National Transportation Safety Board
Aviation Accident Final Report

Location:	LOS ANGELES, California	**Accident Number:**	LAX98GA127
Date & Time:	March 23, 1998, 07:40 Local	**Registration:**	N90230
Aircraft:	Bell 205A-1	**Aircraft Damage:**	Destroyed
Defining Event:		**Injuries:**	4 Fatal, 2 Serious
Flight Conducted Under:	Part 91: General aviation - Public aircraft		

Analysis

During an air ambulance flight in the public-use helicopter, the tail rotor and gearbox separated from the helicopter. The pilot autorotated to a forced landing. During the descent over mountainous terrain, the helicopter collided with trees and impacted hard terrain on its left side which crushed inward. The operator's policy required all crewmembers to wear helmets during flight. Helmets were not provided for the two paramedics. During the crash sequence, the passenger seat stanchions and tubing buckled, which resulted in multiple lap belt anchor point separations and the catapulting of crewmembers into the overhead cockpit panel. Safety Board survival factors documentation in conjunction with helmet crashworthiness analysis revealed helicopter impact forces were within human tolerance. The lack of and/or inadequate strength helmets and the lap belt anchor point failures allowed crewmembers' excursions resulting in head trauma. The tail rotor component separations in flight resulted from a fatigue crack originating in the surface of the yoke onto which the tail rotor blades had been attached. In 1996, Bell issued an Alert Service Bulletin (ASB) number 205-96-68, which was designed to measure yoke deformation resulting from adverse in-flight or ground handling operations which imposed excessive bending loads. The test protocol was found problematic in its accuracy due to technical errors in the bulletin and a lack of clarity. City mechanics failed to adhere to all of the ASB's requirements. The bent yoke fractured at a total time in service of approximately 4,113 hours, about 117 hours after its inspection for evidence of deformation. The yoke's stainless steel composition and requisite metallurgical properties were confirmed by the Safety Board. An x-ray diffraction examination of the yoke revealed reduced compressive residual stress in the fracture origin region which allowed operational loads to initiate and propagate the fatigue crack. This significant reduction of the residual stress was likely due to excessive flexure (bending) of the yoke. The initiating event which overstressed and bent the yoke was not identified.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this accident to be: An excessive bending load applied to the tail rotor blade assembly of an undetermined origin which produced a fatigue crack, the separation of the assembly, and a forced landing. Factors were the lack of suitable terrain to perform a forced landing, the manufacturer's unclear maintenance bulletin instruction and procedures which facilitated the operator's inadequate inspection for the yoke's straightness, and the inadequacy of restraint systems and protective equipment.

Findings

Occurrence #1: ROTOR FAILURE/MALFUNCTION
Phase of Operation: CRUISE

Findings
1. (C) ROTOR SYSTEM,TAIL ROTOR - BENT
2. (C) ROTOR SYSTEM,TAIL ROTOR - FATIGUE
3. (C) ROTOR SYSTEM,TAIL ROTOR - SEPARATION
4. ROTOR DRIVE SYSTEM,TAIL ROTOR GEARBOX(90 DEG) - SEPARATION
5. MAINTENANCE
6. (F) PROCEDURE INADEQUATE - MANUFACTURER
7. (F) INADEQUATE SUBSTANTIATION PROCESS - COMPANY/OPERATOR MGMT

Occurrence #2: FORCED LANDING
Phase of Operation: DESCENT - EMERGENCY

Findings
8. AUTOROTATION - INITIATED - PILOT IN COMMAND

Occurrence #3: HARD LANDING
Phase of Operation: EMERGENCY DESCENT/LANDING

Findings
9. (F) TERRAIN CONDITION - MOUNTAINOUS/HILLY
10. (F) TERRAIN CONDITION - NONE SUITABLE
11. (F) OBJECT - TREE(S)
12. (F) MISC EQPT/FURNISHINGS,SHOULDER HARNESS - NOT INSTALLED
13. SHOULDER HARNESS - OWNER/BUILDER
14. (F) MISC EQPT/FURNISHINGS,SEAT BELT - FAILURE,PARTIAL
15. ACFT/EQUIP,INADEQUATE AIRFRAME - MANUFACTURER
16. (F) MISC EQPT/FURNISHINGS,HELMET - INADEQUATE
17. ACFT/EQUIP,INADEQUATE DESIGN - MANUFACTURER

Factual Information

HISTORY OF FLIGHT

On March 23, 1998, about 0740 hours Pacific standard time, a Bell 205A-1, N90230, owned by the City of Los Angeles, California, and operated by the Los Angeles City Fire Department (LAFD), experienced the separation of its tail rotor blades and the 90-degree gearbox during cruise flight. A forced landing was initiated, and during the autorotative descent the helicopter collided with trees approximately 1.5 statute miles northwest of its destination, Children's Hospital in Los Angeles, California. The purpose of the flight was to provide air ambulance transportation for a seriously injured passenger. Visual meteorological conditions prevailed, and the LAFD was monitoring the helicopter's flight progress. The public-use helicopter was operated under the provisions of Title 14 CFR Part 91. The helicopter was destroyed upon impacting the terrain, and the commercial certificated pilot and one crewmember were seriously injured. Three additional crewmembers and the passenger sustained fatal injuries. The local area flight originated from the Van Nuys Airport, California, about 0722.

Upon dispatch, the helicopter flew about 7 miles northeast and landed about 0731 at the Stonehurst Elementary School playground, near the scene of an automobile traffic accident. At this location, the trauma patient (passenger) was loaded into the helicopter. The pilot took off about 0733.

Using the air traffic control call sign "Lifeguard Fire Three," the pilot flew in a south-southeasterly direction past the Burbank Airport while climbing and leveling off between 1,900 and 2,100 feet mean sea level (msl). Recorded radar track data indicates that the helicopter attained a 104-knot average ground speed.

Between 0737:17 and 0737:22, while cruising over a heavily wooded mountainous area known as Griffith Park, an event occurred which was manifested by an increase in the helicopter's average ground speed to about 118 knots. Seconds later, between 0737:26 and 0737:45, the helicopter's average speed reduced to between 76 and 84 knots, while descending through its last recorded altitude of 1,400 feet msl.

Thereafter, three other pilots and two ground witnesses reported hearing radio transmissions about a helicopter in an emergency or going down in Griffith Park. About 0739 one of these pilots, who was communicating with the Burbank Air Traffic Control Tower, reported hearing an emergency transmission about a helicopter crashing. About 0740, two news media helicopter pilots reported hearing a call from Fire Three that he was experiencing an emergency over Griffith Park. This transmission was followed 20 seconds later with the statement "gonna put it in Griffith Park." Two air support police officers, who were in hangars, heard the following transmissions at 0740: "Fire 3 we have an emergency."

During this approximate time, two hikers were on a mountain trail in Griffith Park. They reported hearing two "bangs" and observing components depart the southerly flying helicopter as it passed west of the Griffith Park Planetarium. Additional witnesses reported seeing the helicopter descend down a canyon and collide with a series of trees before crashing in a partial

clearing.

INJURIES TO PERSONS

Two of the six persons onboard the helicopter survived. No one on the ground was injured.

PERSONNEL INFORMATION

Air Operations Unit Management, Duties & Responsibilities.

The Air Operations Unit (AOU) of the LAFD is headed by a commander (manager) who, on a daily basis, is physically located at the airport unit. The commander reports to superior personnel located in the department's downtown Los Angeles headquarters.

In brief, the commander is responsible for helicopter operations including planning, scheduling of training, maintaining records, implementing department orders and communicating with his headquarters management. The commander does not possess a pilot certificate.

The AOU is staffed on a 24-hour basis with LAFD helicopter pilots. According to the AOU commander, the pilots are responsible for the safety of the helicopter in which they are flying. They are in command of the helicopter, and have the authority to veto any proposed operation, which in the pilot's opinion, would be unsafe. (See the extract from the Air Operations Manual for the statement of pilot responsibility.)

Flight Crewmembers.

On the accident flight, the helicopter crewmembers consisted of one pilot, two helitacs and two paramedics. The helitacs are trained to serve as helicopter crewmembers. In part, they are responsible for overseeing the safety of the working environment including providing guidance to ground personnel. The paramedics perform emergency medical aid to the patient, if required.

Pilot.

A review of the pilot's personal flight record logbook indicates that he began primary flight training in July 1990, and he received a private pilot certificate in November, 1990, with an airplane single engine land rating. In June 1993, he began rotorcraft flight training, and 4 months later he was issued a commercial pilot certificate. The pilot subsequently was issued a certified flight instructor certificate with rotorcraft privileges.

In October 1995, after principally training in the Robinson R22 and the Bell 206 helicopters, the pilot received his first flight in the Bell 205A-1 (accident) helicopter. The pilot continued receiving LAFD flight training in the helicopter, and the following year he completed the checkout process.

By the accident date, the pilot had approximately 1,865 total flight hours, of which about 1,440

hours were flown in rotorcraft. His total experience piloting the Bell 205A-1 helicopter, and his experience flying this model during the 90-day period preceding the accident, were 234 and 15 hours, respectively.

Between 1997 and 1998, the pilot received refresher training in emergency procedures including touchdown autorotations and tail rotor failures. On August 4, 1997, the pilot passed an Federal Aviation Administration (FAA) administered proficiency flight check evaluating his knowledge and skill as an air carrier (FAR Part 135) pilot.

AIRCRAFT INFORMATION

Certification and Operations Base.

The FAA issued the newly manufactured transport category helicopter, serial number 30221, a standard airworthiness certificate on March 12, 1976. On May 10, 1976, the FAA registered the helicopter in the name of the City of Los Angeles.

The helicopter was physically based at the LAFD's Van Nuys Airport Air Operations Unit, which is adjacent to the Los Angeles City Helicopter Operations and Maintenance Facility. The Los Angeles City Director of General Services and maintenance facility management reported that the helicopter was maintained in accordance with FAA regulations including Bell's service bulletins.

Helicopter Modifications and Utilization.

The Los Angeles City maintenance participant reported that the helicopter's interior had never undergone a major modification or overhaul. An external, belly-mounted, water tank had been installed on the bottom of the helicopter.

According to the LAFD, the helicopter was principally used for fire-fighting (water drops) and other activities such as flight and swift water rescue training. Secondarily, it was used as an air ambulance, although it had not been configured with any equipment for such usage. During the accident flight, emergency medical equipment for the care of the patient that the LAFD had required, by policy, to be onboard was not carried. (See the L.A. County Prehospital Care Policy Manual for the list of required equipment absent from helicopter.)

Tail Rotor Design and Yoke Straightness.

The Bell Helicopter participant reported that the company had designed the tail rotor assembly of the helicopter with two tail rotor blades. The blades are bolted to a yoke that holds them together. The yoke assembly is mounted onto the output drive shaft of the tail rotor's 90-degree gearbox, which rotates the yoke. The yoke is referred to as a flex-beam yoke. A portion of the yoke is referred to as the "flexure." This portion accommodates movement or flapping of the tail rotor blades during in-flight rotation.

Additionally, the yoke can flex under certain ground operations, and when exposed to adverse environmental conditions. Bell personnel verbally reported to the National Transportation

Safety Board investigator during a March 26, 1998, telephone conference, that when bending loads are applied to the yoke which exceed its design strength, its relative "straightness" may be altered, and the yoke's anticipated infinite service life will be reduced.

Bell Helicopter initially placed a retirement life limit of 4,000 hours on the yoke. Bell personnel further reported that following a review of the service history and fatigue evaluation data for this model yoke, and with FAA approval, the yoke's retirement life was increased to 5,000 hours. This action occurred in October 1989.

Alert Service Bulletin.

Bell issued an Alert Service Bulletin (ASB), number 205-96-68, dated August 1, 1996, which was pertinent to the yokes installed in all model 205A-1 helicopters between serial number 30001 and 30228, having a time since new greater than zero hours. In summary, Bell indicated that if the yoke encountered adverse bending loads during specific ground handling or in-flight conditions, it could flex and become deformed. Bell provided the following description of events about which it was concerned:

"...When not turning, the tail rotor yoke flexure is susceptible to static overload if it is loaded by external bending forces. Examples of bending loads include high wind gusts (such as those from prop blast), improper ground handling (where the tail rotor blade has been used as a hand hold), improper feathering bearing removal (where the yoke assembly is not properly supported when pressing out bearings), or a static ground strike of some type (such as it being struck by a vehicle). An overload may also occur dynamically during a power-on or off sudden stoppage incident or hard landing."

In the ASB, Bell recommended that the tail rotor blades be secured when exposed to wind gusts in excess of 45 knots. It also issued the following warning statement: "Do not exceed load and/or deflection limits during tiedown procedures for tail rotor. Maximum load allowable at blade tip is 50 lbs."

Bell opined that an undamaged yoke "is reliable for its full retirement life." Notwithstanding the yoke's "reliability," Bell designed the ASB to ferret out if the aforementioned conditions had occurred. It prescribed a procedure combining a historical record review, performance of a dimensional (straightness) inspection check and subsequent recurring inspections for evidence of excessive flapping. The requisite yoke examination procedures directed mechanics to use a Bell-supplied tool, called a "fixture set," during the dimensional testing, and to follow specific procedures described in the ASB. (See the Alert Service Bulletin for complete details, including a drawing of the yoke and the dimensional testing equipment.)

Yoke History, Maintenance and Trunnion Flapping Stops.

A review of the helicopter's maintenance records and pilot squawk sheets indicates that since manufacture, the helicopter was maintained and operated by Los Angeles City personnel. The City indicated that it had performed annual inspections and maintenance in follow-up to FAA requirements, manufacturer's recommendations, and pilot squawks.

The accident yoke, P/N 212-010-744-5, S/N JIDA-2193, was installed by Bell in 1975 upon manufacture of the helicopter. It remained in use until June 16, 1993, when it was removed for overhaul at a total helicopter (and yoke) time of 3,996.7 hours.

The helicopter continued in service with another yoke. On August 2, 1996, the accident yoke was removed from storage and Bell's ASB, Part 1 record review, and the Part 2 dimensional (straightness) check were accomplished. The Los Angeles City participant reported that, following the completed examination, the records indicated the yoke was returned to storage as a usable part.

On July 25, 1997, the accident yoke was removed from storage and reinstalled on the helicopter. Between August and October, 1997, the yoke's trunnion assembly flapping stops, P/N 212-010-738-001, were visually inspected five times for deformation. (According to the inspection process listed in Part 3 of the ASB, if the stops were found bent, the yoke had been exposed to excessive bending (flapping) loads and must be discarded.)

On January 12, 1998, the helicopter received an annual inspection at a total time of 5,097.0 hours, and the flapping stops were again examined for deformation signatures. None of the maintenance records indicated that the flapping stops were bent. The helicopter continued in service until the accident at which time the helicopter and accident yoke had total times of about 5,114.6 and 4,113.4 hours, respectively.

In summary, the accident occurred about 886.6 hours prior to the yoke's 5,000-hour mandatory retirement life. At the time of the crash, the yoke had accumulated about 116.7 hours since undergoing the ASB 205-96-68 Part 2 inspection for straightness, and about 17.6 hours since it was last visually examined pursuant to the ASB for evidence of excessive tail rotor flapping.

METEOROLOGICAL INFORMATION

The closest aviation weather observation station is at the Burbank Airport, about 6 miles from the accident site. During the 1-hour period before and after the accident, Burbank reported 20 miles visibility, clear sky, and calm wind.

AIDS TO NAVIGATION

According to FAA records of facility operation, all electronic aids to navigation pertinent to the helicopter's route of flight were functional.

COMMUNICATION

The Burbank Air Traffic Control Tower was the only FAA facility that recorded communications from the accident helicopter. Burbank's audiotape was reviewed by the FAA and LAFD participants. In summary, they reported that nothing unusual was noted with either the pilot's communications, which sounded routine, or in the background noise during the transmissions. None of the airborne or ground witnesses reported having recorded the accident pilot's transmissions.

WRECKAGE AND IMPACT INFORMATION

Three separated components from the helicopter were found along the flight path leading to the main wreckage. The two separated tail rotor blades, with the associated yoke onto which they were bolted, and the 90-degree gearbox were found about 1 mile north of the main wreckage. The second rotor blade was found on a road. All of the components were within 0.1 mile of each other.

Along a southerly track within about 220 feet north of the main wreckage, severed tree trunks and felled limbs were noted over the down sloping terrain. The estimated elevation of the topped trees was 701, 667, 641, and 638 feet msl. About 75 feet northeast of the main wreckage a portion of one main rotor blade was observed suspended by tree limbs, about 60 feet above ground level.

The main wreckage was found east of the intersection of Red Oak and Fern Dell Drives, at an elevation of about 588 feet msl. The helicopter was observed in the following approximate attitude: 26 degrees nose (pitch) down, 125 degrees left bank (slightly upside-down) and on a southeasterly magnetic heading of 130 degrees. The helicopter was partially straddling a concrete retaining wall separating a grassy parkway and an asphalt footpath, west of the Fern Dell Creek. A visual examination around the perimeter of the wreckage revealed no evidence of skid marks or any secondary impact crater.

The entire right side sliding door, with its attached emergency egress window panels, was found separated from the helicopter. According to the LAFD, upon responding to the crash scene its personnel were unable to slide the door open. To gain entrance they ultimately pulled the entire door off the side of the cabin. The Safety Board investigator noted that the locking pins, which secure the exit windows to the doorframe, were found in the locked position, and the plastic shield covering the emergency release handle was still in place. Upon testing the release mechanism's functionality, no discrepancies were noted. (See the Safety Board's photographs of the door and exit window opening instructions.)

The helicopter was initially inspected on-scene and then a detailed examination was performed following its recovery. The front, left side of the helicopter was observed crushed inward where it had been in contact with the retaining wall and ground. The left pilot seat and floor area were found destroyed, and most of the left forward nose section of the fuselage was observed compressed into this area.

The left side of the cabin was also observed crushed inward and the cabin floor buckled upward. The right side was comparatively intact with no evidence of ground impact signatures. (See the Bell participant's report for specific deformation measurements, and the Safety Board's Survival Factors Group Chairman's Factual Report for additional data.)

Under the direction of Safety Board staff, the investigation team examined the helicopter's various structural components and systems including the flight control, power train, and transmission. With the exception of the separated tail rotor blades and associated 90-degree gearbox, the FAA airworthiness inspector and the Bell participant verbally reported that no

anomalies were noted. All observed damage appeared to be impact-related. (See the Bell participant's Wreckage Investigation Summary for additional details.)

FIRE

A localized area of partially melted aluminum was noted in the vicinity of the engine's exhaust and adjacent cowling which appeared charred. There was no evidence of soot streams aft of the exhaust, parallel to the helicopter's longitudinal axis.

MEDICAL AND PATHOLOGICAL INFORMATION, INJURIES

Pilot Injuries, Survivor.

The LAFD personnel reported that the right front-seated pilot sustained numerous serious injuries. Injuries to his head included multiple facial fractures, a basal skull fracture and a concussion.

Routine toxicology tests on the pilot were ordered. Management at the Los Angeles County Medical Center, Department of Laboratories and Pathology, acknowledged that due to mislabeling of the pilot's specimen, all tests were subsequently canceled.

Helitac Injuries, Survivor.

The left, rear seated helitac sustained numerous serious injuries. Injuries to his head included multiple facial fractures, a forehead avulsion, and an eye injury.

Helitac and Paramedic Injuries, Deceased.

A review of injury data provided by the LAFD and by the Los Angeles County Department of Coroner, revealed that the two paramedics, who were seated between the helitacs, and the right-seated helitac, sustained fatal head injuries.

Autopsy records indicated that body weights for the three fatally injured crewmembers were 180, 190, and 240 pounds, respectively, from the right outboard to the inboard seat locations. The LAFD estimated that with equipment and clothing, their weights increased about 12, 7, and 15 pounds, respectively.

Patient Injuries, Deceased.

A review of autopsy records revealed the patient sustained multiple injuries due to blunt force trauma. An examination of the wooden flat (stretcher) onto which the patient had been strapped revealed it was cracked at numerous locations. The patient's head had been located nearest the left side of the helicopter.

SURVIVAL ASPECTS

Shoulder Harness Installation.

Bell reported that it did not incorporate shoulder harnesses in the design of the restraint system for the forward-facing rear seats on which the helitacs and paramedics were seated. Shoulder harnesses were not required for passenger seating until a change in the Federal Aviation Regulations mandated that all aircraft manufactured after September 16, 1992 were to have a shoulder restraint installed at each seat.

The LAFD management verbally reported that it had not requested the City maintenance facility to install shoulder harnesses for the forward-facing rear seats. Upon initial questioning, neither management at the LAFD or at the City maintenance facility was aware that shoulder harnesses for this seat were available for purchase in the open market.

Lap Belt Usage.

During the examination of the wreckage, lap belts were observed installed at all crewmember seat positions, and the pilot was found to have been secured to his seat with a lap belt and a shoulder harness. Based upon witness statements, a review of medical reports and an examination of the lap belts and related supporting structure, the LAFD opined that all occupants were likely lap-belted into their respective seats at the time of impact, with the possible exception of the left, rear-seated surviving helitac. During an interview with the helitac, he indicated that seconds before the crash he had released his lap belt and moved forward to attend to the patient in front of him. The helitac had no memory of returning to his seat or resecuring his lap belt.

Crewmember Helmets, Usage Policy and Availability.

The AOU commander verbally reported that pilots had been directed not to transport crewmembers (which include paramedics) unless the helicopter was equipped with helmets for each crewmember. Also, two paramedics were required to accompany a patient.

The LAFD reported that in preparation for the accident flight, no helmets had been placed in the helicopter for the paramedics' usage, and they were not wearing helmets at the time of the accident.

The AOU commander provided the Safety Board investigator with documents regarding the LAFD's helmet usage policy and a helmet acquisition request. The AOU policy required pilots, helitacs and paramedic (EMS) crewmembers, to wear flight helmets while engaged in helicopter operations. Management reported that, in theory, helmets were available for all crewmembers. However, in practice, they were not always used.

On April 22, 1998, the AOU commander verbally reported to the Safety Board investigator that the pilot was ultimately responsible for ensuring all required helmets were on board the helicopter. He also indicated that the pilot had evidently not ensured the paramedics' helmets were carried during the accident flight. In a written statement subsequently received, the commander reported that he shared responsibility with the pilot for the helmets' unavailability.

Helmet Style and Manufacturer.

During the accident flight, the pilot was wearing a model HGU-55/P (also known as a model HGU-55) helmet, and the helitacs were wearing model SPH-5 helmets. Principal components (shells, energy absorbing liners) of the helmets had been manufactured by Gentex Corporation, Carbondale, Pennsylvania, and sold to the LAFD by Flight Suits, El Cajon, California.

The LAFD reported that its records indicate the HGU-55 helmet was ordered from Flight Suits in April 1995. The SPH-5 helmets were received from Flight Suits in December 1997.

Gentex personnel confirmed that, based upon its examination of the helmets, the HGU-55 helmet was manufactured in 1995. The SPH-5 helmets were manufactured in 1997.

Appropriateness of Helmets and Acquisition Request.

In May 1997, Flight Suits corresponded with the AOU commander and reported that its firm had recently commenced placing "warning stickers" on the HGU-55 helmets in follow-up to its receipt of a similar warning from Gentex Corporation. According to Flight Suits, the SPH-5 helmet offers "significantly better impact protection...than fixed-wing helmets." Flight Suits additionally reported that "the purpose of the sticker, label, and stamp, are to ensure that you are formally warned that the...HGU-55 helmet is not recommended for use in helicopters."

In September 1997, the AOU commander wrote to his headquarters management staff and requested funding for the purchase of new helmets. The AOU commander indicated that the helmets currently in use by the AOU "are not rated by the manufacturer for helicopter use...(and) in order to provide maximum pilot safety . . . the helmets . . . need to be upgraded to helicopter rated models." At the time of the accident, the requested acquisition was still being processed.

During the 3-week period that followed the accident, the Safety Board investigator performed random checks of helmets available for use by LAFD's pilots. According to one senior helicopter pilot, his helmet bore the aforementioned warning sticker, and he continued to wear it. The Safety Board investigator examined his helmet and observed it was prominently labeled with the following statement: "Warning Use in fixed-wing aircraft only."

Occupant Seat Positions.

During the accident flight, the pilot was located in the front, right seat. The two helitacs were seated in the rear-most, forward facing bench seat, one adjacent to the left sliding cabin door, and one adjacent to the right sliding cabin door. The paramedics were located on the same bench seat next to, but inboard of, the helitacs. The patient was strapped onto a backboard, which was secured to a flat. The flat was secured to the aft-facing seats using the existing helicopter lap belts. The patient was located directly in front of the helitacs and paramedics.

Airframe Deformation and Lap Belt Anchor Point Separations.

The Safety Board's Survival Factors Group Chairman documented airframe deformation signatures in concert with the separation of lap belts and their supporting seat structure. The

observed floor-level crush line was recorded and diagrammed. Its appearance looked consistent with the helicopter's angle of impact with the ground. Roof structure was also found crushed at an angle that was similar to the deformation of the floor structure. Additional impact damage was noted to the seats, structure and equipment inside the cabin.

The pilot's seat was found attached to the helicopter floor structure. The right side of the lap belt, at its anchor point, was found separated from the seat frame tube, which was observed bent and fractured.

The Bell-designed five-place forward-facing passenger bench seat assembly, on which the helitacs and paramedics had been located, was found mounted directly in front of the main transmission bulkhead. The transmission was found separated and deformed downward and forward into the front transmission housing panel. This panel was observed deformed forward, into the cabin, and the roof structure directly above the front transmission wall was destroyed.

The center (unoccupied) bench seat position was designed to be attached to the transmission island bulkhead and to the cabin floor. The outboard ends of the five-place seat were designed to be mounted to vertical stanchions. The bottom of the stanchions was designed to be attached to a floor fitting; the top was designed to be attached to a ceiling fitting.

According to Bell, the stanchions relied on the cabin structural integrity to maintain their position between the ceiling and the floor of the cabin. If the floor or roof of the helicopter shifts from its original position, a stanchion may separate from its attachment mounts.

In part, the cabin examination revealed that the left seat stanchion, located in a heavily impact-damaged area of the cabin, had separated from its ceiling and floor mounts and was bent inward and upward. The cabin floor beneath the stanchion was observed compressed inboard and buckled aft.

The examination of the right seat stanchion revealed it was located in an area having no observable floor deformation. It was found separated from its floor mount; the recessed cabin floor mount fitting was deformed from the stud end of the lower right stanchion and displaced in a forward direction.

A horizontally oriented tube is situated at the lower, back portion of the five seats, and it serves as an anchor for the lap belts. The tube was found displaced and buckled, and it was cracked at lap belt anchor point locations. The fractured areas of the horizontal tube were visually examined. Bell verbally reported that these areas exhibited bending overload signatures. (See the Safety Board's Survival Factors Group Chairman's Factual Report for additional details.)

"The LAFD's safety officer performed an examination of the cabin's interior. In the LAFD's Survivability Factors report the officer opined that the decelerative forces experienced by several of the rear-seated crewmembers had resulted in their being displaced in forward and upward directions. In part, this resulted in their lap belt connection failures and body excursions into upper panel cockpit equipment. (For additional details, see the LAFD's Survivability Factors report.)

Under the direction of the Safety Board's staff, Bell examined the crewmember seats and related structure at its Field Investigation Laboratory. Bell indicated in its Evaluation of 205 Seats report that the seats, lap belts, and their anchor points had separated from supportive structure due to the cabin's structural integrity being compromised during the impact sequence. Because, in part, of the design and location of the lap belts' anchor points, individual belts located adjacent to each other and sharing the same ring shaped anchor point, combined during impact to form a common belt thus supporting two crewmembers. Bell further opined that the seat assemblies were subjected to loads that exceeded their designed and certification strength values, which were based upon a single 170-pound occupant per each of the five seat places. (See the Bell Helicopter Evaluation of 205 Seats report for additional details.)

Helmet Examination and Injury Mechanism.

Gentex reported that the SPH-5 helmets were manufactured in accordance with their respective drawings. They functioned pursuant to their design specification requirements. Gentex's examination of the SPH-5 helmet bearing the name of the helitac who had been seated on the left side of the helicopter did not reveal any assembly discrepancies. A similar examination of the SPH-5 helmet from the right-seated helitac revealed that its custom fitted energy absorbing thermoplastic liner (TPL) had reduced thickness, contrary to drawing requirements. Gentex reported observing evidence that the TPL's outer 2 of its 5 layers had been removed after the helmet was shipped from the factory. In Gentex's "Operation and Maintenance Manual" personnel are warned not to remove the outer TPL layers or helmet stability will not be maintained. Gentex additionally reported that such removal could decrease the helmet's ability to absorb energy.

Gentex verbally reported that its "Operation and Maintenance Manual" for these helmets was not provided to the ultimate helmet purchaser. Moreover, the aforementioned warning statement was not printed in any literature which accompanied the helmets to their end users.

Regarding the model HGU-55/P helmet worn by the pilot, Gentex reported that it had fabricated the helmet's shell, the energy absorbing liner, and the custom fit TPL liner. However, additional components (such as the chinstrap, earpads, napepad) had been supplied by Flight Suits, which may have assembled the helmet. The TPL assembly was found with only 2 of the 5 layers required by the drawing. The custom fitting procedure appeared to have been accomplished by removing the layers rather than by following Gentex's specified procedure. (See Gentex's "Report for the National Transportation Safety Board" for additional details of its examinations.)

The three helmets worn by the two surviving and one deceased crewmember were also examined for the Safety Board investigator by the Head Protection Research Laboratory (HPRL), in Los Angeles, California. Medical records and autopsy reports were reviewed to form a basis for evaluating the injury mechanism. Also, injury reduction countermeasures were suggested. (The HPRL provided the examination to the Safety Board without fee as a public service.)

In partial summary, the HPRL opined that the HGU-55 helmet worn by the pilot provided

minimal crash impact resistance. Due to its design, the impact energy was essentially without attenuation and contributed to the pilot's skull fractures and brain injury.

Regarding the SPH-5 helmets worn by the helitacs, the HPRL reported that the helmet shell was barely capable of resisting impact forces. For the helitac located in the left rear of the helicopter, the helmet made a positive contribution in attenuating impact forces and prevented brain injury. For the fatally injured helitac located in the right rear of the helicopter, the helmet encountered a severe impact due to a major occupant excursion and body motion.

Regarding the two fatally injured paramedics who were seated between (adjacent to and inboard of) the helitacs, the HPRL opined that their "lack of restraint appears to be the cause of the wide area of impact trauma." In one case, use of an appropriate restraint system would have allowed survival. In the other case, use of an appropriate restraint system and a helmet would have made survival highly probable. (See the HPRL's report for details of its investigation and drawings comparing bodily injuries with helmet damage.)

Helmet Design Standards/Specifications.

No federally mandated impact protection (strength) standards/specifications exist for helmets used by occupants in either general aviation or public-use aircraft. Specifications have been issued by private and military organizations. Some of these specifications have been adopted for use by the Gentex Corporation.

On December 10, 1998, the helmet manufacturer verbally reported to the Safety Board investigator that the accident helmets had been designed and manufactured in conformance with standards/specifications principally driven by United States armed forces requirements. Although since manufacture some of the standards have been revised, numerous old helmets continue being used. (See Gentex Corporation's helmet report for additional information regarding the design and development of its helmets.)

TESTS AND RESEARCH

Controllability

In Bell Helicopter's Handling Quality report it evaluated the controllability (handling quality) of the helicopter following the loss of the tail rotor blades and associated 90-degree gearbox. The purpose of the evaluation was to ascertain whether the pilot, given the change to the helicopter's center of gravity and elimination of pedal control, would have been able to sustain level flight.

Bell indicated that the pilot could not have maintained level flight in the attitude which the helicopter was in after the tail rotor system departed. An examination of the helicopter's probable flight attitude during its last 24 seconds of flight revealed that it was approximately consistent with the helicopter being in a 60 knot, 1,400 foot per minute, autorotative descent until just prior to impacting the trees and ground. (See the Handling Quality report memorandum and the helicopter's flight manual for autorotation and glide distance data.)

Engine Examination.

A witness who arrived at the accident site reported observing flames emanating from the engine's tail pipe. However, no engine noise was recalled.

The AlliedSignal Lycoming Model T5313B turboshaft engine was removed from the wreckage. It was transported to AlliedSignal Aerospace Product Safety and Integrity Investigation Laboratory where a teardown examination was performed.

The FAA reported to the Safety Board's investigator that the examination revealed the engine had operated normally until the accident, and no evidence of any preimpact malfunction was noted. Foreign object damage contributed to observed failures of compressor blades. The power turbine experienced fire damage due to the continuation of supplied fuel with no compressor air. (For complete details, see the FAA summary memorandum appended to AlliedSignal's engine teardown report.)

Vertical Fin, Tail Rotor Gearbox Attachment and Tail Rotor Drive.

The vertical fin was examined for deformations, fracture characteristics, and evidence of in-flight malfunctions. The tail rotor gearbox and attachment area were similarly examined. Multiple dents, scrapes, and tears were observed at various locations. Under the direction of the Safety Board's staff, the components were examined at the Bell Helicopter's engineering laboratory. The laboratory reported that all observed damage was consistent with overload failures. No evidence of a fatigue fracture was found.

The tail rotor drive system was examined for failures or malfunctions. The drive system was found intact from the fuselage to the top of the vertical fin. The tail rotor drive 90-degree gearbox was examined in the Safety Board's Materials Laboratory for evidence of malfunctions or failures. The examination revealed that the drive system was intact and the pitch control system components failed in bending overload consistent with tail rotor blade separation. No evidence of preexisting failures or malfunctions were noted. (See the Safety Board's Helicopter Systems Factual Report for additional details.)

Heavy Load Operations.

The LAFD had a water tank attached to the bottom of the helicopter between the skids. The Safety Board's Helicopter System's Group Chairman reported that a review of the external load history for this helicopter revealed it had been involved in numerous water drop missions during the previous year. The flights were recorded in the maintenance records for tracking high torque events. An examination of the water tank revealed there are no quantity gauges associated with the tank and the flight crews' estimate the weight of the water carried in the tank.

Maintenance Records, In-flight Operational Factors and Flight Manual Requirements.

Following a review of maintenance records, a review of pilot squawk sheets regarding helicopter anomalies, and during discussions with the LAFD's pilots and City mechanics, no

evidence was found of any specific "bending load event" (as listed in the ASB) during the time the yoke was installed on the helicopter. Specifically, a record review was performed of all recorded flights in the accident helicopter between the July, 1997, date following the reinstallation of the subject yoke and the accident date. The pilots who flew the helicopter were asked to review the flight log sheet printout to recall the purpose of their respective flights, and to report if any of the following events had been experienced: (1) hard landing; (2) wind gust; (3) ground handling of the tail rotor; (4) propeller blast; (5) vehicle ground strike; or (6) sudden stoppage. None of the reporting pilots recalled experiencing any of the listed conditions or experiencing any related discrepancies.

LAFD line pilots verbally reported to the Safety Board investigator that the tail rotors of the Bell 205A-1 helicopters routinely are not tied down. During the 3-week period that followed the accident, the Safety Board investigator performed random checks of the LAFD's remaining Bell 205A-1 helicopter in addition to the other helicopters that it operated. The checks revealed that on more than 1 dozen occasions the helicopters were observed unattended without their tail rotors tied down. On one occasion, the Safety Board investigator observed that the distance between a parked Bell 205A-1 helicopter and a departing helicopter was 75 feet. The tail rotor of the unattended Bell 205A-1 had not been tied down.

The accident helicopter's FAA approved Flight Manual was reviewed. It contained the following information in Section 2, dated November 28, 1989, revision number 12, indicating that the rotor blades are to be tied down whenever any of the following conditions exist: (1) thunderstorms are in the local area or forecasted; (2) winds in excess of 20 knots or a gust spread of 15 knots exists or is forecasted; (3) helicopter is parked within 150 feet of hovering or taxiing aircraft; or (4) helicopter to be left unattended.

ASB Examination Instructions and Procedures.

The Safety Board investigator reviewed Bell's ASB and observed that it included the following approval statement: "The engineering aspects of this Alert Service Bulletin are FAA approved." In the ASB, specific instructions were listed for preparing the yoke for the straightness examination and for performing the test.

The ASB was examined for evidence of inconsistencies within its instructions and for its clarity. Also, the City mechanics' procedures were examined to ascertain their adherence with the written instructions. The following evidence was found:

In item number 4, on page 7, the ASB indicates that the paint removal procedure to be followed is listed on "page 6" in Bell's Standard Practices Manual. An examination of the manual indicates paint removal processes are listed beginning on page 3 in the manual dated October 1996. When the manual was subsequently revised, the page numbers changed and the ASB was not revised accordingly. Also in item number 4, on page 7, directions are given to remove paint and primer from around the yoke trunnion bearings. However, on page 12, figure 1 indicates that the paint and primer removal is only required on the far sides (tips) of the yoke. Then, on page 13, figure 2 indicates that paint and primer are required in the area of the trunnion bearings when performing the test procedure.

In item number 9, on page 8, the ASB indicates that dial readings were to be recorded in step 6. A review of the instructions listed in step 6 shows they do not address the recording of dial readings. (The reference to recording the dial readings is listed in step 7.)

As to whether the test procedures were performed according to directions, a comparison was made between the written procedures and the statements made by the City mechanics. In item number 4, on page 7 of 21, the ASB indicates that paint remover is to be used to remove the paint and primer from the yoke. City mechanics reported that rather than chemically removing the paint, they had used their plastic media abrasive blasting equipment to mechanically strip the paint.

The Safety Board investigator examined the "media blaster" machine and interviewed mechanics. The mechanics acknowledged that they had not received written instructions for operating the media blaster, and they were generally unfamiliar with user/setup requirements for blasting air pressure limits, impingement angle, and nozzle distance, as specified by Bell. Additionally, Bell indicated that the plastic media abrasive blasting technique may be used to remove all coating finishes except from cadmium-plated surfaces. (The accident yoke was cadmium plated.) The City's quality assurance department management was not familiar with this usage restriction.

Finally, procedural changes in the testing procedure have not been incorporated into Bell's Overhaul Manual. A "WARNING" statement listed on page 11 of the ASB indicates that the "Current procedures for checking for a bent yoke by measuring precone angle as outlined in current 205 Component Repair and Overhaul Manuals are no longer valid, and should not be utilized for determining serviceability of yoke." Two years after the issuance of this "Warning" statement, the Overhaul Manual has not been revised to incorporate this advice.

ASB Straightness Test, Purpose and Design.

In summary, the ASB evaluates the yoke's straightness. The straightness is determined through a precise series of measurements, which provide evidence of any permanent (excessive) bending load events. According to the ASB, during the measurement process if numeric values are obtained which are less than 0.675 inch or greater than 0.755 inch in any of the four readings recorded on each end of the yoke assembly, the yoke assembly is not serviceable. Unserviceable yokes must be destroyed to preclude further use. (See ASB 205-96-68 for complete details.)

ASB Recorded Test Results.

City Quality Assurance management reported its procedure is to accurately record test results in its files. The City produced its archived records of the yoke's testing for review that were hand written on a card. The records indicated the following test results for the yoke arm deflection: Left Hand: .7125 and .7549. Right hand: .7565 and .7142.

Statements by the Bell Representative and City Mechanics.

In summary, a product support Bell employee reported that he had brought the requisite ASB

testing equipment to the City maintenance facility for use in examining the yoke. The test procedure was new to him, and he was present for the testing and dial reading procedure. There were some difficulties in performing the test. Afterwards, the Bell employee suggested that the dial readings be recorded on a card. The yoke was found within limits.

A City mechanic reported that in preparation for the ASB test, paint was removed from the yoke "in the areas required by the Service Bulletin." It was tested and found within specifications. Another City mechanic reported that he believes when the yoke was initially evaluated, before the paint was removed, it was out of limits and the over limit values were recorded by the City in its records. Subsequently the yoke was tested after removal of the paint, and it was found within the tolerances called out in the ASB. For undetermined reasons, the City's records were not corrected to reflect the passing test results.

Paint Removal and ASB Test Accuracy.

In response to the Safety Board investigator's request, the FAA's Rotorcraft Certification Office evaluated the implications of testing a yoke without removing the paint as required by the ASB, or removing the paint from only part of the yoke. The FAA reported that, depending upon where the paint was removed, the yoke's observed (straightness) dimension could be either increased or decreased by the thickness of the paint. Thus, not removing the paint, or removing paint from only a portion of the required areas, could lead to inaccurate measurements. The FAA opined that measurement errors could lead to various mechanic decisions including erroneously accepting a nonconforming part.

Metallurgical Information, SEAL Laboratories.

Under the Safety Board investigator's direction, the separated tail rotor blades, with the fragmented yoke, were initially examined on scene by a metallurgist from SEAL Laboratories. A follow-up examination was performed at SEAL's El Segundo, California, laboratory. The examination revealed that the first tail rotor blade separated from the tail rotor hub due to a fatigue fracture in the yoke, and the second blade separated due to an overload fracture. The bolts attaching the blades to the yoke were found tight and undamaged.

Regarding the fatigued blade, "beach marks" indicative of fatigue fracture propagation were present on the yoke's fracture surface. The fatigue crack had initiated at the trailing edge of the yoke, on its outboard surface. Once the crack in the yoke became 2 inches long, the remainder of the yoke fractured instantaneously into two pieces in an overload manner.

To determine the fatigue crack growth time, the fatigue striation spacing was measured from the scanning electron microscope (SEM) micrographs. Given assumptions regarding the rotor blade's nominal rate of rotation and fatigue crack propagation's rates, SEAL calculated that the fatigue crack had propagated from the outboard surface near the corner of the yoke at the trailing edge to a 2-inch-long fatigue crack over a 1.33 to 2-hour period of time before the yoke's ultimate failure. Therefore, the fatigue crack was not present on the yoke's surface during its last overhaul inspection, 117 hours prior to the crash.

SEAL further reported that although the time required for the fatigue crack to propagate was

within 2 hours of the ultimate failure of the yoke, the time for the fatigue crack to initiate (nucleate) remains undetermined. The fatigue crack initiation time is the period between application of any excessive force the yoke may have experienced and the onset of the initial microscopic fatigue crack.

The yoke was also analyzed for its elemental chemical composition, and the results were compared with Bell's specifications for stainless steel. No discrepancies were noted, and no evidence of corrosion was found. The yoke was found to have been shot peened to improve its fatigue life. No metallurgical defect was present in the fatigue crack origin area. (See the SEAL Laboratories report number 5320 for additional details.)

Metallurgical Information, NTSB and Bell Laboratories.

The Safety Board's Office of Research and Engineering, Materials Laboratory Division, in Washington, D.C., subsequently examined the 90-degree gearbox, related attachment hardware, and the tail rotor yoke. With the exception of the fatigued portion of the yoke, the observed separations and damage noted in the other components, such as the pitch change links, appeared consistent with overstress conditions, and no anomalies were noted.

The yoke had fractured on its inboard flexure which had a reduced cross section area. An examination of the crack origin area did not reveal evidence of mechanical damage or corrosion. The yoke's hardness, material composition, microstructure, and shot peened surface characteristics were evaluated. No anomalies were noted.

The yoke was also examined for damage to its cadmium plating and for its paint thickness. The examination revealed that the cadmium plating was mostly intact but had many small isolated areas where the plating was missing. The cadmium plating thickness measured between 0.0001 and 0.0002 inch in one location. Bell's yoke production specification requires a plating thickness between 0.0003 and 0.00049 inches.

The Safety Board's Materials Laboratory found evidence supporting the City mechanics' statement that the yoke had paint removed and reapplied. The tips of the yoke had a paint thickness that averaged 0.0037 inch. Inboard of the tip the paint thickness averaged 0.00186 inch. No determination was made whether paint had been removed from and reapplied to the sides of the yoke, around the trunnion bearings extending to flexures, as indicated in item number 4, on page 7, of the ASB.

Under the direction of the Safety Board staff, the residual compressive stresses on the surface of the yoke were measured at several locations using a TEC Model 1610-2 x-ray analysis system located at Bell's Fort Worth, Texas, laboratory. According to Bell, the objective of the x-ray diffraction test was to determine if the yoke had been subjected to excessive flexure bending. Excessive flexure bending reduces the compressive residual stresses left in the yoke's surfaces by shot peening which in turn could result in reduced fatigue strength and allow operational loads to initiate and propagate fatigue cracks. The diffraction test results were reported as numeric values of thousands of pounds per square inch (KSI). The values ranged from -2.6 KSI near the origin to a value of -126.0 KSI several inches outboard. (Note, higher negative values (i.e. -126 is higher than -2.6) indicate greater compressive residual stress.) Bell reported

to the Safety Board staff that the surface of the yoke should have a minimum -60 KSI value. Values less than -60 KSI could result in reduced service life and possible onset of fracture development. Bell further reported that the x-ray diffraction test results of the failed yoke indicates it had been subjected to a yielding or bending event prior to its in-flight failure. (For additional details, see the Safety Board's Materials Laboratory Factual Report and Bell's Tail Rotor Fatigue Analysis and X-ray Diffraction Reports.)

ADDITIONAL INFORMATION

FAA Action.

The FAA participated in the Safety Board's on-scene investigation and during follow-up examinations of an exemplar yoke to ascertain the adequacy of Bell's ASB. Following the tests, Bell issued revision A to the ASB. In part, this revision requires performance of a x-ray diffraction test on yokes. Use of the previous fixture set to determine dimensional conformity was terminated, and an airworthiness directive was issued. (See the Priority Letter Airworthiness Directive (AD) 98-11-14 for additional details.)

Additional Parties.

See the "Parties Attachment List" for additional participants to the Safety Board's accident investigation.

Wreckage Release.

The helicopter wreckage was released to its operator, the LAFD, on May 11, 1999. No helicopter parts were retained.

Pilot Information

Certificate:	Commercial; Flight instructor	**Age:**	32,Male
Airplane Rating(s):	Single-engine land	**Seat Occupied:**	Right
Other Aircraft Rating(s):	Helicopter	**Restraint Used:**	
Instrument Rating(s):	None	**Second Pilot Present:**	No
Instructor Rating(s):	Helicopter	**Toxicology Performed:**	No
Medical Certification:	Class 2 Valid Medical--no waivers/lim.	**Last FAA Medical Exam:**	November 14, 1997
Occupational Pilot:	Yes	**Last Flight Review or Equivalent:**	
Flight Time:	1570 hours (Total, all aircraft), 219 hours (Total, this make and model), 1498 hours (Pilot In Command, all aircraft), 21 hours (Last 90 days, all aircraft), 15 hours (Last 30 days, all aircraft)		

Aircraft and Owner/Operator Information

Aircraft Make:	Bell	**Registration:**	N90230
Model/Series:	205A-1 205A-1	**Aircraft Category:**	Helicopter
Year of Manufacture:		**Amateur Built:**	
Airworthiness Certificate:	Transport	**Serial Number:**	30221
Landing Gear Type:	Skid	**Seats:**	15
Date/Type of Last Inspection:	January 12, 1998 Annual	**Certified Max Gross Wt.:**	10200 lbs
Time Since Last Inspection:	18 Hrs	**Engines:**	1 Turbo shaft
Airframe Total Time:	5115 Hrs at time of accident	**Engine Manufacturer:**	Lycoming
ELT:	Installed, activated, did not aid in locating accident	**Engine Model/Series:**	T5313B
Registered Owner:		**Rated Power:**	1250 Horsepower
Operator:		**Operating Certificate(s) Held:**	None

Meteorological Information and Flight Plan

Conditions at Accident Site:	Visual (VMC)	**Condition of Light:**	Day
Observation Facility, Elevation:	BUR,775 ft msl	**Distance from Accident Site:**	6 Nautical Miles
Observation Time:	07:47 Local	**Direction from Accident Site:**	315°
Lowest Cloud Condition:	Clear	**Visibility**	20 miles
Lowest Ceiling:	None	**Visibility (RVR):**	
Wind Speed/Gusts:	/	**Turbulence Type Forecast/Actual:**	/
Wind Direction:	0°	**Turbulence Severity Forecast/Actual:**	/
Altimeter Setting:	30 inches Hg	**Temperature/Dew Point:**	17°C / 10°C
Precipitation and Obscuration:	No Obscuration; No Precipitation		
Departure Point:	LOS ANGELES, CA	**Type of Flight Plan Filed:**	Company VFR
Destination:	LOS ANGELES, CA	**Type of Clearance:**	None
Departure Time:	07:33 Local	**Type of Airspace:**	Class G

Wreckage and Impact Information

Crew Injuries:	3 Fatal, 2 Serious	**Aircraft Damage:**	Destroyed
Passenger Injuries:	1 Fatal	**Aircraft Fire:**	On-ground
Ground Injuries:	N/A	**Aircraft Explosion:**	None
Total Injuries:	4 Fatal, 2 Serious	**Latitude, Longitude:**	34.099372,-118.319046(est)

Administrative Information

Investigator In Charge (IIC):	Pollack, Wayne
Additional Participating Persons:	STEPHEN L FORD; LOS ANGELES,, CA DALLES ST JOHNS; FORT WORTH,, TX DAVID CHAPEL; PHOENIX,, AZ FOR NAMES OF ADDITIONAL PARTIES
Original Publish Date:	February 13, 2003
Note:	
Investigation Docket:	https://data.ntsb.gov/Docket?ProjectID=29962