractured because of a tensile static overload. The physical evidence and the structural analyses showed that the accident lug's and the tested lugs' fracture features were consistent with a cleavage-tension failure observed in composite-bolted joints. Figure 17 shows the load on the flight 587 right rear main attachment lug and a depiction of the cleavage-tension failure mode.
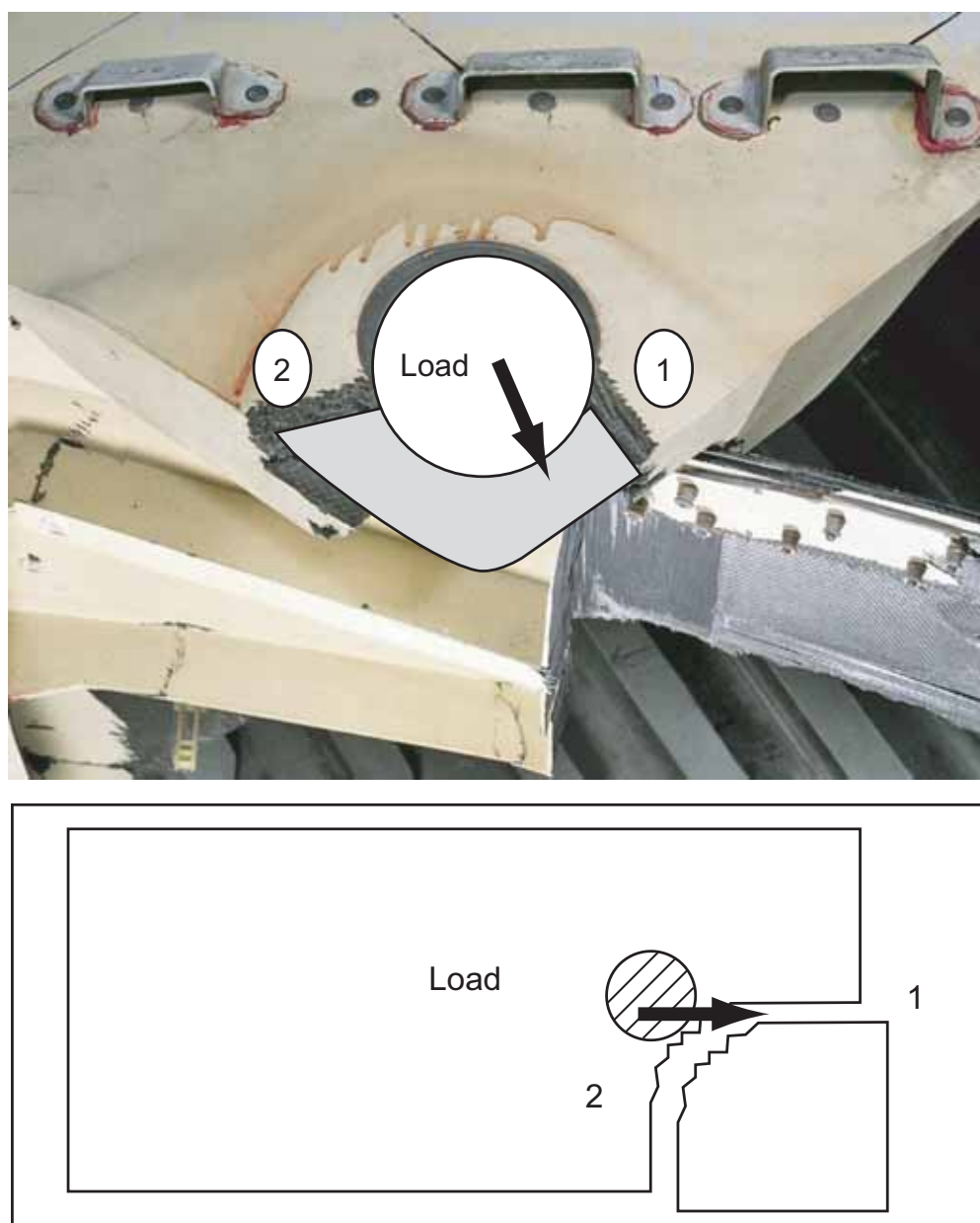
Note: Number 1 is the initiating fracture, and number 2 is the secondary fracture. The circle indicates the location of the pin and bushing, which were missing from the lug when it was found in the wreckage.

Figure 17. Load on the Flight 587 Right Rear Main Attachment Lug and a Depiction of the Cleavage-Tension Failure Mode

The structural analyses also indicated that, after the right rear main attachment lug fractured, all of the remaining lugs fractured sequentially. The fracture of the right rear main attachment lug initiated a nearly instantaneous separation of the vertical stabilizer from the aft fuselage.

1.16.5 Systems Testing

1.16.5.1 Rudder Servo Controls and Linkages

Between March 14 and 22, 2002, the three servo controls and linkages were examined, tested, and disassembled at the TRW Aeronautical Systems (the manufacturer of the rudder servo controls) facility near Paris, France.[113] Each of the rudder servo controls showed some corrosion and superficial damage, but each one functioned satisfactorily. No significant discrepancies were noted during the disassembly.

The control rods and bellcranks were intact from the bottom of the vertical stabilizer to the rudder servo controls, and no freeplay was observed. The three input springrods had white deposits on their internal components but no substantial corrosion. The lower and middle springrods passed a compression test but failed an extension test. The upper springrod could not be tested because it was bent.

1.16.5.2 Artificial Feel and Trim Unit

The artificial feel and trim unit was examined and disassembled on April 11 and 12, 2002, at Airbus' production facility in Hamburg. The examination found that some internal parts had been damaged by the postaccident fire and that the spring feel force could not be tested because melted components impeded the spring from compressing. The examination also found that the rudder trim jackscrew and nut portion were in good condition. As part of the examination, the artificial feel and trim unit was measured and was determined to be in the zero trim position. The disassembly showed no evidence of a malfunction in the unit.

1.16.5.3 Rudder Control System Ground Tests

From September 9 to 12, 2002, ground tests were performed on an A300-600 airplane at Airbus' facility in Toulouse to evaluate the characteristics of the rudder control system. No significant differences existed between the test airplane and the accident airplane regarding the rudder control system and related electronic flight control systems. The tests recorded the response of the rudder to slow and fast pedal inputs and slow and fast yaw autopilot commands.[114]

Data showing rudder pedal position versus rudder position were examined from these tests and from human performance tests that were also conducted in September 2002 at Airbus' facility in Toulouse (see section 1.16.6.2). The data showed a constant relationship between the rudder and pedal positions when the rudder was being driven at a slow rate by the pedal. The data also showed that the pedal led the rudder when the rudder

---

[113] Before this work, the three rudder servo controls had been sent to the Army Research Laboratory, where CT scans were performed.

[114] During the tests, the pedal rates ranged from about 1° per second (slow) to 80° per second (fast), and the yaw autopilot was commanded to move at rates that ranged from 1° per second (slow) to the maximum 37° per second (fast).

was being driven at a fast rate by the pedal (relative to the slow pedal rate data). In addition, the data showed that the pedal lagged behind the rudder when the pedal was being driven at a fast rate by the autopilot (relative to the slow pedal rate data).

The Safety Board did not test how a failure condition involving the yaw damper (specifically, a failure in one of the eight bearings in the differential unit that caused the yaw damper linkage to become jammed to the main bellcrank) would cause the yaw damper to move the rudder pedals. However, because yaw damper and autopilot inputs both occur at the differential unit, which is a relatively rigid structure, the Board determined that the relationship seen when the pedal was being driven at a fast rate by the autopilot—the pedal lagging behind the rudder—would also be seen if a yaw damper had become jammed to the main bellcrank.

1.16.5.4 Yaw Autopilot and Yaw Damper Actuators

On October 17, 2002, the yaw autopilot actuator was examined at the Safety Board's laboratory for proper electrical wiring between the main connectors and the solenoid valve. No determination could be made because of the extensive heat and physical damage to the actuator. On June 2 and 3, 2003, the yaw autopilot actuator was disassembled at the Goodrich Actuation Systems (the yaw autopilot actuator manufacturer) facility in St. Ouen L'Aumone, France, to determine whether the actuator was working properly. Again, no determination could be made because of the extensive heat and physical damage to the actuator.

On June 4 and 5, 2003, the yaw damper actuator was examined at the Goodrich Actuation Systems (the yaw damper actuator manufacturer) facility in Vernon, France, to determine whether the actuator was operating properly. No determination could be made because of the extensive heat and physical damage to the actuator.

1.16.5.5 Flight Control Linkages

FDR data from the accident flight showed large movements of flight control linkages and surfaces, primarily in the yaw and roll axes. As a result, on May 15, 2003, the flight control linkages on an American Airlines A300-600 airplane, N14065, were inspected at the company's maintenance facility in Tulsa for possible cross-coupling[115] or interference with moving parts. No areas of potential flight control linkage coupling or interference with moving parts were identified.

1.16.6 Human Performance Tests

1.16.6.1 Vertical Motion Simulator Tests

The Safety Board conducted tests and observations using the vertical motion simulator (VMS) at NASA's Ames Research Center, Moffett Field, California. The VMS is the largest motion-based simulator in the world. The VMS cab is mounted on a

---

[115] Cross-coupling is binding of the roll control linkages with the yaw control linkages.

6-degrees-of-freedom motion platform that provides a 60-foot vertical, 40-foot lateral, and 12-foot forward and aft motion capability. The cab has two side-by-side pilot stations, each of which is configured with three side-by-side monitors to indicate cockpit displays,[116] a transport-category-style control wheel and column, adjustable rudder pedals, and two throttle levers.

The VMS tests and observations, which were conducted from August 12 to 22, 2002, consisted of a reconstruction of the accident flight sequence using data from the accident airplane's FDR and other available sources. One objective for reconstructing the accident flight sequence was to observe and evaluate accelerations and angular motions that were similar to those that occurred during the accident flight. Another objective was to observe and evaluate cockpit displays, visual cues, and flight control motions that were similar to those experienced during the accident flight. The reconstruction of flight 587 was based on data from the accident airplane's FDR, calculations from the airplane performance study for this accident, and audio information from the accident airplane's CVR. The reconstruction began just before flight 587 departed from JFK and continued until the FDR ceased recording.

The cab motion was driven with the time histories of computed pilot station accelerations (longitudinal, lateral, and vertical) and angular position data that were based on the FDR's accelerometer and angular position data. The VMS motion was driven with computed accelerations that matched, as closely as possible, the accident airplane's motion during the first and second wake encounters. These accelerations were of particular interest because they could serve as possible explanations for pilot reactions on the controls. The VMS was not able to replicate the target longitudinal, lateral, and vertical accelerations for short periods of time during the accident sequence, and the entire sequence could not be replicated in a single series of motion because of limitations in the VMS motion system. Further, it is possible that small differences between the actual acceleration and the derived values (that is, the acceleration between data points) may exist because of the low sample rate of the pitch, roll, and heading data recorded on the FDR.[117]

During the VMS runs, primary flight control inputs, including the rudder pedals, control wheel, control column, and throttles, and heading, altitude, airspeed, attitude, and position data were developed from FDR data and portrayed on the cockpit displays. An outside visual scene based on a database of prominent visual features and coastline near JFK was also presented during VMS runs. In addition, selected VMS runs included a synchronized audio file (played over headsets) that contained portions of the accident flight's CVR recording. For each VMS run, time histories of cab motion parameters,

---

[116] The outboard monitor at each station presented graphical strip charts of input and actual accelerations for the longitudinal, lateral, and vertical axes and flight control positions. The inboard monitor at each station presented a compass rose navigation display of heading and track information and a wind vector indicator with digital readouts of windspeed and direction. The center monitor at each station was a primary flight display that showed altitude, attitude, and airspeed information; displayed a digital readout of event time; and contained an operable sideslip indicator that presented lateral acceleration data (based on Airbus specifications for the A300-600 sideslip indicator).

[117] Pitch, roll, and heading were sampled only one time per second.

including input data and measured cab accelerations values and flight control positions, were displayed on monitors in the VMS control room.[118]

Members of the human performance group for this accident participated in the VMS runs. Many participants described the first notable event experienced in the cab (that is, the first encounter with wake turbulence) as typical of a crossing wake encounter. Some participants felt a slight yaw before the flight controls moved. The slight yaw was described as a characteristic motion of an A300 flying through turbulence. The slight yaw motion was followed by a vertical acceleration, which was described by the participants as a "bump" that seemed to result from the wake encounter rather than flight control movements.

Regarding the second notable event experienced in the cab (that is, the second encounter with wake turbulence), the participants generally agreed that "very slight" cab motions were felt before the first movements of the control wheel and rudder pedal to the right. The cab motions were described as "barely perceptible" left lateral accelerations. Most participants did not experience any cab motion until less than 1 second before the first wheel motion. The first movements of the control wheel and rudder pedal to the right were "large and abrupt." The participants did not observe a visual or acceleration cue that would cause a pilot to apply the observed initial magnitude of wheel and pedal in response to the second notable event. After the first movements of the wheel and pedal to the right, large lateral accelerations were felt, and additional large, abrupt flight control movements in the yaw, pitch, and roll axes were observed. Although the participants felt lateral accelerations, they indicated that it was difficult to sense whether vertical and longitudinal accelerations were also present.

The VMS was also used to evaluate how the same reconstruction would feel with a variable ratio rudder travel limiter system. During those VMS runs in which a variable ratio limiter system was simulated, some participants stated that the movements of the pedals was so fast that it was hard to keep their feet on the pedals as they moved.

1.16.6.2 Control Force and Control Surface Displacement Ground Tests

Between September 10 and 17, 2002, members of the human performance group participated in A300-600 ground tests at Airbus' facility in Toulouse. The purpose of the tests was to record (1) pilot input forces to the rudder pedal, control wheel, and control column under dynamic conditions and (2) the corresponding flight control surface positions. These measurements were compared with the static force versus deflection curves in the Airbus A300-600 Aircraft Maintenance Manual to better understand the

---

[118] Two monitors displayed graphical strip charts of input and actual accelerations for the longitudinal, lateral, and vertical axes and flight control positions (identical to those presented in the cab). Two monitors presented a flight control display that provided dynamic flight control position information and rudder travel limiter position information in a pictorial format. The remaining four monitors presented the out-of-window visual scene, the primary flight display, the navigation display, and a chase plane view.

interaction between the pilots and the airplane during dynamic conditions. The tests were conducted at 165, 190, 240, and 325 knots.[119] The rates of control movements were 0.25, 0.5, and 1 Hz. Direct feedback concerning the pilot's performance was not provided to the three pilot subjects who participated in the tests.

The tests showed that the control wheel and rudder pedal forces applied at the three higher airspeeds—190, 240, and 325 knots—were either similar to, or greater than, the forces applied at the 165-knot airspeed.[120] The tests also showed rate saturation in the flight control surfaces (that is, when control inputs are made at a rate faster than the control surface can move). In addition, the force feel system for the rudder pedal requires a force of 65 pounds for the pedal to reach full travel at 165 knots; the tests showed that average pedal force for all three subjects was almost always above this value regardless of the set airspeed.[121] Similarly, the force feel system for the control wheel requires a force of 11.2 pounds for the wheel to reach full travel; the tests showed that the applied control wheel forces were typically between 30 and 40 pounds.

Tests were also conducted in which the subjects were instructed to move the control wheel and rudder pedal to 50 percent of their available range. The tests showed that the pedal force applied during the 50-percent condition resulted in full rudder travel, even though that force was one-half of the force applied at the 100-percent condition. The tests also showed that the control wheel force applied during the 50-percent condition resulted in reduced aileron motion.

1.16.7 Temperature Tab Study

To determine if heat in the aft fuselage had compromised the integrity of the vertical stabilizer's main attachment and transverse load fittings, a temperature tab study was conducted. Temperature tabs show the temperatures that result from the radiated heat from the APU bleed air duct and from radiant heat from the sun. The tabs have windows that are marked for specific temperatures, and a blackened window indicates that the tabs were exposed to temperatures greater than that marked by the window. Temperatures of 250º and greater degrade composite materials.

Five temperature tabs were installed in the aft fuselage of an American Airlines A300-600 airplane, N70054. The temperature tab ranges were 120º to 180º F, with windows marked in 20º increments, and 180º to 250º F, with windows marked for 180º, 200º, 230º, and 250º F.

---

[119] These four airspeeds represented different amounts of rudder pedal limiting and different amounts of control column force.

[120] Even though the amount of force required to achieve full rudder pedal travel on the A300-600 decreases as airspeed increases, the amount of force to achieve maximum control wheel travel is independent of airspeed.

[121] The lowest average peak force value was 61.1 pounds, which one subject applied during the 240-knot condition.

Two temperature tabs (one showing the 120º-to-180º F range and the other showing the 180º-to-250º F range) were placed adjacent to the fuselage skin. Another temperature tab (showing the 120º-to-180º F range) was placed over the bleed air duct on the left side of the fuselage. The last two temperature tabs (one showing the 120º-to-180º F range and the other showing the 180º-to-250º F range) were placed on the vertical stabilizer access cover. The airplane operated for several months with the five temperature tabs inside the aft fuselage.

On August 1, 2002, the temperature tabs were examined. The tabs that were adjacent to the fuselage skin showed exposure to 120º F, the tab that was placed over the bleed air duct showed exposure to 160º F, and the tabs that were placed on the vertical stabilizer access cover showed exposure to 120º F.

1.16.8 Cockpit Voice Recorder Sound Spectrum Study

The CVR group performed a sound spectrum study to identify any airframe vibration or flutter signals or unknown or unusual sounds during the airborne portion of the CVR recording. The recording was examined on a spectrum analyzer, which presents the frequency content of the signals graphically. The information from this visual presentation allows detailed analyses of the analog waveform and provides detailed timing information.

The CVR group applied a 100-Hz, low-pass filter to the CVR to document any airframe vibration or flutter. This filter passed sound energy below 100 Hz through a signal processor, which calculated the frequency content of the sound energy, and eight spectrograms (also known as voiceprints) displayed the resulting signals. One spectrogram showed signals for the time that the airplane was starting its takeoff roll, and seven spectrograms depicted the last 50 seconds of the cockpit area microphone CVR recording. (Three of the spectrograms were not useable as an examination technique because the sound spectrum analysis could not compensate for the loud noises toward the end of the CVR recording.) The spectrograms did not reveal any unusual vibration or flutter that preceded the sound of two thumps recorded on the CVR at 0915:52.9 (about 1 second before the first officer's statement, "max power").

The CVR group examined all of the CVR channels to document any unknown or unusual cockpit or airplane sounds. The sound of a brief squeak and rattle at 0915:37.3 and the sound of two thumps at 0915:52.9 were associated with movement of cockpit items in response to the airplane's encounter with wake turbulence. The CVR group identified no specific events or noises on the CVR that, by themselves, could be positively associated with the departure of the vertical stabilizer. Also, the Board did not determine the sources of sounds after the airplane was believed to have started its uncontrolled descent.

1.16.9 Speech Study

The Safety Board examined speech evidence from the CVR recording to determine whether nonverbal sounds, physical straining, and indications of psychological stress were present during the accident sequence. The Board made subjective evaluations and computer scorings of the audio information from the CVR hot microphone channels, which captured speech through the boom microphones attached to the headsets worn by each pilot.

The CVR transcript (see appendix B) did not identify any nonverbal sounds for the captain. The transcript did identify varied sounds for the first officer, including the grunt sound at 0916.

Research has shown that fundamental frequency[122] (pitch) can convey information about a speaker's psychological stress.[123] With regard to fundamental frequency, the Safety Board used the following guidelines from two previous accident investigations to evaluate the approximate degree of psychological stress experienced by a pilot and its effect on performance:[124]

- An increase in fundamental frequency by about 30 percent (compared with that individual's speech in a relaxed condition) is characteristic of stage 1 level of stress, which could result in the speaker's focused attention and improved performance.

- An increase in fundamental frequency by about 50 to 150 percent is characteristic of stage 2 level of stress, which could result in the speaker's performance being hasty and abbreviated and thus degraded; however, the speaker's performance would not likely display gross mistakes.

- An increase in fundamental frequency by about 100 to 200 percent is characteristic of stage 3 level of stress, or panic, which would likely result in the speaker's inability to think or function logically or productively.

Each CVR statement was analyzed for computer-generated measures of fundamental frequency. Specifically, average speech measures were examined during the different stages of flight to assess whether the flight 587 pilots responded to presumed increases in stress with corresponding increases in the speech measures. Consistent with

---

[122] Fundamental frequency is the rate (in Hz) at which the vocal chords of the larynx open and close during speech, releasing puffs of air. For example, a fundamental frequency of 150 Hz indicates that the vocal chords open and close 150 times per second.

[123] M. Brenner, E.T. Doherty, and T. Shipp, "Speech Measures Indicating Workload Demand," *Aviation, Space, and Environmental Medicine*, Vol. 65 (1994): 21-26.

[124] For more information, see National Transportation Safety Board, *Uncontrolled Descent and Collision With Terrain, USAir Flight 427, Boeing 737-300, N513AU, Near Aliquippa, Pennsylvania, September 8, 1994*, Aircraft Accident Report NTSB/AAR-99-01 (Washington, DC: NTSB, 1999). Also see National Transportation Safety Board, *EgyptAir Flight 990, Boeing 767-366ER, SU-GAP, 60 Miles South of Nantucket, Massachusetts, October 31, 1999*, Aircraft Accident Brief NTSB/AAB-02/01 (Washington, DC: NTSB, 2001).

previous psychophysiological evidence,[125] the speech study assumed that, under normal operations, the pilots would be the most relaxed when the airplane was parked at the gate (pre-taxi), their stress level would increase as they began taxi operations, and their stress level would be the greatest during takeoff.

The study found that both the captain and the first officer appeared to respond with characteristic changes in speech fundamental frequency to the increasing demands of the different stages of flight (pre-taxi, taxi, and takeoff). The first officer showed a large response to the wake encounters, but the captain did not show such a response. As a result, the average fundamental frequency values for each statement made by the captain and the first officer during the takeoff and wake encounter segments of the flight were evaluated. The evaluation indicated that the captain displayed a relatively uniform profile of stress that remained within a generally alerted level (stage 1). The first officer's last three statements before 0915:58.4 (when the right rear main attachment fitting fractured) showed progressively increasing fundamental frequency values that were significantly higher than those of his previous statements. These last three statements reached a high stress level associated with degraded performance (stage 2) but remained below a stress level associated with panic (stage 3).

1.17 Organizational and Management Information

American Airways was incorporated in 1930, and its name changed in 1934 to American Airlines, Inc. American Airlines is owned by the AMR Corporation and is headquartered in Dallas, Texas. American provides passenger and cargo service throughout North America, South America, the Caribbean, Latin America, Europe, and the Pacific. AMR Corporation also owns and operates American Eagle, a regional airline that provides service at American's hubs and other cities throughout the United States, Canada, the Bahamas, and the Caribbean. American Airlines acquired Reno Air in February 1999 and Trans World Airlines (TWA) in April 2001.

As of November 2001, American Airlines' fleet consisted of 869 transport-category airplanes, 35 of which were A300-600 airplanes (including the accident airplane).[126] Other airplanes in American's fleet at the time were the Boeing 717, 727, 737, 757, 767, and 777; the Fokker F.100; and the McDonnell Douglas MD-80. As of March 2002, American Airlines employed 12,746 pilots. (Of the 869 airplanes in American's fleet and the 12,746 company pilots, 107 airplanes and 1,906 pilots were acquired through TWA.)

---

[125] For more information, see J.J. Speyer, R.D. Blomberg, and J.P. Fouillot, "Evaluation of the Impact of New Technology Cockpits: Onwards From A300FF, A310, A320 to A330, A340." Presented at the International Conference, Human Machine Interaction and Artificial Intelligence in Aeronautics and Space, Toulouse, France, 1990, and reprinted in the Airbus Industrie publication *Workload and Vigilance, Physiologic Ambulant Monitoring, Automation and Error Tolerance, Cockpit Resource Management*. Also see G.F. Wilson, "An Analysis of Mental Workload in Pilots During Flight Using Multiple Psychophysiological Measures," *International Journal of Aviation Psychology,* Vol. 12, No. 1 (2002): 3-18.

[126] In 1988, American Airlines became the first A300-600 customer in the United States, ordering 25 airplanes initially and then another 10 airplanes.

1.17.1 Flight Crew Training

American Airlines' flight crew training academy is located in Fort Worth, Texas. The American Airlines General Flight Training Manual (dated September 1, 2001) indicated that pilot training was grouped into four categories: indoctrination, qualification (also known as initial training, transition training, and upgrade training), continuing qualification (also known as recurrent training), and special training (any training that was not covered by the three other categories). The manual also indicated that courses could be divided into four segments: distributed training, ground training, flight training, and qualification.

Distributed training included electronic material distributed via computer system, computer disk, or the Internet; paper material, such as handouts, study guides, or flight operations manuals; and videotapes. Ground training consisted primarily of systems and procedures training conducted by professional ground school instructors who were not qualified as line pilots. Flight training consisted primarily of maneuvers and line operational simulator training. The maneuvers training was primarily conducted by professional simulator instructors who were not qualified as line pilots. The line operational simulator training was conducted by American Airlines check airmen who were qualified as line pilots. Qualification training consisted of training to qualify and/or certify pilots in a specific airplane.

The American Airlines A300 fleet standards manager stated, during public hearing testimony, that A300 pilots receive about 225 hours of initial training before they qualify on the airplane. The fleet standards manager also stated that A300 pilots receive about 25 hours of recurrent ground school and simulator training every 9 months.[127] The recurrent training is presented during 2 days of ground school and 2 days (4 hours each) of simulator training.

1.17.1.1 Selected Event Training

On August 16, 1995, the FAA issued Flight Standards Handbook Bulletin for Air Transportation (HBAT) 95-10, "Selected Event Training." The HBAT defined selected event training as "voluntary flight training in hazardous inflight situations which are not specifically identified in FAA regulations or directives" and contained guidance and information on the approval and implementation of selected event training for Part 121 operators that use flight simulation devices as part of their flight training programs. The FAA issued the HBAT in response to Safety Board recommendations regarding training in unusual attitude recovery but expanded the HBAT to include recognition and containment of situations that might lead to unusual attitudes.

HBAT 95-10 indicated that some examples of selected event training were false stall warning (stickshaker) at rotation; full stalls; excessive (greater than 90º) roll attitudes; high (greater than 35º) pitch attitudes; engine failure at low altitude and airspeed, after

---

[127] On September 1, 2001, American Airlines changed its recurrent training cycle for pilots from 12 to 9 months.

takeoff, and during go-around; engine-out minimum control speed on autopilot; and engine-out instrument landing system to a missed approach with the autopilot engaged. HBAT 95-10 further indicated that, because of the broad range of operations and equipment in use in the air transportation industry, the maneuvers included as selected event training could vary among operators.

Just before HBAT 95-10 was issued, American Airlines initiated a selected events training program. Specifically, on July 27, 1995, American Airlines' managing director of flight training and standards sent a letter to the American Airlines principal operations inspector (POI), explaining that the company had made changes to its training manual and asking that these changes be approved. The letter stated, "based on recent NTSB concerns and recommendations for operators to provide flight crewmembers with flight training in hazardous inflight situations, we are taking the initiative to conduct this type of training during simulator flight training periods." The letter cited examples of maneuvers to be included during this training, including unusual attitude recoveries at excessive (90º or beyond) roll attitudes and high (35º or beyond) pitch attitudes. The POI approved the revisions to American Airlines' training manual on August 1, 1995.

1.17.1.2 Advanced Aircraft Maneuvering Program

American Airlines conducts the AAMP as the upset training module of its selected event training program. The AAMP is presented during initial, recurrent, transition, and upgrade training with descriptions highlighting the aerodynamic differences in airplane designs and varying engine, wing, and flight control configurations. According to American Airlines, the AAMP has evolved during the past several years as additional input has been received from various sources. Sections 1.17.1.2.1 through 1.17.1.2.5 present information on the development of the program, AAMP ground school training, AAMP simulator training, AAMP training materials, and comments on the program, respectively. Section 1.17.1.2.6 presents the results of the Safety Board's training simulator study, which examined an AAMP exercise involving recovery from an excessive bank angle, and section 1.17.1.2.7 discusses the Board's comparison of rudder pedal responses in an A300-600 airplane and American Airlines' A310/300 training simulator.

1.17.1.2.1 Development of the Program

AAMP development began in 1996 after a review of worldwide accidents from 1987 to 1996 involving large multiengine transport-category airplanes[128] found that the leading causal factor for these accidents was loss of control.[129] According to American Airlines, the aviation industry believed that many of the accidents might have been prevented if the pilots had been trained to specifically recognize and respond to airplane upsets. At that time, pilots of large transport-category airplanes generally did not receive

---

[128] This review was done as part of the development of the joint industry *Airplane Upset Recovery Training Aid* (see section 1.17.2.2.2).

[129] Other causal factors included controlled flight into terrain (CFIT), windshear, and wake vortex encounters.

any training in upset recovery or perform upset recovery maneuvers during flight operations.

American Airlines involved airplane manufacturers in the early development of the AAMP. The chief test pilot from McDonnell Douglas was one of the airplane manufacturer representatives who provided comments on the AAMP during its early development. The AAMP course developer (an American Airlines captain) indicated that the chief test pilot's comments were "very helpful" and that he "pretty much wrote the book" on the flight handling characteristics segment of the program. In a postaccident interview, the chief test pilot stated that "the rudder was the main area for discussion" because it needed to be "very well understood." The chief test pilot was also concerned about the use of simulation outside of the range of valid data.

The AAMP course developer and American Airlines' director of training traveled to the Boeing Company in Seattle, Washington, to present the AAMP. They asked test pilots and aeronautical engineers to observe the program to help "make the program better" and "ensure the accuracy of the program." Airbus was also invited to participate, but, according to the AAMP course developer, no test pilot or representative from Airbus attended the course at the time.

American Airlines held a 2-day AAMP Industry Conference on May 29 and 30, 1997, in Dallas. Participants included the FAA, the Safety Board, airlines, Boeing, McDonnell Douglas, Airbus, and the U.S. military. The first day of the conference was a presentation of AAMP ground school training, and the second day consisted of a question and answer session and a simulator demonstration. During the conference, American Airlines' chief pilot and vice president of flight requested feedback on the AAMP from the Boeing Commercial Airplane Group, the Boeing Douglas Products Division, Airbus, and the FAA. Section 1.17.1.2.5 discusses the coordinated response from these organizations.

1.17.1.2.2 Ground School Training Information

AAMP initial ground school training consisted of 6.5 hours of classroom instruction, and recurrent AAMP ground school training consisted of videotapes that included classroom subjects and a simulator briefing.[130] American Airlines provided initial AAMP ground school training to existing company pilots after the program was developed. The accident captain attended AAMP ground school training in May 1997, and the accident first officer attended AAMP ground school training in March 1997. Company pilots that were subsequently hired received initial AAMP ground school training during their initial training.

American Airlines also distributed an AAMP flight training booklet to pilots during their initial AAMP ground school training. The booklet included information that

---

[130] The videotapes shown during recurrent training were excerpts from AAMP videotapes that were created and distributed to company pilots beginning in December 1997. See section 1.17.1.2.3 for information about the AAMP videotapes.

supplemented the AAMP training and provided space for pilots to take notes during the training. The A300 fleet standards manager indicated that the booklet was not intended to be a stand-alone document and that the booklet was not handed out during recurrent AAMP ground school training. Section 1.17.1.2.4 provides additional details on the AAMP flight training booklet.

American Airlines' A300 fleet standards manager stated that, as a result of the flight 587 accident, AAMP ground school training for each fleet now includes discussions about the design maneuvering speed; the rudder travel limiter system; and the sensitivity, restrictive movement, and limited displacement of the rudder pedal. Also, the training now cautions pilots that only a small amount of rudder should be used, if needed, for roll upset recovery.

1.17.1.2.3 Simulator Training Information

The presentation at the public hearing by the American Airlines A300 fleet standards manager indicated that the following AAMP simulator profiles were designed to develop and reinforce specific flying skills:

- High AOA [angle of attack] maneuvering demo – NOT full stalls[131]

- Unusual attitudes – nose high & nose low[132]

- Microburst – demanding level

- Engine failure – low altitude & low energy

- GPWS [ground proximity warning system] – mode 2 'Terrain' profile

- High altitude upset – fleet specific

The accident captain received his initial AAMP simulator training in December 1997 and his recurrent AAMP simulator training in July 1998, July 1999, July 2000, and June 2001. The accident first officer received his initial AAMP simulator training in November 1997 and his recurrent AAMP simulator training in November 1998, November 1999, and December 2000. The first officer was scheduled to receive his next recurrent AAMP simulator training at the end of November 2001.

The A300 fleet standards manager indicated that, in response to HBAT 95-10, one AAMP simulator exercise involved an uncommanded roll to at least 90º. The fleet standards manager stated that, for this exercise, the simulator instructor told pilots that they were following a heavy jet (some instructors specifically stated that the airplane was a Boeing 747) and issued the appropriate wake turbulence warnings. The Safety Board notes that the NASA aviation safety reporting system (ASRS)[133] contained only a few wake turbulence reports that involved a large transport-category airplane, such as the

---

[131] According to the A300 fleet standards manager, American Airlines did not conduct full stall exercises because the simulators could not replicate them.

[132] The excessive bank angle exercise discussed later in this section was presented during this AAMP simulator profile.

A300, as the trailing airplane, but the available reports of such events between 1988 and 1999 indicated that the maximum bank angle estimated by pilots was usually 30º or less and was no more than 60º. The Board further notes that a study conducted by the Flight Safety Foundation,[134] which included a review of the Board's accident data, the FAA's incident data, and ASRS pilot reports, concluded that wake turbulence encounters were less frequent and less severe for large transport-category airplanes, such as the A300-600, than for smaller transport-category airplanes.

American Airlines' manager of simulation engineering stated that, during this exercise, the simulator instructor pressed a touch-screen button that was programmed to roll the airplane about 10º either left or right and then roll the airplane in the opposite direction past 90º.[135] The simulator inhibited the use of the ailerons, spoilers, and rudder until the airplane reached a bank angle of 50º or a maximum of 10 seconds had elapsed. After the airplane's bank angle reached 50º, yaw and roll control were phased back in during the next 1.3 seconds. The phasing in of control authority and the angular momentum of the airplane resulted in a bank angle of at least 90º. The roll rate after about 50º and the final bank angle (that is, the bank angle before recovery) depended on how effectively the pilot responded to the upset.

According to one of the American Airlines A300 simulator instructors who provided the first officer's most recent simulator training, if pilots just used aileron during the roll maneuver, they would put themselves into a sideslip condition, so "a little bit" of rudder was necessary. The instructor also stated that recovery from the roll maneuver was better when the pilots got on the flight controls earlier and that pilots needed to make corrections immediately.

After the flight 587 accident, American Airlines changed the manner in which it conducted upset recovery training. The simulator instructor now uses programmed buttons in the simulator to place the airplane into an upset. Once an unusual attitude is established, the instructor freezes the simulator at this position, and the pilot is able to study the situation while the instructor discusses it. Afterward, the instructor initiates the exercise and releases the simulator back to the pilot, who must execute the proper recovery. Also, the exercise is no longer described as a departure behind a heavy jet.

The American Airlines A300 fleet standards manager stated that American Airlines recognized that simulators had some limitations (for example, a simulator cannot replicate lateral, positive, and negative G forces or full stalls) but that simulators were the best tools available to teach upset recovery. His presentation at the public hearing indicated that American had invited Boeing, McDonnell Douglas, and Airbus to review AAMP simulator data. Further, the American Airlines manager of simulation engineering

---

[133] ASRS is a national repository for reports regarding aviation safety-related issues and events. ASRS reports are voluntarily submitted by pilots and other aviation professionals when they want to alert others about a potentially unsafe condition or event.

[134] P.R. Veillette, "Data Show That U.S. Wake-Turbulence Accidents Are Most Frequent at Low Altitude and During Approach and Landing." *Flight Safety Digest*, Flight Safety Foundation, March-April 2002.

[135] During climbout, the simulator replicated some light chop.

stated that sideslip and AOA were monitored when the AAMP simulation exercises were developed, each AAMP rolling and pitching exercise was flown and evaluated in each simulator fleet type, AAMP roll and pitch maneuvers stayed within valid simulator data, and the aerodynamic coefficient data tables provided by aircraft manufacturers for the simulators were not changed.

According to the A300 fleet standards manager, the AAMP was not intended to be a turbulence recovery training aid, but the program recognized that some situations involving wake turbulence could result in an upset.[136] The fleet standards manager stated that, at the time that the AAMP was being developed, more than 50 percent of American's fleet consisted of McDonnell Douglas Super 80s and F.100s, which have short wingspans and are thus possibly susceptible to an upset from an encounter with wake turbulence. He also stated that American never thought that the larger airplanes in its fleet at the time— the DC-10, MD-11, Boeing 757, Boeing 767, and A300—could end up in an upset from a "normal" encounter with wake turbulence.

1.17.1.2.4 Training Materials

As stated in section 1.17.1.2.2, American Airlines distributed an AAMP flight training booklet to company pilots during their initial AAMP ground school training. The original booklet, dated October 1, 1996, contained, among other things, information on the aerodynamics of swept-wing airplanes, unusual attitude recovery procedures, events that cause airplane upsets, and air mass anomalies (that is, windshear, microbursts, wake turbulence, and mountain wave activity). The booklet has been revised several times; the version that was current at the time of the accident was dated May 1, 2000.

The booklet that the accident pilots received during their initial AAMP training was dated January 1, 1997. That booklet contained the following information regarding pilot responses to wake turbulence:[137]

- Rolling moment on aircraft with shorter wing spans can be dramatic.

- Resulting attitude may be nose low with more than 90º of bank.

- Apply the appropriate unusual attitude recovery procedure.

  - Do not apply any back pressure on yoke at more than 90º of bank. ROLL FIRST – THEN PULL.

  - High AOA maneuvering = RUDDER.[138]

  - Corner speed – high lift devices extended.

---

[136] The Safety Board notes that, in December 1994, the FAA issued HBAT 94-17, "Pilot Training in Heavy Wake Vortex Turbulence: Awareness and Containment," to address this issue.

[137] The booklet described wake turbulence as a factor that had caused an increase in loss of control accidents and incidents.

[138] The September 1, 1997, booklet deleted the word "maneuvering" and added the word "coordinated" before "rudder." American Airlines made this change to address airplane manufacturers' concerns about the company's emphasis on the use of the rudder (see section 1.17.1.2.5).

The January 1, 1997, booklet contained the following aerodynamic information:

The effectiveness of the rudder as a roll control will increase with increasing AOA. At the higher angles of attack, THE <u>RUDDER</u> becomes the most effective roll control.

Smooth application of coordinated rudder[139] will improve roll response <u>significantly at higher AOA.</u>

The January 1, 1997, booklet contained the following information about high AOA maneuvering demonstrated during AAMP simulator training:

- Apply climb power
- Maintain 15º to 30º deck angle
- Respect the stick shaker (Fly in the PLI [pitch limit indication])
- Now roll alternately left and right to 40º of bank –
MAINTAIN HIGH AOA

  - First, use only ailerons and spoilers
    – Note: Sluggish roll response – Developing sink rate

  - Second, use <u>only rudder</u> – (smoothly)[140]
    – Note: Improved roll response – Developing <u>climb</u> rate

  - Third, practice combination (both aileron & rudder)
    – Note: Optimum <u>roll</u> response

In addition to the AAMP flight training booklet, American Airlines created a series of five AAMP videotapes, which presented the following subjects: unusual attitude recoveries, automation dependency, CFIT and mountain wave, control malfunctions and flight instrument anomalies, and microbursts. The videotapes on unusual attitude recoveries, automation dependency, and control malfunctions and flight instrument anomalies were distributed to company pilots for use in their personal libraries. The videotapes on CFIT and mountain wave and microbursts were not distributed to pilots, but information from these videos, as well as the other three videos, was presented during recurrent training.

The videotape on unusual attitude recoveries was dated December 19, 1997, and was made during an actual AAMP training class that occurred during either March or April 1997. The class was attended by about 200 company pilots and was taught by the AAMP course developer. The unusual attitude recoveries videotape emphasized the

---

[139] The vice president of training for Airbus North America customer services stated, during public hearing testimony, that the term "coordinated rudder" was "essentially to zero sideslip" and that this term would have been well understood by the airline pilot community. Similarly, American Airlines' manager of simulation engineering stated at the public hearing that coordinated rudder was "flying the airplane without sideslip or yaw."

[140] The September 1, 1997, booklet added the words "note lead/lag [response times]" within the parentheses. This information was not in the booklet that the captain and the first officer received but was current at the time of the accident.

smooth application of rudder with small inputs for coordinated use and suggested avoiding, at high AOAs, large rudder inputs that would induce large sideslip angles. The videotape discussed information about lead and lag response times for the rudder and emphasized that a lack of understanding of the rudder could lead to overcontrolling the airplane. The videotape also demonstrated a high AOA control application in the simulator. The instructor on the videotape stated the following regarding recovery from unusually nose-high situations:

> Now some of you [pilots attending the AAMP training class] out there might say 'well, I'm going to use a little coordinated rudder[141] to help the nose come down.' Fine, that's fine, that's good technique. A little, OK, smoothly applied, I mean, understand right here: if you jam full right rudder, that's the spin entry procedure, see?

To address airplane manufacturers' concerns about the company's emphasis on the use of the rudder (see section 1.17.1.2.5), American Airlines included a segment at the end of the videotape that reinforced the proper use of the rudder. The segment repeated warnings about how powerful the rudder could be, reiterated that rudder-generated sideslip could lead to a loss of control, and reemphasized that the rudder must be applied in smooth, appropriate amounts.

The A300 fleet standards manager indicated that, "AAMP always taught…the pilots to respect the power of the rudder." His presentation at the public hearing included the following excerpts that were included in the December 1997 videotape:

> To complete this unusual attitude recovery procedure segment of the Advanced Aircraft Maneuvering Program, I'd like to briefly review the proper use of rudder at high angles of attack. As I stated in the aerodynamics segment, smooth application of small amounts of rudder, coordinated with the aileron, will significantly improve the roll response at high angles of attack. I'd like to emphasize that we have very large, powerful rudders on our aircraft. We do not want to introduce high sideslip angles at high angles of attack, by either kicking the rudder or applying the rudder in excess at high alpha. It only requires a small amount, smoothly applied for a coordinated rudder to achieve the desired result. This coordinated rudder will significantly improve the roll response at high angles of attack.

At the public hearing, the vice president of training for Airbus North America customer services stated that he had previously reviewed this videotape and was concerned that it had defined coordinated rudder as "rudder in the direction of the roll." The Airbus vice president also stated that he was concerned that the videotape taught procedures rather than awareness.

The videotape on control malfunctions and flight instrument anomalies, dated March 1, 1999, also discussed the use of the rudder. The crossover AOA was presented to

---

[141] The AAMP instructor specifically stated that the term "coordinated rudder" meant moving the control wheel and the rudder pedal in the same direction.

show that the rudder became more powerful than the aileron and spoilers at high AOAs. A Boeing test flight pilot demonstrated that forward yoke pressure on the control column would regain aileron and spoiler control over the rudder by reducing the AOA.

1.17.1.2.5 Comments on the Program

In a May 22, 1997, letter to the chief test pilot at Airbus, an American Airlines A300 technical pilot indicated his concern that AAMP handout pages stated that "at higher angles of attack, the rudder becomes the primary roll control." The technical pilot's letter also expressed concern that "the program infers that aileron application in these situations is undesirable since it will create drag caused by spoiler deflection." Further, the letter stated that the AAMP instructor had been teaching pilots to use the rudder to control roll in the event of a wake turbulence encounter. The American Airlines A300 technical pilot asked the Airbus chief test pilot for his thoughts on this subject and suggested a teleconference a few days later. In a May 23, 1997, facsimile, the chief test pilot stated that he shared the A300 technical pilot's concern about the use of rudder at high AOAs and agreed to a teleconference to discuss the matter.

In a June 13, 1997, internal letter to colleagues, the Airbus chief test pilot indicated that he had spoken with American Airlines. The letter detailed the chief test pilot's general views regarding the use of the rudder at low airspeeds and the use of flight training simulators, which he had discussed during the teleconference. The letter stated that, although the rudder becomes more effective for roll control as airspeed is reduced, normal lateral control (aileron and spoilers) is effective down to the stall speed. The letter indicated Airbus' recommendation to use the rudder as necessary to avoid sideslip but not as the primary source of roll. The letter also indicated that flight training simulators could not be expected to be accurate at the edges of the flight envelope and did not include dynamic maneuvers outside the normal flight envelope. In addition, the letter stated that simulators were "particularly inaccurate for large sideslip angles" and that a pilot might draw the wrong conclusion from maneuvers involving the use of rudder at low airspeeds.

As stated in section 1.17.1.2.1, during the May 1997 AAMP Industry Conference, American Airlines' chief pilot and vice president of flight requested feedback on the program from the Boeing Commercial Airplane Group, the Boeing Douglas Products Division, Airbus, and the FAA. In an August 20, 1997, letter, representatives from these organizations provided their joint response, indicating that the AAMP was already an "excellent" program and that the intent of the letter was to provide "additional and corrected technical information as well as the benefit of [the representatives'] experience in unusual areas of the flight envelope for training pilots in various airplane models." The letter addressed six subject areas, including the use of rudder and airplane recovery from upsets.

Regarding the use of rudder, the letter stated that "the excessive emphasis on the superior effectiveness of the rudder for roll control vis-à-vis aileron and spoilers, in high angle of attack, is a concern" and that a more appropriate standard would be to first use the full aileron control and, if the airplane is not responding, to then use rudder as necessary to obtain the desired airplane response. Also, the letter stated that sideslip angle was a

"crucial" parameter that needed to be discussed in the program because "it is probably not well understood by many line pilots but has a significant impact on an airplane's stability and control."

Regarding airplane recovery from upsets, the letter indicated that, in a high AOA, nose-high upset, the wing should be unloaded first using down elevator and down stabilizer trim before roll is introduced.[142] The letter stated that roll should only be introduced after exhausting the use of pitch axis controls and considering the reduction of thrust (on airplanes with wing-mounted engines). The letter further stated that "introducing roll angles at extremely high angles of attack creates sideslip" and that "sideslip introduced by rapid roll may result in departure from controlled flight." In addition, the letter indicated that reducing thrust on wing-mounted engines is another way to assist a pilot in lowering an airplane's nose.

In a letter dated October 6, 1997,[143] American Airlines' chief pilot and vice president of flight responded to the letter from the representatives from the Boeing Commercial Airplane Group, the Boeing Douglas Products Division, Airbus, and the FAA. The chief pilot and vice president of flight explained that American Airlines does not advocate using "rudder first" or "rudder only." Also, he pointed out that four different sections of the AAMP emphasized that, when an airplane is not responding to aileron and spoiler control, smooth application of coordinated rudder should be used to obtain the desired roll response.

American Airlines' chief pilot and vice president of flight also disagreed with the position taken in the representatives' letter concerning airplane recovery from upsets, stating that company pilots "will not hesitate to roll the lift vector off the vertical [axis] to generate the required nose down pitch rate" if unloading with elevator does not result in an adequate nose-down pitch rate. He further stated, "any delay in initiating the roll (if required) could lead to a very tenuous situation." In addition, he stated that American Airlines would not teach its pilots to use nose-down stabilizer trim as the next step after unloading because of the "significant risks associated with running stabilizer trim during an upset recovery" or to reduce thrust before rolling the lift vector off the vertical axis because it may be "counter-productive" for airplanes with wing-mounted engines.

On February 6, 2003, American Airlines provided the Safety Board with a copy of a May 27, 1997, memorandum from the company's managing director of flight operations technical to the company's chief pilot and vice president of flight. The memorandum stated that the managing director of flight operations technical had "grave concerns about some flawed aerodynamic theory and flying techniques that have been presented in the AAMP." The memorandum also stated that it was wrong and "exceptionally dangerous"

---

[142] The AAMP recovery procedure at the time for this type of upset instructed the pilot to unload with forward yoke pressure toward zero G force and roll (limiting the bank angle to about 70°) toward the nearest horizon to lower the airplane nose. (The current procedure limits the bank angle to about 60°, as indicated in section 1.17.2.2.)

[143] In a December 2, 2002, letter to the Safety Board, Airbus indicated that this letter from American Airlines was not received until January 20, 1998.

to teach pilots to use the rudder as the primary means of roll control in recoveries from high AOAs. The managing director of flight operations technical asked the chief pilot and vice president of flight to consider several points, including the following:

- The use of excessive roll at high AOAs will cause a spin or a snap roll.

- The rolling moment caused by rudder input is generated by sideslip, which is slow to take effect but then rapidly becomes uncontrollable, resulting in a spin, snap roll, or pilot-induced oscillation.

- Yaw dampers remain active at high AOAs, with unpredictable and perhaps adverse consequences.

- Transport-category airplanes are designed so that ailerons are effective at slow airspeeds and high AOAs.

- The Boeing chief test pilot said that he "vehemently disagreed" with the aggressive use of rudder at high AOAs because "it is extremely dangerous and unpredictable." The McDonnell Douglas chief test pilot expressed "serious concerns and disagreement" about the rudder theories presented in the AAMP.

In addition, the memorandum stated that American Airlines was conducting high AOA training in simulators that did not accurately replicate the behavior of the airplane and was "very likely" to provide a false sense of confidence to pilots. The managing director of flight operations technical suggested that American Airlines take "immediate corrective action to change our training programs and advise our flight crews of the correct nature and danger of rudder inputs at high angles of attack."

1.17.1.2.6 Training Simulator Study

On December 4, 2002, members of the human performance group conducted a study in the American Airlines A310/300 training simulator to examine the AAMP excessive bank angle recovery exercise that the accident pilots completed.[144] After receiving initial AAMP ground training and an AAMP simulator briefing,[145] six pilots from the group performed the exercise multiple times using different pilot input strategies.

The simulator instructor set up the exercise as a departure behind a 747 and initiated a roll event when the airplane was banked at an altitude between 2,000 and 2,500 feet and an airspeed of about 240 knots. The airplane exhibited an uncommanded roll in one direction (determined arbitrarily by the computer) followed immediately by a substantial uncommanded roll in the opposite direction. The simulator momentarily inhibited the airplane's response to pilot roll and yaw inputs during the event to allow the

---

[144] The training simulator study did not include any of the changes to the excessive bank angle recovery exercise that were introduced after the flight 587 accident.

[145] During the briefing, the simulator instructor stated that the amount of bank generated during the exercise could be a function of the pilot's response, a quick reaction might prevent an excessive amount of roll, and some coordinated rudder should be used during the recovery. This simulator instructor provided the accident first officer with his A300-600 upgrade training and his initial A300-600 recurrent training.

airplane to reach a substantial bank angle before recovery began. Each pilot was instructed to recover the airplane according to the method detailed in the AAMP ground training.

This procedure was repeated five additional times for each pilot except that the roll maneuver was initiated during level flight after the pilot indicated his readiness. Also, the pilots were instructed to use each of the following five specific recovery methods: partial wheel and no rudder, full wheel and no rudder, full wheel and partial rudder, full wheel and full rudder, and the pilot's preference.

The first of the six trials had an upset initiation when the airplane was typically flying with a 20° left bank at an airspeed of 235 knots. All of the pilots responded with a full control wheel input (between 77° and 80°) supported by a rudder pedal input (ranging from 6.7° to 14.5° with an average of 10.8°). Five of the six pilots had essentially simultaneous rudder pedal and control wheel inputs. Three of the pilots recovered the airplane before it had reached a maximum bank angle of 90°, and the other three pilots recovered the airplane with a maximum bank angle between 108° and 114°. In post-trial comments, four of the pilots stated that they were surprised by the onset of the event.

The four recovery methods used during the second through fifth trials showed little difference among the average maximum bank angle reached (between 104° and 107°), and none of the recoveries was achieved before the airplane reached a bank angle of 100°, even with the wide variation of the inputs made. Three of the six pilots reported that partial wheel and no rudder was the worst recovery method, and all six pilots questioned whether this method provided sufficient control authority to achieve recovery. Two of the pilots reported that a recovery with full wheel and full rudder was the worst method because of the possibility of overcontrol.

Data from the fifth trial (full wheel and full rudder) suggested a discrepancy between the simulator and the airplane concerning compliance in the rudder control system.[146] Specifically, at an airspeed of 240 knots, the maximum pedal travel on the A300-600 should be limited to 7.9°. When the pilots made full rudder inputs, the maximum pedal travel varied from 10.3° to 18.9°. Some of the pilots reported that they did not have a sensation of going past a pedal stop when making the full pedal inputs.

During the last of the six trials (the pilot's recovery method preference), most of the pilots responded with nearly full control wheel and partial rudder pedal inputs. Slightly less input was made on both controls than during the first trial, and the pedal response was typically delayed by at least 1 second after the control wheel response.

On the basis of post-trial comments and pilot actions during the first and last trial, the pilots appeared to prefer a recovery strategy of full wheel and limited rudder in

---

[146] Compliance in the rudder control system can result from several factors, but it is predominately the result of the cables stretching elastically when forces applied to the rudder pedal are in excess of the forces required to reach the pedal stop. According to American Airlines and Airbus, the compliance of the rudder control system in the simulator is mathematically computed rather than determined by actual cables.

response to the simulator exercise. Also, five of the six pilots indicated, at least once during the six trials, that there was a lack of flight control response during the initial upset.

1.17.1.2.7 Comparison of Rudder Pedal Responses in the A300-600 Airplane and the American Airlines A310/300 Training Simulator

From January 31 to February 2, 2002, Safety Board investigators performed tests on an American Airlines A300-600 airplane at American's maintenance facility in Tulsa. With the assistance of an American Airlines representative, the investigators measured rudder pedal limits at different airspeeds (30, 150, 165, 190, 220, 240, 250, 275, 310, and 335 knots), the travel of the control wheel, and the dimensions of the wheel. To measure the pedal limits, an investigator sat in the left cockpit seat and pushed the left pedal until the stop was contacted (normal force) while another investigator in the right cockpit seat recorded the actual pedal motion. The investigator in the left cockpit seat then pushed the left pedal as hard as he could (high force), and the actual pedal motion was again recorded.

Safety Board investigators repeated these tests on April 23, 2003, in the American Airlines A310/300 training simulator. With the assistance of two American Airlines representatives, the investigators assessed how the portrayal of rudder pedal characteristics in the simulator compared with those of the actual A300-600 airplane. The investigators found that the rudder pedal motion in the simulator and the airplane produced by normal and high pilot input forces resulted in different pedal displacements despite the pedal travel limits, as shown in figure 18. The differences were attributed to the software representation of the elastic cable stretch in the simulator, which was less stiff than the cable stretch on the A300-600 airplane.
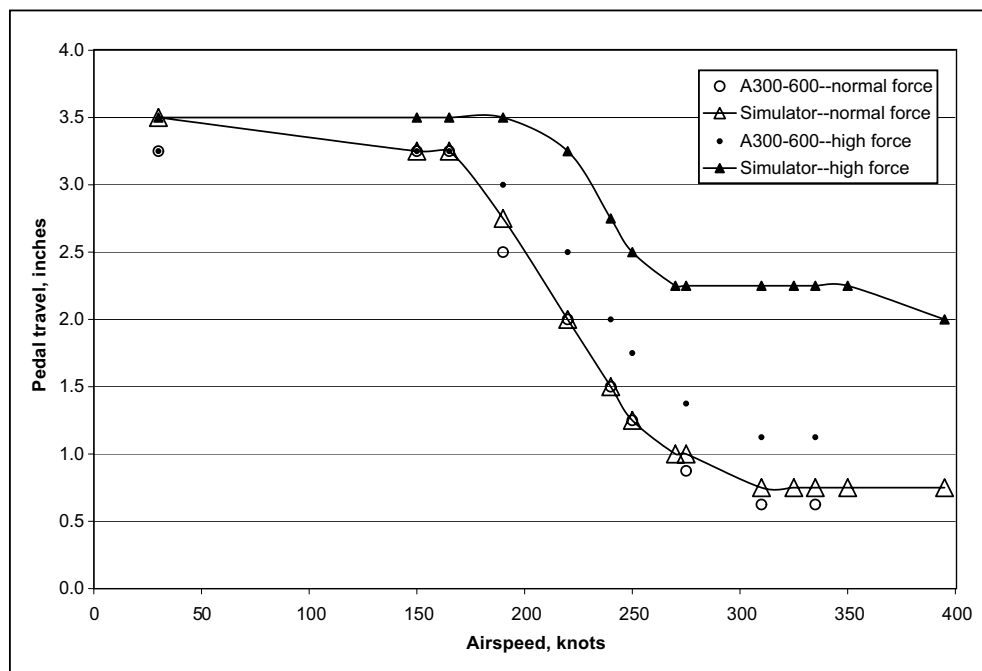
Figure 18. Rudder Pedal Motion With Normal and High Pilot Pedal Force in the A300-600 Airplane and the American Airlines A310/300 Training Simulator

1.17.1.3 Postaccident A300 Pilot Training

In early 2003, the American Airlines A300 fleet standards manager and an A300 technical pilot provided classroom training to every company A300 pilot on the airplane's rudder control system. The training covered vertical stabilizer side force characteristics, 14 CFR Part 25 certification, rudder travel limiter effects, rudder pedal force and displacement, and pilot input/yaw damper interaction.[147]

The training emphasized several points. First, certification standards do not account for a maneuver with alternating rudder inputs, even though such a maneuver may result in excessive loads on the vertical stabilizer. Second, as airspeed increases, the rudder pedals become more sensitive. Third, applying a rudder pedal force of 110 pounds or more will override any yaw damper input. Last, if pilot control inputs cause undesirable or unexpected airplane motion, the pilot should place the control in its neutral position until the airplane stabilizes. In addition, the A300 pilots were informed that the training presentation was available on the company's pilot Web site and that they would be receiving additional training on the A300 rudder control system during recurrent training.

1.17.2 Flight and Operations Manuals

1.17.2.1 Use of Rudder

American's A300 Operating Manual, Land, page 3 (dated November 15, 2001), contained a reference to the use of alternating rudder inputs in the "L/G [Landing Gear] UNSAFE INDICATION" procedure when the landing gear handle is selected down. The procedure included the following note:

> If one gear remains unlocked, perform turns to increase load factor and perform
> alternating side slips in an attempt to lock the gear. Prior to performing any side
> slip maneuver, ensure all Flight Attendants and passengers are seated.

On July 17, 2002, American Airlines issued A300 Operating Manual Bulletin number 300-1-141, "L/G [Landing Gear] UNSAFE INDICATION" procedure. The bulletin contained a warning not to perform the alternating sideslips described in the note for the procedure. The bulletin revised the note to state the following:

> If one gear remains unlocked, perform coordinated turns to increase load factor
> (not to exceed 45° of bank). Prior to performing the turns, ensure that all Flight
> Attendants and passengers are seated with seat belts fastened.

---

[147] Training in these areas had been identified as weak or nonexistent.

American's A300 Operating Manual, Flight Controls, page 8, dated September 8, 1999, indicated the following information under the heading "Yaw Control System/Rudder Control":

> Two independent rudder travel limiting systems, controlled by the rudder travel feel and limitation computers, progressively decrease the maximum rudder travel from ± 30° below 165 knots (low speed range) to ± 3.5° above 310 knots (high speed range).

American's A300 Operating Manual, Abnormals/Flight Controls, page 6, dated March 26, 2001, contained procedures for a rudder travel fault, which included the following note: "use rudder with care above 170 knots to prevent overcontrolling with loss of rudder travel limiter."

1.17.2.1.1 Manufacturer's Information

Airbus' A300-600 FCOM volume 2, Procedures and Techniques, page 1, revision 25 (dated February 2001), contained one restriction on the use of rudder, which appeared in the procedures for a recovery from stall warning. The procedures stated that, if an airplane was out of a stall and no threat of ground contact existed, the pilot was to retract the landing gear (if extended), recover normal speed, and select the flaps as required. If one engine was inoperative, the pilot should "use with care" power and rudder. In March 2002, Airbus issued an A310/A300-600 FCOM bulletin that included, among other things, information about restrictions on rudder use. Section 1.18.4.1.2 provides details about the information in this bulletin.

Airbus' A300-600 FCOM, volume 2, Abnormal Procedures, page 5, revision 25 (dated February 2, 2001), included the following procedure for a "landing gear unsafe" indication if the landing gear is selected down: "If one gear remains unlocked, accelerate to V_{MAX} [maximum selectable speed for landing gear extended], perform turns to increase the load factor and perform alternating side slips in an attempt to lock the gear." Revision 26 (dated March 2002) added a note to the procedure. The note stated the following:

> Sideslip is used to generate aerodynamic loads on the landing gear structure to force the downlock into position. The sideslip should be initiated using the rudder on the same side of the aircraft as the unsafe gear indication, i.e., if the right main landing gear is unlocked, slowly apply right rudder up to full deflection if necessary while maintaining wings level to generate sideslip. If the gear still fails to lock, then slowly return the rudder to neutral, allow the airplane to stabilize, and then slowly apply opposite rudder. If necessary, repeat this cycle in an attempt to lock the gear.

Airbus' A300-600 FCOM contained one reference before the accident to the reduction in rudder pedal travel at higher airspeeds. The reference appeared in volume 1 in the Flight Controls/Yaw Control section, page 1, and stated "the rudder travel limiter

reduces the pedals and rudder deflection from ± 30º at speeds below 165 kt [knots] to ±3.5º at 310 kt and above."[148]

1.17.2.2 Unusual Attitude Recovery

American Airlines' A300 Operating Manual, Maneuvers, discussed unusual attitude recognition and recovery. Page 12, dated November 15, 1997, stated the following procedure for a nose-high recovery:

- Unload with forward yoke pressure toward "0" g force.

- Roll the airplane toward the nearest horizon – limit bank angle to approximately 60º.

- Increase thrust in most nose high recoveries.

- As airplane symbol approaches the horizon, make a coordinated roll to wings level with a slight nose down attitude.

- Adjust airspeed, thrust, and pitch as necessary.

On March 8, 2002, American Airlines issued A300 Operating Manual Bulletin number 300-1-137, "Upset Recovery/Unusual Attitudes." The information contained in the bulletin provided piloting techniques, maneuvers, and guidelines for recovery from an upset/unusual attitude, as recommended by Airbus, and replaced the unusual attitude information dated November 1997. The bulletin included the following procedure for a nose-high recovery:

Pilot-Flying and Pilot-Not-Flying
- Recognize and confirm the situation.

Pilot-Flying
- Apply nose-down elevator up to full deflection.

- Apply nose-down trim as appropriate.

- Reduce thrust (altitude permitting).

- Roll to obtain a nose down pitch rate (if necessary).

- Complete the recovery:

    - When approaching the nearest horizon, roll to wings level.

    - Check airspeed and adjust thrust.

    - Establish pitch attitude.

Pilot-Not-Flying
- Call out attitude, airspeed, and altitude throughout the recovery.

- Verify all required actions have been completed and call out any omissions.

---

[148] This FCOM information was not correctly cited. The rudder deflection is limited to 3.5° at 390 knots rather than 310 knots, and the rudder deflection is limited to 5° at 310 knots (as stated in section 1.6.2). According to Airbus, the FCOM has been corrected.

1.17.2.2.1 Manufacturer's Information

Airbus' A300-600 FCOM, volume 2, Procedures and Techniques, page 2 (dated February 2002), stated the following lateral and directional control information:

> Unusually large amounts of aileron and spoiler input may be required to recover from an upset.
>
> If during this upset, the angle of attack increases beyond a certain value (stick shaker and buffeting), then the airflow over the wing separates and the efficiency of ailerons and spoilers decreases. Since the rudder is rarely aerodynamically stalled, it is still possible to generate induced roll rate using the rudder.
>
> CAUTION: At high angle of attack, pilots must be extremely careful when using the rudder for assisting lateral control. Excessive rudder can cause excessive sideslip, which could lead to departure from controlled flight.

Page 3 of the Procedures and Techniques section of the FCOM included the following information regarding recovery techniques from a high bank angle:

> Though the bank angle for an upset has been defined as unintentionally more than 45 degrees, it is possible to experience bank angles greater than 90 degrees.
>
> A smooth application of up to full lateral control should provide enough roll control to establish a very positive recovery roll rate. If full roll control application is not satisfactory, it may then be necessary to apply some rudder in the direction of the desired roll.
>
> CAUTION: Only a small amount of rudder is needed. Too much rudder applied too quickly or held too long may result in loss of lateral and directional control or structural failure.

In addition, page 4 of the Procedures and Techniques section of the FCOM contained the nose-high recovery procedures that American Airlines included in its Upset Recovery/Unusual Attitudes A300 Operating Manual Bulletin issued in March 2002 (see section 1.17.2.2).

1.17.2.2.2 Airplane Upset Recovery Training Aid

In June 1996, the Air Transport Association proposed that, in response to increasing Safety Board interest in loss of control airplane accidents (including the September 1994 accident involving USAir flight 427), a joint industry working group be formed to produce a training aid for airplane upset recovery. The working group consisted of representatives from airplane manufacturers (Boeing, Airbus, and McDonnell Douglas), airlines (including American Airlines, United Airlines, and Delta Air Lines, which were already using upset recovery programs in simulator training), the FAA, and pilots' unions. The effort was the first time that the three airplane manufacturers worked together on technical, noncommercial issues.

In public hearing testimony, the vice president of training for Airbus North America customer services indicated that the manufacturers wanted upset training to be developed as awareness training because of the infinite number of variables that could be experienced. The Airbus vice president also stated that many of the carriers wanted to develop upset training procedures that could be adapted to all of their fleets.

The joint industry *Airplane Upset Recovery Training Aid* was distributed to operators in August 1998. The training aid, which included a workbook, videotape, and CD-ROM, was aimed at preventing loss of control accidents on large, swept-wing airplanes. The training aid provided information for air carrier pilots and managers on jet aerodynamics, stability, control, and upset recovery and a model curriculum for classroom and flight simulator training in unusual attitude recovery. The training aid defined an upset as an airplane in flight that "unintentionally exceeds the parameters normally experienced in line operations or training." The parameters were a pitch attitude greater than 25° airplane nose up or 10° airplane nose down and a bank angle greater than 45°. The training aid also defined an upset as an airplane in flight that was "within the above parameters but flying at airspeeds inappropriate for these conditions."

The Airbus vice president of training indicated that the *Airplane Upset Recovery Training Aid* was intended to be a stand-alone document, as with previous joint industry training products, such as the *Controlled Flight Into Terrain Training Aid* and the *Wake Turbulence Training Aid*. He also indicated that each operator could decide how to use the information in the training package and that there could thus be differences among operators regarding upset training.

The Airbus vice president for training further indicated that consideration was given to adopting one of the airlines' existing upset training programs as the joint industry training aid. He stated that, even though the programs had good points that would be included in the industry training aid, the idea of including the programs in their entirety was rejected because the manufacturers had concerns in some areas. For example, the Airbus vice president indicated that the manufacturers were concerned about the AAMP's emphasis on rudder and utilization of simulation. Airbus did not initially favor the use of simulators for upset recovery training because the forces that a pilot would experience in terms of increased weight or G loading, both vertically and laterally, could not be duplicated in a simulator. Also, Airbus was concerned about simulator fidelity and the "high possibility" of negative training[149] if simulator training were not conducted properly.[150]

---

[149] Negative training is a situation in which training leads to less effective performance in the operational environment than would have occurred if no training had been conducted.

[150] The Airbus vice president indicated that there could be some value to simulator training if the simulator is properly tuned, instructors are properly qualified, and parameters are tightly maintained so that the training a pilot receives is valid. He further stated that, because of the risk that a pilot would not receive valid training, and considering that the *Airplane Upset Recovery Training Aid* is for awareness education and is not a procedure-based initiative, other tools are probably more appropriate than simulators to teach upset training.

The joint industry *Airplane Upset Recovery Training Aid* was also distributed to the participants at Airbus' 10th Performance and Operations Conference,[151] which was held in San Francisco, California, from September 28 to October 2, 1998. At the conference, the chief test pilot in Airbus' flight division presented a paper on the *Airplane Upset Recovery Training Aid.* The Airbus chief test pilot stated that, from the beginning of the working group's efforts, a conflict existed between the technical advice provided by the manufacturers' training pilots and the views expressed by the airlines that were already practicing upset training. As a result, the chief flight test pilots from Airbus, Boeing, and McDonnell Douglas became members of the working group. The Airbus chief test pilot indicated that the three test pilots, despite different backgrounds and work experiences, did not disagree with each other's technical advice but that the disagreement between the airplane manufacturers and the airlines regarding airplane handling and recovery techniques continued until January 1998.

Two of the areas in which the airplane manufacturers and the airlines had differing opinions were the use of rudder and the use of simulators. Regarding the use of rudder, the Airbus chief test pilot indicated that the existing upset recovery simulator training courses emphasized using rudder for roll control at low airspeeds. He stated that, although the rudder remained effective down to very low airspeeds, the airplane manufacturer test pilots were "very wary" of using rudder close to stall speed.[152]

According to the Airbus chief test pilot, the airplane manufacturers were able to convince the airline training managers to deemphasize the use of the rudder in their existing courses. The airplane manufacturer test pilots advocated that aileron inputs could be assisted, if necessary, by coordinated rudder in the direction of the desired roll. They also cautioned, "excessive rudder can cause excessive sideslip, which could lead to departure from controlled flight."

Regarding the use of simulators, the Airbus chief test pilot indicated that the airplane manufacturers were concerned about the types of maneuvers that were being flown in simulators and the conclusions that were being drawn from them. Specifically, the airplane manufacturers were concerned that the airline training managers were developing handling techniques that were outside of the simulator's guaranteed domain. The airplane manufacturers believed that simulator upset training should be confined to an airplane's normal flight envelope and that the training should stop at the stall warning.

American Airlines' A300 fleet standards manager stated, in public hearing testimony on this accident, that American was "a little surprised" at some of the comments

---

[151] All Airbus operators are invited to attend the Performance and Operations Conferences.

[152] The Airbus chief test pilot indicated that fighter pilots are accustomed to using the rudder for evasive maneuvers when flying not far from stall speed but that large airplanes are not similar to fighter airplanes.

made by the Airbus chief test pilot and did not think that his comments reflected what American was teaching in the AAMP. For example:

- The Airbus chief test pilot indicated that "the thrust effects of underwing-mounted engines were being ignored, whereas it has a significant influence on recovery." American's presentation at the public hearing indicated that the AAMP flight training booklet states, "the thrust vector effect on all AA [American Airlines] fleet aircraft is significant. The low-mounted engines on the B-757/767 & A-300 fleets add a powerful moment to the pitch axis. The DC-10 & MD-11 can also produce a very significant pitch moment."

- The Airbus chief test pilot stated that "the training being given in the airlines at the time to recover from excessive nose-up pitch attitudes emphasized rolling rapidly towards 90° of bank." American's presentation at the public hearing indicated that "AAMP taught pilots to roll the aircraft only if pushing the yoke forward does not lower the pitch attitude. It also noted the danger of loss of control caused by an overly aggressive roll."

According to the vice president of training for Airbus North America customer services, the *Airplane Upset Recovery Training Aid* was being revised to address, among other things, the issues discussed in the Safety Board's Safety Recommendations A-02-01 and -02 (see section 1.18.4.1). On August 5 and 6, 2003, representatives from airlines (including American), aircraft manufacturers (including Airbus), the FAA, the Safety Board, the Air Line Pilots Association, and private companies with an interest in upset training attended a conference to review and provide comments on a draft, dated April 28, 2003, of the revised training aid. The conference participants received another draft of the revised training aid, dated May 19, 2004, for final review. On August 6, 2004, the revised training aid was issued. As a result of the flight 587 accident, the training aid now includes the following language:

> It is important to guard against control reversals. There is no situation that will require rapid full-scale control deflections from one side to the other.

> The rudders on modern jet transport airplanes are sized to counter the yawing moment associated with an engine failure at very low takeoff speeds and to ensure yaw control throughout the flight envelope, using up to maximum pedal input. This very powerful rudder is also capable of generating large sideslips. An inappropriate rudder input can produce a large sideslip angle, which will generate a large rolling moment that requires significant lateral control input to stop the airplane from rolling. The rudder should not normally be used to induce roll through sideslip because the transient sideslip can induce very rapid roll rates with significant time delay. The combination of rapid roll rates and time delay can startle the pilot, which in turn can cause the pilot to overreact in the opposite direction. The overreaction can induce abrupt yawing moments and violent out of phase roll rates, which can lead to successive cyclic rudder deflections, known as rudder reversals. *Large aggressive control reversals can lead to loads that can exceed structural design limits.*

From a structural capability standpoint, the pilot does not have to be concerned about how fast or how hard to push the rudder pedal in one direction (from zero to full available pedal deflection) throughout the normal flight envelope. However, it is important to emphasize that limiters do not protect against the structural loads or excessive sideslip angles that can be generated from rapid full deflection flight control reversals.

In most cases effective situational awareness will avoid an upset from developing in the first place. However, it is important that the first actions for recovering from an airplane upset be correct and timely. Exaggerated control inputs through reflex responses must be avoided. It is worth repeating that inappropriate control inputs during one upset recovery can lead to a different upset situation.

1.17.2.3 Design Maneuvering Speed

American's A300 Operating Manual at the time of the accident contained only one reference to V_A. This reference appeared along with the following information about the turbulence penetration speed: "Turbulence Penetration Speed—VA (AFM)[153], 270 knots/.78 Mach, whichever is lower."

1.17.2.3.1 Manufacturer's Information

The Airbus A300-600 AFM, Limitations, page 1, dated February 3, 1988, contained a table under the heading "Airspeeds." Under the table heading "Conditions," the following text appeared: "Full application of rudder and aileron controls, as well as maneuvers that involve angles of attack near the stall, should be confined to speeds below V_A." Under the table heading "Airspeeds," a graph showed the relationship of Mach 0.78 (V_A) to airspeed and altitude. The Airbus A300 AFM was not distributed to line pilots. The vice president of training for Airbus North America customer services testified at the public hearing that V_A was a design speed and not an operational speed.

1.17.3 Federal Aviation Administration Oversight

The FAA's certificate management office (CMO) for the AMR Corporation (which owns American) is located in Dallas. At the time of the accident, the CMO organizational staffing consisted of 84 positions, 2 of which were temporary and 10 of which were vacant. Within the CMO were certificate management units for American Airlines and for American Eagle. At the time of the accident, staffing for the certificate management unit for American Airlines consisted of 53 positions, including 1 temporary position and 8 vacant positions.

The American Airlines POI was responsible for supervising 25 inspectors, including the A300 aircrew program manager (APM). The POI was also responsible for directing the work of eight geographic inspectors located at remote work sites.

---

[153] AFM is the abbreviation for airplane flight manual.

The FAA indicated that oversight of the AAMP is performed two ways. First, each inspector receives AAMP ground and simulator training when the inspector undergoes initial and recurrent training. Second, the A300 APM and assistant APM monitor the AAMP during ground instruction observations and initial and recurrent training observations of check airmen and designated pilot examiners. In March 2002, the American Airlines POI and A300 APM reviewed the AAMP ground and simulator portions of the A300 training program. According to the FAA, the training the POI and APM observed matched the descriptions in the approved training program curriculum.

1.17.3.1 National Simulator Program

The FAA's National Simulator Program (NSP) helps to ensure that a simulator is properly programmed to replicate the respective airplane for flight crew training programs approved by the POI. Two ACs that detail the process for evaluating and qualifying simulators are AC 121-14, "Airplane Simulator and Visual Systems Evaluation," and AC 120-40, "Airplane Simulator Qualification."

According to the ACs, the simulator evaluation process includes an objective evaluation and a subjective evaluation. During an objective evaluation, the actual instrumentation and controls in the flight simulator are examined, and the flight simulators are tested to ensure that they perform and respond in the same manner as the aircraft being simulated (within certain specific performance tolerances). The tests described in the ACs can be replicated in a simulator because they have been accomplished in the actual aircraft during flight. The data from these flights are the data to which the simulator performance must be matched (within the published tolerances). During a subjective evaluation, the simulator is compared with the aircraft in a much broader operational envelope that more closely represents normal flight operations. According to the FAA, the NSP does not place limits on the aerodynamic parameters beyond which the simulator is not qualified to represent the real aircraft.

The unusual flight attitudes (that is, extreme pitch and roll angles) that are demonstrated during selected event training (including AAMP simulator training) are not contained in the ACs for simulator qualification. Because the aircraft manufacturers provided no flight test data to validate these maneuvers, the NSP was not able to ensure that the simulators were properly programmed to replicate the manufacturers' respective airplanes throughout these maneuvers. HBAT 95-10 states that each operator is responsible for reviewing its simulator capabilities to ensure that the simulators used to perform selected event training maneuvers have the ability to accurately support the inclusion of those maneuvers in an approved training program.

The NSP conducts annual recurrent evaluations of simulators in accordance with the requirements of the applicable AC. The last NSP annual recurrent evaluation of the American Airlines A300 simulator before the accident was on September 7, 2001.[154]

---

[154] American Airlines performs secondary evaluations 6 months after an NSP evaluation. The APMs regularly attend these evaluation sessions. The A300 simulator received a secondary evaluation on January 9, 2002, and none of the findings related to the circumstances of this accident.

1.18 Additional Information

1.18.1 Flight 587 Witness Information

Several pilots witnessed the flight 587 accident. The captain of Northwest Airlines flight 1867, which was in line to take off from runway 31L at JFK, saw pieces falling from the flight 587 airplane and then saw the airplane enter a nose dive and crash. The Northwest Airlines first officer indicated that the airplane's wings appeared to be intact and that the airplane appeared to be rolling to the left and diving. The first officer also indicated that no fire was visible but that traces of smoke were visible.

Jet Blue flight 41 was holding short of runway 31L while Northwest Airlines flight 1867 was awaiting takeoff clearance. The Jet Blue captain observed an airplane that was out of control in a left bank position and then in a near-vertical descent. The captain also observed the airplane rolling back and forth while in a nose-down position and a fire in the right wing area. The captain stated that the airplane impacted the ground with a deep orange fireball that was about twice the length of the fuselage and that dark smoke from the fire turned to light smoke about 10 minutes later. The Jet Blue first officer observed an airplane in a "vertical rocking nose-down position." The first officer also observed a smoke trail and, about 4 seconds before airplane impact, an orange ball of flame (about the size of an engine) in the middle of the airplane. The first officer stated that, after airplane impact, a large fireball with bright orange flames and black smoke was visible. He also stated that the weather was clear with no bird activity visible.

Jet Blue flight 79 was holding short of runway 31L waiting for takeoff clearance. The captain of that flight observed an airplane spinning and spiraling in a downward direction. The captain also observed a silver-colored object falling (but not as fast as the airplane) and described the object to be of a size between an engine and a tail. The captain stated that, as the airplane descended, a whitish-gray smoke cloud enveloped the airplane. The captain also stated that the airplane appeared to be intact when it impacted the ground and that, about 1/2 second after impact, an orange-yellow flame was visible, which was followed by gray smoke. The Jet Blue first officer of this flight observed an airplane rolling to the left at a 90º bank and falling. The first officer also observed, about 3 seconds before airplane impact, a fireball (yellow to white in color and the size of an engine) behind the wing. The first officer further observed a flying object tumbling through the air near the airplane, and he stated that the object could have been the horizontal stabilizer. The first officer also stated that the airplane appeared to be intact when it impacted the ground at an 85º to a 90º angle and that the airplane exploded instantly, with black smoke and orange flames visible.

In addition to the pilot witnesses, about 400 witnesses and potential witnesses[155] to this accident were identified through information collected by the Safety Board; the Federal Bureau of Investigation (FBI); the Port Authority of New York and New Jersey

---

[155] A witness was considered to be an individual who reported observing the accident airplane in flight and was able and willing to provide information regarding the observation.

Police Department; and the Rockaway, New York, Police Department. The level of detail provided by the witnesses varied significantly. Some witnesses provided specific details, whereas the only information provided by other witnesses was that they observed an airplane crash.

To give the witnesses an opportunity to provide the Safety Board with a first-hand account of their observations, 355 questionnaires were mailed between November 21, 2001, and January 9, 2002. (Of the 355 questionnaires, 18 were returned to the Board as undeliverable.) In the questionnaire, the witnesses were asked to provide a written statement that indicated where they were located and what they observed and/or heard. The questionnaire also asked the witnesses to discuss the direction the airplane was traveling, any parts that might have separated or fallen from the airplane, any indications of smoke or fire coming from the airplane, the duration of their observation, and their final view of the airplane. The Board also established an Internet e-mail address on its Web site for witnesses to the accident who had not been in contact with Board personnel. Six categories were established to document and track the reported witness observations: sources of witness information, reports of in-flight fire, reports of in-flight smoke, reported sounds while the airplane was in flight, observed movements while the airplane was in flight, and reports of in-flight airframe/component separations.

After all of the witness information was received, the Safety Board determined that a total of 354 witnesses had provided sufficient detail to document. Of the 354 witnesses, 138 (39 percent)[156] provided written accounts to the Board, and 66 (19 percent) participated in interviews with Board personnel. Also, the FBI provided the Board with interview summaries for 141 witnesses (40 percent), and the Port Authority and Rockaway Police Departments provided the Board with information for 224 witnesses (63 percent).[157] The Board's review of this information revealed the following regarding the witnesses' observations:

- **Fire:** 198 witnesses (56 percent) reported observing the airplane or a portion of the airplane on fire at some point during their observation. The most frequent response specified as the location of the fire was the fuselage.

- **Smoke:** 82 witnesses (23 percent) reported that they observed smoke emanating from the airplane at some point during their observation. The two most frequent responses specified as the location of the smoke were smoke involving a miscellaneous area and smoke involving the fuselage.

- **Noise:** 176 witnesses (50 percent) reported a sound or sounds associated with the airplane during their observation.

- **Motion:** 279 witnesses (79 percent) reported seeing downward motion of the airplane, and 69 witnesses reported seeing spinning, corkscrewing, or cartwheeling motion. Also, 67 witnesses (19 percent) saw the airplane in a left bank or turn, and 27 witnesses (8 percent) saw the airplane in a right bank or

---

[156] Percentages in this section have been rounded to the nearest whole number.

[157] Some witnesses provided information about the flight 587 accident to more than one organization.

turn. In addition, 29 witnesses (8 percent) saw the airplane climb, and 47 witnesses (13 percent) described the airplane's motion as wobbling, dipping, or rocking in a left-right motion.

- **Parts separation:** 225 witnesses (64 percent) reported that they saw something separate or fall from the airplane at some point during their observation. Of these 225 witnesses, 126 indicated that they had seen a miscellaneous part or object fall from the airplane, 39 saw a part separate from the vertical stabilizer, 37 saw a part separate from the left engine, and 26 saw a part separate from the right engine.

1.18.2 Airbus Vertical Stabilizers That Reached High Loads

In addition to the flight 587 airplane, another A300-600 airplane and an A310 airplane had vertical stabilizers that exceeded ultimate load during in-service events. The event involving the A300-600 airplane was American Airlines flight 903 in May 1997 (see section 1.18.2.1), and the event involving the A310 was a flight by the German airline Interflug in February 1991 (see section 1.18.2.2). Table 7 shows information for these events and for other A300-600 and A310 vertical stabilizer high loading in-service events.

The Safety Board compared the number of A300-600 and A310 vertical stabilizer high loading events with those for Airbus' other airplane models. As shown in table 8, the A300-600 and A310 airplanes each experienced three high loading events in which rudder pedal use was involved. Table 8 also shows that the A300B2/B4, which has a comparable number of flight hours as the A310 and more flight hours than the A300-600, experienced no high loading events and that no later-model Airbus airplanes experienced similar events.[158]

---

[158] Although the A340 has experienced two high loading events, neither event showed any evidence of rudder pedal use. One event, which involved turbulence, reached a limit load of 1.04; the other event, which involved the loss of the air data computer, reached a limit load of 1.17.

Table 7. A300-600 and A310 Vertical Stabilizer High Loading Events

Date	Category	Speed (knots)	Configuration	Description	Crew rudder input	Alternating rudder inputs	Side loads (Gs)	Limit load (1.0)	Inspection information
A300-600 Airplanes									
11/01	**Operation**	**250**	**Clean**	**Successive alternating rudder inputs**	**Yes**	**Yes**	**0.38**	**1.83 to 2.14**	**Flight 587 accident airplane**
5/97	**Operation**	**190 to 230**	**Clean**	**Stall; loss of control; several alternating rudder inputs**	**Yes**	**Yes**	**0.55 and 0.7**	**1.53**	**Inspection on 3/11/02. Local damage at rear RHS attachment found.**
5/99	System malfunction	180 to 190	Slats extended	Rudder oscillations during go-around at A/P disconnect	No	No	0.32	1.16	Inspection on 3/13/02. No findings.
5/89	Operation	250	Clean	Rudder jerk	Yes	Yes	0.38	1.11	Inspection on 3/16/02. No findings.
A310 Airplanes									
2/91	**Operation**	**50 to 300**	**15º slats and 0º flaps**	**Missed approach; three successive stalls; loss of control with repetitive rudder movements**	**Yes**	**Yes**	**0.36 and 0.69**	**1.55 and 1.35**	**Inspection on 4/3/02. No findings.**

Date	Category	Speed (knots)	Configuration	Description	Crew rudder input	Alternating rudder inputs	Side loads (Gs)	Limit load (1.0)	Inspection information
A310 Airplanes									
9/94	Operation	190 to 225	15º slats and 15º flaps	Missed approach and stall	Yes	No	0.37	1.12	Inspection on 3/26/02. No findings.
11/99	System malfunction	275	Clean	Rudder trim runaway with A/P engaged; lateral upset at A/P disconnect	Yes	Yes	0.49	1.06	Inspection on 3/28/02. No findings.

Source: Airbus

Note: American Airlines flight 587 (November 2001), American Airlines flight 903 (May 1997), and the Interflug flight (February 1991) are shown in bold print.

Limit load compares the bending moment for the event with the discrete tuned gust condition at the time of certification. The data are estimates based on Airbus' linear loads model. The loads were calculated in early 2002 and are shown for the A300-600 and A310 airplanes in order of severity (most to least).

RHS, right horizontal stabilizer; A/P, autopilot. A "clean" configuration indicates that the flaps, slats, and landing gear have all been retracted.

Table 8. Airbus Service History of Vertical Stabilizer High Loading Events

Airplane model	Number of events exceeding limit load	Number of events involving rudder pedal input	Number of flight hours of fleet worldwide
A300B2/B4	0	0	9,765,529
A310	3	3	9,552,784
A300-600	4	3	6,694,865
A320	0	0	32,720,365
A330	0	0	4,210,781
A340	2	0	6,059,301

Source: Airbus

Note: The number of flight hours were as of February 2004.

In addition, a Boeing representative stated that his company maintained records of significant in-flight events, as reported by airlines, involving Boeing- and McDonnell Douglas-designed airplanes. According to the representative, Boeing was not aware of any events involving the company's products in which a vertical stabilizer experienced an in-flight maneuver or a gust greater than limit load.

1.18.2.1 1997 American Airlines Flight 903 Accident

On May 12, 1997, American Airlines flight 903, an Airbus A300-600, N90070, experienced an in-flight loss of control near West Palm Beach, Florida. Of the 2 flight crewmembers, 7 flight attendants, and 156 passengers aboard the airplane, 1 passenger sustained serious injuries and 1 flight attendant received minor injuries during the upset. The airplane sustained minor damage.

The flight was assigned an airspeed of 230 knots and was cleared to descend from 24,000 to 16,000 feet in preparation for landing at MIA. The FDR indicated that, while the autopilot was engaged in the descent, the power levers moved from the mechanical autothrottle limit of 44° to the manual limit of 37°. As the airplane leveled off at 16,000 feet, its airspeed decreased. The pilot began a right turn to enter a holding pattern and added some power, which stabilized the airspeed at 178 knots. However, the right bank and the resultant AOA were increasing, despite left aileron input by the autopilot.

The airplane's bank angle increased past 50°, and the AOA increased rapidly from 7° to 12°. At this point, the stickshaker activated, the autopilot independently disconnected, and the pilot increased power and used full left rudder to arrest the roll. The bank angle reached 56°, and the AOA reached 13.7° at 177 knots. The airplane then pitched down and entered a series of pitch, yaw, and roll maneuvers as the flight controls

oscillated for about 34 seconds. The maneuvers eventually dampened, and the flight crew recovered the airplane at an altitude of about 13,000 feet.

The Safety Board determined that the probable cause of this accident was the flight crew's failure to maintain adequate airspeed during level-off, which led to an inadvertent stall, and its subsequent failure to use proper stall recovery techniques. Contributing to the cause of the accident was the flight crew's failure to properly use the autothrottle.

Airbus indicated that the bending moment on the flight 903 airplane's vertical stabilizer reached 1.53 times that defined by the lateral gust limit load condition when the first fully recorded alternating rudder input occurred. The high loading was the result of a 5° overtravel of the rudder. Subsequent alternating rudder inputs were not recorded on the FDR but were estimated to have produced loads beyond ultimate load. At the public hearing on the flight 587 accident, the Airbus loads and dynamics manager stated that, at the time of the flight 903 event, Airbus assessed the loads level using "engineering judgment" that accounted for the movement of the airplane and the rudder deflections but did not perform a loads evaluation. The Airbus manager further stated that the early 2002 loads calculations (shown in table 8) confirmed the results of the 1997 assessment.

1.18.2.1.1 Flight 903 Postaccident Actions

In a June 12, 1997, facsimile, Daimler-Benz Aerospace, which assessed the lateral loads on the flight 903 airplane, urgently recommended that Airbus inspect the vertical stabilizer and its attachments, the rudder and its attachments, the rear fuselage, and the horizontal stabilizer attachments because they could have encountered loads that exceeded the design limit loads for the A300-600. A June 19, 1997, internal Airbus memorandum indicated that Airbus' analysis of the FDR data confirmed high longitudinal and lateral load factors. The memorandum also indicated that design limit loads were apparently exceeded in some areas of the airplane and that ultimate design loads could have been reached in some other areas, including the vertical stabilizer. Further, the memorandum stated that a close inspection of the airplane was needed as soon as possible. That same day, Airbus informed American Airlines, via e-mail, that some areas of the airplane, particularly the aft part, had sustained very high loads and that the loads required that the airplane be "deeply inspected." Airbus requested that American send the details and the findings of the airplane inspections already performed. (American had conducted inspections of the airplane at MIA after the event.)

In a June 20, 1997, facsimile, American Airlines provided Airbus with details on the inspections that were performed. According to Airbus, American's inspection report indicated that all inspections of the vertical stabilizer elements were "OK" and that the airplane had sheared fasteners, deformed nacelles, and engine component damage. That same day, an internal Airbus memorandum indicated that, on the basis of the inspection results, Airbus had no reason to recommend grounding the airplane. The memorandum also indicated that American Airlines would perform additional inspections no later than the airplane's next A check.

On June 24 and 25, 1997, Airbus provided American with a list of inspection tasks to be performed on the airplane and indicated that it wanted to receive information on the inspection results. On June 27, 1997, American forwarded Airbus the results of the additional inspections tasks. According to Airbus, the inspection report noted some damage to the wing areas and engine nacelles but no damage on the vertical stabilizer or fittings. A June 30, 1997, internal Airbus memorandum indicated that American had conducted the inspections with an airline structural engineer present and that no findings resulted from the inspections.

On March 11, 2002, the vertical stabilizer on the airplane was inspected for damage at American Airlines' maintenance facility in Tulsa. As stated in section 1.16.4.2 and in table 7, this nondestructive inspection revealed delamination damage (ply separation) on the right rear main attachment fitting. The delamination area was connected to the lughole surface, but this area is not normally visible unless the attachment pin has been removed. After the inspection, American removed the vertical stabilizer from service, and the left and right rear main attachment fittings were tested at Airbus' Hamburg facility (see section 1.16.4.2).

1.18.2.2 1991 Interflug Incident

On February 11, 1991, an Airbus A310 operated by the German airline Interflug experienced an in-flight loss of control during a missed approach to runway 25L at Sheremetyevo Airport in Moscow, Russia. None of the 9 crewmembers and 100 passengers was injured.

The flight, which had departed from Schonefeld Airport in Berlin, Germany, was uneventful until the airplane was at an altitude of 1,550 feet. At that point, ATC instructed the pilots to go around because of a blocked runway. The pilots initiated the go-around maneuver with the autopilot engaged at an altitude of 1,275 feet. Afterward, the airplane entered an extreme pitch angle, which resulted in a severe loss of speed and, at an altitude of 4,000 feet, a breakdown of airflow over the wing and a subsequent stall. The airplane descended to 1,700 feet, at which point the pilots used full engine power to make a steep climb. The airplane subsequently stalled three more times. After several minutes, the pilots stabilized the airplane at 11,000 feet. The pilots landed the airplane manually.

The probable cause of this incident was movement of the control column by the pilot while the airplane was flying in go-around mode under AFS authority. The crew was not informed about AFS behavior at this stage of the flight.[159]

According to FDR data (provided to the Safety Board after the flight 587 accident), the Interflug pilot made alternating rudder inputs of about one-third of the full pedal deflection. The speed of the airplane varied during this time. When the airplane

---

[159] *Report on the Investigation of the Abnormal Behaviour of an Airbus A310-304 Aircraft on 11.02.1991 at Moscow*, Air Accident Investigation Department at the German Federal Office of Aviation, Reference 6X002-0/91.

reached high speed, the pedal inputs resulted in ultimate loads on the vertical stabilizer, but the same pedal inputs at low speed did not result in high loads on the vertical stabilizer.

1.18.2.3 2002 American Airlines Incident

On October 28, 2002, American Airlines flight 934, an A300-600, was en route from Guayaquil, Ecuador, to MIA. When the airplane was at an altitude of 31,000 feet and an airspeed of 290 knots, the pilots requested a deviation around clouds south of Panama. The first officer stated that he wanted to see the winds indicated on the airplane's inertial reference system display. When the first officer reached up to select the wind mode on the display, he inadvertently kicked the left rudder pedal with his left foot and disconnected the autopilot. The captain (the flying pilot) reported that he felt a violent tail shift from the left to the right followed instantly by the autopilot disconnect and warning chime. Less than 1 second later, the airplane began to climb slowly and bank 25° to the right. The airplane then entered a Dutch roll.

In a postincident interview, the captain stated that he moved his feet onto the rudder pedals and his hands onto the control wheel. The captain also stated that he input some right rudder because he thought the airplane was "skidding" and that, while holding right rudder, he neutralized the ailerons after rolling wings level to deal with the Dutch roll. The captain further stated that he asked the first officer to check whether the yaw dampers were engaged because the captain thought that might have been the cause of the rudder problems. (The yaw dampers were engaged.) In addition, the captain stated that the event was "prolonged" and that the airplane might have swung three or four times before it was under control. Finally, the captain stated that the airplane climbed 750 feet before the Dutch roll stopped and that, afterward, the airplane descended slowly to rejoin the airway.

In a postincident interview, the first officer stated that his action caused a "bump" on the left rudder pedal rather than a steady force application. The first officer also stated that he did not think he hit the control column with either foot or moved the column. The first officer reported that, during the event, the airplane began a climbing right turn and the airplane's nose was yawing to the right. He also reported that the airplane felt as if it were "skidding sideways" and that the motion felt "pretty violent." The first officer stated that the event lasted about 20 seconds and that he did not get on the flight controls during the recovery. The first officer further stated that the captain was hand-flying the airplane and that he was "extremely light" on the controls.

The Safety Board analyzed FDR data from the incident and determined that the first officer made a rudder pedal input (which did not reach the stop) in one direction and that the captain made a full rudder pedal input in the other direction, which he held for several seconds. The captain indicated that he did not know that he had input full rudder or that the pedal changed its range of travel.[160] The Safety Board calculated the loads on

---

[160] At an airspeed of 290 knots, only about 0.8 inch of rudder pedal travel and 28 pounds of pedal force were needed for full rudder.

the vertical stabilizer, using Airbus' linear loads model, and determined that they were below limit load.

1.18.3 Federal Aviation Administration Airworthiness Directives

1.18.3.1 Airworthiness Directive 2001-23-51

On November 16, 2001, the FAA, along with the DGAC, issued emergency AD 2001-23-51, which required operators of A300-600 and A310 series airplanes to perform a one-time detailed visual inspection to prevent a failure of the vertical stabilizer-to-fuselage attachment points and rudder-to-vertical stabilizer attachment points.[161] The AD indicated that such a failure could result in the loss of the vertical stabilizer and/or rudder and a consequent loss of control of the airplane.

The purpose of the visual inspection was to detect repairs and alterations to, and damage of, the vertical stabilizer main attachment fittings and transverse load fittings; the rudder hinge fittings, hinge arms, and support fittings for all rudder hinges; and rudder actuator support fittings. The AD indicated that (1) damage of the metallic areas would include pulled or loose fasteners, wear areas, distorted flanges, cracks, and corrosion and (2) damage of the composite areas would include delamination; distorted surfaces that might indicate delamination; cracks in the paint surface; evidence of moisture damage; and cracked, slitting, or frayed fibers. The AD required that any identified damage be repaired and that operators report the results of their inspection findings to the FAA. The AD was effective upon receipt and was required to be accomplished within 15 days.

1.18.3.2 Airworthiness Directive 2002-06-09

On March 15, 2002, the FAA issued AD 2002-06-09, which required detailed inspections to detect and correct reduced structural integrity of A300 and A310 series airplanes after an extreme in-flight lateral loading event. The AD stated that operators were to determine whether the lateral load factor equaled or exceeded 0.3 G and that acceptable methods for making this determination included aircraft communication addressing and reporting system information, FDR data, or quick access recorder data.

The AD provided a specific list of tasks that were to be accomplished during the inspections and indicated that any damage found during the inspections had to be repaired before the airplane was returned to service. The AD stated that operators were to submit to Airbus a report of the inspection results and other relevant information. The AD indicated that, for airplanes with a lateral load factor of greater than or equal to 0.3 G but less than 0.35 G, operators were to submit the report within 5 days after accomplishing the

---

[161] On November 15, 2001, American Airlines issued Fleet Campaign Directive EF0351X, which required a detailed visual inspection of the vertical stabilizer-to-fuselage attachment points and the rudder-to-vertical stabilizer attachment points for the company's A300-600 fleet. The purpose of the inspection was to look for evidence of unusual conditions or degradations to the attachment points or adjacent structure. On November 17, 2001, American Airlines issued Fleet Campaign Directive EF0351B, which was an upgraded version of Fleet Campaign Directive EF0351X that met the inspection requirements mandated by FAA AD 2001-23-51.

inspections. After the inspection and reporting requirements were accomplished, the airplane could be returned to service. For airplanes with a lateral load factor of equal to or greater than 0.35 G, the AD did not specify a time requirement for reporting the inspection results to Airbus, but the AD did indicate that the airplane could not be returned to service once the inspection and reporting requirements were accomplished.

The AD also stated that Airbus would develop an airplane loads assessment and would recommend, if necessary, supplementary inspections of applicable areas of the airplane. For airplanes with a lateral load factor of greater than or equal to 0.3 G but less than 0.35 G, supplementary inspections were to be conducted within 30 days of the extreme lateral loading event, but the airplane could be in service before these inspections were completed. The AD did not specify a time requirement for conducting supplementary inspections for airplanes with a lateral load factor of equal to or greater than 0.35 G, but the AD did indicate that these inspections had to be completed before further flight of the airplane.

1.18.4 Previous Safety Recommendations Related to the Circumstances of the Flight 587 Accident

1.18.4.1 Safety Recommendations A-02-01 and -02

After the flight 587 accident, the Safety Board learned that many pilot programs did not include information on the structural certification requirements for the vertical stabilizer and rudder on transport-category airplanes and that sequential full opposite rudder inputs (even at speeds below V_A) might result in structural loads that exceed those addressed by the requirements. The Board became concerned that pilots might have the impression that rudder travel limiter systems would prevent sequential full opposite rudder deflections from damaging the structure. However, the structural certification requirements for transport-category airplanes do not take such maneuvers into account. As a result, sequential opposite rudder inputs, even when a rudder limiter is in effect, can produce loads that are higher than those required for certification and may exceed the structural capabilities of the airplane.

Because of its concerns, the Safety Board issued Safety Recommendation A-02-01 and -02 on February 8, 2002. Safety Recommendations A-02-01 and -02 asked the FAA to take the following actions:

> Require the manufacturers and operators of transport-category airplanes to establish and implement pilot training programs that: (1) explain the structural certification requirements for the rudder and vertical stabilizer on transport-category airplanes; (2) explain that a full or nearly full rudder deflection in one direction followed by a full or nearly full rudder deflection in the opposite direction, or certain combinations of sideslip angle and opposite rudder deflection can result in potentially dangerous loads on the vertical stabilizer, even at speeds below the design maneuvering speed; and (3) explain that, on some aircraft, as speed increases, the maximum available rudder deflection can be obtained with comparatively light pedal forces and small pedal deflections. The FAA should

also require revisions to airplane and pilot operating manuals that reflect and reinforce this information. In addition, the FAA should ensure that this training does not compromise the substance or effectiveness of existing training regarding proper rudder use, such as during engine failure shortly after takeoff or during strong or gusty crosswind takeoffs or landings. (A-02-01)

Carefully review all existing and proposed guidance and training provided to pilots of transport-category airplanes concerning special maneuvers intended to address unusual or emergency situations and, if necessary, require modifications to ensure that flight crews are not trained to use the rudder in a way that could result in dangerous combinations of sideslip angle and rudder position or other flight parameters. (A-02-02)

In an April 15, 2002, letter, the FAA stated that it agreed with the intent of these safety recommendations. The FAA indicated that several aviation safety inspectors reviewed the training programs of the three main U.S. operators of Airbus airplanes. This review determined that none of the operators were training their pilots to use dangerous combinations of sideslip angles and rudder position or other flight parameters.

The FAA also stated that, on February 15, 2002, it issued Notice N8400.28, "Transport Category Airplanes – Rudder and Vertical Stabilizer Awareness," to notify POIs of air carriers that operate transport-category airplanes about the Safety Board's concerns regarding the operational use of rudder pedals and the potential subsequent effects on the vertical stabilizer. The notice directed POIs to inform their air carriers of the following:

> Sequential full opposite rudder inputs (sometimes referred to as "rudder reversals"), even at speeds below the design maneuvering speed, may result in structural loads that exceed those addressed by the 14 CFR Part 25 requirements. In fact, pilots may have the impression that the rudder limiter systems installed on most transport-category airplanes prevent sequential full opposite rudder deflections from damaging the structure. However, the 14 CFR Part 25 structural certification requirements for transport-category airplanes do not take such maneuvers into account; therefore, such sequential opposite rudder inputs, even when a rudder limiter is in effect, can produce loads higher than those required for certification and may exceed the structural capabilities of the aircraft.

> Pilots may not be aware that, on some airplane types, full available rudder deflections can be achieved with small pedal movements and comparatively light pedal forces. In these airplanes, at low speeds the rudder pedal forces required to obtain full available rudder may be three times greater than those required to obtain full available rudder at higher airspeeds.

> Notwithstanding the concerns noted above regarding the potential danger of large and/or sequential rudder inputs in flight, it should be emphasized that pilots should not become reluctant to command full rudder when required and when appropriate, like during an engine failure shortly after takeoff or during strong or gusty crosswind takeoffs or landings. The instruction of proper rudder use in such conditions should remain intact, but should also emphasize the differences

between aircraft motion resulting from a single, large rudder input and that resulting from a series of full or nearly full opposite rudder inputs.

The POIs were to provide a copy of FAA Notice N8400.28 to representatives of each transport-category airplane operator for information and voluntary implementation as deemed appropriate by the operator.[162]

In addition, the FAA stated that, on February 15, 2002, it contacted selected manufacturers and industry organizations to inform them that it shared the Safety Board's concerns regarding pilot training on the use of the rudder in transport-category airplanes and subsequently sent a letter to raise awareness of the Board's safety recommendations. In response, the manufacturers prepared flight technical operations bulletins (see sections 1.18.4.1.2 and 1.18.4.1.3), which the FAA believed would convey the best information available from each manufacturer regarding the Board's concerns.

The FAA stated that Notice N8400.28 was an interim step to ensure that the shared concerns of the Board and the FAA were known to transport-category airplane operators and that the concerns were conveyed to the operators' pilots as quickly as possible. The FAA added that changing training program requirements by rulemaking was "usually a time-consuming process with no guarantee of final passage into rule." The FAA indicated that the procedures contained in HBAT 99-07, "Flight Standards Policy – Company Operating Manuals and Company Training Program Revisions for Compliance with Current Airplane [or Rotorcraft] Flight Manual Revisions," allowed certain changes in the approved sections of AFMs to be more readily captured into pilot training programs.

The FAA further stated that, as manufacturers developed pertinent safety information, changes in their respective AFMs might be appropriate. Training programs could also be changed by mutual agreement between the operator and the FAA based on the information in the flight technical operations bulletins. The FAA stated that it would continue to review the information developed by the manufacturers and the information resulting from the Safety Board's ongoing investigation of the flight 587 accident. The FAA indicated that it might consider initiating rulemaking to change training program requirements, as appropriate, as more information becomes available.

In a July 22, 2002, letter, the Safety Board noted that the FAA's review of training programs was limited to the programs of Airbus airplane operators. The Board believed that the training programs of operators of other manufacturers' airplanes also needed to be reviewed. The Board stated that the FAA's plan to use nonregulatory means to meet the intent of Safety Recommendation A-02-01 might be an acceptable alternative action but recognized that the FAA indicated that it might ultimately make a regulatory change. The Board stated that it would assume, unless the FAA indicated otherwise, that the FAA

---

[162] In a February 19, 2002, letter to American Airlines' vice president for safety, security, and environmental, the POI for AMR Corporation relayed the language in Safety Recommendations A-02-01 and -02 and indicated that his office wanted to meet to discuss American Airlines' response to the Safety Board's recommendations. A copy of FAA Notice 8400.28 was enclosed with the POI's letter. See section 1.18.4.1.1 for American's response to the Board's recommendations.

would develop some regulatory changes in pilot training programs in response to Safety Recommendation A-02-01. Pending completion of changes to pilot training programs in response to the recommendations, the determination of whether these revisions would be implemented through the procedures in HBAT 99-07 or through regulatory changes, and the FAA's consideration of reviewing the training programs of operators of other manufacturers' airplanes, Safety Recommendations A-02-01 and A-02-02 were classified "Open—Acceptable Response."

1.18.4.1.1 American Airlines Flight Operations Technical Informational Bulletin

In February 2002, American Airlines issued Flight Operations Technical Informational Bulletin 2002-02, "Jet Transport Aircraft Flight Controls," in response to the Safety Board's recommendations. The bulletin included information on rudders, rudder travel limiters, rudder reversals, sideslip angle, and vertical stabilizer loading. The bulletin stated that a rudder travel limiter was "designed into the directional control system to reduce the available rudder throw as airspeed increases to avoid excessive structural loads on the vertical stabilizer." The bulletin also stated that a rudder reversal was also known as a "rudder doublet" and was defined as "a large rudder deflection input in one direction followed immediately by a rudder deflection input in the opposite direction."[163] In addition, the bulletin stated that "large 'rudder reversals' or 'rudder doublets' must be avoided on Transport Category Aircraft" because "these inputs can result in loss of control or structural failure of the aircraft."

During postaccident interviews, American Airlines pilots indicated that they were familiar with the function of the rudder travel limiter, and most of these pilots thought that the rudder travel limiter would prevent an overload of the vertical stabilizer. The pilots also indicated that they did not know about the rudder doublet concept.[164]

1.18.4.1.2 Airbus Flight Crew Operating Manual Bulletin

In March 2002, Airbus issued A310/A300-600 FCOM Bulletin number 15/1, "Subject No. 40, Use of Rudder on Transport Category Airplanes, in response to the Safety Board's recommendations." The bulletin emphasized proper operational use of the rudder and highlighted certification requirements and rudder control system design characteristics. The bulletin included the following information in a box labeled "CAUTION:"

> Sudden commanded full, or nearly full, opposite rudder movement against a sideslip can generate loads that exceed the limit loads and possibly the ultimate loads and can result in structural failure.

---

[163] At the time of the accident, neither American's AFM nor its A300 Operating Manual used the terms "rudder doublets" or "rudder reversals."

[164] The American Airlines A300 fleet standards manager and the vice president of training for Airbus North America customer services indicated, during public hearing testimony, that most pilots would not have heard of rudder doublets before the flight 587 accident unless they were test pilots.

This is true even at speeds below the maximum design maneuvering speed, V_A.

Certification regulations do not consider the loads imposed on the structure when there is sudden full, or nearly full, rudder movement that is opposite of the sideslip.

The bulletin also made the following operational recommendation:

RUDDERS SHOULD NOT BE USED:

– To induce roll, or

– To counter roll, induced by any type of turbulence.

Whatever the airborne flight condition may be, aggressive, full or nearly full, opposite rudder inputs must not be applied. Such inputs can lead to loads higher than the limit, or possibly the ultimate loads and can result in structural damage or failure.

The rudder travel limiter system is not designed to prevent structural damage or failure in the event of such rudder system inputs.

Note: Rudder reversals must never be incorporated into airline policy….[165]

As far as dutch roll is concerned, yaw damper action and natural aircraft damping are sufficient to adequately dampen dutch roll oscillations. The rudder should not be used to complement the yaw damper.

Note: Even if both yaw damper systems are lost, the rudders should not be used to dampen the dutch roll. Refer to the YAW DAMPER FAULT procedure.

At the public hearing on this accident, the American Airlines A300 fleet standards manager testified that American had not received "such specific limitations or prohibited maneuvers on the rudder use" before the flight 587 accident.

1.18.4.1.3 Boeing Flight Operations Technical Bulletin

On May 13, 2002, Boeing issued a flight operations technical bulletin titled, "Use of Rudder on Transport Category Airplanes," in response to the Safety Board's recommendations. The bulletin applied to all Boeing, Douglas, and McDonnell Douglas airplane models and included information on rudder maneuvering considerations, V_A, and

---

[165] At the time of the accident, Airbus' FCOM did not contain the terms "rudder doublets" or "rudder reversals."

actions taken in response to the Board's recommendations. The summary section included the following information:

- It is important to use the rudder in a manner that avoids unintended large sideslip angles and resulting excessive roll rates. The amount of roll rate that is generated by using the rudder is proportional to the amount of sideslip, NOT the amount of rudder input.

- If the pilot reacts to an abrupt roll onset with a large rudder input in the opposite direction, the pilot can induce large amplitude oscillations. The large amplitude oscillations can generate loads that exceed the limit loads and possibly the ultimate loads, which could result in structural damage.

In addition, an attachment to the bulletin provided answers to commonly asked questions regarding rudder usage.

1.18.4.2 Safety Recommendations A-03-41 Through -44

On November 17, 2002, Delta Connection flight 5109, a Canadair CRJ-2, N868CA, operated by Comair, encountered severe turbulence while in a descent near Rockville, Virginia. Flight 5109 was a scheduled passenger flight from Atlanta, Georgia, to Washington, D.C., with 2 pilots, 1 flight attendant, and 48 passengers aboard. No one aboard the airplane was injured during the incident, and the airplane was returned to service the next day after it was visually inspected for damage in accordance with the manufacturer's procedures.

Analysis of the data from the incident airplane's FDR showed that large vertical accelerations occurred during the turbulence event. Further analysis of the data by Canadair showed that, during the event, the airplane's wing experienced loads that were outside of their certified design envelopes. Specifically, Canadair's analysis revealed that the airplane experienced vertical accelerations ranging from 4.3 G positive to 1.9 G negative. The inspection procedures in Canadair's aircraft maintenance manual for severe turbulence or extreme maneuvers included a minimum positive G threshold for a vertical acceleration but no minimum threshold for negative G excursions or for lateral G excursions.[166]

In addition, the investigations of American Airlines flight 587 and flight 903 revealed that both airplanes experienced lateral accelerations of about 0.4 G. After the flight 903 accident, American Airlines conducted a visual inspection of the airplane in accordance with the applicable procedures in its A300 Operating Manual. The inspection procedures specified the threshold criteria for positive and negative vertical G excursions but not for lateral G excursions.

---

[166] On December 20, 2002, as a result of its engineering and loads assessment, Canadair performed supplemental inspections of the airplane to ensure its structural integrity. No damage was identified.

The Safety Board found that some manufacturers' maintenance manuals did not include inspections for damage caused by extreme (positive or negative) lateral accelerations or extreme negative vertical accelerations. The Board was concerned that existing inspection criteria might not be adequate to detect damage after high loading events that greatly exceeded the manufacturers' threshold and that airplanes that encountered such high loads might be returned to service in an unairworthy condition. As a result, on September 4, 2003, the Safety Board issued Safety Recommendations A-03-41 through -44, which asked the FAA to take the following actions:

> Require all manufacturers of transport-category airplanes to review and, if necessary, revise their maintenance manual inspection criteria for severe turbulence and extreme in-flight maneuvers to ensure that loads resulting from positive and negative vertical accelerations, as well as lateral accelerations, are adequately addressed. (A-03-41)

> Require all manufacturers of transport-category airplanes to establish and validate maximum threshold values for positive and negative vertical and lateral G accelerations beyond which direct manufacturer oversight and intervention is required as a condition for returning the airplane to service. (A-03-42)

> Require all operators of airplanes that have experienced accelerations exceeding the threshold values established as a result of Safety Recommendation A-03-42 (or that the operator has reason to believe might have exceeded those thresholds), as determined from FDR and other available data, to notify the FAA immediately of such high loading events and provide all related loads assessment and inspection results. (A-03-43)

> Require manufacturers of transport-category airplanes to immediately notify the appropriate certification authority of any event involving accelerations exceeding the threshold values (or that the manufacturer has reason to believe might have exceeded those thresholds) necessitating the intervention of the manufacturer, and provide all related loads assessment and inspection results. (A-03-44)

On November 20, 2003, the FAA stated that it issued AD 2002-06-09 on March 15, 2002, which required certain inspections of A300, A300-600, and A310 airplanes after extreme lateral loading events (see section 1.18.3.2). The FAA also stated that it planned to work in partnership with industry to address the issues raised in Safety Recommendations A-03-41, -42, and -44, including pilot reporting, operations and maintenance manuals, FDR capabilities, and operator/manufacturer/authority interface. The FAA noted that many of the issues would be challenging and would require coordination with, and the participation of, numerous civil aviation organizations, including the Air Line Pilots Association and the Air Transport Association. The FAA stated that it should have a detailed plan for this work by March 2004.

In response to Safety Recommendation A-03-43, the FAA stated that manufacturers have not currently established maximum threshold values for positive and negative vertical and lateral G accelerations but that implementation of the actions recommended in Safety Recommendation A-03-43 would occur automatically once

manufacturers establish such thresholds (as recommended in Safety Recommendation A-03-42). The FAA further stated that it would develop a bulletin to provide guidance for inspectors to use in determining that appropriate manufacturer oversight and intervention occurs as a condition for returning an airplane to service.

On April 21, 2004, the Safety Board stated that it looked forward to reviewing the FAA's plan to work with industry in addressing the issues discussed in Safety Recommendations A-03-41, -42, and -44. Pending the FAA's development of this plan, its review by the Board, and the FAA's actions in response to the recommendations of the plan, Safety Recommendations A-03-41, -42, and -44 were classified "Open—Acceptable Response."

The Safety Board also stated that, although the planned actions in response to Safety Recommendation A-03-43 are positive steps, the Board was concerned that these actions might not be fully responsive to the intent of the recommendation. The Board expressed its concern that airplanes might be exceeding design and certification standards more frequently than was previously known or expected and that, as a result, such events needed to be tracked and evaluated. The Board further stated that, at a March 16, 2004, meeting, staff from the FAA and the Board discussed the Board's position that relying solely on the pilot-in-commend to report exceeded threshold values was not a reliable tracking and evaluation method and that the evaluation of acceleration threshold exceedances needed to be based on FDR or other available data. The FAA indicated that it would consider a requirement to regularly check the FDR for evidence of an airplane having exceeded the acceleration threshold values established in response to Safety Recommendation A-03-42. Pending the development of a system for the FAA to track and evaluate acceleration events that exceed a manufacturer's threshold values, as determined from FDR and other available data and not solely from pilot-in-command reports, Safety Recommendation A-03-43 was classified "Open—Acceptable Response."

On August 23, 2004, the FAA stated that the Aerospace Industries Association and the Air Transport Association were convening a working group "to review current maintenance manual inspection process for high load events and to develop an advisory 'best practices' standard for using flight data in these processes." The FAA also stated that both organizations were in identifying working group participants and developing a meeting schedule. The FAA anticipated that working group would complete its activities within 1 year.

1.18.5 Previous Safety Recommendations Related to the Circumstances of the Flight 903 Accident

After the flight 587 accident, the Safety Board reexamined FDR data from the May 1997 American Airlines flight 903 accident (see section 1.18.2.1).[167] The Board determined that the flight 903 airplane's rudder exceeded its designed travel limits because of a rapid increase in airspeed during the upset and apparent high forces applied to the rudder pedal when it was at the in-flight limit.

As stated in section 1.6.2, the A300-600 rudder has the following travel limits in terms of indicated airspeed: a maximum of 30° at 165 knots and below; 14.5° at 220 knots; 9.3° at 250 knots; 7° at 270 knots; 5° at 310 knots; 4° at 350 knots; and 3.5° at 395 knots and above. The flight 903 investigation determined that the rudder travel limiter could only maintain these limits in response to airspeed changes that occurred at a moderate rate, such as those typically experienced during normal commercial operations. The investigation also determined that the rudder travel limiter could not maintain these limits in response to more rapid airspeed changes, such as those experienced during the flight 903 upset.

The flight 903 investigation specifically determined that, in the airspeed range of 165 to 220 knots, the rudder travel limiter could maintain the designed rudder travel limitations for airspeed changes up to about 2.4 knots per second. However, during the flight 903 upset, the airplane experienced a much more rapid airspeed increase—from 190 to 220 knots in 3 seconds—which equated to an increase of up to 10 knots per second and exceeded the rate at which the rudder travel limiter system could respond by as much as four times. The airspeed then continued to increase during the next 20 seconds at a rate of 2.6 knots per second. Because of the increasing airspeed, the rudder travel limiter position lag (introduced by the previous 3-second rapid increase) was present throughout most of the upset (even though the position lag was decreasing).

Because of the rapid initial airspeed change and continued airspeed increase, the rudder exceeded its designed rudder travel limit for about 20 seconds. During that time, the rudder moved four times in response to pilot input; the rudder exceeded the design limit by about 8° twice and by about 5° twice. The Safety Board stated that rudder travel beyond the designed rudder travel limits could lead to high loads on the vertical stabilizer and that this potential would be especially high during in-flight upsets because rapid airspeed changes accompanied by rudder inputs are more likely to occur during upsets than during normal flight.

A review of the flight 903 FDR data for rudder position showed that, even after accounting for the slow response rate of the rudder travel limiter, the rudder still appeared to exceed the estimated position at which it should have been limited by the rudder travel

---

[167] The Safety Board agreed to include a statement in this report to address the claims that a linkage exists between American Airlines flight 587 and American Airlines flight 903. By including this statement, the Board seeks to set forth the reasons for declining to make a causal connection between the two events. See appendix C for an explanation of the differences.

limiter. This exceedance was as high as 4° near the end of the upset. Testing of the rudder travel limiter determined that, if a pilot applied a sufficiently large pedal force when the pedal was at its travel limit, such a pedal force would further slow or stop the movement and, consequently, the effectiveness of the rudder travel limiter. The flight 903 event demonstrated that slowing or stopping the rudder travel limiter by application of large pedal forces could result in the rudder position substantially exceeding the designed travel limit. The Safety Board was concerned that such an increase in available rudder beyond its designed rudder travel limits could permit excessive rudder movements and possibly result in high loads on the vertical stabilizer.

As a result of its concerns, the Safety Board issued Safety Recommendations A-04-44 and -45 on May 28, 2004. Safety Recommendations A-04-44 and -45 asked the FAA to take the following actions:

> Require Airbus to develop a design modification for the A300-600 rudder travel limiter system so that it can respond effectively to rapid airspeed changes such as those that might be experienced during upsets and not be adversely affected by pedal forces, and issue an airworthiness directive to require the installation of that modification. (A-04-44)

> Evaluate other transport-category airplanes with rudder limiting systems to determine whether any of those systems are unable to effectively respond to rapid airspeed changes such as those that might be experienced during upsets, or whether any of those systems are adversely affected by pedal forces and, if so, require corrective modifications to those systems. (A-04-45)

The FAA responded to Safety Recommendations A-04-44 and -45 on August 12, 2004. Regarding Safety Recommendation A-04-44, the FAA stated that it was aware that the Board was considering additional design-related safety recommendations pertaining to the A300-600 flight control systems. The FAA also stated that it would like to assess these recommendations before making any final decisions about the design of the A300-600 flight control system.

Regarding Safety Recommendation A-04-45, the FAA stated that its aircraft certification offices would ask transport-category airplane manufacturers for information regarding the maximum expected airplane accelerations and maximum rudder travel limiter rates. The FAA indicated that the offices would be also asking the manufacturers if rudder pedal forces might adversely affect their rudder limiting devices. The FAA further stated that, after the manufacturers' systems information was received and analyzed, the FAA would be in a position to determine whether any of those systems would be unable to respond effectively to airspeed changes, such as those that might be experienced during upsets, and would be adversely affected by pedal forces. Such information, according to the FAA, would help determine what airworthiness actions might be required.

1.18.6 Previous Safety Recommendations Related to Upset Recovery Training

1.18.6.1 Safety Recommendation A-96-120

On October 18, 1996, the Safety Board issued Safety Recommendation A-96-120. This recommendation was issued in response to three uncommanded roll and/or yaw events that occurred while Boeing 737 airplanes were approaching to land: the March 3, 1991, United Airlines flight 585 accident in Colorado Springs, Colorado; the September 8, 1994, USAir flight 427 accident near Aliquippa, Pennsylvania; and the June 9, 1996, Eastwind Airlines flight 517 incident in Richmond, Virginia. Safety Recommendation A-96-120 asked the FAA to take the following action:

> Require 14 CFR Part 121 and 135 operators to provide training to flight crews in the recognition of and recovery from unusual attitudes and upset maneuvers, including upsets that occur while the aircraft is being controlled by automatic flight control systems, and unusual attitudes that result from flight control malfunctions and uncommanded flight control surface movements.

On January 16, 1997, the FAA stated that it agreed with this recommendation and that it was considering a notice of proposed rulemaking (NPRM) "to require that air carriers conduct training that will emphasize recognition, prevention, and recovery from aircraft attitudes normally not associated with air carrier flight operations." On July 15, 1997, the Safety Board classified A-96-120 "Open—Acceptable Response." However, on April 19, 1999, the Board classified the recommendation "Open—Unacceptable Response" because the FAA had not taken the necessary regulatory action to require unusual attitude training for air carrier pilots.

On August 11, 1999, the FAA stated that it initiated an NPRM proposing to revise 14 CFR Part 121, Subparts N and O. The FAA indicated that the NPRM would include training in the recognition and recovery of unusual attitudes and upset maneuvers. The FAA anticipated that the NPRM would be published in December 2000. On December 20, 1999, the Safety Board stated that, on the basis of the FAA's planned actions, Safety Recommendation A-96-120 was classified "Open—Acceptable Response."

On February 11, 2003, FAA staff advised the Safety Board that an NPRM package with changes to 14 CFR Subparts N and O was being coordinated internally and was expected to be submitted to the Office of the Secretary of Transportation in May 2003. On June 16, 2004, FAA staff advised the Board that an aviation rulemaking committee was reviewing the NPRM effort and that the issuance of the NPRM was unlikely before the end of 2004.

1.18.6.2 Other Upset Recovery Training Safety Recommendations

The Safety Board had issued three safety recommendations to the FAA (before A-96-120) for upset recovery training for airline pilots. First, on May 1, 1970, the Safety Board issued Safety Recommendation A-70-21 as a result of the November 16, 1968,

accident in which a flight crew lost control of a Boeing 737 near Detroit, Michigan, during poor weather conditions. Safety Recommendation A-70-21 recommended that

> Airlines be required to provide additional flightcrew training, whereby pilots would be required to demonstrate periodically, proficiency in the area of recovery from unusual attitudes. It was suggested that a simulator be utilized to provide flightcrew familiarization in the following areas. A. The various instrument displays associated with and resulting from encounters with unusual meteorological conditions. B. The proper flightcrew response to the various displays. C. Demonstration of and recovery from possible ensuing unusual attitudes.

On May 21, 1970, the FAA stated that unusual attitude maneuvers had been deleted from the pilot proficiency check in 1965 but that airline training now emphasized the proper use of trim, attitude control, and thrust, which the FAA believed was far more effective than the practice of recovery from unusual attitude maneuvers. The FAA also stated that it was inconceivable to require training maneuvers that would place a large jet airplane in a nose-high, low airspeed, high AOA situation. On July 8, 1970, the FAA stated that changes in airline training and operational procedures had resulted from this safety recommendation and cited a "marked decrease in upset events" as evidence that these actions had addressed the intent of the recommendation. The FAA further stated that it would discuss with industry representatives the feasibility of simulating large excursions from flightpath caused by abnormal meteorological conditions. Because no further action was taken by the FAA, the Safety Board classified Safety Recommendation A-70-21 "Closed—Unacceptable Action" on August 17, 1972.

Second, on September 15, 1972, the Safety Board issued Safety Recommendation A-72-152 as a result of the March 31, 1971, accident involving a Boeing 720B, which yawed and crashed while the flight crew was attempting a three-engine missed approach from a simulated engine-out instrument landing system approach. The Safety Board was concerned about the flight crew's inability to rapidly assess the situation and recover. Safety Recommendation A-72-152 recommended that

> [Title] 14 CFR 61, Appendix A, and 14 CFR 121, Appendices E and F be amended to include a requirement for pilots to demonstrate their ability to recover from abnormal regimes of flight and unusual attitudes solely by reference to flight instruments. For maximum safety, these demonstrations should be conducted in an appropriate flight simulator. Should existing or proposed simulators be incapable of realistically duplicating aircraft performance in the regimes of flight beyond normal operation, it is further recommended that the FAA take appropriate measures to require that such existing or proposed simulators be replaced or modified to include such a capability.

On September 26, 1972, the FAA stated that it did not believe that simulators were capable of simulating certain regimes of flight that were beyond the normal flight envelope of an aircraft. The FAA further stated that, because an aircraft simulator was not a required part of an air carrier training program, the FAA could not require that a simulator be replaced or modified to simulate regimes of flight outside the flight envelope

of the aircraft. As a result of the FAA's response, the Safety Board classified Safety Recommendation A-72-152 "Closed—Unacceptable Action" on January 16, 1973.

Third, on April 29, 1992, the Safety Board issued Safety Recommendation A-92-20 as a result of the July 10, 1991, L'Express Airlines Beech C99 accident at Birmingham, Alabama. The airplane was on an instrument approach into clearly identified thunderstorm activity, resulting in a loss of control of the airplane from which the flight crew was unable to recover. Safety Recommendation A-92-20 asked the FAA to take the following action:

> Require that recurrent training and proficiency programs for instrument-rated pilots include techniques for recognizing and recovering from unusual attitudes.

On July 9, 1992, the FAA stated that pilots were required to demonstrate recovery from unusual flight attitudes on their private pilot examination. The FAA also stated that an instrument rating required a pilot to be proficient in recovery from unusual attitudes. The FAA noted that, by the time a pilot had the required experience to become a pilot with an air carrier operating under 14 CFR Part 121 or 135, the pilot would have received extensive training and flight checks for procedures and techniques in recovery from unusual attitudes.

On January 26, 1993, the Safety Board stated that instrument-rated pilots should receive recurrent training in techniques for recognizing and recovering from unusual attitudes and that proficiency programs should include this same training. The Board also stated that requiring such training annually would greatly enhance a pilot's ability to safely recover from an unusual attitude. Because the FAA planned no actions on this recommendation, the Safety Board classified Safety Recommendation A-92-20 "Closed—Unacceptable Action."

1.18.7 Previous Safety Board Actions Regarding Data Filtering

1.18.7.1 Safety Recommendations A-94-120 and -121

The Safety Board participated in the investigations of three Boeing 767 accidents that occurred overseas during either 1992 or 1993. The investigations determined that flight control position data recorded on the airplanes' FDRs were filtered by the engine instrument crew alert system (EICAS). As a result, the Board issued Safety Recommendations A-94-120 and -121 on June 16, 1994. Safety Recommendation A-94-120 asked the FAA to take the following action:

> Require design modification to the Boeing 757/767 so that flight control position data to the DFDR [digital flight data recorder] is accurate and not filtered by the EICAS. The sample rate should also be increased to an appropriate value.

In an August 29, 1994, letter, the FAA indicated its belief that it was not necessary to redesign the Boeing 757 and 767 FDR to record unfiltered data control positions because the airplanes' FDR installations met the accuracy requirements of

14 CFR 121.343. In an August 1, 1995, letter, the Safety Board disagreed with the FAA's position and stated that the current method used to record flight control position for the Boeing 757 and 767 would meet the regulatory requirement for static, but not dynamic, conditions. (Under dynamic conditions, the parameter is undergoing change at the maximum rate that can be expected.)

On November 20, 1996, the FAA indicated that it issued NPRM 96-7, which proposed to upgrade recorder capabilities in most transport-category airplanes, including the Boeing 757 and 767, and to preclude the use of a filter. On May 16, 1997, the Safety Board noted that the proposed rule appeared to preclude the use of a filter by a statement in new appendixes for 14 CFR Parts 121, 125, and 135. The statement indicated that recorded values had to meet accuracy requirements during dynamic and static conditions; thus, data filtering techniques, including EICAS-filtered data parameters, would not meet this proposed requirement. The Board further noted that airplanes using data filtering systems would need to be retrofitted or would need to undergo design modifications to meet the proposed requirement. The Board indicated that the NPRM was a positive step toward ensuring that correct and adequate control position data would be recorded on FDRs but was concerned that airplane manufacturers and air carriers might overlook the new rules in the appendixes or not realize that data filtering systems had to be replaced. The Board stated that it would appreciate information on the FAA's plans if it did not intend to issue alerts highlighting the new requirements and the time schedule detailed in the NPRM.

In a September 10, 1997, letter, the FAA stated that, on July 9, 1997, it issued the final rule (14 CFR 121.344, Appendix M) to upgrade recorder capabilities in most transport-category airplanes. (The final rule also amended 14 CFR Parts 125 and 135 to require certain operators to upgrade recorder capabilities.) The FAA also stated that the final rule precluded the use of a filter for FDR data and specified the sampling rate for all parameters. On August 4, 1998, the Safety Board noted that the FAA's letter did not mention any alerts or alternate plans to highlight the new requirements. However, the Board thought that the FAA appeared to refer to the Board's concern within the "Discussion of Comments to the NPRM" section of the final rule. In that section, the FAA agreed that further explanation of the dynamic test condition requirement was necessary and stated that it intended to issue an AC to clarify the recording of dynamic and static data and other acceptable means to comply with the rule. The Board stated that it was pleased that the FAA had recognized the need to further emphasize the means for compliance with the new requirements and to notify operators of the elimination of filtered data. The Board urged the FAA to expedite the issuance of the AC because operators and manufacturers had begun preparations to retrofit their fleets.

In a February 25, 2000, letter, the FAA indicated that, on October 5, 1999, it issued AC 20-141, "Airworthiness and Operational Approval of Digital Flight Data Recorder Systems," which addressed all filtered data and not just EICAS data. The AC stated that the applicant must identify any parameters that are filtered before they are recorded and must show, by test, that "no significant difference" exists between these parameters and the recorded parameter data under static and dynamic conditions. On May 11, 2000, the

Safety Board indicated that the final rule and the AC satisfied the intent of Safety Recommendation A-94-120 and classified it "Closed—Acceptable Action."

Safety Recommendation A-94-121 asked the FAA to take the following action:

Review other airplane designs to ensure that flight control position data filtered by systems such as EICAS are not substituted for accurate data.

In an August 29, 1994, letter, the FAA indicated that it had reviewed the flight control position data to the FDR on McDonnell Douglas MD-80/90 and MD-11 airplanes and found that the flight control positions were recorded accurately. On November 20, 1996, the FAA indicated that it reviewed the flight control position data to the FDR of aircraft manufactured by Aerospatiale, CASA, Cessna, Grumann, Gulfstream, Israel Aircraft Industries, Lockheed, and Saab and concluded that the data filtered by systems such as EICAS were not substituted for accurate data. The FAA also indicated that it was planning to complete similar reviews for airplanes manufactured by Airbus, Canadair, Dassault (Falcon), DeHavilland, Dornier, Embraer, Fokker, Jetstream, Lear, LET, and Illyushin. Further, the FAA indicated that it would take "whatever steps were necessary" to ensure that the recorded data were accurate and representative of control surface positions. In a May 16, 1997, letter, the Safety Board indicated that it was pleased with the FAA's review efforts and commitment to take any necessary action.

On February 9, 1998, the FAA stated that it had issued its final rule to amend 14 CFR Parts 121, 125, and 135, which required certain operators to record additional FDR parameters and precluded the use of a filter. The FAA considered its action to be completed on this safety recommendation. On August 4, 1998, the Safety Board indicated that the FAA's February 9 letter made no mention of the status of its planned review of other manufacturers' airplane designs. The Board stated that, regardless of the issuance of the rulemaking and the rulemaking's elimination of filtering, the FAA should finish its review and notify the Board of the findings. Further, the Board stated that, if the FAA found additional airplanes with filtered control surface data, then it should ensure that all affected operators take the necessary steps to record accurate data.

On April 4, 2000, the FAA indicated that it had completed a review of Embraer and Dassault (Falcon) aircraft and concluded that the recorded data were accurate and representative of control surface positions. The FAA stated that there was "no need to continue an independent review of the remaining existing airplanes" because "implementation of the final rule ensures that the recorded data are accurate and representative of control surface positions." The FAA further stated that its principal aviation safety inspectors assigned to 14 CFR Part 121, 125, and 135 operators were familiar with the rule change and that the inspectors would ensure that their operators comply with the rules. In addition, the FAA stated that it had issued AC 20-141 in response to Safety Recommendation A-94-120.

On August 9, 2000, the Safety Board indicated that it was disappointed that the FAA did not complete the review of airplane designs because it would have provided an additional level of assurance that accurate FDR data were being recorded. However, the

Board stated that it was pleased overall with the FAA's actions on this safety recommendation. As a result, Safety Recommendation A-94-121 was classified "Closed—Acceptable Action."

1.18.7.2 Postaccident Correspondence on Data Filtering

In a February 6, 2002, letter, the Safety Board indicated that the flight 587 investigation revealed that vital flight control surface position information was not directly recorded on the accident airplane's FDR because of the SDAC filter (see section 1.11.2). The Board believed that the filtered data supplied by the SDAC did not meet the accuracy requirements under dynamic conditions called for in 14 CFR 121.344, Appendix M.

The Safety Board stated that the presence of filtered data was "surprising and disappointing," considering the FAA's actions regarding Safety Recommendations A-94-120 and -121 (see section 1.18.7.1). Specifically, the Board indicated that it accepted the FAA's assertion that the issuance of the 1997 final rule (which precluded the use of a filter and added the requirement for a dynamic test condition) and AC 20-141 (which specified test procedures for recorded parameter data under static and dynamic conditions), as well as the work of POIs, would ensure that operators would not record filtered FDR data.

The Safety Board believed that the FAA needed to take immediate steps to identify those A300 airplanes that recorded filtered flight control surface data and to take corrective actions as soon as possible to bring these airplanes into compliance with existing regulations. The Board also noted that it was important for the FAA to complete the review called for in Safety Recommendation A-94-121 to ensure that all aircraft that record filtered data are identified and brought into compliance with regulations as soon as possible. In addition, the Board expressed concern that older aircraft, which have not historically recorded filtered data, could be retrofitted with new or upgraded avionics that supply filtered data to the FDR. The Safety Board requested that, within 30 days, the FAA advise the Board, in writing, of the steps that the FAA intended to take to address the problem involving A300 airplanes that record filtered data and to identify and correct any other aircraft that are similarly recording filtered data.

In a March 6, 2002, letter, the FAA stated that, when Safety Recommendations A-94-120 and -121 were issued, it surveyed all transport-category airplane manufacturers to determine if FDR data on their airplane models were filtered. The FAA indicated that the manufacturers might not have had a clear understanding of what filtered data meant in the context of Safety Recommendation A-94-121 and that, as a result, the manufacturers defined "filtered" as they saw fit. The FAA further indicated that Airbus reported that the FDRs on its airplanes did not record filtered data.

The FAA recognized that it gave assurances to the Safety Board that the wording of its 1997 final rule on data filtering would preclude the recording of filtered flight control position data on most transport-category airplanes. However, the FAA stated the following regarding the wording of the final rule:

Although it [the final rule] did not specifically preclude filtering, it was thought that filtering was technically unfeasible in a compliant system. However, the preamble to the rule left the option open for filtering by use of the undefined term 'readily retrievable.' Filtered data was accepted as long as there was a method of readily retrieving the data.

The FAA added that AC 20-141, which was introduced several months after the final rule, specifically addressed filtering but did not disallow it. The FAA stated, "again, it was thought that the technical guidance outlined in the AC made filtering unfeasible."

The FAA stated that, as a result of the recent concerns about data filtering, it compiled all historical data surrounding Safety Recommendations A-94-120 and -121 and conducted a new survey of transport-category airplane manufacturers to determine whether FDRs on their airplane models recorded filtered flight control position data. The FAA also stated that it contacted Airbus to find out whether the Safety Board's assertions regarding FDR data filtering on its models were accurate. Airbus indicated, contrary to its earlier position, that it did record filtered data but that the filtering did not conflict with the requirements of 14 CFR 121.344.

On September 3, 2002, the Safety Board indicated that it had provided the FAA with a detailed list of concerns regarding filtered data and was prepared to discuss these issues at a planned October 1, 2002, meeting with the FAA and Airbus. The specific issues discussed at this meeting included compliance with FDR rules as they pertained to the recording of filtered data on Airbus airplanes, the possible impact of data filtering and sampling rate on a pending flight recorder NPRM, and the FAA's findings in response to its new manufacturer survey (see section 1.18.7.3).

1.18.7.3 Safety Recommendation A-03-50

At the October 1, 2002, meeting with Airbus and the Safety Board, the FAA reported on the results of Phase I of the new manufacturer survey. The FAA stated that Boeing had reported that the 747-400 recorded filtered data for four parameters. The FAA also stated that Phase I of the survey would be complete once Airbus' results were received. Airbus stated that its understanding of the regulatory requirements pertaining to filtered data differed from the intent of the rule but that it was willing to work with the FAA to correct the problem.

In an October 25, 2002, letter to the FAA, Airbus provided the results of its survey, which indicated that the A310 and A300-600 models recorded filtered data for five parameters: aileron left, aileron right, rudder, elevator, and stabilizer position. Airbus also stated that it was willing to develop a service bulletin to increase the sampling rate for flight control parameters on existing and newly manufactured Airbus airplanes.

On November 6, 2003, the Safety Board issued Safety Recommendation A-03-50, which asked the FAA to take the following action:

> Require that within 2 years, all Airbus A300-600/A310 and Boeing 747-400 airplanes and any other aircraft that may be identified as recording filtered data be retrofitted with a flight data recorder system capable of recording values that meet the accuracy requirements through the full dynamic range of each parameter at a frequency sufficient to determine a complete, accurate, and unambiguous time history of parameter activity, with emphasis on capturing each parameter's dynamic motion at the maximum rate possible, including reversals of direction at the maximum rate possible.

On February 2, 2004, the FAA stated that FDRs either should not record filtered flight control surface parameters[168] or, if filtered data were recorded, a proven and unambiguous method must exist for retrieving, to within required tolerances, the original unfiltered values from the filtered data. The FAA also stated that the most recent information on filtered flight control surface parameters revealed that the Boeing 747-400 does not filter such data, contrary to what was originally reported. The most recent information also revealed that the A320 rudder position parameter was filtered and not retrievable. Thus, the only transport-category airplanes determined by the FAA to have filtered, nonretrievable flight control surface parameters are the Airbus A310, A300-600, and A320.

The FAA stated that it planned to initiate clarifying rulemaking to ensure that existing airplane FDR systems that record filtered, nonretrievable flight control surface parameters were corrected and to prevent future occurrences of such filtering. The FAA expressed its concern that 2 years would not be sufficient time to accomplish the necessary rulemaking, design, and incorporation of a cost-effective corrective action.

On May 10, 2004, the Safety Board stated that the FAA's planned actions were responsive to the intent of the recommendation. The Board recognized that displays of information used by a pilot to fly an airplane could be filtered but believed that a global exception that allowed filtering of all signals displayed to the pilot was unacceptable. The Board pointed out that unfiltered, high-sampling-rate flight control position data were critically important for accident/incident investigation purposes. These data could be displayed to pilots in many A310, A300-600, and A320 airplanes, but the pilots would not normally use this information to fly the airplane. The Board believed that the recording of filtered data should be limited only to those data that were normally displayed and used by the pilot for flying the airplane. Pending the issuance of the FAA's planned rulemaking, Safety Recommendation A-03-50 was classified "Open—Acceptable Response."

---

[168] The FAA stated that it found no regulatory agreement on which non-flight control parameters, if any, should be unfiltered. According to the FAA, the European airworthiness authorities and the FAA agreed that certain recorded parameters should reflect the data displayed to the pilots and not the raw sensor data on which the displayed values were based. The FAA further stated that it planned to address the filtering of non-flight control parameters at a forum with participation from industry, airworthiness authorities, and the Safety Board and then take action on this issue based on the results of the forum.

1.18.7.3.1 Public Meeting on Safety Recommendation A-03-50

On July 7, 2004, the FAA held a public meeting to discuss issues related to Safety Recommendation A-03-50. The purpose of the meeting was to determine the aviation industry's position on the definitions of "parameter filtering" and "readily retrievable data," the parameters that should not be filtered, and the impact of incorporating the Safety Board's recommendation. Representatives from the Safety Board, Airbus, Boeing, the Allied Pilots Association, and the Air Line Pilots Association made presentations at the meeting. All of the meeting participants indicated that they were against data filtering except Airbus, which indicated that its airplanes met the intent of 14 CFR 121.344.

1.18.8 Aircraft-Pilot Coupling

According to a 1997 report by the National Research Council (NRC),[169] "unfavorable aircraft-pilot coupling (APC) events are rare, unexpected, and unintended excursions in aircraft attitude and flight path caused by anomalous interactions between the aircraft and the pilot." APC events can be oscillatory or divergent, and the coupling between the pilot and the aircraft can either be open- or closed-loop, depending on the complexity with which the pilot is controlling the aircraft. When the pilot dynamics and the aircraft dynamics, including the flight control system dynamics, combine to produce an undesirable and unstable system, an APC event results. Although these events are rare, they can be catastrophic.

APC events include a trigger, which causes the pilot to alter his or her control strategy; specifically, the pilot switches from a low-gain to a high-gain piloting technique.[170] The three types of triggers associated with APC events are pilot triggers, which result when a pilot overcontrols the aircraft or responds with an inappropriate reaction to a stimulus; environmental triggers,[171] which typically involve an environmental circumstance that causes the pilot to enter destabilizing control inputs (for example, atmospheric turbulence or the threat of imminent collision); or vehicle triggers, which typically involve changes in the aircraft's response to control inputs or changes in the feedback to the pilot, resulting in inconsistencies between the pilot's input strategy and the aircraft dynamics.[172]

A trigger alone will not result in an APC event; the dynamics of the aircraft's flight control system also have to be susceptible to such an event. Although much research has been completed concerning adverse interactions between pilots and aircraft, APC events are often complex situations that are difficult to analyze. As a result, during flight testing

---

[169] National Research Council, *Aviation Safety and Pilot Control – Understanding and Preventing Unfavorable Pilot-Vehicle Interactions* (Washington, DC: National Academy Press, 1997).

[170] According to the NRC report, pilot gain is the sensitivity with which the pilot reacts to a given stimulus. If the situation is urgent, the pilot is likely to react with large corrective inputs, even for small system errors. When this situation happens, the pilot is said to be exhibiting high gain. More relaxed responses imply a lower pilot gain.

[171] An environmental trigger may increase a pilot's stress level, resulting in increased pilot gain.

[172] Environmental or vehicle triggers often precede pilot triggers.

and certification, test pilots perform specific maneuvers to help reveal potential aircraft susceptibility to APC events (see section 1.18.8.1).

The NRC report provided specific design goals to be used in developing flying qualities requirements for APC prevention. These design goals include the following:

- The system should perform consistently throughout as much of the flight envelope as possible so that the pilot will not incorrectly change behavior based on the system response.

- The system should achieve predictable input-output characteristics, should be designed for linear proportional responses, and should avoid nonlinear control system characteristics (that is, responses that are not proportional to input).

- The maximum maneuvering rates and severe turbulence should not result in actuator rate and/or position limiting.

- The system should strive to minimize the number of modes and failure states consistent with aircraft performance requirements.

Finally, the NRC report made the following finding and recommendation, respectively:

Operational line pilots have little or no exposure to APC potential and are not trained to recognize the initial symptoms or to understand that APC does not imply poor airmanship. This may limit reporting of APC events.

Insufficient attention to APC phenomena generally seems to be associated with a lack of understanding and relevant experience. This shortcoming should be addressed through improved education about APC phenomena for pilots and other personnel involved in aircraft design, simulation, testing, certification, operation, and accident investigation.

1.18.8.1 Aircraft-Pilot Coupling Testing Maneuvers

AC 25-7, "Flight Test Guide for Certification of Transport Category Airplanes," which was issued in April 1986, provided guidelines for flight test methods and procedures to show compliance with the regulations contained in subpart B (airplane performance and handling characteristics) of 14 CFR Part 25. AC 25-7A was issued in March 1998 and was revised in June 1999. AC 25-7A contained APC testing guidance that was not included in AC 25-7.

AC 25-7A stated that capture (gross acquisition) tasks and fine tracking tasks could highlight APC problem areas that might exist.[173] For example, AC 25-7A stated that

---

[173] AC 25-7A states that capture tasks can give the pilot a general impression of the handling qualities of the airplane. Various capture tasks—for pitch attitude, bank angle, heading, flightpath angle, AOA, and G— can be done to evaluate different aspects of the airplane's response as long as the necessary cues are available to the pilot. AC 25-7A also states that capture tasks should not be used as the only evaluation task because they would not expose all of the problems that might arise in closed-loop, fine tracking tasks.

heading capture tasks (usually small heading changes of 5º or less) could be used to evaluate the "yaw controller" (that is, the rudder) alone. The AC did not include bank angle capture tasks for evaluating the yaw controller. Also, AC 25-7A stated that fine tracking tasks using pitch and roll controls would expose APC susceptibility of an airplane flying in turbulence. These fine tracking tasks would not involve the use of the rudder.

In addition, AC 25-7A listed upset and/or collision avoidance maneuvers that were found to be effective in evaluating APC susceptibility when the airplane was flying at high altitude and under lateral load conditions of 0.3 G. None of these maneuvers would involve the use of the rudder. Finally, AC 25-7A stated that "artificial trim and feel systems which produce controllers with too small a displacement and light force gradients may also lead to severe over control."

1.18.9 Reports of Rudder Use in Upset Recovery Efforts

NASA's ASRS included the results of a special study of uncommanded, in-flight upsets aboard multiengine turbojet aircraft in the United States. During a 6-month period from May 1 to October 31, 1995, 33 such upsets were reported, most of which were induced by wake turbulence. Structured telephone interviews were conducted for all pilots who reported those upsets. The telephone interviews indicated that wake turbulence was the most common cause of these upsets and that pilots used rudder during recovery efforts in 11 (one-third) of the 33 reported upset events.

The Safety Board reviewed the ASRS database and found the following reports of rudder use by transport-category pilots in response to wake turbulence events:

- The flight crew of a 737 being vectored on approach reported that the airplane sustained a high rate of roll from wake turbulence that resulted in an estimated bank angle of 20º. The flying pilot responded by applying a substantial amount of rudder in addition to most of the available aileron.

- The captain of a 737 airplane on final approach reported that the airplane encountered a steady roll to the left from wake turbulence and reached an estimated bank angle of about 25º. The flying pilot (a student captain on an initial operating experience examination) applied full right rudder and aileron to recover. The flying pilot subsequently stated that unusual attitude training was an important factor in his "proper" response.

- The flight crew of a 757 on short final reported that the airplane experienced wake turbulence, resulting in two rolling events. The captain, who was the flying pilot, reported that he applied rudder and aileron to stop the initial bank angle, which was estimated to be about 15º to 20º. The airplane then rolled sharply in the opposite direction. The captain reported that he applied full rudder and aileron until the airplane reached a bank angle of about 40º to 45º, at which time he initiated a successful missed approach. The FDR showed bank angles of 15º or less.

- The captain of a 727 flying at an altitude of 12,000 feet and an airspeed of 250 knots reported that the airplane experienced wake turbulence, resulting in two rolling events. The first officer (the flying pilot) applied full rudder and aileron to stop the first roll at about 35° of bank. The first officer then applied full rudder and aileron in the opposite direction to stop a second bank, which began about 3 to 4 seconds later in the opposite direction and might have resulted in more than 35° of bank. The captain commended the first officer for regaining control without overcontrolling and aggravating the situation.

1.18.10 Airbus Technical Note

On April 8, 2004, Airbus issued a technical note, titled "AAL 587 – Pedals Force Analysis," that provided Airbus' estimate of the rudder pedal forces during the seconds before the vertical stabilizer separated from the airplane. Airbus used FDR data for rudder pedal position, estimates of rudder position, estimates of yaw damper position, and ground test data to derive the pedal force estimate.

The technical note indicated that, during the accident sequence, the forces applied by the first officer to the rudder pedals were much higher than the forces required to reach the rudder travel limit for 240 knots. Airbus found that the highest force applied by the pilot during the accident sequence was about 140 pounds but that the pedal force required to reach the rudder travel limit during that time was about 30 pounds. The note further indicated that the rudder control cable was stretched each time that the rudder travel limit was contacted.

2.   Analysis

2.1   General

The captain and the first officer (the flying pilot) were properly certificated and qualified under Federal regulations. No evidence indicates any preexisting medical conditions that may have adversely affected the flight crew's performance during the flight. Flight crew fatigue was not a factor in this accident.

The accident airplane was properly maintained and dispatched in accordance with Federal regulations. Before takeoff, the number 2 pitch trim and yaw damper system would not engage. American Airlines avionics technicians found a fault with the number 2 flight augmentation computer, and the fault cleared when the circuit breaker for this computer was reset.

The air traffic controllers who handled American Airlines flight 587 were properly trained and qualified. The local controller complied with Federal Aviation Administration (FAA) wake turbulence spacing requirements when handling flight 587 and Japan Air Lines flight 47, which departed immediately before flight 587.

Flight 587's vertical stabilizer and rudder separated from the fuselage before impact and were recovered separately about 1 mile before the main wreckage site. At 0915:58.5, the flight data recorder (FDR) recorded a 0.2 G lateral acceleration, which corresponded to the sound of a loud bang recorded by the cockpit voice recorder (CVR) at the same time. The Safety Board's airplane performance study indicated that this change in lateral acceleration and the ensuing out-of-control airplane motion resulted from the separation of the vertical stabilizer from the fuselage. In addition, the study showed that, before vertical stabilizer separation, the airplane responded properly to all rudder deflections and that the rudder remained properly attached until the vertical stabilizer broke off the fuselage. (The vertical stabilizer separation is discussed further in section 2.2.)

Both engines separated from the airplane before ground impact. Neither engine showed evidence of uncontainments, case ruptures, or preimpact failure, and engine operation was normal throughout the airplane's ground operations, takeoff, and initial climb. FDR and CVR data showed that engine separation occurred during the out-of-control airplane motion that followed the separation of the vertical stabilizer. Fuel may have been ignited during the engine separation and may have caused a flash fire. Also, during the airplane's descent, the out-of-control motion would have disrupted the airflow into the engines and likely caused engine compressor surges. (Visible flames emanating from the engines are typical during engine compressor surges.) Therefore, the

Safety Board concludes that the witnesses who reported observing the airplane on fire[174] were most likely observing a fire from the initial release of fuel or the effects of engine compressor surges.

Shortly after takeoff, flight 587 encountered wake turbulence from Japan Air Lines flight 47—first at 0915:36 and again at 0915:51. Immediately after the onset of flight 587's second wake turbulence encounter (about 7 seconds before the vertical stabilizer separation), the FDR recorded a series of five cyclic movements of the rudder and rudder pedals. The Safety Board's investigation did not reveal any indication of a mechanical failure that could have caused these movements. The Board's ground tests of the rudder control system on another A300-600 revealed that rudder movement created by a yaw damper or an autopilot input to the system resulted in an FDR recording of the rudder and rudder pedal parameters that did not match the timing and sequence of the movements recorded by flight 587's FDR. The only way to move the rudder in a manner that created an FDR trace of these parameters that matched flight 587's FDR trace was for the pilot to depress the rudder pedals. Therefore, the Safety Board concludes that flight 587's cyclic rudder motions after the second wake turbulence encounter were the result of the first officer's rudder pedal inputs. (Possible explanations for the first officer's rudder pedal inputs are discussed in section 2.3.)

During the time that the first officer was making the five cyclic rudder pedal inputs, the captain began to question him (at 0915:55 he asked, "you all right?") and coached him (at 0915:56 he said, "hang on to it"). However, the captain did not intervene or take control of the airplane, which would have been within his authority as pilot-in-command. It appears that the captain believed that the wake was causing the airplane motion, even after the vertical stabilizer had separated from the airplane (saying, at 0916:12, "get out of it, get out of it"). It would have been difficult for the captain to observe the first officer's rudder pedal inputs.[175] Accordingly, given the captain's limited knowledge of the circumstances and the short duration of the accident sequence, the captain's response to the situation was understandable.

2.2   Separation of the Vertical Stabilizer

The in-flight separation of the vertical stabilizer from the fuselage of a transport-category airplane is an extremely rare,[176] if not unprecedented, occurrence. To evaluate and understand the circumstances of the vertical stabilizer separation on flight 587, the Safety Board examined the vertical stabilizer structure to evaluate its conformity with design specifications, analyzed the fracture and damage patterns indicated by the wreckage, calculated the aerodynamic loads on the vertical stabilizer and analyzed their effects on the structure during flight, assessed the most likely failure

---

[174] Of the 354 witnesses that provided sufficient detail to document, 56 percent reported seeing the airplane or a portion of the airplane on fire at some point during their observation.

[175] It is not possible to determine whether the captain's feet were resting on his rudder pedals. However, if his feet had been resting on the pedals, the captain could have felt the pedal movements made by the first officer.

scenarios using vertical stabilizer structural models, conducted three postaccident static lug tests, and evaluated certification documents.

No deviations from the original design and materials specifications were found in the vertical stabilizer (including the repair to the left center lug area that was made during manufacturing) that would have contributed to the vertical stabilizer separation. Also, a detailed inspection of flight 587's wreckage, including an extensive examination of the vertical stabilizer main attachment fitting fractures, revealed that each main attachment fitting had features that were consistent with overstress fracture and exhibited no evidence of fatigue features or other preexisting degradation. Fracture features and damage patterns on the right forward, center, and rear lugs were consistent with overstress failure under tensile loading. The right rear lug, in particular, had fracture features that were consistent with failure in the cleavage-tension mode. Fracture features and damage patterns on the left forward, center, and rear lugs had features that were consistent with the vertical stabilizer bending to the left after separation of the lugs on the right side.

Safety Board investigators conducted an airplane performance study to describe the motion of the accident airplane, identify the causes of the motion, and calculate the resulting aerodynamic loading on the vertical stabilizer.[177] The airplane performance study revealed that the first officer's cyclic rudder pedal inputs, which began about 7 seconds before the vertical stabilizer separation, led to increasing sideslip angles that, along with the continued rudder deflections, produced extremely high aerodynamic loads on the vertical stabilizer. The airplane performance study indicated that, at 0915:58.4, when the vertical stabilizer separation began, the aerodynamic loads on the vertical stabilizer were about two times the loads defined by the limit load design envelope (see figure 15).[178]

Given the aerodynamic loads at the time that the vertical stabilizer separated, it can be determined that the vertical stabilizer's structural performance was consistent with design specifications and had exceeded certification requirements. However, to determine if stresses in the vertical stabilizer at the time of failure corresponded to a material failure,

---

[176] On March 5, 1966, British Overseas Airways flight 911, a Boeing 707, departed Tokyo for Hong Kong with 124 people and the cabin crew aboard. Because of the clear weather at the time, the pilot asked for and received an amendment to the scheduled flight plan that would allow his passengers an up-close view of Mt. Fuji. Shortly after the airplane began its descent toward the mountain, witnesses reported seeing the airplane trailing white vapor and shedding pieces. The witnesses also reported that they saw a large puff of vapor that came from the airplane's vertical stabilizer and that the airplane pitched up and entered a flat spin. The witnesses further reported that the vertical stabilizer assembly and engines were missing, the outer wing had failed, the forward fuselage broke off, and the airplane continued in a flat spin until it crashed into the base of Mt. Fuji. All of the airplane occupants were killed. The report on this accident indicated that, when approaching Mt. Fuji, the airplane was violently impacted by a severe mountain wave, which led to vertical stabilizer failure and subsequent in-flight breakup. (A U.S. Navy aircraft, which was dispatched to search for the flight 911 wreckage, encountered extreme turbulence near the area of the crash. In fact, the G meter installed on the U.S. Navy aircraft registered +9 to -4 Gs during the flight.) The report also identified the white vapor as jet fuel flowing out of the airplane after separation of the engines.

[177] For more information about the airplane performance study, see section 1.16.2.

[178] Limit load is the maximum load to be expected in service, and ultimate load is limit load multiplied by a safety factor of 1.5. During public hearing testimony, an FAA airframe engineer stated that airplanes are expected to experience limit load only once in their lifetime and are never expected to experience ultimate load. For more information, see section 1.6.4.1.1.

the Safety Board conducted a detailed structural analysis of the accident condition. The structural analysis was to determine if the aerodynamic loading on the flight 587 vertical stabilizer was sufficient for fracture of the attachment lugs and subsequent separation of the vertical stabilizer and the sequence in which such a separation would progress.

The structural analysis included an assessment of Airbus' full-scale certification test, which was conducted during the design and certification process to demonstrate that the vertical stabilizer could withstand limit and ultimate loads. During the test, the vertical stabilizer was loaded to about two times the design limit load for the lateral gust condition before the left rear main attachment lug fractured because of a tensile static overload. The test revealed that the lug fractured with a resultant lug force of about 905 kiloNewtons (kN), which was about twice the calculated resultant lug force at limit load for the A300-600 lateral gust condition (454 kN when calculated using hot and wet conditions). The test also revealed that the failure mode of the rear main attachment lug was consistent with a cleavage-tension failure.

In the structural analysis of the accident condition, computational models predicted that, with increasing aerodynamic loads, the right rear lug would experience increasingly higher stresses that would eventually exceed the strength of the lug material and the right rear lug would be the first structural component to fracture. The models showed that this fracture would occur when the resultant lug forces and associated stresses reached about twice those defined by the lateral gust limit load condition; that is, they were well in excess of the forces and stresses corresponding to ultimate load (which are 1.5 times those defined by the lateral gust limit load condition). The models further showed that the fracture would be consistent with failure in the cleavage-tension mode and would quickly progress through the lug until it completely fractured. The remaining five main attachment fittings and six transverse load fittings would then fracture, causing the vertical stabilizer to separate from the fuselage.

In addition, the results of a postaccident analysis of Airbus' full-scale certification test were consistent with the results of that test. The postaccident analysis revealed that the lug stress and strain profiles for the accident condition were in agreement with the full-scale certification test.

To validate the computational models used in the structural analysis, the Safety Board performed static lug tests on three vertical stabilizer rear attachment lugs and compared the test results to the predictions of the models. For all three lug tests, the resultant forces and strain levels at failure were about twice those defined by the limit load lateral gust condition, as predicted by the computational models. Further, the fracture of each lug was consistent with failure in the cleavage-tension mode, as predicted by the computational models and observed on the accident right rear lug.

Thus, on the basis of all of the evidence discussed in this section, the Safety Board concludes that flight 587's vertical stabilizer performed in a manner that was consistent with its design and certification. The vertical stabilizer fractured from the fuselage in overstress, starting with the right rear lug while the vertical stabilizer was exposed to aerodynamic loads that were about twice the certified limit load design envelope and were

more than the certified ultimate load design envelope. Because these aerodynamic loads were caused by the first officer's rudder pedal inputs, the analysis of these rudder pedal inputs is of central importance to this investigation.

2.3 Analysis of the First Officer's Rudder Pedal Inputs

The Safety Board's investigation determined that three main factors influenced the first officer's rudder use during the accident sequence: a tendency to react aggressively to wake turbulence, as evidenced by his responses to previous wake turbulence encounters; his pilot training, including the training he received at American Airlines regarding wake turbulence, upset recovery, and rudder pedal use; and the characteristics of the A300-600 rudder control system. This analysis describes each of these factors and considers how they may have affected the first officer's rudder use (that is, his initial rudder input in response to the second wake turbulence encounter and his subsequent series of cyclic rudder pedal inputs) during the flight 587 accident sequence.

2.3.1 First Officer's Reactions to Wake Turbulence Encounters

Safety Board investigators interviewed several American Airlines pilots who had flown with the first officer. Even though the comments were generally positive, two pilots provided noteworthy accounts concerning the first officer's reaction to wake turbulence encounters.

One pilot, a 727 captain, recalled a 1997 flight on which the accident first officer was the flying pilot. According to the captain, the airplane encountered wake turbulence at an altitude of 1,000 to 1,500 feet during climbout. The captain said that the encounter was momentary and that he thought it required only a small aileron input to roll the airplane to wings level. However, the first officer responded by making a series of rapid, alternating full rudder pedal inputs. The captain recalled being startled by the first officer's response and thinking the rudder pedal inputs were quite aggressive. He recalled that the inputs created an uncomfortable yawing moment with heavy side loads on the airplane.[179] The captain said that he had never seen any other pilot react to wake turbulence in this manner. On the basis of the captain's recollections, it appears that the first officer overreacted to this wake turbulence encounter.

---

[179] The Safety Board notes that the 727, which has fuselage-mounted engines, requires comparatively less yawing moment from the rudder to counter an engine-out condition than airplanes with wing-mounted engines, such as the A300-600. Consequently, the yawing moment (and airplane response) resulting from a given rudder deflection is likely to be less pronounced on the 727 than on the A300-600.

According to the 727 captain, when he questioned the first officer about his rudder pedal inputs, the first officer stated that he had used the rudder to level the wings and insisted that the company's Advanced Aircraft Maneuvering Program (AAMP) training directed him to use rudder in that manner.[180] The captain stated that he counseled the first officer to be less aggressive in his rudder inputs.[181] The captain recalled that, on a subsequent flight, the first officer was still very quick to use the rudder during a wake turbulence encounter, although he did not think the first officer had pushed the rudder pedal to its stops on that occasion.

The other pilot who provided an account concerning the first officer's reaction to wake turbulence encounters was the flight engineer on a 1997 flight in a 727 being flown by the accident first officer. According to the flight engineer, when the airplane was on approach at an altitude of between 3,000 and 5,000 feet and about 7 miles from the runway, the airplane encountered wake turbulence from a preceding 737. The flight engineer said that the airplane rolled, but he did not think that the bank angle was greater than 30°. According to the flight engineer, the first officer reacted by immediately applying maximum engine power and executing a go-around. The flight engineer said that it was one of the more memorable events in his flying career. The Safety Board notes that the 727 is larger than the 737 (the airplane producing the wake) and that the flight was operating at an altitude with adequate ground clearance at the time of the wake turbulence encounter. In this situation, a go-around would not have been necessary; therefore, it appears the first officer overreacted to this wake turbulence encounter.

Two wake turbulence issues were also present before the accident sequence. First, after receiving clearance for takeoff, the first officer asked the captain whether he was happy with the separation distance behind Japan Air Lines flight 47.[182] The captain indicated that he was satisfied, and the takeoff proceeded. The first officer's question would be expected in this situation and shows that he was aware of the potential for encountering wake turbulence after flight 587 became airborne. Second, about 0915:36, flight 587 encountered mild wake turbulence from Japan Air Lines flight 47. The effect of the turbulence was typical of a minor wake encounter—a momentary 0.3 G drop in normal load factor, a 0.04 G drop in longitudinal load factor, and a 0.07 G shift in lateral load factor. However, the first officer reacted to this first wake turbulence encounter by moving the control wheel rapidly right and left several times, with large control wheel deflections up to 37° right and 34° left.[183] Board investigators noted, during vertical

---

[180] The influence that the AAMP training may have had on the first officer is discussed in section 2.3.2.2.

[181] The Safety Board notes that the captain did not admonish the first officer for using the rudder in response to wake turbulence but rather for the magnitude of his rudder pedal inputs. The use of rudder by other pilots in response to wake turbulence is discussed in section 2.4.1.1.

[182] Air traffic control had cautioned the pilots about wake turbulence from Japan Air Lines flight 47 while instructing them to taxi into position and hold.

[183] The Safety Board notes that the maximum available wheel deflection is 78° in either direction. Despite the first officer's rapid wheel movements, the airplane remained in relatively level flight because the inputs were not held long enough to allow the airplane to respond.

motion simulator testing, that these wheel movements seemed excessive for the momentary effect that the wake turbulence encounter had on the airplane.

On the basis of the two pilots' accounts of the accident first officer's response to wake turbulence on prior flights and his reaction to flight 587's first wake turbulence encounter, the Safety Board concludes that the first officer had a tendency to overreact to wake turbulence by taking unnecessary actions, including making excessive control inputs.

2.3.2 Training Factors

The Safety Board's investigation determined that pilots have generally had little exposure to, and therefore may not fully understand, the effect of large rudder pedal inputs in normal flight or the mechanism by which rudder deflections induce roll on a transport-category airplane. In addition, American Airlines' AAMP training may have reinforced the first officer's tendency to respond aggressively to wake turbulence, encouraged the use of full rudder pedal inputs and misrepresented the airplane's actual response to large rudder inputs. Finally, A300-600 pilots (including those at American Airlines) were not well trained regarding the airplane's reduction in rudder pedal travel with increasing airspeed.

2.3.2.1 Lack of Pilot Exposure Regarding Airplane Response to Large Rudder Pedal Inputs

Most control inputs on transport-category airplanes occur in the pitch and roll axes. Consequently, through flight experience and training, pilots readily understand how airplanes respond to control column and wheel inputs during normal flight conditions. However, many pilots have only limited exposure to airplane responses to rudder pedal inputs (which primarily affect the yaw axis). In transport-category airplanes, rudder pedal inputs in the yaw axis are generally limited to aligning the airplane with the runway during crosswind landings and controlling engine-out situations. These maneuvers do not provide a sense of how large-magnitude rudder inputs at a high airspeed will create a yaw rate and sideslip angle buildup followed by a very large rolling moment. Abrupt rudder inputs can result in an overswing,[184] which results in much greater yaw and sideslip angles than a steady-state sideslip. The roll rate resulting from this overswing is also amplified.

Aligning the airplane with the runway during a crosswind landing involves using the rudder to create a sideslip (the resulting rolling moment is countered with the control wheel), and controlling an engine-out situation involves deflecting the rudder to counteract the yaw asymmetry resulting from the failed engine and minimize sideslip. Crosswind landings are relatively common. Engine-out situations are rare, but pilots receive extensive simulator training in handling engine-out situations. The most demanding engine-out situations occur shortly after takeoff, when an engine failure

---

[184] An overswing results when a rapid rudder input is applied. An overswing is a sideslip angle that is initially greater than the steady-state sideslip angle resulting from the same rudder input and occurs because of the slightly underdamped nature of the airplane's motion in the yaw axis.

creates a large yawing moment because of the high thrust setting of the engines and when the effectiveness of the rudder is reduced by low airspeeds. In such situations, up to full deflection of the rudder may be required to balance the engine thrust. Both landing alignment maneuvers and engine-out maneuvers on takeoff occur at low airspeeds, so pilots' use of a significant rudder deflection (and, consequently, their exposure to the characteristics of the rudder control system) occurs predominately at low airspeeds. Neither maneuver involves using the rudder to roll the airplane.

Further, a pilot who attempts to use the rudder pedals to roll a transport-category airplane will experience a significant phase lag between the pedal input and the development of roll rate. The phase lag exists in part because the roll response is a secondary effect of the yawing moment generated by rudder movement; roll does not result from the rudder input directly. The airplane will initially yaw in response to a rudder pedal input, creating a change in sideslip angle; as the sideslip angle develops, it generates a rolling moment that rolls the airplane. Consequently, the rolling moment depends primarily on the sideslip angle (not the rudder angle), and the airplane can continue to develop a rolling moment in one direction, even though the rudder is subsequently deflected in the opposite direction. The rolling moment will only reverse after the sideslip angle reverses. If the motion of the airplane becomes highly dynamic with large yaw and roll rates and sideslip angles (such as those that would result from large rudder inputs), the relationship between the pedal inputs and the roll response of the airplane can become confusing.

The coupling of the yaw and roll axes, the magnitude of the rolling moment that can eventually develop from the large rudder inputs, and the potential for yaw overswing resulting from abrupt rudder inputs are phenomena that are likely outside of most line pilots' experience. Therefore, it is likely that most line pilots have not developed sufficient awareness and understanding to correctly anticipate an airplane's response to such large rudder inputs. As a result, they would likely be surprised and confused if they were to encounter such responses in flight. (This issue is discussed in more detail in section 2.3.3.)

2.3.2.2 American Airlines Advanced Aircraft Maneuvering Program

2.3.2.2.1 Ground School Training

During the AAMP ground school that the first officer attended (in March 1997), pilots were instructed that the rudder could be used to assist in controlling the airplane's roll angle during upsets and unusual attitudes. For example, a videotape that was made during an actual AAMP class that occurred during March or April 1997 showed the instructor telling pilots that, under certain circumstances, a small, smooth application of rudder in the same direction as the control wheel was a good piloting technique. The tape showed the instructor stating, "Now some of you out there might say, 'well, I'm going to use a little coordinated rudder to help the nose come down.' Fine, that's fine, that's good technique. A little, OK, smoothly applied."[185]

---

[185] For more information about the content of the AAMP, see section 1.17.1.2.

Further, the AAMP flight training booklet, which accompanied the AAMP ground school instruction at the time that the first officer attended the training, discussed wake turbulence as a factor that had caused an increase in loss of control accidents and incidents and reiterated the use of rudder as the most effective roll control device at high angles of attack. Pilots were also instructed during classroom training that even full rudder inputs could be appropriate in certain extreme situations. Therefore, the Safety Board concludes that the American Airlines AAMP ground school training encouraged pilots to use rudder to assist with roll control during recovery from upsets, including wake turbulence.

2.3.2.2.2 Simulator Training

The AAMP excessive bank angle recovery simulator exercise[186] may also have contributed to an inaccurate understanding of the need for, or effects of, rudder use in response to wake turbulence. The Safety Board notes that this simulator exercise scenario was somewhat similar to the circumstances of flight 587. During the simulator exercise, pilots were told they were taking off behind a heavy 747 and were issued the appropriate wake turbulence warnings. As a result, pilots would likely expect the possibility of a wake turbulence encounter. During climbout, the simulator depicted a little light chop, followed by the airplane rolling in one direction to about 10° The similarity to flight 587 ended at this point because the simulator then depicted the airplane quickly rolling to beyond 90° in the opposite direction.[187]

The presentation of the upset would, more than likely, cause pilots to associate the uncontrollable roll to beyond 90° with a wake turbulence encounter. However, this wake turbulence encounter scenario is unrealistic for an A300-600. The Safety Board is aware of no accidents involving a heavy transport-category airplane departing from controlled flight as the result of a wake turbulence encounter.[188]

A study conducted by the Flight Safety Foundation, which reviewed Safety Board accident data, FAA incident data, and NASA Aviation Safety Reporting System (ASRS) pilot reports, concluded that wake turbulence encounters were less frequent and less severe for large transport-category airplanes such as the A300-600 than for smaller transport-category airplanes. Also, ASRS wake turbulence reports indicated that the maximum bank angle estimated by pilots was usually 30° or less, and none were greater than 60°.[189] Further, the Board's experience shows that pilot estimates of bank angle disturbances are often overstated and inaccurately large compared with actual FDR data.

---

[186] For more information about this exercise, see section 1.17.1.2.3.

[187] According to American Airlines, the objective of the excessive bank angle recovery exercise was to force the airplane into an unusual roll attitude (beyond 90°) to train pilots to recognize and recover from this flight condition.

[188] According to the Safety Board's aviation accident database, the last fatal air carrier accident caused by wake turbulence in the United States involved a DC-9 (a large transport-category airplane) in 1972 before the current air traffic control separation standards were adopted. See *Delta Air Lines, Inc., McDonnell Douglas DC-9-14, N3305L, Greater Southwest International Airport, Fort Worth, Texas, May 30, 1972*, Aircraft Accident Report NTSB/AAR-73/03 (Washington, DC: NTSB, 1973).

[189] These wake turbulence events occurred between 1988 and 1999 and involved a large transport-category airplane, such as the A300-600, as the trailing airplane.

Consequently, the AAMP excessive bank angle simulator exercise, which rolled an A300 to more than 90° as the result of an implied wake turbulence encounter, was misleading and might have contributed to an inaccurate expectation that wake turbulence encounters in an A300 could be potentially catastrophic events, requiring immediate and aggressive pilot response.

The Safety Board also learned that, to ensure that the airplane reached a 90° bank angle during the excessive bank angle simulator exercise, American Airlines inhibited the aerodynamic effectiveness of control wheel and rudder pedal inputs during the initial portion of the roll upset. The effectiveness of the ailerons and rudder was not restored until 10 seconds after the upset was introduced or a bank angle of 50° was achieved (whichever came first), allowing the airplane to recover. Pilots were unaware that the flight controls were ineffective during the initial portion of the upset, yet instructors commonly briefed pilots to react quickly to the upset.[190]

The suppression of the aileron and rudder inputs during the initial part of the excessive bank angle simulator exercise would have promoted an inaccurate understanding of the proper use and effectiveness of the flight controls. Because no control input could prevent the airplane from rolling to 90° or more, a pilot might learn to position the controls at their full deflections to minimize the recovery time after the maximum bank angle was reached, even though the flight condition at the time might not call for full deflections. Because such full control inputs would have been an effective and appropriate recovery technique during the simulator exercise, a pilot might understandably expect similar results in an actual airplane.

Because the excessive bank angle simulator exercise was programmed so that the airplane would not initially respond to control inputs, the exercise suggested that an external influence (the wake) was overpowering the controls and deprived the pilot of an opportunity to experience the actual airplane response to such inputs (including sideload accelerations), thus leaving the pilot with a misperception of the real effects of the inputs. This misperception could cause a pilot to be surprised or confused at the airplane's actual significant response to full control wheel and full rudder pedal inputs during flight.

The Safety Board recognizes that the intent of the AAMP excessive bank angle simulator training exercise was to teach pilots how to recover from an upset involving an unusual roll attitude of 90°. However, the scenario was unrealistic and might have had the unintended consequence of providing pilots with negative training in how to respond to wake turbulence. The presentation of an unrealistic scenario and the inhibition of flight controls could cause a pilot to develop control strategies that were effective in the simulator but might be inappropriate or even dangerous in an actual airplane. Therefore, the Safety Board concludes that the American Airlines AAMP excessive bank angle

---

[190] Safety Board investigators interviewed three of the instructors who taught AAMP simulator exercises to the first officer. Two of the instructors stated that they taught pilots to input some rudder in this exercise; one instructor stated that, if pilots used only aileron to recover, they would put themselves in a sideslip, so a "little bit" of rudder was necessary. All three instructors indicated that a quick reaction was important.

simulator exercise could have caused the first officer to have an unrealistic and exaggerated view of the effects of wake turbulence; erroneously associate wake turbulence encounters with the need for aggressive roll upset recovery techniques; and develop control strategies that would produce a much different, and potentially surprising and confusing, response if performed during flight.

2.3.2.3 Lack of Pilot Training on Restricted A300-600 Rudder Pedal Travel

The Safety Board learned that, before the flight 587 accident, A300-600 pilots (including those at American Airlines) were not trained to understand that rudder pedal travel becomes limited as airspeed increases. (This feature of the A300-600 rudder control system is described in more detail in section 2.3.3.) Although the American Airlines A300 Operating Manual at the time of the accident noted that rudder deflection progressively decreased with airspeed and specified the amount of the deflection for low- and high-speed ranges, it contained no reference to the reduction in rudder pedal travel at higher airspeeds. Also, a company representative stated that, before the flight 587 accident, pilots were not instructed about the restricted rudder pedal displacement at higher airspeeds.[191] In addition, although the Airbus A300-600 Flight Crew Operating Manual (FCOM) at the time of the accident noted that rudder pedal travel and rudder deflection were restricted as airspeed increased, the FCOM specified only the range of the restriction for the rudder deflection; the FCOM did not quantify the range of the restriction for the rudder pedals or mention that the pedal forces required to achieve maximum available rudder would be reduced as a result of the restricted pedal travel.

A pilot's lack of knowledge regarding restricted rudder pedal travel could lead to confusion if an unexpected pedal limit was encountered in flight. Specifically, as discussed further in section 2.3.3, at high airspeeds, less pedal travel is required to develop a yaw rate and sideslip angle than at low airspeeds; as a result, the airplane's high-airspeed response to pedal inputs may seem out of proportion to the pedal input if the pilot is unaware of the pedal restriction and expects the range of pedal travel to be the same at all airspeeds.[192] In such a situation, the pilot may fail to associate the airplane response with control inputs, instead attributing the response to some external cause (such as wake turbulence). Consequently, the pilot may not recognize the potential risk to the airplane and may continue making inappropriate control inputs. The Safety Board concludes that, before the flight 587 accident, pilots were not being adequately trained on what effect rudder pedal inputs have on the Airbus A300-600 at high airspeeds and how the airplane's rudder travel limiter system operates.

The Safety Board addressed this issue in Safety Recommendation A-02-01, which was issued February 8, 2002. Safety Recommendation A-02-01 asked the FAA to require

---

[191] During the first quarter of 2003, the American Airlines A300 fleet standards manager went to the pilot bases and gave a presentation to all A300 pilots concerning subject areas that were identified as weak or nonexistent in training. The subject areas included vertical stabilizer sideforce characteristics, 14 *Code of Federal Regulations* (CFR) Part 25 certification, rudder travel limiter effects, rudder pedal force and displacement, and pilot input/yaw damper interaction. For more information, see section 1.17.1.3.

[192] The use of the rudder at high airspeeds, other than for an engine failure, is rare.

manufacturers and operators of transport-category airplanes to establish and implement pilot training programs that explained several points regarding rudder use, including that "certain combinations of sideslip angle and opposite rudder deflection can result in potentially dangerous loads on the vertical stabilizer, even at speeds below design maneuvering speed" and that, "on some aircraft, as speed increases, the maximum available rudder deflection can be obtained with comparatively light pedal forces and small pedal deflections." In response, the FAA issued a notice that directed all principal operations inspectors (POI) to inform their air carriers about the Board's concerns and contacted airplane manufacturers to inform them about the Board's concerns. Airbus and Boeing prepared flight technical operations bulletins that highlighted these concerns, and the FAA indicated that resulting changes to the manufacturers' airplane flight manuals might also result in changes in operators' manuals.

The Safety Board urges the FAA to verify that the actions taken to date in response to Safety Recommendation A-02-01 will result in all transport-category pilots gaining an accurate understanding of the operation of rudder travel limiter systems and the effects of rudder pedal inputs at high airspeed. The Board looks forward to receiving updated information on the FAA's continuing efforts to implement Safety Recommendation A-02-01.

2.3.3 Characteristics of the A300-600 Rudder Control System Design

The first officer's use of rudder during the accident sequence may also have been influenced by characteristics of the A300-600 rudder control system design. As further explained in this section, the Safety Board analyzed the sensitivity of the rudder control system and determined that, even though the A300-600 rudder control system was found to have met all of the certification standards, the system is more sensitive than that on other transport-category airplanes.

Pilots use the rudder to control an airplane about its yaw axis; however, as previously noted, pilots rarely exercise such control in flight except for aligning the airplane with the runway during crosswind landings and for controlling engine-out situations. On the basis of the results of the certification flight testing and the absence of any reported operational difficulties in controlling the airplane in these situations, the A300-600 rudder control system appears to meet all the certification requirements for yaw axis control and is well suited for these typical rudder use scenarios.

With the advent in the mid-1990s of advanced maneuvering and upset training, such as the AAMP, transport-category pilots began to be trained to use the rudder in more than just the typical alignment maneuver and engine-out scenarios. Specifically, some airlines, including American, instructed their pilots that the rudder could also be used to assist the ailerons and spoilers in roll control under certain circumstances. However, because the rudder was not designed and certified for roll control, rudder systems might not be well suited for this use. Furthermore, the authority and sensitivity of the rudder

control system may be much more critical when it is used for roll control than for the conventional scenarios.

The Safety Board evaluated the sensitivity of the A300-600 rudder system to determine whether it played a role in the accident. Because there is no industry standard measure of pedal sensitivity, Board investigators defined, for the purposes of this evaluation, rudder pedal sensitivity as the lateral acceleration produced in the cockpit per pound of rudder pedal force above breakout force. Investigators also developed four metrics[193] to compare various aspects of the A300-600 rudder control system design related to rudder pedal sensitivity with those of other transport-category airplanes, including the A300-600's predecessors, the A300B2 and A300B4 (as shown in table 5).[194] At 250 knots calibrated airspeed (KCAS), the A300-600 rudder pedal design showed the lightest pedal forces of all airplanes evaluated.

In designing the A300-600, Airbus made two changes to the rudder control system originally used on the A300B2/B4, both of which had a significant effect on rudder pedal sensitivity. First, the amount of force required to depress the rudder pedals was decreased. According to Airbus, this change was made to maintain consistency with the control wheel forces, which were reduced in response to pilot feedback indicating a desire for lighter roll control (wheel) forces. The decrease in pedal force resulted in an increase in the A300-600 rudder pedal sensitivity. Second, the rudder travel limiter system was changed from a variable ratio design to a variable stop design. The variable ratio design allows a constant range of pedal travel but reduces the maximum possible deflection of the rudder through an internal limiter as airspeed increases. Consequently, a given pedal input results in reduced rudder deflection as airspeed increases. In contrast, the variable stop design limits both rudder deflection and rudder pedal travel as airspeed increases. With this design, a given amount of pedal input results in the same rudder deflection at all airspeeds, but the pedal travel (and consequently, pedal force) required to hit the pedal stops decreases as airspeed increases.

With a variable ratio design, a given pedal input produces about the same airplane response in sideslip angle, yaw rate, and lateral accelerations at all airspeeds, but, with a variable stop design, a given pedal input produces a greater response for those parameters as airspeed increases. In other words, a variable stop design becomes more sensitive as airspeed increases. Specifically, as shown in figure 8, the A300B2/B4 variable ratio design has a relatively constant rudder pedal sensitivity at all airspeeds, whereas, with the A300-600 variable stop design, rudder pedal sensitivity significantly increases as airspeed increases. For example, the A300-600 is twice as responsive to a pedal displacement at 250 KCAS as it would be at 165 KCAS. The A300-600's increase in rudder pedal

---

[193] The metrics were (1) the ratio of maximum force to breakout force, (2) the degrees of rudder commanded per pound of force above the breakout force, (3) the pedal displacement as a percent of total displacement at low airspeed, and (4) the work involved in pushing the pedal to maximum. For more information, see section 1.6.2.3.

[194] The Safety Board recognizes that these four metrics are not an exhaustive list and that other airplane design features may also affect rudder pedal sensitivity. For example, the Board's metrics do not account for the yaw inertia of the airplane, which can depend on configuration characteristics, such as the number and location of engines.

sensitivity as airspeed increases creates a control system change that pilots may not expect.

Pilots may not be aware of the type of rudder control system that is installed on their airplanes or fully understand the characteristics of a variable ratio or variable stop rudder control system design because of the lack of explicit training or experience in this area. If a pilot assumed that the sensitivity of the rudder on any airplane remained relatively constant across a range of airspeeds, this assumption would lead to the erroneous expectation on an airplane equipped with a variable stop rudder travel limiter system that the response to a given pedal input, including the subsequent rolling moment, would be about the same regardless of the airspeed. The Safety Board emphasizes that the sensitivity of the variable stop rudder travel limiter system may be confusing to pilots only at higher airspeeds. In fact, the Board has found no indication of any undesirable sensitivity during conventional rudder use scenarios (that is, crosswind landings or engine-out situations).

The Safety Board concludes that the Airbus A300-600 rudder control system couples a rudder travel limiter system that increases in sensitivity with airspeed, which is characteristic of variable stop designs, with the lightest pedal forces of all the transport-category aircraft evaluated by the Safety Board during this investigation. These characteristics likely played a role in the accident sequence, as discussed in section 2.4.

2.4   Analysis of the Accident Sequence

The accident sequence began when the first officer made a right rudder pedal input in response to the second wake turbulence encounter. The accident sequence continued for 6.5 seconds as the first officer made five subsequent alternating full rudder pedal inputs until the vertical stabilizer separated from the airplane. As further explained in this section, a combination of the three factors discussed in section 2.3—the first officer's tendency to react aggressively to wake turbulence, his pilot training, and characteristics of the A300-600 rudder control system design—influenced the first officer's initial rudder pedal input and his subsequent alternating full rudder inputs.

2.4.1 Initial Rudder Pedal Input

The second wake turbulence encounter occurred at 0915:51 while flight 587 was in a 23° left bank. This encounter produced momentary changes in the airplane's load factor that were similar to those experienced during the first wake turbulence encounter 15 seconds earlier—a 0.4 G drop in normal load factor, a 0.06 G drop in longitudinal load factor, and a 0.05 G shift to the left in lateral load factor. The first officer reacted to this

second wake encounter by moving the control wheel rapidly to the right. Further, unlike his response to the first wake encounter, the first officer also depressed the right rudder pedal.[195]

The Safety Board considered why the first officer responded differently to the second wake turbulence encounter than he did to the first encounter. One possibility is the difference in the bank angle at the beginning of the two encounters. For the first encounter, the airplane was approximately wings level. Before the second encounter, the airplane was already in a 23º left bank, and, according to the Board's simulations, the rolling moment generated by the second wake would have acted to roll the airplane (in the absence of countering control inputs) about 10º farther to the left and would have resulted in no significant yaw.[196] However, if the first officer sensed a roll acceleration to the left while already in a left bank, he may have been prompted to react with a more aggressive control response.

The Safety Board emphasizes that the second wake encounter did not place flight 587 in an upset condition, and the airplane's response to the wake did not indicate that an upset was imminent.[197] Therefore, the Safety Board concludes that the first officer's initial control wheel input in response to the second wake turbulence encounter was too aggressive, and his initial rudder pedal input response was unnecessary to control the airplane. In analyzing the reason for these inputs, the Board evaluated the three factors discussed in section 2.3: the first officer's reactions to wake turbulence encounters, training factors, and the A300-600 rudder control system design.

2.4.1.1 First Officer's Reactions to Wake Turbulence Encounters

As discussed in section 2.3.1, the first officer had a tendency to overreact to wake turbulence encounters, indicating an exaggerated concern with such encounters. The first officer expressed concern before takeoff about the spacing between Japan Air Lines flight 47 and flight 587, so he was clearly aware of the possibility of encountering wake turbulence. Further, the first wake turbulence encounter, although brief and minor, would have heightened the first officer's awareness of the possibility of additional wake turbulence, thus preparing him to react to any subsequent encounter. Therefore, the initial rudder pedal input in response to the second wake turbulence encounter was consistent

---

[195] Minor pedal movements (about 1º) were recorded on the FDR after the first wake encounter. However, these movements were not likely deliberate pedal inputs by the first officer. Further, the rudder movements recorded during this time were within the authority of the yaw damper and could have been the result of yaw damper inputs.

[196] Nominal movement of the control wheel (and the corresponding aileron and spoiler deflection) could have countered this amount of additional roll. Further, the yaw damper is designed to compensate for yaw disturbances produced by standard wake turbulence.

[197] The Airbus A300-600 FCOM and the joint industry *Airplane Upset Recovery Training Aid* defined upsets to include unintentional bank angles of greater than 45°. According to FAA Flight Standards Handbook Bulletin for Air Transportation 95-10, "Selected Event Training," and American Airlines' selected event training program, upset conditions include "excessive (greater than 90°) roll attitudes" and "high (greater than 35°) pitch attitudes."

with the first officer's tendencies to overreact and overcontrol the airplane in response to wake turbulence encounters.

The Safety Board notes that the first officer was not unique in responding to a wake turbulence encounter with a rudder pedal input. The ASRS special study of uncommanded, in-flight upsets found that pilots used rudder pedal inputs during recovery efforts in 11 (one-third) of the 33 reported events, most of which were induced by wake turbulence.[198] Even the captain of the earlier 727 flight on which the first officer made a series of alternating full rudder pedal inputs did not admonish him for using the rudder in response to wake turbulence; rather, the captain cautioned the first officer only against making such large inputs.

2.4.1.2 Training Factors

As discussed in section 2.3.2.2.2, the AAMP excessive bank angle simulator exercise was unrealistic because the airplane quickly achieved a 90° bank angle that pilots were led to believe resulted from the effects of a wake turbulence encounter. The roll upset recovery techniques taught during this exercise may have resulted in inappropriate (negative) training regarding the effects of wake turbulence and the proper response to it. Further, the inhibition of the flight controls during the initial part of the exercise misrepresented the true airplane response to large rudder inputs and could have led pilots to believe that large wheel and rudder pedal inputs would initially have little effect on the airplane. This misrepresentation could have imparted inappropriate training to overcontrol the airplane during a wake encounter and could contribute to surprise and confusion if large wheel and rudder pedal inputs were attempted in an actual wake turbulence encounter.

Given his prior experiences with this simulator exercise,[199] it is possible that, as the second wake hit flight 587, the first officer may have been concerned that the airplane was about to enter a hazardous bank angle upset and, therefore, responded with both the control wheel and rudder pedal as he had been encouraged to do in the simulator. However, the airplane's response to the control wheel and rudder pedal was not what the first officer would have expected based on his simulator experience. In the simulator, despite using full wheel and possibly pedal, the airplane would still roll to 90°. However, during the accident sequence, the airplane responded to the first officer's initial right control wheel input with an immediate and large right rolling moment. In addition, the airplane responded to the initial right rudder pedal input with a yawing moment to the right, which resulted in a left sideslip and an associated additional rolling moment to the right.[200] Thus, the first officer was faced with an abrupt and aggravated rolling moment to the right while the airplane was developing a substantial right yaw and an abrupt heading change to the right.

---

[198] For more information, see section 1.18.9.

[199] The first officer received AAMP simulator training four times between November 1997 and December 2000.

[200] The resulting rolling moment from the rudder input was slightly delayed from the lateral acceleration.

2.4.1.3 A300-600 Rudder Control System

It is not known whether the first officer intended to command a large or a partial rudder deflection when he made his initial rudder pedal input.   If his intention was to command a partial deflection, characteristics of the A300-600 rudder control system design might have contributed to the large magnitude of the deflection. As previously discussed, on the basis of the AAMP excessive bank angle simulator exercise (which depicted reduced control effectiveness) and the first officer's apparent perception of the wake turbulence as an upset event, it is possible that the first officer thought a full rudder input would be an appropriate response. However, it is equally possible that the first officer may have intended to react to the wake turbulence with only a partial rudder pedal input and that the full rudder deflection that he achieved may have been the result of his lack of knowledge concerning the pedal restrictions or the sensitivity of the rudder control system. In either case, because of his lack of understanding of the rudder control system and the airplane's response to rudder inputs at high airspeeds, the first officer was likely surprised and confused at the airplane's response to his control inputs.

2.4.2 Subsequent Rudder Pedal Inputs

The initial control wheel and rudder pedal inputs were not sufficient to develop the aerodynamic loads that ultimately caused the vertical stabilizer to separate from the airplane. The effects of four additional full rudder deflections (left-right-left-right) allowed the buildup of enough sideslip angle to achieve those loads.

After the first officer made his initial rudder pedal input, he made a series of alternating full rudder inputs. The Safety Board's airplane performance study revealed that the resulting motion of the airplane, including the hazardous buildup in sideslip angle that eventually led to the high loads that resulted in separation of the vertical stabilizer, was solely the result of these rudder pedal inputs and was not associated with the effects of wake turbulence. In fact, if the first officer had stopped making these inputs at any time before the vertical stabilizer separation, the natural stability of the airplane would have returned the sideslip angle to near 0º, and the accident would have been avoided. Therefore, it is crucial to analyze the factors that contributed to the sustained nature of the rudder pedal inputs made by the first officer: the role of training, the airplane's response to the initial rudder pedal input as a potential triggering event for an adverse aircraft-pilot coupling (APC) event, and the characteristics of the A300-600 rudder control system design that may facilitate sustained, alternating rudder inputs.

2.4.2.1 Role of Training

The Safety Board considered the role of training in the first officer's inaccurate assessment of the airplane's response to his initial rudder input. As already discussed, because most pilots are not trained in, and have no experience with, the effects of large or rapid rudder inputs at high airspeeds, it is likely that the large right yaw and subsequent rolling moment resulting from the first officer's initial rudder pedal input were surprising and confusing to him.   The first officer may have failed to perceive that his control wheel

and rudder pedal inputs were the cause of the airplane motion in part because that motion may have appeared out of proportion to his pedal inputs. At 240 knots, the pedal would reach its stop with only about 30 percent of the pedal movement required during the rudder control check on the ground. In the absence of any specific training to the contrary, the first officer may have perceived that he was only using about 30 percent of the rudder authority (as opposed to all of it), making it harder for him to associate the airplane motion with his pedal inputs.

This misperception of the cause of the airplane motion may also have been reinforced by the AAMP excessive bank angle exercise, during which the application of full rudder would have initially had no effect in recovering the airplane. Further, if the first officer was expecting the wake turbulence to have a large effect on the airplane, he may have found it very easy to ascribe the undesired motion to the wake rather than to his own control inputs.

In addition, because the first officer's initial control wheel and rudder pedal inputs to the right were apparently applied in response to the wake-induced roll to the left, the sudden acceleration of the airplane to the right (in response to his control inputs) could have been surprising. If the first officer believed that the airplane motion was a result of the wake, the sudden acceleration to the right may have led him to believe that the wake was acting to roll the airplane to the right. This belief, in turn, may have prompted a full and immediate application of control wheel and rudder pedal to the left. (This sequence of events would also be consistent with the AAMP excessive bank angle simulator exercise, which depicted a 10° roll in one direction followed by a 90° roll in the opposite direction after taking off behind a heavy airplane.)

In summary, the first officer's lack of training in the airplane's actual response to rudder pedal inputs at high airspeeds and the negative training he received from the AAMP excessive bank angle simulator exercise may have contributed to his incorrect assessment of his interaction with the airplane during the accident sequence. In other words, because of these factors, the first officer likely did not recognize that the airplane's motion was being caused by his control inputs rather than the wake turbulence.

2.4.2.2 Airplane Response to Initial Input as Triggering Event for an Adverse Aircraft-Pilot Coupling

A 1997 National Research Council (NRC) report provides a broad definition of aircraft-pilot coupling (APC) events. According to the report, unfavorable or adverse aircraft-pilot coupling APC events are "rare, unexpected, and unintended excursions in aircraft attitude and flight path caused by anomalous interactions between the aircraft and the pilot." APC excursions can be oscillatory or divergent (non-oscillatory) and can be catastrophic. They occur when the dynamics of the airplane and the dynamics of the pilot combine to produce an unstable system.[201]

---

[201] For more information, see section 1.18.8.

APC events do not typically occur unless a triggering event is present. The trigger is critical because it causes a pilot to alter his or her control strategy. After a trigger, a pilot switches from a low-gain control behavior or piloting technique to a high-gain behavior or technique, that is, one that uses large corrective inputs even for small errors.[202] A trigger can be caused by a pilot who overcontrols an aircraft or responds in an inappropriate manner to a flight condition. According to the NRC report, either an environmental trigger[203] or a vehicle trigger[204] often precedes such a pilot trigger.

The first officer's initial overcontrol (wheel and pedal inputs to the right) was in response to an environmental trigger—the second wake encounter. His initial overcontrol and lack of an appropriate understanding regarding the airplane's response to rudder pedal inputs at a higher airspeed (240 knots) may have combined to serve as a pilot trigger for an APC event. Consistent with the APC scenarios described in the NRC report, the environmental and pilot triggers increased the first officer's gain, resulting in large corrective inputs that hindered a return to normal flight.

The flight 587 accident was a more complex event than those events discussed in the NRC report because all three axes (pitch, roll, and yaw) were involved at the same time and the rudder was used to control roll, resulting in a phase lag. Nevertheless, the NRC report provides a valid framework and starting point for industry to use in fully developing the issues associated with the flight 587 accident and those events that involve the coupling of flight control inputs and catastrophic flightpath excursions.

2.4.2.3 Characteristics of the A300-600 Rudder Control System Design That May Be Conducive to Sustained Alternating Inputs

The coupling of motion in the roll and yaw axes and the associated phase lag between pedal inputs and roll response in transport-category airplanes are phenomena that are not present in the pitch and roll axes and are likely unfamiliar to pilots. Because of these phenomena, an attempt to control roll with the rudder pedals could lead to confusion; increased pilot gain; and sustained, detrimental inputs on the controls. Certain rudder control system design characteristics may exacerbate these effects. Specifically, light rudder pedal forces and small displacements at high airspeeds, which are A300-600 design characteristics, have been identified as factors in some APC events.

The FAA's Advisory Circular (AC) 25-7A, "Flight Test Guide for Certification of Transport Category Airplanes," addresses APC susceptibility and cautions against flight controls with small displacements and light force gradients—features that are both present

---

[202] According to the NRC report, pilot gain is the sensitivity with which the pilot reacts to a given situation. If the situation is urgent, and the pilot reacts with large corrective inputs, even for small system errors, the pilot is said to be exhibiting high gain. More relaxed responses imply a lower pilot gain.

[203] An environmental trigger typically involves an environmental circumstance that results in destabilizing control inputs. Atmospheric turbulence has been cited as an example of an environmental trigger. In addition, an environmental trigger may increase the pilot's stress level, resulting in an increase in pilot gain.

[204] A vehicle trigger typically involves a change in the effective aircraft dynamics, resulting in inconsistencies between the pilot's input strategy and the aircraft dynamics.

on the A300-600 rudder system at higher airspeeds. The AC indicates that such features can be associated with APC, which could help explain the first officer's series of alternating full rudder inputs.

Another design characteristic of the A300-600 rudder system that may increase its susceptibility to an APC event is the changing performance as airspeed increases (a characteristic of all variable stop rudder systems). For APC prevention, the NRC report notes that a flight control system should be designed "to perform consistently throughout as much of the flight envelope as possible."[205] Although the design characteristics of the A300-600 provide a consistent ratio between the rudder pedal and rudder surface deflection at all airspeeds, the response of the airplane to a given rudder pedal input increases as airspeed increases, resulting in significantly different performance characteristics at opposite ends of the design envelope.

In the flight 587 accident sequence, the small pedal displacements of the A300-600 rudder control system at 240 knots may have facilitated the first officer's large, rapid inputs to the rudder system. The first officer performed sustained full alternating rudder pedal inputs that led to a hazardous buildup in sideslip angle in a short period of time. A system with large pedal displacements would make achieving these inputs more demanding physically, providing greater feedback regarding the magnitude of the pilot's efforts on the controls. Thus, the ability to achieve full rudder deflection with the small pedal displacements on the A300-600 at 240 knots was a likely factor in sustaining the flight 587 event.

2.4.3 Summary

The first officer's rudder pedal inputs, which created airloads that were sufficient to cause the vertical stabilizer to separate from the airplane, resulted from the confluence of several factors. First, the first officer had a predisposition to overreact to wake turbulence encounters. Second, his concerns about the effect of wake turbulence were likely exacerbated by the AAMP training provided by American Airlines, whose excessive bank angle simulator exercise portrayed wake turbulence encounters as capable of quickly upsetting an A300-600 to extreme bank angles and could have encouraged pilots to make large magnitude flight control inputs, including rudder pedal inputs, to roll the airplane out of such an upset. Third, as with most line pilots, the first officer likely did not understand the airplane's response to large rudder inputs at high airspeeds or the mechanism by which the rudder rolls a transport-category airplane. Finally, light rudder pedal forces and small pedal displacement contributed to the high sensitivity of the A300-600 rudder pedal system at high airspeeds and increased the airplane's susceptibility to a rudder APC event.

---

[205] The NRC report notes that the consistent performance of the system would minimize the chance that the pilot would change a control strategy to compensate for the system response characteristics.

2.5 Prevention of High Loads Resulting From Pilot Rudder Pedal Inputs

2.5.1 Rudder Pedal Inputs at High Airspeeds

Rudder control systems with a variable ratio rudder travel limiter may provide better protection against high loads from sustained rudder pedal inputs at high airspeeds than systems with a variable stop rudder travel limiter because variable ratio rudder travel limiter systems require more physical effort from a pilot (in terms of force and displacement) to produce cyclic full rudder inputs. For airplanes with variable stop rudder travel limiter systems, protection from dangerous structural loads resulting from sustained alternating large rudder pedal inputs can be achieved by reducing the sensitivity of the rudder control system (for example, by increasing the pedal forces), which would make it harder for pilots to quickly perform alternating full rudder inputs.

As discussed previously, there is no certification standard regarding rudder pedal sensitivity or any requirement for the sensitivity to remain constant at all airspeeds. The Safety Board concludes that certification standards are needed to ensure that future airplane designs minimize the potential for APC susceptibility and to better protect against high loads in the event of large rudder inputs. Accordingly, the Safety Board believes that the FAA should modify 14 CFR Part 25 to include a certification standard that will ensure safe handling qualities in the yaw axis throughout the flight envelope, including limits for rudder pedal sensitivity. The Safety Board further believes that, after the yaw axis certification standard has been established, the FAA should review the designs of existing airplanes to determine if they meet the standard. For existing airplane designs that do not meet the standard, the FAA should determine if the airplanes would be adequately protected from the adverse effects of a potential APC after rudder inputs at all airspeeds. If adequate protection does not exist, the FAA should require modifications, as necessary, to provide the airplanes with increased protection from the adverse effects of a potential APC after rudder inputs at high airspeeds.

The Safety Board notes that some rudder control system designs incorporate features (such as hinge moment capacity limits or yaw damper characteristics) that can help attenuate the hazardous buildup of sideslip and/or vertical stabilizer loads resulting from alternating rudder pedal inputs at high airspeed, even though these features may not have been designed for this purpose. However, because alternating pedal inputs are not considered in the airplane certification standards, the absence of rudder system features that, in addition to their primary function, mitigate the hazards posed by such inputs does not necessarily constitute a design deficiency.

Some airplanes have hinge moment restrictions to limit the hydraulic force that the rudder actuator can apply.[206] With this design feature (also called a blowdown limit), the hydraulic power available to move the rudder is limited and cannot overcome high vertical

---

[206] The A300-600 does not have this design feature.

stabilizer aerodynamic loads regardless of the pilot's commands. This feature adds an extra level of safety to prevent high vertical stabilizer aerodynamic loads.

In addition, the yaw damper can provide an additional level of protection against inappropriate alternating full rudder inputs commanded by the pilot. Most transport-category airplanes have yaw damper systems that automatically input a small amount of rudder deflection to dampen lateral-directional oscillations. These yaw damper systems, including the one on the A300-600, typically act independently of pedal commands, so the yaw damper may add to or subtract from the rudder commanded by the pilot.

The yaw damper is not intended to correct for or contain inappropriate oscillatory rudder pedal inputs commanded by the pilot. However, because the yaw damper can suppress all lateral-directional oscillations, it will tend to have such an effect and will consequently delay the buildup of the sideslip angle that can result from such pedal commands.

The Safety Board notes that the A300-600 yaw damper system allows a pilot input to override a yaw damper command when the rudder is at the full deflection limit permitted by the rudder travel limiter system for a particular airspeed. Under these conditions, a pilot input can override a yaw damper command in the opposite direction and keep the rudder at the full deflection limit by providing increasing pressure on the rudder pedals. Simulation and FDR data indicated that the first officer's rudder pedal inputs during the flight 587 accident sequence were consistent with a suppression of yaw damper inputs at the rudder deflection limits. The simulations indicated that, if the yaw damper inputs had not been suppressed, the yaw damper would have moved the rudder partially back toward neutral, thereby lessening (but not preventing) the buildup of the sideslip angle and aerodynamic loads on the vertical stabilizer. Such a delay could have provided an additional level of safety because the initial response of the airplane to a sustained rudder pedal input would not have been as severe and could have reduced the chance of pilot surprise or confusion.

The Safety Board concludes that, because of its high sensitivity (that is, light pedal forces and small pedal displacements), the Airbus A300-600 rudder control system is susceptible to potentially hazardous rudder pedal inputs at higher airspeeds. Therefore, the Safety Board believes that the FAA and the Direction Général de l'Aviation Civile should review the options for modifying the Airbus A300-600 and the Airbus A310 to provide increased protection from potentially hazardous rudder pedal inputs at high airspeeds and, on the basis of this review, require modifications to the A300-600 and A310 to provide increased protection from potentially hazardous rudder pedal inputs at high airspeeds.

2.5.2 Alternating Full Control Inputs

Alternating full inputs on the control wheel and rudder pedals, such as those made by the first officer, should not be necessary to control a transport-category airplane under

any circumstance.[207] Industry literature (that is, the NRC report and AC 25-7A) indicates that an effective way to stop an APC event is to cease the inputs.[208] Recognition of an APC event by either the pilot making the inputs or the nonflying pilot before structural damage is crucial. However, according to the NRC report, pilots are not trained to recognize the initial indications or to understand that APC does not necessarily imply poor airmanship.

The Safety Board concludes that, to minimize the potential for APC events, transport-category pilots would benefit from training about the role that alternating full control inputs can play in such events and training that emphasizes that alternating full rudder inputs are not necessary to control a transport-category airplane. Therefore, the Safety Board believes that the FAA should develop and disseminate guidance to transport-category pilots that emphasizes that multiple full deflection, alternating flight control inputs should not be necessary to control a transport-category airplane and that such inputs might be indicative of an adverse APC event and thus should be avoided.

2.5.3 Pilot Guidance on Design Maneuvering Speed

During this accident investigation, the Safety Board learned that many pilots might have an incorrect understanding of the meaning of the design maneuvering speed (V_A) and the extent of structural protection that exists when the airplane is operated below this speed.

From an engineering and design perspective, maneuvering speed is the maximum speed at which, from an initial 1 G flight condition, the airplane will be capable of sustaining an abrupt, full control input limited only by the stops or by maximum pilot effort. In designing airplanes to withstand these flight conditions, engineers consider each axis (pitch, roll, and yaw) individually and assume that, after a single full control input is made, the airplane is returned to stabilized flight conditions. Full inputs in more than one axis at the same time and multiple inputs in one axis are not considered in designing for these flight conditions.

The American Airlines managing director of flight operations technical told the Safety Board, during a postaccident interview, that most American Airlines pilots believed that the airplane would be protected from structural damage if alternating full rudder pedal inputs were made at an airspeed below maneuvering speed. The American Airlines A300 fleet standards manager confirmed this belief during testimony at the Board's public hearing for this accident. The Board notes that the American Airlines A300 Operating Manual contained only one reference to design maneuvering speed, which indicated that it was the turbulence penetration speed (270 knots). However, as evidenced by flight 587,

---

[207] As a result of the flight 587 accident, the industry-developed *Airplane Upset Recovery Training Aid* now states, "it is important to guard against control reversals. There is no situation that will require rapid full-scale control deflections from one side to the other."

[208] Within the AC, see chapter 2, "Flight," and section 3, "Controllability and Maneuverability."

cyclic rudder pedal inputs, even when made at airspeeds below maneuvering speed, can result in catastrophic structural damage.

Existing regulations and guidance pertaining to maneuvering speed may have contributed to the misunderstanding regarding the degree of structural protection provided by operating below maneuvering speed. Title 14 CFR 25.1583, "Operating Limitations," lists maneuvering speed among the airspeed limitations that must be furnished to the pilots of transport-category airplanes and states that, along with maneuvering speed, pilots must also be furnished "with a statement that full application of rudder and aileron controls, as well as maneuvers that involve angles of attack near the stall, should be confined to speeds below this value." Although it is true that full control inputs should be confined to airspeeds below maneuvering speed, the statement in Section 25.1583 could also be read to incorrectly imply that an airplane could withstand any such inputs so long as they were made below maneuvering speed. The explanation of design maneuvering speed in AC 61-23C, "Pilot's Handbook of Aeronautical Knowledge," may be even more misleading, stating that, "any combination of flight control usage, including full deflection of the controls, or gust loads created by turbulence should not create an excessive air load if the airplane is operated below maneuvering speed." This statement strongly—and incorrectly—suggests that, if multiple control inputs were made below maneuvering speed, the airplane would be protected against structural damage.

The Safety Board has no reason to believe that the misunderstanding about maneuvering speed is limited to A300-600 pilots. As a result, the Safety Board concludes that there is a widespread misunderstanding among pilots about the degree of structural protection that exists when full or abrupt flight control inputs are made at airspeeds below the maneuvering speed. Therefore, the Safety Board believes that the FAA should amend all relevant regulatory and advisory materials to clarify that operating at or below maneuvering speed does not provide structural protection against multiple full control inputs in one axis or full control inputs in more than one axis at the same time.

2.6 Upset Recovery Training

In October 1996, the Safety Board issued Safety Recommendation A-96-120, which recommended that the FAA "require 14 CFR Part 121 and 135 operators to provide training to flight crews in the recognition of and recovery from unusual attitudes and upset maneuvers, including upsets that occur while the aircraft is being controlled by automatic flight control systems, and unusual attitudes that result from flight control malfunctions and uncommanded flight control surface movements."[209]

More than 8 years have passed since the issuance of Safety Recommendation A-96-120. Although the FAA has expressed agreement with the intent of the recommendation, it has not yet taken the necessary regulatory action to require unusual attitude training for air carrier pilots. In contrast, the air carrier industry has

---

[209] This recommendation was classified "Open—Acceptable Response" on December 20, 1999. For more information, see section 1.18.6.1.

recognized the need for such training by voluntarily developing programs, such as the American Airlines AAMP, and issuing the Airplane Upset Recovery Training Aid. There is widespread agreement among operations and training managers that unusual attitude training helps prepare flight crews for such unusual situations. However, without a regulatory requirement and published guidance from the FAA, the design and adoption of such programs has been voluntary, and approval of the POI assigned to the individual operators has been without the benefit of broader guidance from training experts within the FAA.

As discussed in section 2.3.2.2, the Safety Board's investigation found deficiencies in the American Airlines AAMP, including the following:

- ground school training that encouraged the use of rudder for roll control;

- a simulator exercise in which pilots were encouraged to employ large rudder inputs without being fully trained in the operating properties of the specific rudder control system or fully understanding the structural loads that might be imposed on the airframe by certain inputs;

- a simulator exercise that provided unrealistic portrayals of an airplane response to wake turbulence and significantly suppressed control input effectiveness to induce a large rolling potential that was unlikely to occur with an airplane as large as an A300-600; and

- a simulator exercise that encouraged the use of rudder in a highly dynamic situation without portraying the large buildup in sideslip angle and sideload that would accompany such rudder inputs in an actual airplane.

The Safety Board's review of other carriers' upset recovery programs indicated that the shortcomings in the AAMP are not unique and that inconsistencies exist among programs, especially regarding simulator use. The Safety Board concludes that FAA standards for unusual attitude training programs that take into account industry best practices and are designed to avoid inaccurate or negative training would lead to improvement and standardization of industry training programs. Accordingly, the Safety Board urges the FAA to take expeditious action to require such unusual attitude training, as recommended in Safety Recommendation A-96-120.

Pending the completion of such regulatory action by the FAA, the Safety Board reclassifies Safety Recommendation A-96-120 "Open—Unacceptable Response." Further, the Safety Board believes that the FAA should adopt and disseminate written guidance for use in developing and accepting upset recovery programs; such guidance could take the form of an AC and should reflect the industry's best practices and be designed to avoid inaccurate or negative training.

Regarding simulator training, the Safety Board recognizes that some members of the training community advocate the introduction of upset situations in simulators by having pilots close their eyes or look away as the upset is established, rather than by attempting a simulated context for the onset. The Board also recognizes that some

members of the training community believe that advanced simulators should not be used in upset training because the range of simulator fidelity is relatively narrow and the portrayal of accelerations is not comparable with what could occur during an aggressive upset.[210] Therefore, the Safety Board concludes that the use of lower levels of automation, such as simulators without motion or simple computer screen displays, may be more appropriate to provide the necessary awareness training with less danger of introducing incorrect information. Accordingly, the Safety Board believes that, along with developing upset recovery program guidance, the FAA should evaluate issues concerning the level of automation appropriate to teaching upset training and develop and disseminate guidance that will promote standardization and minimize the danger of inappropriate simulator training.

---

[210] For example, see the testimony of the vice president of training for Airbus North America customer services at the Safety Board's public hearing (p. 232 of the public hearing transcript).

3.　Conclusions

3.1　Findings

1. The captain and the first officer (the flying pilot) were properly certificated and qualified under Federal regulations. No evidence indicates any preexisting medical conditions that may have adversely affected the flight crew's performance during the flight. Flight crew fatigue was not a factor in this accident.

2. The accident airplane was properly maintained and dispatched in accordance with Federal regulations.

3. The air traffic controllers who handled American Airlines flight 587 were properly trained and qualified. The local controller complied with Federal Aviation Administration wake turbulence spacing requirements when handling flight 587 and Japan Air Lines flight 47, which departed immediately before flight 587.

4. The witnesses who reported observing the airplane on fire were most likely observing a fire from the initial release of fuel or the effects of engine compressor surges.

5. Flight 587's cyclic rudder motions after the second wake turbulence encounter were the result of the first officer's rudder pedal inputs.

6. Flight 587's vertical stabilizer performed in a manner that was consistent with its design and certification. The vertical stabilizer fractured from the fuselage in overstress, starting with the right rear lug while the vertical stabilizer was exposed to aerodynamic loads that were about twice the certified limit load design envelope and were more than the certified ultimate load design envelope.

7. The first officer had a tendency to overreact to wake turbulence by taking unnecessary actions, including making excessive control inputs.

8. The American Airlines Advanced Aircraft Maneuvering Program ground school training encouraged pilots to use rudder to assist with roll control during recovery from upsets, including wake turbulence.

9. The American Airlines Advanced Aircraft Maneuvering Program excessive bank angle simulator exercise could have caused the first officer to have an unrealistic and exaggerated view of the effects of wake turbulence; erroneously associate wake turbulence encounters with the need for aggressive roll upset recovery techniques; and develop control strategies that would produce a much different, and potentially surprising and confusing, response if performed during flight.

10. Before the flight 587 accident, pilots were not being adequately trained on what effect rudder pedal inputs have on the Airbus A300-600 at high airspeeds and how the airplane's rudder travel limiter system operates.

11. The Airbus A300-600 rudder control system couples a rudder travel limiter system that increases in sensitivity with airspeed, which is characteristic of variable stop designs, with the lightest pedal forces of all the transport-category aircraft evaluated by the National Transportation Safety Board during this investigation.

12. The first officer's initial control wheel input in response to the second wake turbulence encounter was too aggressive, and his initial rudder pedal input response was unnecessary to control the airplane.

13. Certification standards are needed to ensure that future airplane designs minimize the potential for aircraft-pilot coupling susceptibility and to better protect against high loads in the event of large rudder inputs.

14. Because of its high sensitivity (that is, light pedal forces and small pedal displacements), the Airbus A300-600 rudder control system is susceptible to potentially hazardous rudder pedal inputs at higher airspeeds.

15. To minimize the potential for aircraft-pilot coupling events, transport-category pilots would benefit from training about the role that alternating full control inputs can play in such events and training that emphasizes that alternating full rudder inputs are not necessary to control a transport-category airplane.

16. There is a widespread misunderstanding among pilots about the degree of structural protection that exists when full or abrupt flight control inputs are made at airspeeds below the maneuvering speed.

17. Federal Aviation Administration standards for unusual attitude training programs that take into account industry best practices and are designed to avoid inaccurate or negative training would lead to improvement and standardization of industry training programs.

18. The use of lower levels of automation, such as simulators without motion or simple computer screen displays, may be more appropriate to provide the necessary awareness training with less danger of introducing incorrect information.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the in-flight separation of the vertical stabilizer as a result of the loads beyond ultimate design that were created by the first officer's unnecessary and excessive rudder pedal inputs. Contributing to these rudder pedal inputs were characteristics of the Airbus A300-600 rudder system design and elements of the American Airlines Advanced Aircraft Maneuvering Program.[211]

---

[211] Members Carmody and Healing voted against the Vice Chairman's revision, which reversed the order of the two contributing factors shown in the staff draft report. For more information, see the Board Member Statement that follows section 4, "Recommendations."

4. Recommendations

4.1 New Recommendations

As a result of the investigation of this accident, the National Transportation Safety Board makes the following recommendations:

To the Federal Aviation Administration:

Modify 14 *Code of Federal Regulations* Part 25 to include a certification standard that will ensure safe handling qualities in the yaw axis throughout the flight envelope, including limits for rudder pedal sensitivity. (A-04-56)

After the yaw axis certification standard recommended in Safety Recommendation A-04-56 has been established, review the designs of existing airplanes to determine if they meet the standard. For existing airplanes designs that do not meet the standard, the FAA should determine if the airplanes would be adequately protected from the adverse effects of a potential aircraft-pilot coupling (APC) after rudder inputs at all airspeeds. If adequate protection does not exist, the FAA should require modifications, as necessary, to provide the airplanes with increased protection from the adverse effects of a potential APC after rudder inputs at high airspeeds. (A-04-57)

Review the options for modifying the Airbus A300-600 and the Airbus A310 to provide increased protection from potentially hazardous rudder pedal inputs at high airspeeds and, on the basis of this review, require modifications to the A300-600 and A310 to provide increased protection from potentially hazardous rudder pedal inputs at high airspeeds. (A-04-58)

Develop and disseminate guidance to transport-category pilots that emphasizes that multiple full deflection, alternating flight control inputs should not be necessary to control a transport-category airplane and that such inputs might be indicative of an adverse aircraft-pilot coupling event and thus should be avoided. (A-04-59)

Amend all relevant regulatory and advisory materials to clarify that operating at or below maneuvering speed does not provide structural protection against multiple full control inputs in one axis or full control inputs in more than one axis at the same time. (A-04-60)

Adopt and disseminate written guidance for use in developing and accepting upset recovery programs; such guidance could take the form of an advisory circular and should reflect the industry's best practices and be designed to avoid inaccurate or negative training. (A-04-61)

Along with developing the guidance recommended in Safety Recommendation A-04-61, evaluate issues concerning the level of automation appropriate to teaching upset training, and develop and disseminate guidance that will promote standardization and minimize the danger of inappropriate simulator training. (A-04-62)

To the Direction Général de l'Aviation Civile:

Review the options for modifying the Airbus A300-600 and the Airbus A310 to provide increased protection from potentially hazardous rudder pedal inputs at high airspeeds and, on the basis of this review, require modifications to the A300-600 and A310 to provide increased protection from potentially hazardous rudder pedal inputs at high airspeeds. (A-04-63)

4.2 Previously Issued Recommendations Resulting From This Accident Investigation

As a result of the investigation of this accident, the Safety Board issued the following recommendations to the Federal Aviation Administration:

Require the manufacturers and operators of transport-category airplanes to establish and implement pilot training programs that: (1) explain the structural certification requirements for the rudder and vertical stabilizer on transport-category airplanes; (2) explain that a full or nearly full rudder deflection in one direction followed by a full or nearly full rudder deflection in the opposite direction, or certain combinations of sideslip angle and opposite rudder deflection can result in potentially dangerous loads on the vertical stabilizer, even at speeds below the design maneuvering speed; and (3) explain that, on some aircraft, as speed increases, the maximum available rudder deflection can be obtained with comparatively light pedal forces and small pedal deflections. The FAA should also require revisions to airplane and pilot operating manuals that reflect and reinforce this information. In addition, the FAA should ensure that this training does not compromise the substance or effectiveness of existing training regarding proper rudder use, such as during engine failure shortly after takeoff or during strong or gusty crosswind takeoffs or landings. (A-02-01)

Carefully review all existing and proposed guidance and training provided to pilots of transport-category airplanes concerning special maneuvers intended to address unusual or emergency situations and, if necessary, require modifications to ensure that flight crews are not trained to use the rudder in a way that could result in dangerous combinations of sideslip angle and rudder position or other flight parameters. (A-02-02)

Require all manufacturers of transport-category airplanes to review and, if necessary, revise their maintenance manual inspection criteria for severe turbulence and extreme in-flight maneuvers to ensure that loads resulting from positive and negative vertical accelerations, as well as lateral accelerations, are adequately addressed. (A-03-41)

Require all manufacturers of transport-category airplanes to establish and validate maximum threshold values for positive and negative vertical and lateral G accelerations beyond which direct manufacturer oversight and intervention is required as a condition for returning the airplane to service. (A-03-42)

Require all operators of airplanes that have experienced accelerations exceeding the threshold values established as a result of Safety Recommendation A-03-42 (or that the operator has reason to believe might have exceeded those thresholds), as determined from FDR and other available data, to notify the FAA immediately of such high loading events and provide all related loads assessment and inspection results. (A-03-43)

Require manufacturers of transport-category airplanes to immediately notify the appropriate certification authority of any event involving accelerations exceeding the threshold values (or that the manufacturer has reason to believe might have exceeded those thresholds) necessitating the intervention of the manufacturer, and provide all related loads assessment and inspection results. (A-03-44)

Require that within 2 years, all Airbus A300-600/A310 and Boeing 747-400 airplanes and any other aircraft that may be identified as recording filtered data be retrofitted with a flight data recorder system capable of recording values that meet the accuracy requirements through the full dynamic range of each parameter at a frequency sufficient to determine a complete, accurate, and unambiguous time history of parameter activity, with emphasis on capturing each parameter's dynamic motion at the maximum rate possible, including reversals of direction at the maximum rate possible. (A-03-50)

For additional information about Safety Recommendations A-02-01 and -02, see section 1.18.4.1 of this report. For additional information about Safety Recommendations A-03-41 through -44, see section 1.18.4.2 of this report. For additional information about Safety Recommendation A-03-50, see section 1.18.7.3 of this report.

4.3 Previously Issued Recommendations Classified in This Report

Safety Recommendation A-96-120 (previously classified "Open—Acceptable Response") is classified "Open—Unacceptable Response" in section 2.6 of this report. For more information about this recommendation, see sections 1.18.6.1 and 2.6 of this report.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

ELLEN ENGLEMAN CONNERS
Chairman

CAROL J. CARMODY
Member

MARK V. ROSENKER
Vice Chairman

RICHARD F. HEALING
Member

DEBORAH A. P. HERSMAN
Member

Adopted: October 26, 2004

Board Member Statements

Member Carol J. Carmody's Statement, in which Member Richard F. Healing joined

I support the probable cause language in the original staff draft, which listed contributing factors as the American Airlines Advanced Aircraft Maneuvering Program and characteristics of the A300-600 rudder system. I heard no reason either during the staff presentations, or in the explanation provided by the Vice Chairman in submitting his substitute, to reverse this order. To diminish the role of the AAMP in the accident is to downplay the role it played in the pilot's actions which caused the accident. One of the undeniable facts of this accident is the pilot's inappropriate use of rudder. Staff was unable to find any example of unusual rudder use by the pilot before his AAMP training. When questioned by a captain for using the rudder in an earlier incident, the first officer "insisted that the AAMP directed him to use the rudder pedals in that manner." To elevate the characteristics of the A300-600 rudder system in the hierarchy of contributing factors ignores the fact that this system had not been an issue in some 16 million hours of testing and operator experience—until the AAMP trained pilot flew it. The justification for the change was that the Board must address the future and, therefore, must give more attention to the aircraft rudder characteristics. That is what our recommendations are designed to do, and our recommendations do address the design issues. The probable cause should reflect accurately what the investigation and the report demonstrate; the substitute probable cause does not do that.

5.   Appendixes

Appendix A
Investigation and Public Hearing

Investigation

The National Transportation Safety Board was initially notified of this accident on November 12, 2001, about 0930 eastern standard time. A full go-team was assembled and departed from Ronald Reagan Washington National Airport in Washington, D.C., for New York shortly thereafter. The team arrived on scene later that day. Accompanying the team to New York was former Chairman Marion Blakey and former Board Member George Black.

The following investigative teams were formed: Aircraft Operations, Human Performance, Aircraft Structures, Aircraft Systems, Powerplants, Maintenance Records, Air Traffic Control, Meteorology, Aircraft Performance, Witnesses, and Materials. Specialists were also assigned to conduct the readout of the flight data recorder and transcribe the cockpit voice recorder in the Safety Board's laboratory in Washington, D.C.

In accordance with the provisions of Annex 13 to the Convention on International Civil Aviation, the Safety Board's counterpart agency in France, the Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (BEA) participated in the investigation as the representative of the State of Design and Manufacture. Parties to the investigation were the Federal Aviation Administration (FAA), American Airlines, the Allied Pilots Association, National Air Traffic Controllers Association, Association of Professional Flight Attendants, General Electric Aircraft Engines, Honeywell Engines and Systems, and the Federal Bureau of Investigation. Airbus Industrie participated in the investigation as a technical advisor to the BEA, as provided in Annex 13.

Public Hearing

The Safety Board held a public hearing on this accident from October 29 to November 1, 2002, in Washington, D.C. Acting Chairman Carol Carmody presided over the hearing; former Board Members John Hammerschmidt, John Goglia, and George Black also participated in the hearing. The issues presented at the hearing were the design and certification of the Airbus 300-600 vertical stabilizer; the design, certification, and operation of the A300 rudder system; wake turbulence; and American Airlines' operations and training.

The technical panel comprised investigators from the Safety Board and the BEA. Parties to the public hearing were the FAA, American Airlines, Airbus, and the Allied Pilots Association.

Appendix B
Cockpit Voice Recorder Transcript

The following is the transcript of the Fairchild A-100A cockpit voice recorder, serial number missing, installed on American Airlines flight 587, an Airbus A300-600, N14053, which experienced an in-flight separation of the vertical stabilizer shortly after takeoff from John F. Kennedy International Airport in Jamaica, New York, on November 12, 2001.

	LEGEND
HOT	Crewmember hot microphone voice or sound source
RDO	Radio transmission from accident aircraft
CAM	Cockpit area microphone voice or sound source
RMP	Radio transmission from local ramp control
PA	Voice transmitted over aircraft public address system
INT	Voice transmitted over aircraft interphone system
GND	Radio transmission from JFK ground control
TWR	Radio transmission from JFK control tower
JAL47	Radio transmission from Japan Airlines flight 47
PD14	Radio transmission from police department flight 14
DEP	Radio transmission from New York departure control
-1	Voice identified as Pilot-in-Command (PIC)
-2	Voice identified as Co-Pilot (SIC)
-3	Voice identified as pushback crewman
-?	Voice unidentified
*	Unintelligible word
@	Non-pertinent word
#	Expletive
- - -	Break in continuity
( )	Questionable insertion
[ ]	Editorial insertion
…	Pause

Note 1: Times are expressed in eastern standard time (EST).

Note 2: For ATC transmissions, generally, only radio transmissions to and from the accident aircraft were transcribed.

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT

0845:35
START of RECORDING
START of TRANSCRIPT

0845:50
CAM   [sound similar to paper rustling]

0846:04
CAM-1   [unintelligible comment]

0846:05
HOT-2   now what?

0846:08
HOT-2   it's part of the job. quick nap. [sound of yawn]

0846:44
CAM-1   ** seagulls getting in *. why are they flying around that con-
struction site?

0846:50
CAM-1   oh, coffee truck.

0846:51
HOT-2   [sound of chuckle] flying around 'cause it looks like a dump.
that's why. they don't know any better.

0847:02
HOT-2   good question.

0847:10
HOT-2   this thing's going triple the speed it was.

0847:18
HOT-2   did you see that thing the union passed just before they ap-
proved the whole thing they changed some something with
the list or something.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
0847:24 **CAM-1**	St. Louis thing.		
0847:26 **HOT-2**	what did they do?		
0847:28 **CAM-1**	aah, you know.... we were talking about this last time, I guess you know. @ @ was (always saying) how I, I was getting the, the information, and um, I guess there were some uh, holes in the previous document, where the pilots of TWA guys in St. Louis given a certain scenario could cross through the fence and come out of the AA system as Captains.		
0848:00 **HOT-2**	eeewh.		
0848:03 **CAM-1**	beyond that I, I don't, I can't really explain it. * uh, but my understanding is, they, they plugged those holes in the fence.		
0848:13 **HOT-2**	'kay.		
0848:20 **CAM-1**	sit there and read this, this the legalese stuff * . I mean you really have to sit down and study this to get it.		
0848:25 **HOT-2**	really hard. oh yeah.		
0848:32 **HOT-2**	and it's also a "mute" point seeing how it's passed now.		
0848:35 **CAM-1**	yeah.		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
0848:39 **HOT-2**	which is good which means @ @ was causing trouble and he.... plugged the hole.		
0848:44 **CAM-1**	you know he's a force now. he outta run for aaaah, union job.		
0848:58 **CAM-1**	boy, he's a New Yorker with an attitude.		
0849:02 **HOT-2**	we need a new @.		
0849:04 **CAM-1**	yeah.		
0849:06 **CAM-1**	well, @. irreplaceable. what was he saying to you this morning, anything?		
0849:11 **HOT-2**	nothing.		
0849:12 **CAM-1**	'cause he's still on the inside, isn't he?		
0849:14 **HOT-2**	oh yeah.		
0849:15 **CAM-1**	huh?		

INTRA-COCKPIT COMMUNICATION   **AIR-GROUND COMMUNICATION**

TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT

0849:16
HOT-2   he's a @.... he's on the inside, very much so.... he still goes
down, you know, DDR, doing you know.... whatever.... he's
very much on the inside. trust me, when friggin has a problem
he goes.... this guy did this or whatever. call @ man. @ got a
friggin wealth of knowledge sitting there. it's like @.... except
that there's a wealth of knowledge on how to give things back
which we shouldn't have been tapping.

0849:54
CAM-1   what?

0849:57
HOT-2   @ was calling up @. you know we were paying @? this # un-
ion didn't even tell us way back then.

0850:02
CAM-1   is that right?

0850:03
HOT-2   oh yeah. @ was hired as a consultant. and taken off flight....
no one told us about that.

0850:15
CAM-1   I didn't know that.

0850:16
HOT-2   yeah.

0850:17
CAM-1   so they, they really didn't tell us.

0850:18
HOT-2   oh no.

0850:19
CAM-1   they still haven't told us. we just found out.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
0850:21 HOT-2	[sound of hiccup and cough] excuse me, I was just reading uh, aaaah I think I found it out in the accounting thing. I was scouring through um, APA's accounting. all the people that got flight time pay and how much it was. you know and that's where I found it, that @ got removed from, trip pay. paid by APA, which could only be one, I mean, what else is he doing?		
0850:50 CAM-1	yeah.		
0851:03 HOT-2	[sound similar to yawn]		
0851:11 HOT-2	[sound of singing]		
0851:24 HOT-2	I think across from it, it said consulting. [sound of chuckle]		
0851:27 CAM-1	said what?		
0851:28 HOT-2	said removed from trip. it said like reason or whatever. it said consulting or something.		
0851:32 CAM-1	*.		
0851:33 HOT-2	consultant, yeah.		
0851:56 HOT-2	well we're getting paid, that's nice. thank you very much. can't beat that.		
0852:17 CAM-1	***.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
0852:18 **CAM**	[sound of clunk]		
0852:44 **HOT-1**	the door is closed.		
0852:46 **HOT-2**	*.		
0852:50 **HOT-?**	before *.		
0852:52 **HOT-2**	*.		
		0852:53 **INT-3**	ground to cockpit?
		0852:54 **INT-1**	hello.
		0852:55 **INT-3**	hello cockpit. we just locked up and we're all secure below, standing by.
		0852:58 **RDO-2**	American five eighty eight, ready to do push-back.
		0853:01 **INT-1**	okay, brakes released. standby for the clearance.
		0853:03 **RMP**	five eighty seven, stand by. you're gonna be number two to push. I'll give you a call.
		0853:06 **RDO-2**	stand by, American five eighty seven.

INTRA-COCKPIT COMMUNICATION		**AIR-GROUND COMMUNICATION**	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
0853:08 **HOT-2**	uuuuh, probe heat.		
0853:11 **HOT-1**	on.		
0853:11 **HOT-2**	ECAM doors display, slides?		
0853:12 **HOT-1**	green and armed.		
0853:13 **HOT-2**	beacon, nav lights?		
0853:14 **HOT-1**	on, on.		
0853:15 **HOT-2**	cabin ready?		
0853:15 **HOT-1**	received.		
0853:18 **HOT-2**	checklist is done. we're not cleared.		
0853:21 **HOT-1**	okay.		
0853:24 **HOT-2**	number two.		
0853:26 **HOT-1**	three four and all right five thousand pounds heavy?		
0853:47 **HOT-1**	hmmmm.		

INTRA-COCKPIT COMMUNICATION	AIR-GROUND COMMUNICATION

TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
		0853:55 **INT-1**	I guess there's traffic out there somewhere.
0853:58 **HOT-1**	where's the TPS?		
		0854:05 **INT-3**	oh yeah, it's just pulling up now.
0854:18 **HOT-1**	two.... three.... oh, two three nine, okay.		
0855:23 **HOT-2**	[sound of humming]		
0855:27 **HOT-1**	what's the temperature?		
0855:57 **PA-1**	well ladies and gentlemen, Captain States again. we're all but-toned up ready to go. we're just waiting for an airplane behind us uuuh, to move on out of our way, and then we will be pushing back.		
0856:07 **CAM**	[sound of hi-lo chime]		
0856:08 **PA-4**	[sound of male flight attendant beginning passenger an-nouncement in Spanish]		
		0856:08 **RMP**	American five eighty seven....
		0856:09 **RDO-2**	yes.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
		0856:11 **RMP**	five eight seven, do you still have a ground crew there?
		0856:12 **RDO-2**	I believe we have ground crew.
0856:14 **HOT-2**	yes, we have ground crews still?		
		0856:15 **RMP**	American five eighty seven, (have your ground crew to reference the company seven thirty seven departing the alley), you're cleared to push.
0856:16 **HOT-1**	huh? what?		
		0856:20 **RDO-2**	reference the seven three, we're cleared to push, American five eighty seven heavy.
		0856:30 **INT-1**	evidently there's a seven thirty seven back there uh, once you see him, we're cleared to push.
		0856:31 **INT-3**	okay cockpit um, they just disconnected and, should be another couple of minutes.
		0856:37 **INT-1**	okay, whatever you like.
0856:49 **HOT-2**	I can't believe how much money GE makes just renting little shacks to construction people. you know if GE's in uh, it's huge money. I mean they don't, they don't....		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
0856:56 **HOT-1**	they're, they're, you know if you looked into it, you could probably find GE in virtually, everything.		
0857:02 **HOT-2**	GE is actually like one of the largest banks in the world. it's like the largest bank in the world.		
0857:05 **HOT-1**	yeah.		
0857:07 **HOT-2**	they have more flexibility because they don't have the restrictions of a bank. banks have certain restrictions as to what they can and can't do as far as, their hands tied. ah,ah, it's unbelievable.		
0857:22 **HOT-2**	they, they own more aircraft than American Airlines.		
0857:25 **HOT-1**	GE does?		
0857:32 **HOT-2**	I'm not gonna say size wise but a lot of those corporate jets and all that other stuff....		
0857:35 **HOT-1**	yeah.		
0857:36 **HOT-2**	...more aircraft.		
0857:37 **HOT-1**	just numbers, yeah.		
		0858:00 **INT-3**	hey cockpit, that aircraft is clear, we'll start our pushback.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
		0858:04 **INT-1**	brakes released, cleared to push.
0858:10 **HOT-1**	three sixty nine, what were we threeeee.... forty nine.		
0858:17 **HOT-2**	what do you need?		
0858:32 **HOT-1**	fifty one, fifty one, one fifty six, twenty one one. * change, forty two C.		
		0859:27 **INT-3**	ground to cockpit, you're cleared to start.
		0859:29 **INT-1**	cleared to start.
0859:34 **HOT-1**	starting two.		
0859:37 **HOT-1**	valves open.		
0859:37 **CAM**	[sound similar to ECAM chime]		
		0859:53 **INT-3**	parking brakes park.
		0859:55 **INT-1**	brakes are parked, cleared to disconnect, see you out front.
		0859:58 **INT-3**	ground to cockpit, disconnecting, see ya out front.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
		0900:00 **INT-1**	so long.
		0900:02 **INT-3**	so long.
0900:15 **HOT-2**	forty five N two.		
0900:17 **HOT-1**	the valve is closed.		
0900:21 **HOT-1**	starting one.		
0900:25 **HOT-1**	valve's open.		
0900:47 **HOT-1**	see ya salute, four guys going away.		
0901:03 **HOT-2**	forty five N two.		
0901:05 **CAM**	[sound similar to Selcal buzzer]		
0901:07 **HOT-2**	APU?		
0901:07 **HOT-1**	valves closed, done.		
0901:13 **HOT-2**	you got your four guys, all set?		
0901:13 **HOT-1**	yep, dos, tres.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
		0901:14 **RDO-2**	American five eighty seven, we're gonna be going over to ground. we'll talk to you later.
		0901:15 **RMP**	five eighty seven, cleared to contact ground, have a good flight.
		0901:20 **RDO-2**	good day.
		0901:24 **RDO-2**	morning ground, it's American five eighty seven heavy with the information Delta coming out of uh, Tango Alpha.
0901:30 **HOT-2**	clear right.		
0901:31 **HOT-1**	clear left. fifteen when you're ready.		
0901:32 **CAM**	[sound of several clicks]		
		0901:33 **GND**	American five eighty seven heavy Kennedy ground, runway three one left for departure. taxi left on Bravo. hold short of Juliet.
		0901:39 **RDO-2**	left Bravo, short of Juliet, American five eighty seven heavy.
0901:55 **HOT-2**	come back.		
0902:05 **HOT-1**	your leg, you check the rudders.		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT

0902:23
HOT-2   rudders check.

0902:26
HOT-1   okay.

0902:40
HOT-2   taxi checklist is complete.

0902:59
HOT-2   takeoff checklist, anti-ice?

0903:01
HOT-1   off.

0903:02
HOT-2   auto-brakes.

0903:03
HOT-1   max.

0903:38
HOT-2   okay, the box is updated. we have, stand alone sheet, for....
runway thirty one left. flaps fifteen, bleeds on. assumed tem-
perature is supposed to be forty two. we have forty two set.
weight was three forty nine point three. and your stand alone
sheet's for three forty nine three. weights check, temperature
check. and I'm gonna double check the winds here. forty two
degrees is supposed to give us one oh one point one. we got
one oh one point one. numbers are one fifty, fifty four and fifty
six.... three thirty at eleven. winds checked. takeoff data and
TRP for thirty one left.

0904:28
HOT-1   two hundred forty six people, crew of nine, two hundred fifty
five SOBs. takeoff data, set and cross-checked, flex power.
three one left, Kennedy.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
0904:36 **HOT-2**	set and cross-checked. takeoff data and TRP.		
0904:39 **HOT-2**	AFS panel and radios?		
0904:41 **HOT-1**	aah, fifty six is preset, two forty two, everything else remains the same, set checked.		
0904:45 **HOT-2**	gotcha.		
0904:47 **HOT-2**	flaps fifteen, stab trim is nose up point seven.... stab trim?		
0904:53 **HOT-1**	uuuuh, point seven nose up set.		
0904:56 **HOT-2**	slats and flaps?		
0904:57 **HOT-1**	calls for fifteen, fifteen, set at fifteen, fifteen, fifteen. fifteen, uploaded.		
0905:01 **HOT-2**	verified fifteen, fifteen.		
0905:05 **HOT-2**	ECAM?		
0905:06 **HOT-1**	checked.		
0905:08 **HOT-2**	takeoff config?		

INTRA-COCKPIT COMMUNICATION   **AIR-GROUND COMMUNICATION**

TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
0905:09 **HOT-1**	norm f' takeoff.		
0905:11 **HOT-2**	takeoff briefing?		
0905:12 **HOT-1**	all right, you start out. if something happens prior to V one, call what you see, I'll decide whether or not to abort. uuh, unless it an engine failure or an inability to fly, we'll plan on continuing the takeoff. uh, it's a hundred feet and then uh, a left turn to what?		
0905:40 **HOT-1**	uh, runway heading to three hundred feet, that's a heading to two one zero to a thousand feet and then it's the uh, engine uh, clean-up or the airplane clean-up stuff.... after the immediate action items you have the airplane, the radio we'll plan on left hand traffic to come back to uh, either one of the three ones.... highest min safe altitude on runway heading is twenty eight hundred foot, and once you make a left turn over water it's eighteen hundred feet. the terrain is flat with towers. otherwise you plan on about a heading two two zero, five thousand feet. questions?		
0906:15 **HOT-2**	no.		
0906:16 **HOT-1**	briefing complete.... the Concorde returns.		
		0906:53 **GND**	Japan Air forty seven, continue via Bravo, turn right at Juliet, cross runway four left.
		0907:00 **JAL47**	Japan Air forty seven, on Bravo, Juliet cross runway two two uh, four left.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
		0907:07 **GND**	Japan Air four seven, that's correct, thanks.
0907:55 **HOT-2**	I was flying in here about three nights ago, comin' innnn, 'bout ten o'clock, doing that twelve, twelve, thirty departure turn, Dingo turn. so I don't know comin' in here, not ten o'clock somewhere there, nine o'clock, somewhere, and uh....		
		0908:01 **GND**	Japan Air forty seven heavy, monitor the tower one one niner point one. so long.
		0908:05 **JAL47**	one one nine one, Japan Air forty seven, so long.
0908:12 **HOT-2**	Egypt Air, was told to do. they were rocketing off towards the city and they were told to....		
0908:17 **HOT-1**	Egypt Air was told to do what?		
0908:19 **HOT-2**	turn thirty degrees, somewhere you know, like, you know, it was thirty degrees off their course. they were turn told to pick up a heading, and he said "roger" and he didn't turn. and the controller said, "pick up this heading." and he didn't turn. he says, "you need to turn immediately now Egypt Air, and I wanna know why you're not turning." finally he turned he says, "Egypt Air, we need to discuss on the ground why it took you fifteen miles to make a heading change when I asked you and you responded." they were really....		
0908:47 **HOT-1**	pissed.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
0908:48 HOT-2	...pissed, and uh I think they were like ready to....		
0908:51 HOT-1	launch the fleet.		
0908:52 HOT-2	oh yeah, 'cause he was heading towards the city. he was....		
0908:54 HOT-1	oh really.		
0908:56 HOT-2	oh yeah, that's why he's ticked, that's why he's so ticked.		
		0908:58 GND	American five eighty seven heavy, follow the Japan Air heavy Boeing seven forty seven ahead. monitor the tower one one niner point one. so long.
		0909:03 RDO-2	follow Japan Air over to tower nineteen one, American Five Eighty seven heavy.
0909:09 HOT-2	really ticked.		
0909:13 HOT-1	follow JAL.		
0909:17 HOT-2	these guys just uh, merged. with Japan and another j.... what's the other Japan company?		
0909:20 HOT-1	All Nippon?		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
0909:21 **HOT-2**	no, not Nippon, there's another one I think. they merged this morning.		
0909:27 **HOT-1**	really.		
0909:27 **HOT-2**	[sound of yawn] yeah. the big news, Japan and what other Japanese airline is .... I *, I don't think it was All Nippon it was uh....		
0910:15 **HOT-1**	crossing two two right. clear on the left.		
0910:20 **HOT-2**	on the right.		
		0910:27 **TWR**	Japan Airlines forty seven heavy, Kennedy tower, runway three one left, taxi into position and hold.
		0910:32 **JAL47**	runway three one left, taxi into position and hold.
		0910:34 **TWR**	PD fourteen uh, caution wake turbulence, there'll be uh, several heavy jets departures over Canarsie momentarily.
		0910:41 **PD14**	roger that PD fourteen, we'll be looking.
0910:44 **CAM**	[sound of clunk]		
0910:51 **PA-1**	well ladies and gentlemen, at long last, we are number two for takeoff. uuh, toward the northwest today. immediately after takeoff we'll be in a left hand turn heading for the shoreline		

INTRA-COCKPIT COMMUNICATION		**AIR-GROUND COMMUNICATION**	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
	and uh, getting ourselves pointed southbound. 'bout another two or three minutes it'll be our turn to go. flight attendants, prepare for takeoff please.		
		0911:08 **TWR**	Japan Airlines forty seven heavy, wind three zero zero at one zero runway three one left, cleared for takeoff.
		0911:12 **JAL47**	runway three one left, cleared for takeoff, Japan Air forty seven heavy.
0911:27 **HOT-1**	yeah, I guess that controller was bent outta shape, huh?		
0911:29 **HOT-2**	ticked.		
0911:33 **HOT-1**	can't hardly blame him.		
0911:35 **HOT-2**	ah, I'm sure.		
		0911:36 **TWR**	American five eighty seven heavy Kennedy tower, caution wake turbulence runway three one left, taxi into position and hold.
		0911:41 **RDO-2**	position and hold three one left, American five eighty seven heavy.
0911:44 **HOT-1**	position and hold. I see traffic out there. hopefully he's going to the right side.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
0911:55 HOT-2	takeoff briefing we got, PA?		
0911:57 HOT-1	[sound of single chime]		
0911:58 HOT-1	complete.		
0912:00 HOT-2	ignition.		
0912:05 HOT-1	Reach? ignition's off.		
0912:07 HOT-2	bleeds?		
0912:09 HOT-1	bleeds are on.		
0912:12 HOT-1	he say Reach?		
0912:13 HOT-2	Reach four oh one or something like that yeah.		
0912:16 HOT-1	Air Force is coming to Kennedy.		
0912:19 HOT-2	is that a Reach, that's the Air Force?		
0912:20 HOT-1	yeah, that's the....		
0912:20 HOT-2	transponder?		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
0912:21 HOT-1	TARA.		
0912:22 HOT-1	it's a tanker.		
0912:24 HOT-1	the call sign. that looks like a seven four out there though.		
0912:30 HOT-1	all right, position and hold on the uh, left side.		
0912:36 HOT-1	final appears clear, transponder is TARA....		
0912:38 HOT-2	brake.... thank you. brake fans?		
0912:39 HOT-1	fans are off.		
0912:40 HOT-2	lights to go. I'm gonna make... left turn two twenty. go out the Bridge five thousand feet's the top. if we have a problem, I'll clean it up at six.... ten.... left traffic for this runway....		
		0913:05 TWR	Japan Air forty seven heavy, fly the Bridge Cimb, contact New York departure, good morning.
		0913:10 JAL47	Bridge Climb, switch to departure, Japan Air four seven, good morning.
0913:21 HOT-1	you have the airplane.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
0913:21 **HOT-2**	I got the brakes.		
0913:22 **HOT-1**	I have the radios.		
		0913:27.6 **TWR**	American five eight seven heavy, wind three zero zero at niner, runway three one left, cleared for takeoff.
		0913:31.7 **RDO-1**	cleared for takeoff, American ah, five eight seven heavy.
0913:35.3 **HOT-2**	you happy with that distance?		
0913:38.5 **HOT-1**	aah, he's.... we'll be all right once we get rollin'. he's supposed to be five miles by the time we're airborne, that's the idea.		
0913:45.5 **HOT-2**	so you're happy. lights?		
0913:47.1 **HOT-1**	yeah, lights are on.		
0913:47.8 **HOT-2**	takeoff check's complete, I'm on the roll. thank you sir.		
0913:53.5 **HOT-1**	thrust SRS, runway.		
0913:54.7 **CAM**	[sound similar to increase in engine RPM]		
0914:03.8 **HOT-2**	you got throttles.		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
0914:08.9 HOT-1	eighty knots, thrust blue.		
0914:23.4 HOT-1	V one.		
0914:24.3 HOT-1	rotate.		
0914:25.7 HOT-1	V two		
0914:28.5 HOT-1	V two plus ten.		
0914:30.4 HOT-2	positive rate, gear up please.		
0914:31.5 HOT-1	gear up.		
0914:33.1 CAM	[sound of thump and two clicks]		
0914:38.5 HOT-2	heading select.		
0914:41.9 HOT-1	clear left.		
		0914:42.6 TWR	American five eight seven heavy, turn left. fly the Bridge Climb. contact New York departure. good morning.
		0914:48.3 RDO-1	American five eighty seven heavy, so long.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
0914:51.4 **HOT-1**	gear's up.		
0914:52.5 **HOT-2**	check speed, level change.		
0914:54.8 **HOT-2**	flaps up.		
0914:56.5 **HOT-2**	climb power.		
0914:57.1 **CAM**	[sound of click]		
		0915:00.0 **RDO-1**	ah New York, American five eighty seven heavy, thirteen hundred feet, we're climbing to five thousand.
		0915:04.7 **DEP**	American five eight seven heavy, New York departure. radar contact. climb maintain one three thousand.
		0915:10.2 **RDO-1**	one three thousand feet, American five eighty seven heavy.
0915:14.6 **HOT-2**	one three I see, slats retract.		
0915:16.5 **HOT-1**	slats.		
0915:17.2 **CAM**	[sound of several clicks]		
0915:28.5 **HOT-1**	clean machine.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
0915:28.5 **HOT-2**	[sound similar to yawn] thank you.		
		0915:36.4 **DEP**	American five eighty seven heavy, turn left, proceed direct WAVEY.
0915:37.3 **HOT-1**	[sound of brief squeak and a rattle]		
		0915:41.0 **RDO-1**	uh, we'll turn direct WAVEY, American five eighty seven heavy.
0915:44.4 **HOT-2**	left turn direct WAVEY….		
0915:44.7 **HOT-1**	little wake turbulence, huh?		
0915:45.6 **HOT-2**	…yeah.		
0915:47.3 **HOT-2**	[sound similar to five sets of stabilizer trim switch clicks]		
0915:48.2 **HOT-2**	two fifty thank you.		
0915:51.8 **CAM**	[sound of a thump]		
0915:52.3 **CAM**	[sound of click]		
0915:52.9 **CAM**	[sound of two thumps]		
0915:54.2 **HOT-2**	max power. [spoken in strained voice]		

INTRA-COCKPIT COMMUNICATION

AIR-GROUND COMMUNICATION

TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
0915:55.0 HOT-1	you all right?		
0915:55.3 HOT-2	yea, I'm fine.		
0915:56.3 HOT-1	hang onto it. hang onto it.		
0915:56.6 CAM	[sound of snap]		
0915:57.5 HOT-2	let's go for power please.		
0915:57.7 CAM	[sound of loud thump]		
0915:58.5 CAM	[sound of loud bang]		
0916:00.0 HOT-2	[sound similar to human grunt]		
0916:00.2 CAM	[roaring noise starts and increases in amplitude]		
0916:01.0 HOT-2	holy #.		
0916:01.0 CAM	[sound similar to single ECAM chime]		
0916:02.0 CAM	[sound similar to single ECAM chime]		
0916:04.4 CAM	[sound similar to stall warning repetitive chime for 1.9 seconds]		

INTRA-COCKPIT COMMUNICATION   **AIR-GROUND COMMUNICATION**

TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT

0916:06.2
CAM   [roaring noise decreases and ends]

0916:07.5
HOT-2   what the hell are we into *. we're stuck in it.

0916:07.5
CAM   [sound similar to continuous repetitive chimes for one second]

0916:09.6
CAM   [sound similar to continuous repetitive chimes for three seconds]

0916:12.8
HOT-1   get out of it, get out of it.

0916:14.8
END of RECORDING
END of TRANSCRIPT

Appendix C
Differences Between American Airlines
Flights 903 and 587

American Airlines flight 903 entered a stall and experienced a loss of control because the flight crew did not maintain an adequate airspeed during the level-off. At the start of the stall event, the airplane was in a 42º right bank and was rolling farther to the right, despite a full control wheel input to the left. The flight crew did not recognize that the airplane had entered a stall, did not use proper stall recovery techniques, and did not recover the airplane in a timely manner. As a result, the airplane remained in a stalled condition for more than 35 seconds, during which time the effectiveness of the lateral controls was reduced because of the stall.

When lateral controls are ineffective and the airplane is in an uncontrolled roll toward an extreme bank angle, the use of the rudder to help control the bank angle is appropriate, even though rudder use in a stall poses a significant risk of exacerbating the stall and departing farther from controlled flight. The proper response to recover from a stall is to move the control column forward, thereby decreasing the angle of attack and restoring lateral control. In the absence of this corrective action, the continued use of the rudder to keep the airplane upright may be necessary. Such was the case in the flight 903 stall event.

During this event, flight 903 entered a series of pitch, yaw, and roll maneuvers as the flight controls oscillated. The airplane was eventually recovered at an airspeed of 280 knots. No evidence from the flight 903 investigation indicated that Airbus A300-600 rudder control sensitivity at high airspeeds was a safety issue. The flight crew did not have any difficulty in regaining control of the airplane after exiting the stall, even though the stall recovery occurred at an airspeed at which the rudder control system sensitivity would have been similar to that during flight 587's second wake encounter. A contributing factor to the high loads experienced by flight 903 was the slow moving rudder travel limiter; the Safety Board issued safety recommendations to address the rudder travel limiter system on May 28, 2004.

Flight 587 had not entered a stall and was not in an upset. Further, the lateral controls were always fully effective; consequently, the use of the rudder to assist with roll control during the second wake encounter was only discovered during the flight 587

investigation. A slow moving rudder travel limiter was not a factor in the flight 587 accident (see table C-1 for a comparison of the issues from both investigations).

Table C-1. Comparison of the Issues From the Flight 903 and Flight 587 Investigations

Issue	903		587
Pilot training	Yes	→	Yes
Stall/loss of control	Yes	✖	No
Rudder input necessary	Yes	✖	No
High speed sensitivity	No	✖	Yes
Slow moving rudder travel limiter	Yes	✖	No