Use of Visual Imagery for the NIST World Trade Center Investigation

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INTRODUCTION

The attack on the World Trade Center (WTC) in New York City on September 11, 2001 by terrorists flying hijacked commercial aircraft into the two towers (WTC 1 and WTC 2) was among the worst building disasters in the history of the United States. In response, Congress requested that the National Institute of Standards and Technology (NIST) investigate the technical causes for the disaster. NIST publicly announced its Building and Fire Safety Investigation of the World Trade Center Disaster on August 21, 2002. On October 1, 2002, the National Construction Safety Team Act was passed by Congress, and the Investigation was carried out under the authority provided by this act.

A draft copy of the final report dealing with the WTC towers was released for public comment on June 23, 2005. [1] It consists of an overall summary report, eight project reports, and 34 supporting technical reports totaling over 10,000 pages. The final version will be available in late September or early October. Complete versions are available on the Investigation website at wtc.nist.gov. The eight projects that made up the Towers Investigation dealt with applicable building codes, baseline building performance and aircraft impact, analysis of structural steel, active fire protection, thermal environment, structural collapse mechanisms, occupant egress, and emergency response.

Since both towers collapsed, little physical evidence was available to guide the investigation. As a result, models for the aircraft impact, fire behavior, heat transfer to structural elements, and building performance were crucial for determining the causes of the collapses. Primary sources of information for estimating initial conditions, guiding, and validating the results of the models were analyses of structural steel, review and analysis of available imagery of the event, and eyewitness accounts. This presentation focuses on the collection, organization, and use of visual imagery during the Investigation.

The visual analysis task was carried out as part of Project 5, which is summarized in the Project Report *Reconstruction of the Fires in the World Trade Center Towers*. [2] The work that forms the basis of this presentation is described in detail in the Task Report *Visual Evidence, Damage Analysis, and Timeline Analysis*. [3] The primary output for this task was a series of Excel worksheets describing window-by-window observations of window condition (open or closed), smoke flow (none visible, light, or heavy) and fire (none visible, spot fire, fire inside, and external flaming). Worksheets were generated for each of the four faces of the two towers for multiple times between the times that the aircraft struck a tower and the collapse of that tower. The intervals between worksheets varied between two and six minutes.

IMAGERY COLLECTION

The World Trade Center was located on Manhattan Island in New York City. New York City is a media, fashion, and tourist center in the United States. As a result, there were a large number of skilled professional and amateur photographers and videographers in the immediate vicinity. September 11th was a clear day. Since the aircraft struck high on the towers (near the 96th floor, roughly 1175 feet above ground for WTC 1 and near the 80th floor, roughly 990 feet above ground for WTC 2) the fireballs and ensuing building fires and smoke were visible from long distances and large numbers of people immediately began recording imagery. The WTC disaster was the most photographed event of its type in history.

Even though the amount of visual material available was immense, it was recorded and owned by a wide range of professional and governmental organizations and individuals. Identifying sources and making

arrangements for the material to be used by the Investigation represented significant challenges. NIST worked with numerous organizations such as the commercial photo agencies, local and network television, local newspapers, the New York City Police Department, the Fire Department of the City of New York, and various archives assembled to document the events of September 11th. Additional imagery shot by individuals was identified by searches on the world-wide web, by referrals from other sources, and by public appeals during public Investigation progress updates. Ultimately, over 300 hours of video and 10,000 photographs were collected by NIST.

IMAGERY STORAGE AND DATA BASING

The collection of visual material was only an initial step. Once the material was available, it was necessary to review the material and organize it in such a way that it could be utilized for the purposes of the Investigation. The decision was made to save visual material in digital electronic formats. A distributed digital storage system consisting of eight personal computers and four large hard drives was assembled for this purpose. A total of 1.6 terabytes of storage were available. The entire system was connected by high-speed Ethernet and controlled by a server to form a single secured network.

A goal of the collection effort was to obtain as high as quality imagery as possible. For digital photographs and videos this meant direct digital copies of original material, which were then saved in the digital storage system. For analog material, it was first necessary to digitize the material with high fidelity before saving it in the system.

Once imagery was available on the storage system, it was still necessary to provide means for accessing and searching the large amount of collected material. This was accomplished using a commercial database program, Cumulus[*], which is designed to provide access to and organization of visual assets. A large number of attributes including such details as faces of the towers visible, whether or not fire was visible, imagery showing the aircraft impacts, presence of NYPD or FDNY personnel, etc. were associated with each asset. Separate data entry sheets were developed for photographs and videos within Cumulus. It was possible to perform sophisticated searches of the database based on these attributes. The results of these searches could be displayed as thumbnails, which allowed quick review of large numbers of assets.

Ultimately, the database grew to include 7,118 photographs and 6,932 video clips representing over 75 hours of video. In additional to material from numerous organizations, videos from approximately 40 individuals and photographs from over 140 individuals were included.

VISUAL ASSET TIMING

A major focus of this effort was the development of timelines for the observed fire behavior in the towers. In order to accomplish this task it was necessary to provide times of known accuracy for the visual assets. Some relative timing information was available from digital photographs and videos, which often include embedded camera clock times in their outputs. However, the absolute accuracy of such internal clocks varied widely, and the times were not generally sufficiently well known. Analog material usually did not contain time information and had to be timed individually by comparison with material of known times.

An approach was adopted for timing in which assets in the database were tied directly or indirectly to a single event, the impact of the aircraft on WTC 2, which was defined to have occurred at 9:02:54 a.m. based on information available in an earlier FEMA investigation [4] of the events on September 11th. Numerous photographs and over 20 videos recorded the approach and impact of this aircraft. By utilizing

[*] Certain commercial equipment, instruments, or materials are identified in this document. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products identified are necessarily the best available for the purpose.

this material, it was possible to time material that did not include the aircraft impact by a "bootstrap" process in which untimed material was compared with imagery with known times. In this way, it was possible to provide accurate times for imagery spanning the entire event from the impact of the first aircraft on WTC 1 at 9:46 a.m. to the collapse of WTC 1 just after 10:28 a.m.

By review of television broadcasts it was ultimately determined that the initial time assigned for the aircraft impact on WTC 2 was in error by 5 seconds. Reported times are therefore obtained by adding 5 seconds to the times included in the database.

Estimates of timing uncertainty are included in the database. Ultimately, 3,357 of 7,118 photographs and 2,789 of the 6,982 video clips in the data base were timed with 3 second accuracy or better. The times of the following four major events are believed to be accurate to one second: aircraft impact on WTC 1, 8:46:30 a.m.; aircraft impact on WTC 2, 9:02:59 a.m.; collapse of WTC 2, 9:58:59 a.m.; and collapse of WTC 1, 10:28:22 a.m.

AIRCRAFT IMPACTS, FIREBALL BEHAVIOR, INITIAL DAMAGE

American Airlines Flight 11 struck near the center of the north face at the 96th floor of WTC 1 at 9:46:30 a.m. Based on the period required for the aircraft to enter the tower, its speed was estimated as 443 mph ± 30 mph. Very shortly after impact burning aviation fuel was forced from openings created on the north, east, and south faces of the tower, ultimately forming large fireballs that dissipated in about 10 seconds. Close-up images of the north face were used to derive detailed diagrams for the significant exterior damage caused by the aircraft. The only other major structural damage was on the south face, where a 3-story high by three column wide section of steel was removed from the center of the face and landed nearly 690 feet away with an aircraft wheel stuck in one of the windows. Damage elsewhere on the tower, consisting primarily of broken windows and displaced façade, was isolated near the center of the east face and on the west side of the south face.

United Airline Flight 175 struck the south face of WTC 2 near the 80th floor with an estimated speed of 545 mph ± 18 mph. Intense fireballs then formed on the south, east, and north faces. In addition to the damage created by the aircraft entry on the south face, significant façade damage and window breakage was present across the east face and the east side of the north face. Large piles of debris were evident on multiple floors in the northeast corner of the tower and near the center of the 79th floor on the north face. The tower swayed following the aircraft impact. A moiré analysis of a video recorded on a stationary tripod allowed the primary period of this motion to be measured as 11.4 s ± 0.1 s with amplitude of 12 in. ± 1 in. at the 70th floor. Images indicated that a large section of the 83rd floor on the east side of the tower was dislodged and settled downwards immediately following the aircraft impact.

FIRE BEHAVIORS IN WTC 1 AND WTC 2

The primary output of this project was the series of Excel datasheets detailing the window, smoke, and fire observations in both towers. These maps have been visualized using color-coded maps showing the observations on drawings of the tower facades.

In WTC 1, the fires initially died down following the large fireballs generated by the aircraft impact. Initial fire growth occurred in areas on the north, east, and south sides of the towers near locations where the fireballs exited the tower. However, extremely rapid fire spread and growth was observed shortly on the west face of the 97th floor in a lightly damaged area, suggesting acceleration by unburned aviation fuel. These initial fires continued to spread throughout the 102 minutes between the aircraft impact and the tower collapse. In general, the fires seemed to go through "normal" cycles of fire growth, sustained burning, and decay, with burning periods of roughly 20 minutes. The fires ultimately burned over large fractions of the floor areas on the 92nd to 99th floors. An intense, apparently isolated, fire also grew on the west side of the 104th floor after 10:00 a.m. Numerous windows were broken out by these fires, with

the number of open windows increasing by a factor of 5 as compared to the number following aircraft impact over the fire period.

One of the last areas that appeared to be affected by fire was the southeast tower corner, with significant flames reaching the area around 80 minutes following aircraft impact. Western sides of the 95th to 98th floors on the south face were burning considerably earlier. Severe inward bowing of south-face steel columns was observed several minutes before collapse initiation.

The global fire behavior observed for WTC 2 was somewhat different. Relatively large fires were observed on the debris piles in the northeast corner and near the center of the north face immediately following the dissipation of the fireballs generated during the aircraft impact. These fires were long-lived and were still burning when the tower collapsed 56 minutes later. While some fire growth and spread was observed on multiple floors on the south, east, and north faces of the tower, it was more limited than was seen in WTC 1. Fire was not observed on the west face prior to collapse. The differences in fire spread behavior are likely associated with differences in fuel distributions and ventilation pathways (recall that large numbers of windows on the east and north sides of WTC 2 were opened during the aircraft impact).

Several unusual fire behaviors were observed for WTC 2. On at least seven occasions, intense fires and smoke release that lasted roughly one minute were observed coming from multiple floors. These fires would then apparently die down. A possible explanation for these occurrences is that isolated areas of aviation fuel deposited during the aircraft impact were igniting and burning.

Within ten minutes following the aircraft impact, bowing of steel columns on the east face over the impact floors was noted. This bowing increased with time, and collapse initiation was observed in the area over 40 minutes later.

FINAL REMARKS

The visual record from September 11th has allowed the time behaviors of the fires that spread along the peripheries of the towers to be documented. These timelines were used extensively during the modeling of fires necessary to predict heat transfer to the structures. Changes in ventilation were captured using the window condition timelines, and fire observations were used to assess the validity of the calculated fire behavior. The image database was also employed by other Investigation projects, particularly the aircraft impact modeling and structural response efforts.

REFERENCES

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