

NIST

[NIST Time](#) | [NIST Home](#) | [About NIST](#) | [Contact Us](#) | [A-Z Site I](#)

Engineering Laboratory

[About EL](#) ▾ | [Publications](#) | [Topic/Subject Areas](#) | [Products/Services](#) ▾ | [News/Multimedia](#) | [Programs/Projects](#) | [Events](#)

[NIST Home](#) > [EL](#) > [Disaster and Failure Studies](#) > [World Trade Center](#) > [About the NIST World Trade Center Disaster Investigation](#)

Disaster and Failure Studies

- [Home](#)
- [About Disaster Studies](#)
- [Advisory Committee](#)
- [Current Activities](#)
- [Disaster and Failure Data Repository](#)
- [Impacts and Recommendations](#)

WTC Disaster Study

- [Overview](#)
- [About](#)
- [FAQs](#)
- [News Archive](#)
- [Meetings and Presentations](#)
- [Photos, Videos, and Simulations](#)
- [Publications](#)
- [Recommendations](#)

Select Language
*

Powered by [Google Translate](#)

About the NIST World Trade Center Investigation

- [Investigation Team Members](#)
- [Awarded Contracts](#)
- [Meetings and Presentations](#)

GENESIS OF THIS INVESTIGATION

On August 21, 2002, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the World Trade Center (WTC) disaster.¹ This WTC Investigation was then conducted under the authority of the National Construction Safety Team (NCST) Act, which was signed into law on October 1, 2002. A copy of the Public Law is included in Appendix A.

The goals of the investigation of the WTC disaster were:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the WTC disaster after terrorists flew large jet-fuel laden commercial airliners into the WTC towers.
- To serve as the basis for:
 - Improvements in the way buildings are designed, constructed, maintained, and used;
 - Improved tools and guidance for industry and safety officials;
 - Recommended revisions to current codes, standards, and practices; and
 - Improved public safety

The specific objectives were:

- Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
- Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
- Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
- Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

APPROACH

To meet these goals, NIST complemented its in-house expertise with an array of specialists in key technical areas. In all, over 200 staff contributed to the Investigation. NIST and its contractors compiled and reviewed tens of thousand of pages of documents; conducted interviews with over a thousand people who had been on the scene or who had been involved with the design, construction, and maintenance of the WTC; analyzed 236 pieces of steel that were obtained from the wreckage; performed laboratory tests, measured material properties, and performed computer simulations of the sequence of events that happened from the instant of aircraft impact to the initiation of collapse for each tower.

Cooperation in obtaining the resource materials and in interpreting the results came from a large number of individuals and organizations, including The Port Authority of New York and New Jersey and its contractors and consultants; Silverstein Properties and its contractors and consultants; the City of New York and its departments; the manufacturers and fabricators of the building components; the companies that insured the WTC towers; the building tenants; the aircraft manufacturers; the airlines; the public, including survivors and family members;

and the media.

The scarcity of physical evidence that is typically available in place for reconstruction of a disaster led to the following approach:

- Accumulation of copious photographic and video material. With the assistance of the media, public agencies and individual photographers, NIST acquired and organized nearly 7,000 segments of video footage, totaling in excess of 150 hours and nearly 7,000 photographs representing at least 185 photographers. This guided the Investigation Team's efforts to determine the condition of the buildings following the aircraft impact, the evolution of the fires, and the subsequent deterioration of the structure.
- Establishment of the baseline performance of the WTC towers, i.e., estimating the expected performance of the towers under normal design loads and conditions. The baseline performance analysis also helped to estimate the ability of the towers to withstand the unexpected events of September 11, 2001. Establishing the baseline performance of the towers began with the compilation and analysis of the procedures and practices used in the design, construction, operation, and maintenance of the structural, fire protection, and egress systems of the WTC towers. The additional components of the performance analysis were the standard fire resistance of the WTC truss-framed floor system, the quality and properties of the structural steels used in the towers, and the response of the WTC towers to the design gravity and wind loads.
- Simulations of the behavior of each tower on September 11, 2001, in four steps:
 - The aircraft impact into the tower, the resulting distribution of aviation fuel, and the damage to the structure, partitions, thermal insulation materials, and building contents.
 - The evolution of multi-floor fires.
 - The heating and consequent weakening of the structural elements by the fires.
 - The response of the damaged and heated building structure, and the progression of structural component failures leading to the initiation of the collapse of the towers.

For such complex structures and complex thermal and structural processes, each of these steps stretched the state of the technology and tested the limits of software tools and computer hardware. For example, the investigators advanced the state-of-the-art in the measurement of construction material properties and in structural finite element modeling. New modeling capability was developed for the mapping of fire-generated environmental temperatures onto the building structural components.

The output of the four-step simulations was subject to uncertainties in the as-built condition of the towers, the interior layout and furnishings, the aircraft impact, the internal damage to the towers (especially the thermal insulation for fire protection of the structural steel, which is colloquially referred to as fireproofing), the redistribution of the combustibles, and the response of the building structural components to the heat from the fires. To increase confidence in the simulation results, NIST used the visual evidence, eyewitness accounts from inside and outside the buildings, laboratory tests involving large fires and the heating of structural components, and formal statistical methods to identify influential parameters and quantify the variability in analysis results.

- Combination of the knowledge gained into probable collapse sequences for each tower,² the identification of factors that contributed to the collapse, and a list of factors that could have improved building performance or otherwise mitigated the loss of life.
- Compilation of a list of findings that respond to the first three objectives and a list of recommendations that responds to the fourth objective.

SUMMARY OF FINDINGS

Objective 1: Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft.

- The two aircraft hit the towers at high speed and did considerable damage to principal structural components (core columns, floors, and perimeter columns) that were directly impacted by the aircraft or associated debris. However, the towers withstood the impacts and would have remained standing were it not for the dislodged insulation (fireproofing) and the subsequent multi-floor fires. The robustness of the perimeter frame-tube system and the large size of the buildings helped the towers withstand the impact. The structural system redistributed loads from places of aircraft impact, avoiding larger scale damage upon impact. The hat truss, a feature atop each tower

which was intended to support a television antenna, prevented earlier collapse of the building core. In each tower, a different combination of impact damage and heat-weakened structural components contributed to the abrupt structural collapse.

- In WTC 1, the fires weakened the core columns and caused the floors on the south side of the building to sag. The floors pulled the heated south perimeter columns inward, reducing their capacity to support the building above. Their neighboring columns quickly became overloaded as columns on the south wall buckled. The top section of the building tilted to the south and began its descent. The time from aircraft impact to collapse initiation was largely determined by how long it took for the fires to weaken the building core and to reach the south side of the building and weaken the perimeter columns and floors.
- In WTC 2, the core was damaged severely at the southeast corner and was restrained by the east and south walls via the hat truss and the floors. The steady burning fires on the east side of the building caused the floors there to sag. The floors pulled the heated east perimeter columns inward, reducing their capacity to support the building above. Their neighboring columns quickly became overloaded as columns on the east wall buckled. The top section of the building tilted to the east and to the south and began its descent. The time from aircraft impact to collapse initiation was largely determined by the time for the fires to weaken the perimeter columns and floor assemblies on the east and the south sides of the building. WTC2 collapsed more quickly than WTC 1 because there was more aircraft damage to the building core, including one of the heavily loaded corner columns, and there were early and persistent fires on the east side of the building, where the aircraft had extensively dislodged insulation from the structural steel.
- The WTC towers likely would not have collapsed under the combined effects of aircraft impact damage and the extensive, multi-floor fires that were encountered on September 11, 2001, if the thermal insulation had not been widely dislodged or had been only minimally dislodged by aircraft impact.
- In the absence of structural and insulation damage, a conventional fire substantially similar to or less intense than the fires encountered on September 11, 2001, likely would not have led to the collapse of a WTC tower.
- NIST found no corroborating evidence for alternative hypotheses suggesting that the WTC towers were brought down by controlled demolition using explosives planted prior to September 11, 2001. NIST also did not find any evidence that missiles were fired at or hit the towers. Instead, photographs and videos from several angles clearly showed that the collapse initiated at the fire and impact floors and that the collapse progressed from the initiating floors downward, until the dust clouds obscured the view.

Objective 2: Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response.

- Approximately 87 percent of the estimated 17,400 occupants of the towers, and 99 percent of those located below the impact floors, evacuated successfully. In WTC 1, where the aircraft destroyed all escape routes, 1,355 people were trapped in the upper floors when the building collapsed. One hundred seven people who were below the impact floors did not survive. Since the flow of people from the building had slowed considerably 20 min before the tower collapsed, the stairwell capacity was adequate to evacuate the occupants on that morning.
- In WTC 2, before the second aircraft strike, about 3,000 people got low enough in the building to escape by a combination of self-evacuation and use of elevators. The aircraft destroyed the operation of the elevators and the use of two of the three stairways. Eighteen people from above the impact zone found a passage through the damaged third stairway (Stairwell A) and escaped. The other 619 people in or above the impact zone perished. Eleven people who were below the impact floors did not survive. As in WTC 1, shortly before collapse, the flow of people from the building had slowed considerably, indicating that the stairwell capacity was adequate that morning.
- About 6 percent of the survivors described themselves as mobility impaired, with recent injury and chronic illness being the most common causes; few, however, required a wheelchair. Among the 118 decedents below the aircraft impact floors, investigators identified seven who were mobility impaired, but were unable to determine the mobility capability of the remaining 111.
- A principal factor limiting the loss of life was that the buildings were one-third to one-half occupied at the time of the attacks. NIST estimated that if the towers had been fully occupied with 20,000 occupants each, it would have taken just over 3 hours

to evacuate the buildings and about 14,000 people might have perished because the stairwell capacity would not have been sufficient to evacuate that many people in the available time. Egress capacity required by current building codes is determined by single floor calculations that are independent of building height and does not consider the time for full building evacuation.

- Due to the presence of assembly use spaces at the top of each tower (Windows on the World restaurant complex in WTC 1 and the Top of the World observation deck in WTC 2) that were designed to accommodate over 1,000 occupants per floor, the New York City Building Code would have required a minimum of four independent means of egress (stairs), one more than the three that were available in the buildings. Given the low occupancy level on September 11, 2001, NIST found that the issue of egress capacity from these places of assembly, or from elsewhere in the buildings, was not a significant factor on that day. It is conceivable that such a fourth stairwell, depending on its location and the effects of aircraft impact on its functional integrity, could have remained passable, allowing evacuation by an unknown number of additional occupants from above the floors of impact. If the buildings had been filled to their capacity with 20,000 occupants, the required fourth stairway would likely have mitigated the insufficient egress capacity for conducting a full building evacuation within the available time.
- Evacuation was assisted by participation in fire drills within the previous year by two-thirds of survivors and perhaps hindered by a Local Law that prevented employers from requiring occupants to practice using the stairways. The stairways were not easily navigated in some locations due to their design, which included "transfer hallways," where evacuees had to traverse from one stairway to another location where the stairs continued. Additionally, many occupants were unprepared for the physical challenge of full building evacuation.
- The functional integrity and survivability of the stairwells was affected by the separation of the stairwells and the structural integrity of stairwell enclosures. In the impact region of WTC 1, the stairwell separation was the smallest over the building height—clustered well within the building core—and all stairwells were destroyed by the aircraft impact. By contrast, the separation of stairwells in the impact region of WTC 2 was the largest over the building height—located along different boundaries of the building core—and one of three stairwells remained marginally passable after the aircraft impact. The shaft enclosures were fire rated but were not required to have structural integrity under typical accidental loads: there were numerous reports of stairwells obstructed by fallen debris from damaged enclosures.
- The active fire safety systems (sprinklers, smoke purge, fire alarms, and emergency occupant communications) were designed to meet or exceed current practice. However, with the exception of the evacuation announcements, they played no role in the safety of life on September 11 because the water supplies to the sprinklers were damaged by the aircraft impact. The smoke purge systems operated under the direction of the fire department after fires were not turned on, but they also would have been ineffective due to aircraft damage. The violence of the aircraft impact served as its own alarm. In WTC 2, contradictory public address announcements contributed to occupant confusion and some delay in occupants beginning to evacuate.
- For the approximately 1,000 emergency responders on the scene, this was the largest disaster they had even seen. Despite attempts by the responding agencies to work together and perform their own tasks, the extent of the incident was well beyond their capabilities. Communications were erratic due to the high number of calls and the inadequate performance of some of the gear. Even so, there was no way to digest, test for accuracy, and disseminate the vast amount of information being received. Their jobs were complicated by the loss of command centers in WTC 7 and then in the towers after WTC 2 collapsed. With nearly all elevator service disrupted and progress up the stairs taking about 2 min per floor, it would have taken hours for the responders to reach their destinations, assist survivors, and escape had the towers not collapsed.

Objective 3: Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1 and WTC 2.

- Because of The Port Authority's establishment under a clause of the United States Constitution, its buildings were not subject to any state or local building regulations. The buildings were unlike any others previously built, both in their height and in their innovative structural features. Nevertheless, the actual design and approval process produced two buildings that generally were consistent with nearly all of the provisions of the New York City Building Code and other building codes of that time that were

reviewed by NIST. The loads for which the buildings were designed exceeded the New York City code requirements. The quality of the structural steels was consistent with the building specifications. The departures from the building codes and standards identified by NIST did not have a significant effect on the outcome of September 11.


- For the floor systems, the fire rating and insulation thickness used on the floor trusses, which together with the concrete slab served as the main source of support for the floors, were of concern from the time of initial construction. NIST found no technical basis or test data on which the thermal protection of the steel was based. On September 11, 2001, the minimum specified thickness of the insulation was adequate to delay heating of the trusses; the amount of insulation dislodged by the aircraft impact, however, was sufficient to cause the structural steel to be heated to critical levels.
- Based on four standard fire resistance tests that were conducted under a range of insulation and test conditions, NIST found the fire rating of the floor system to vary between 3/4hour and 2hours; in all cases, the floors continued to support the full design load without collapse for over 2 hours.
- The wind loads used for the WTC towers, which governed the structural design of the external columns and provided the baseline capacity of the structures to withstand abnormal events such as major fires or impact damage, significantly exceeded the requirements of the New York City Building Code and other building codes of the day that were reviewed by NIST. Two sets of wind load estimates for the towers obtained by independent commercial consultants in 2002, however, differed by as much as 40 percent. These estimates were based on wind tunnel tests conducted as part of insurance litigation unrelated to the Investigation.

1 NIST is a nonregulatory agency of the U.S. Department of Commerce. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by P.L.107-231).

2 The focus of the Investigation was on the sequence of events from the instant of aircraft impact to the initiation of collapse for each tower. For brevity in this report, this sequence is referred to as the "probable collapse sequence," although it includes little analysis of the structural behavior of the tower after the conditions for collapse initiation were reached and collapse became inevitable.

The National Institute of Standards and Technology (NIST) is an agency of the [U.S. Department of Commerce](#).

[Privacy Policy](#) / [Security Notice](#) / [Accessibility Statement](#) / [Disclaimer](#) / [Freedom of Information Act \(FOIA\)](#) / [Environmental Policy Statement](#) / [No Fear Act Policy](#) / [NIST Information Quality Standards](#) / [Scientific Integrity Summary](#)

 Sign Up for NIST E-mail alerts:

Date created: June 30, 2011 | Last updated: August 11, 2011 | Contact: [Webmaster](#)