Chapter 1
INTRODUCTION

The destruction of the World Trade Center (WTC) Complex in New York City on September 11, 2001, resulted in immense loss of life and property. Much of the loss occurred as a result of the collapse of the towers following the aircraft impacts. This task is a part of the Investigation of the technical causes for the disaster authorized by the United States Congress and performed by the National Institute of Standards and Technology (NIST). Details concerning the objectives and approach of the Investigation are incorporated in the preface to this report.

This report summarizes the results of one of the component tasks of Project 5 *Reconstruction of Thermal and Tenability Environment*. Project 5 was one of the eight projects that comprised the NIST WTC Investigation. This particular task, referenced as Task 5A, was entitled "Visual Collection and Analysis."

The objective of the task was "to utilize photographs, videos, and other relevant information to develop detailed time lines for the spread and growth of fires at the peripheries of World Trade Center Buildings 1, 2, and 7 and to organize the information such that it can be utilized by other investigation team members." This report focuses specifically on the WTC towers, WTC 1 and WTC 2. In practice, the scope of the task was expanded, and its staff provided significant technical support and analysis to Investigation Projects 2, 3, 4, 6, 7, and 8, while meeting the principal objective of developing time lines for the fires observed in the towers.

Based on media coverage on September 11, 2001, and afterward, it was evident that the World Trade Center disaster had been visually documented to a degree that was unusual for such an emergency. An extraordinary number and variety of photographs and videos were shown publicly, starting with live television coverage shortly after the first aircraft impact. There are a variety of factors that contributed to the creation of this extensive visual record, including the location of the disaster in the of a center major metropolitan area, the overwhelming magnitude of the attack and loss, and the length of time the event lasted.

Members of the NIST technical staff recognized that this visual record might offer an unparalleled opportunity to document the disaster and contribute to understanding its technical causes. Very shortly after September 11, informal efforts to collect visual material that might prove useful to an eventual investigation were initiated. Prior to the formal authorization and funding of the Investigation by the United States Congress, NIST had initiated several small, internally funded projects related to the September 11 disaster. One of these projects was a more organized effort to begin the identification and collection of relevant visual material. These efforts accelerated greatly once the formal Investigation was authorized, and these activities became a formal part of the Investigation.

This task consisted of four major subtasks: 1) identification, collection, data basing, and cataloging of visual material, 2) timing of material incorporated into the NIST visual database, 3) development of fire time lines and additional analyses based on the visual material, and 4) documentation.

This report is the documentation of this task (subtask 4). Earlier reports released by the Investigation include interim updates on progress on the task. (NIST SP-1000-3, 2003; NIST SP-1000-4, 2003; NIST SP-1000-5, 2004)

The report is organized as follows:

Chapter 2 provides a general description of the visual material that was recorded on September 11, 2001, and approaches that were developed for identifying, collecting, data basing, and cataloging the material that was collected (subtask 1). Since a major focus of the task was the development of time lines, it was necessary to assign accurate times to the photographs and videos incorporated into the database. Chapter 3 describes the approaches developed for timing and an assessment of their effectiveness (subtask 2).

Chapter 4 provides background information about such topics as the local geography, wind direction, relevant tower structural and architectural details, a numbering system for describing window locations on the towers, and some interior details, such the locations of air intake and exhaust louvers on mechanical equipment room floors and floor plan layouts for certain affected floors. The tower geometry affected the accuracy of findings based on visual analysis. Such effects are discussed in the last section of this chapter.

Chapter 5 includes details concerning the various types of analysis and procedures employed to develop time lines for fire behavior in the two towers. The primary output was a series of numerical data sheets as a function of time that provided window-by-window assessments of whether or not a fire was present, and, if present, a measure of the local intensity, whether or not smoke was flowing from a particular window and, if observed, an indication of whether the flow was light or heavy, and whether or not glass was in place for a given window. The criteria and the key used for these assessments are discussed. The usefulness of the datasheets was enhanced by visualizing the contents using various types of color façade maps. In addition to the window-by-window data sheets, a number of other observations related to the fire behavior were documented, including the formation of streamers, smoke marks on column covers, unusual burning and smoke behaviors, and human observations (subtask 3).

Chapters 6 and 7 contain time lines describing external observations related to the aircraft impacts and subsequent fireballs for WTC 1 and WTC 2, respectively. The aircraft impacts caused significant damage to the towers and released aviation fuel, which ignited inside the towers, leading to the formation of external fireballs immediately afterwards. Even those these aviation-fueled fires rapidly burned out, they ignited nascent fires within the towers that were the sources for the fire spread and growth observed following the aircraft impacts. These chapters also include descriptions of the damage inflicted by the aircraft based on observation of the exteriors of the towers and debris observed on the ground. Observed fire distributions shortly after the aircraft impacts are documented. Estimates for the speeds of the aircraft at the time of impact are provided that are based on video analysis of the impacts. For WTC 2, additional analyzes of available videos allowed the motion of the tower in response to the aircraft impact to be assessed (subtask 3).

Chapter 8 and Chapter 9 provide detailed discussions of observed fire behaviors in WTC 1 and WTC 2, respectively. The results presented in these two chapters, along with the associated data sheets, fulfill the primary objective of the task (subtask 3).

A number of additional details are incorporated into appendices for this report. Appendix A includes diagrams for the locations of air intake and exhaust louvers at the peripheries of mechanical equipment rooms located on the 108th and 109th floors and the 75th and 76th floors. Appendix B provides floor plan layouts for a number of floors in the vicinities where the aircraft impacted the towers. Appendix C to Appendix J include detailed façade maps incorporating window data on fire, smoke, and window condition as a function of time for the four faces of each tower. Appendix K provides additional details concerning an analysis of the motion of WTC 2 that resulted from the impact of the aircraft. Appendix L includes a table of observations of streamers released from WTC 1 during the fires, and Table M summarizes observations concerning people falling from WTC 1.

1.1 REFERENCES

May 2003 Progress Report on the Federal Building and Fire Safety Investigation of the World Trade Center Disaster, NIST Special Publication 1000-3.

December 2003 Public Update on the Federal Building and Fire Safety Investigation of the World Trade Center Disaster, NIST Special Publication 1000-4.

Appendix H: Interim Report on Evolution of WTC Fires, Smoke, and Damage Based on Image Analysis, in June 2004 Progress Report on the Federal Building and Fire Safety Investigation of the World Trade Center Disaster, NIST Special Publication 1000-5.

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Chapter 2
COLLECTION AND HANDLING OF VISUAL MATERIAL

2.1 BACKGROUND

The New York City area is a major center in the United States for the media, being the home for several newspapers, numerous local television stations, and the national headquarters for several television network news organizations. It is a large city, and there are numerous freelancers who make their living shooting photographs and video. The American fashion industry, which supports additional photographers and videographers, is centered in New York. City. New York City is also a major tourist destination, attracting thousands of visitors daily who bring along their cameras to record their experiences. As a result of these traits, the New York City area, and particularly Manhattan, likely has one the highest concentrations of cameras per area in the world, along with people skilled in their use.

On September 11, 2001 numerous events were taking place in New York City that increased the number of cameras in the vicinity of the World Trade Center. A primary election was being held in the city, and numerous news organizations were covering it. It was Fashion Week, and the number of fashion photographers was higher than usual. School had just opened for the fall, and numerous parents carried cameras when they took their children to school that morning.

The fact that this event occurred in lower Manhattan in the midst of a sea of cameras, resulted in incredible fireballs and smoke plumes that immediately attracted people's attention, was visible from vast distances due to the heights and sizes of the towers, and took place over several hours meant that thousands of people, both professional and amateur, turned their cameras toward the World Trade Center and recorded some type of visual record of the events of September 11. As a result, the World Trade Center disaster is one of the most photographed events in world history. Portions of this visual record were shown publicly starting on September 11, 2001 and continue to be shown today. The dramatic images have molded public perceptions of what occurred on that day in a way that written or verbal descriptions could not have accomplished.

Due to the location, certain types of imagery are more available than might have been anticipated. As an example, aerial images were recorded from at least seven different helicopters. Several video cameras were stationary, and in some cases long uninterrupted views of the towers were recorded. These video recordings have not only proven invaluable for timing purposes, but have allowed analysis approaches that provide unprecedented details concerning certain aspects the disaster. In an unlikely occurrence, an infrared camera was trained on the burning towers for brief periods.

The WTC towers (WTC 1 and WTC 2) were immensely tall, and they dominated the New York City skyline. When WTC 1 was struck by American Airlines Flight 11 at 8:46:30 a.m., the approach of the aircraft was captured by at least two videographers who were coincidentally filming nearby. Other photographers and videographers in the vicinity began recording within a few seconds after the impact. As fires grew in the tower, smoke pouring from the building formed a plume that could be seen for miles in all directions in the clear sky of September 11, 2001. People in Manhattan, Brooklyn, Queens, and New Jersey began to turn their cameras toward the WTC complex. The major news organizations began coverage almost immediately and began moving professionals into position to cover the event. Numerous other videographers and photographers, both professional and amateur, started moving toward the WTC in order to create their own visual records.

When United Airlines Flight 175 struck WTC 2 at 9:02:59 a.m., the approach and collision of the aircraft were recorded by numerous cameras from a variety of directions. Many people continued to record images until WTC 2 collapsed at 9:59:59 a.m. Following this collapse, the amount of visual material decreased markedly as people rushed to escape the area and the huge dust clouds generated by the collapse obscured the site.

Even as the disaster unfolded, it was clear that a large amount of visual material was being recorded. The resulting visual record offered an unparalleled opportunity to contribute to the technical understanding of the tragedy of September 11. Even though it was clear that an extensive visual record of the events of September 11 existed, approaches for obtaining access to photographs and videos and cataloging the material had to be developed. These critical tasks are discussed in the following sections.

2.2 SOURCES FOR VISUAL MATERIAL

Potential sources of visual material were identified in a number of ways. Recordings of newscasts from September 11, 2001 and afterward, documentaries, and other remembrances provided information directly, but also pointed toward other potential sources of material. The major photo clearinghouses, such as AP, Reuters, and Corbis, have World Wide Web sites that were reviewed for material related to September 11th. Members of the media suggested sources. Several collections of visual material have been assembled for charitable or historical purposes. Collections from the Here is New York City exhibition and the September 11 Digital Archive were reviewed. Many photographs and videos began appearing on the World Wide Web as early as September 11, 2001. These could often be identified by Web searches, and in many cases contact information was provided. Public appeals for visual material were made during Investigation news conferences and updates. News accounts of these events led many to contact NIST using the toll-free number or by e-mail. Frequently, a new source would provide suggestions about other potential sources. Members of the New York City Police and Fire Departments recorded numerous photographs and videos that were made available to NIST for review.

NIST hired a visual media consultant, Mr. Valentine Junker, to act as its representative in the New York City area. In addition to interacting with a number of individuals, his efforts were particularly valuable in interfacing with the major television networks and local New York City stations, as well as the major photographic news services.

2.3 COLLECTION PROCEDURES

The identification of sources was only the first step in the collection process. It was then necessary to contact the source, request the material, and make arrangements for its transfer. Special considerations such as copyright and privacy issues often needed to be addressed. Once an agreement was reached, arrangements were made to review and transfer copies of the material to NIST.

In the collection process, emphasis was placed on obtaining material in a form that was as close as possible to the original in order to maintain as much spatial and timing information as possible. In the case of digital photographs and videos, this implied a direct digital copy. For film or slide photographs, it would be a high-resolution digitized version of the original media, and for analog video, a direct copy from the original source. While it was not always possible to maintain these standards, the majority of material ultimately collected was handled in this manner.

2.4 GENERAL DESCRIPTION OF VISUAL MATERIAL COLLECTED

As expected, the amount of visual material from September 11 was immense. NIST was able to obtain access to a significant amount of relevant imagery. In excess of 300 hours of video on nearly 150 separate tapes were assembled and logged. Video footage was provided by NBC, CBS, ABC, CNN and local New York City stations WABC, WCBS, WNBC, WPIX, WNYW and New York City One. In many cases, the videos provided not only included material broadcast (known as air checks), but also material that was recorded but not broadcast (known as outtakes). Additionally, videos recorded by more than 40 individuals were received.

Photographs have been provided by a number of sources including commercial photo services, the New York City Police Department (NYPD), The Fire Department of the City of New York (FDNY), and individuals. Well in excess of 7,000 photographs, representing more than 200 photographers, were received. Professional news organizations that provided material include AP, Corbis, Reuters, the New York Times, the Daily News, and the Star Ledger. Many of these organizations also provided access to unpublished photographs. The majority of photographs came from individual photographers, both professional and amateur.

It is difficult to estimate the actual amount of relevant visual material recorded on September 11, 2001, and thus, to estimate how complete the collection efforts were. There is certainly material that has not been identified and collected. However, NIST believes that the extraordinarily large collection of video material that it assembled is sufficient for purposes of the Investigation.

2.5 DATABASING AND CATALOGING

It would have been impossible to effectively use the vast amount of visual material collected for the Investigation without some means of organizing and cataloging the material. This section summarizes the approaches and procedures used for these purposes.

2.5.1 Digital Storage

Very early in the task, the decision was made to save all material in digital format on large digital data storage devices. This approach had several advantages. Because the material was in digital form, it could be assessed quickly. It was not necessary to search for a particular photographic collection or videotape, and no special equipment was required to display it. Because most material was received in other forms, the digital storage was, in effect, a backup system for the original. Additional redundancy was provided by backing up the entire digital storage system at regular intervals. Because videos were saved digitally, they could be analyzed using a variety of commercially available editing software.

Various storage solutions were considered. An approach was adopted in which a central server along with two 325 gigabyte, one 200 gigabyte and one 160 gigabyte external hard drives were connected with eight personal computers equipped with 70 gigabyte hard drives. The personal computers not only provided additional disk storage, but also served as workstations for data entry and analysis. All of the systems were connected by high-speed ethernet to form a single network configured such that the entire system became, in effect, a single mass storage device. The total amount of storage available was roughly 1.6 terabytes. Due to security concerns related to the sensitive nature of some of the visual material and copyright issues, the computer network was set up with its own dedicated connections and was isolated from the internet backbone of NIST. Policies were adopted that required all viewing and analysis of the material to be done in secured rooms using secured networks.

2.5.2 Digitizing Techniques

When new visual material was received at NIST, it was stored digitally on the dedicated system. If the material was already in digital form, this simply required copying and saving it on the system. Analog material had to be first digitized in some manner. For instance, a photograph might be scanned and digitized, or an analog video might be converted to a digital video format (typically mini-DV) and then copied to the data storage system.

Each arriving video was logged into VideoList, a Microsoft Access database application that was written specifically for this task. Each video entered in the database was assigned a unique identification number. Pertinent information concerning the tape was recorded, including its duration, the network and broadcast date, if applicable, its format (e.g., VHS, Hi-8, or mini-DV), where the physical tape was stored, whether the tape was an original or a copy, its source, whether it had been digitized, whether it contained embedded time code, and general notes on its content.

Figure 2 1 shows an example of the entry sheet for the VideoList database. Videos to be stored digitally were copied onto mini-DV media, and each copy was also logged into the database. VideoList also contained a calculator for assisting in the calculation of clip timing as described in Section 3.1.2. Selected video material was then transferred to hard disk for storage.

Video material was often found to have natural breaks, such as when the camera was turned off and on (e.g., by an individual videographer) or when multiple cameras were used (e.g., during a newscast). It is advantageous to treat each of these breaks as the end of an individual video. This was accomplished by a process known as “clipping.” By using Adobe Premiere software and a personal computer to control the video player, it was possible to identify and note such breaks in a “clip file.” The clip file could also contain notes related to the material. Once a clip file was generated for an entire tape, the software could take control of the video player and go through and automatically generate multiple data files containing the video material. The material that was clipped was stored in “avi” format, which maintained all of the digital information. The maximum video file size that could be handled by this system was 1 gigabyte. This corresponds to slightly more than 4 1/2 min of avi video. Longer continuous video segments were broken into lengths having roughly this period. Breaking up longer videos in this manner also made them easier to search and catalog.

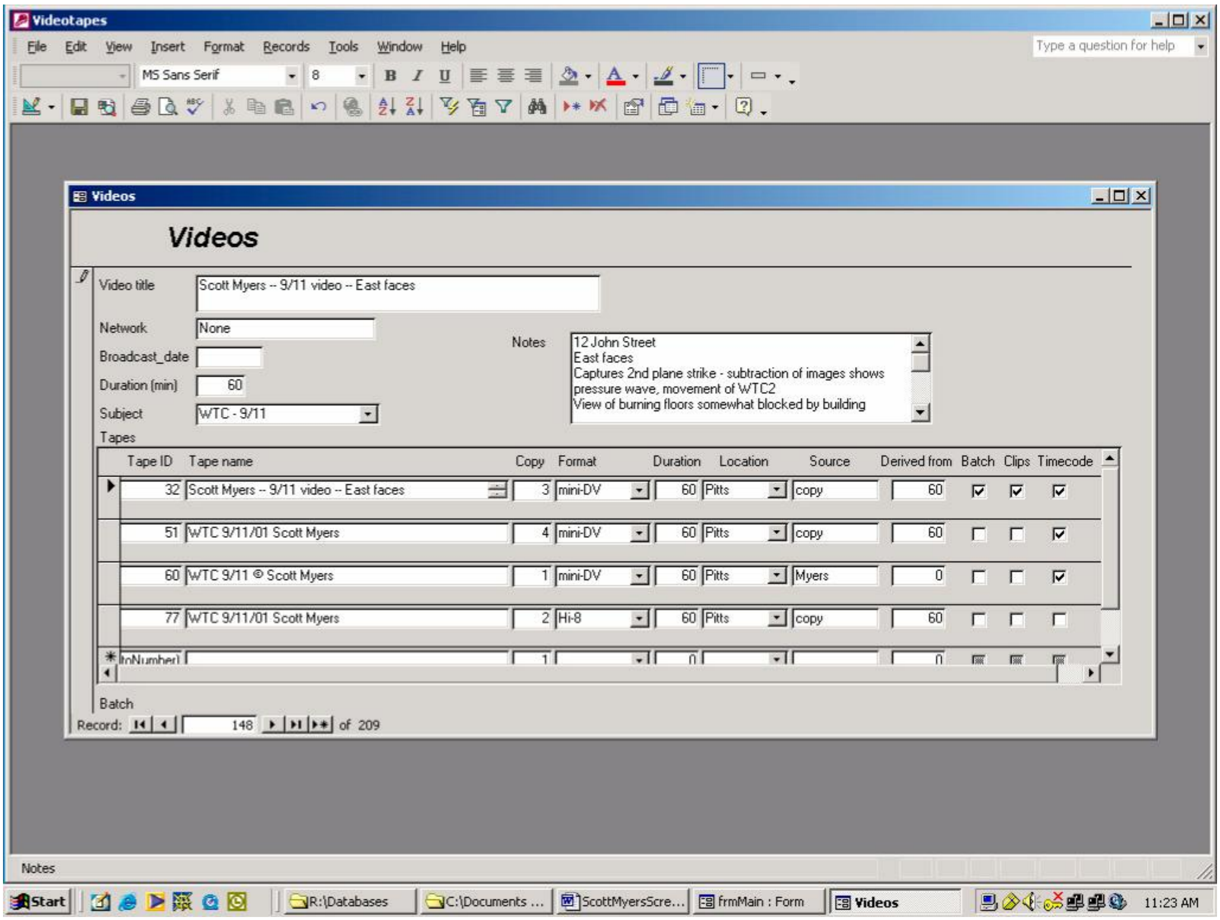


Figure 2-1. An example of the VideoList data entry sheet for video assets is shown.

2.5.3 Searchable Database

As noted earlier, a vast amount of visual material was collected and saved digitally as part of the investigation. Without some organization, it would have been impossible to use this material effectively. A commercial database program written specially for organizing visual material, Cumulus, was chosen for this purpose. This software is designed to collect individual "assets" in specified catalogs and to allow the assets to be characterized with a variety of attributes. It is possible to generate specific attributes and include these in specially designed forms for data entry. Once a catalog had been assembled, it was possible to search for assets having a specific attribute or combinations of attributes. Quite sophisticated searches could be created. It was also possible to order assets based on a particular attribute. As an example, when dates and times were assigned, the assets could be ordered in chronological order.

Two separate catalogs, one for photographs and one for video clips, were created for visual materials collected as part of the Investigation. Each catalog had a similar set of attributes that was used to characterize the assets that were included. These attributes were chosen based on the needs of this task, dealing with fire conditions within WTC 1, WTC 2, and WTC 7, and by consultation with staff of other Investigation projects. Table 2 1 and Table 2 2 list the attributes used for the photographic and video catalogs, respectively. A description of each attribute is provided along with details on how information concerning the attribute was input into the worksheet. Figure 2 2 shows an example of the first screen for the photographic data entry form.

Table 2-1. Attributes for photographic assets.

Attribute	Definition	Entry Choice
Asset Reference	Location of photograph in file system	Set by Cumulus
Categories	List of categories under which the photograph is listed, typically the photographer's name or source	Set by Cumulus
Record Name	File name of photograph	Set by Cumulus
Photographer	Photographer's name	Text
Received from	Where photograph was obtained ("Other" may refer to a third party, for example)	Photographer WWW Other
Original Source	How photograph was added to the collection	Digital Copy of Original Digital Copy from Program Digitized Slide or Negative Digitized Photograph Uploaded from Web
Use Limited	Photographer has requested that use of the photograph be limited	Checkbox
Copyright	A copyright exists	Checkbox
Copyright Agreement	Usage agreement with NIST	Text
Shot From	Location of photographer	Text
Date Recorded	Date and time of shot	Date and time
Time Uncertainty (s)	Number of seconds uncertainty in the time assigned	Integer
View Direction	Location of photographer with respect to the WTC	North Northeast East Southeast South Southwest West Northwest
WTC Faces WTC 1 North Face WTC 1 East Face WTC 1 South Face WTC 1 West Face WTC 2 North Face WTC 2 East Face WTC 2 South Face WTC 2 West Face WTC 7 North Face WTC 7 East Face WTC 7 South Face WTC 7 West Face	Building face(s) visible in the photograph	Checkbox for each choice

Attribute	Definition	Entry Choice
Distance Near Medium Far	Clarity of the photograph Near = Can make out details within windows Medium = Can count windows Far = Unable to count windows	Checkbox for each choice
Building WTC 1 WTC 2 WTC 7 Other Building	Building(s) visible in photograph	Checkbox for each choice
1st Plane Strike	Photograph shows the plane strike on WTC 1	Checkbox
2nd Plane Strike	Photograph shows the plane strike on WTC 2	Checkbox
WTC 1 Collapse	Photograph shows the collapse of WTC 1	Checkbox
WTC 2 Collapse	Photograph shows the collapse of WTC 2	Checkbox
WTC 7 Collapse	Photograph shows the collapse of WTC 7	Checkbox
Street	Street scene, or a street is visible in the photograph	Checkbox
Debris Aircraft Debris Collapse Debris Debris Inside Building Street Debris	Debris is visible in the photograph Type of debris: Aircraft = Can be identified as plane debris (e.g., tires, engines) Collapse = Resulting from collapse Inside Building = Visible through windows or openings Street = On street	Checkbox for each choice
Fireball	Initial fireball from plane strike is visible	Checkbox
Thermal	The thermal is a tall region of the smoke plume that results from the lift caused by the hot gases of the initial fireball	Checkbox
Plume	Smoke plume generated by the fires within the towers and blown downwind. This marker is checked if the smoke plume in the photograph extends farther than a single tower width.	Checkbox
Flames Visible	Flames are visible in the photograph	Checkbox
People Inside Falling Outside	The photograph includes people Inside = People inside the buildings, at the windows or climbing down Outside = People on the street	Checkbox for each choice
Falling building component	The photograph shows a building component falling (e.g., aluminum cladding)	Checkbox
Streamers Falling	The photograph shows a streamer, an object that emits smoke as it falls and leaves a trail	Checkbox
Dripping	Molten material dripping from WTC 2 is visible	Checkbox
Hanging Floor	A sagging or hanging object suggesting a floor is visible within the windows	Checkbox

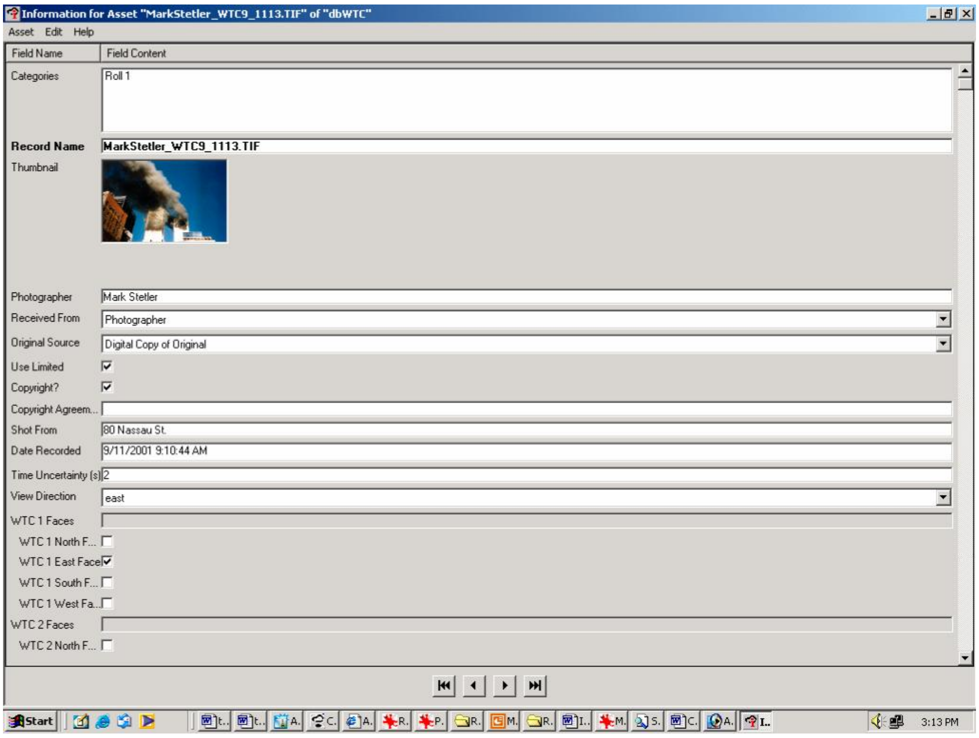
Attribute	Definition	Entry Choice
Building Core	Photograph shows the core of WTC 1 or WTC 2 — both remained standing briefly during collapse before falling	Checkbox
FDNY FDNY Apparatus FDNY Personnel	FDNY personnel or vehicles are visible, including EMTs, fire trucks, and ambulances	Checkbox for each choice
NYPD NYPD Apparatus NYPD Personnel	NYPD personnel or vehicles are visible, also includes FBI and other police officials	Checkbox for each choice
Impact Aircraft	Photograph shows aircraft approaching WTC 1 or WTC 2 before or during the strike	Checkbox
Other Aircraft	Aircraft other than the impact aircraft are included in the photograph, such as helicopters or fighter jets	Checkbox
Good for Analysis	Mark photograph for possible window-by-window analysis	Checkbox
Analyzed	The photograph has been used for window-by-window analysis	Checkbox
Notes	Notes, including a description of how the photograph was timed	Checkbox

Table 2-2. Attributes for video assets.

Attribute	Definition	Entry Choice
Asset Reference	Location of video clip in the file system	Set by Cumulus
Categories	List of categories under which the video clip is listed, typically the photographer's name or source	Set by Cumulus
Record Name	File name of video clip	Set by Cumulus
Videographer	Videographer's name	Text
Content	Content of video clip WTC 9/11 Footage = Events before collapse of WTC 7 Street Scene (no timing) Debris field = Ground Zero after WTC 7 collapse Construction = Construction of WTC towers from documentary Normal Operation = Normal operation of building, usually from documentary Animation = Animation of 9/11 events from documentary Still(s) = Photographs contained within documentary Interview = Clip only shows interview	WTC 9/11 Footage Street scene (no timing) Debris field Construction Normal operation Animation Still(s) Interview
Use Limited	Videographer has requested that use of the videotape be limited	Checkbox
Copyright	A copyright exists	Checkbox
Copyright Agreement	Usage agreement arrangements with NIST	Text
Shot From	Location of videographer	Text
Date Recorded	Date and time of beginning of video clip	Date and time
End Recording	Date and time of end of video clip	Date and time
Duration	Number of minutes:seconds contained in clip	Real number
Time Uncertainty (s)	Number of seconds uncertainty in the time recorded / end recording	Integer
View Direction	Location of videographer with respect to the WTC	North Northeast East Southeast South Southwest West Northwest

Attribute	Definition	Entry Choice
WTC Faces WTC 1 North Face WTC 1 East Face WTC 1 South Face WTC 1 West Face WTC 2 North Face WTC 2 East Face WTC 2 South Face WTC 2 West Face WTC 7 North Face WTC 7 East Face WTC 7 South Face WTC 7 West Face	Building face(s) visible in the video clip	Checkbox for each choice
Distance Near Medium Far	Clarity of the video clip Near = Can make out details within windows Medium = Can count windows Far = Unable to count windows	Checkbox for each choice
Building WTC 1 WTC 2 WTC 7 Other Building	Building(s) visible in video clip	Checkbox for each choice
1st Plane Strike	Clip shows the plane strike on WTC 1	Checkbox
2nd Plane Strike	Clip shows the plane strike on WTC 2	Checkbox
WTC 1 Collapse	Clip shows the collapse of WTC 1	Checkbox
WTC 2 Collapse	Clip shows the collapse of WTC 2	Checkbox
WTC 7 Collapse	Clip shows the collapse of WTC 7	Checkbox
Street	Street scene, or a street is visible in the video clip	Checkbox
Debris Aircraft Debris Collapse Debris Debris Inside Building Street Debris	Debris is visible in the video clip Type of debris: Aircraft = Can be identified as plane debris (e.g., tires, engines) Collapse = Resulting from collapse Inside Building = Visible through windows Street = On street	Checkbox for each choice
Fireball	Initial fireball from plane strike is visible	Checkbox
Thermal	The thermal is a tall region of the smoke plume that results from the lift caused by the hot gases of the initial fireball	Checkbox
Plume	Smoke plume generated by the fires within the towers and blown downwind. This marker is checked if the smoke plume in the video clip extends farther than a single tower width.	Checkbox
Flames Visible	Flames are visible in the video clip	Checkbox

Attribute	Definition	Entry Choice
People Inside Falling Outside	The video clip includes people Inside = People inside the buildings, at the windows, or climbing down Outside = People on the street	Checkbox for each choice
Falling building component	The video clip shows a building component falling (e.g., aluminum cladding)	Checkbox
Streamers Falling	The video clip shows a streamer, an object that emits smoke as it falls and leaves a trail	Checkbox
Dripping	Molten material dripping from WTC 2 is visible	Checkbox
Hanging Floor	A sagging object suggesting a floor is visible within the windows	Checkbox
Building Core	Video clip shows the core of WTC 1 or WTC 2 – both remained standing briefly during collapse before falling	Checkbox
FDNY FDNY Apparatus FDNY Personnel	FDNY personnel or vehicles are visible, including EMTs, fire trucks, and ambulances	Checkbox for each choice
NYPD NYPD Apparatus NYPD Personnel	NYPD personnel or vehicles are visible, also includes FBI and other police officials	Checkbox for each choice
Aircraft Impact Aircraft Other Aircraft	Aircraft are visible in the video clip Impact: Shows aircraft approaching WTC 1 or WTC 2 before or during the strike Other: Helicopters or fighter jets	Checkbox for each choice
Major Change Major Fire Change Major Smoke Change Windows Opened	One of the following events takes place in the video clip: Major Fire Change: Fire flares up, dies down, or spreads to a new region Major Smoke Change: Smoke bursts, dies down, or spreads to a new region Windows Opened: Window breaks open, either due to fire or to people	Checkbox for each choice
Good for Analysis	Mark video clip for possible window-by-window analysis	Checkbox
Analyzed	The video clip has been used for window-by-window analysis	Checkbox
Notes	Notes, including a description of how the video clip was timed	Text

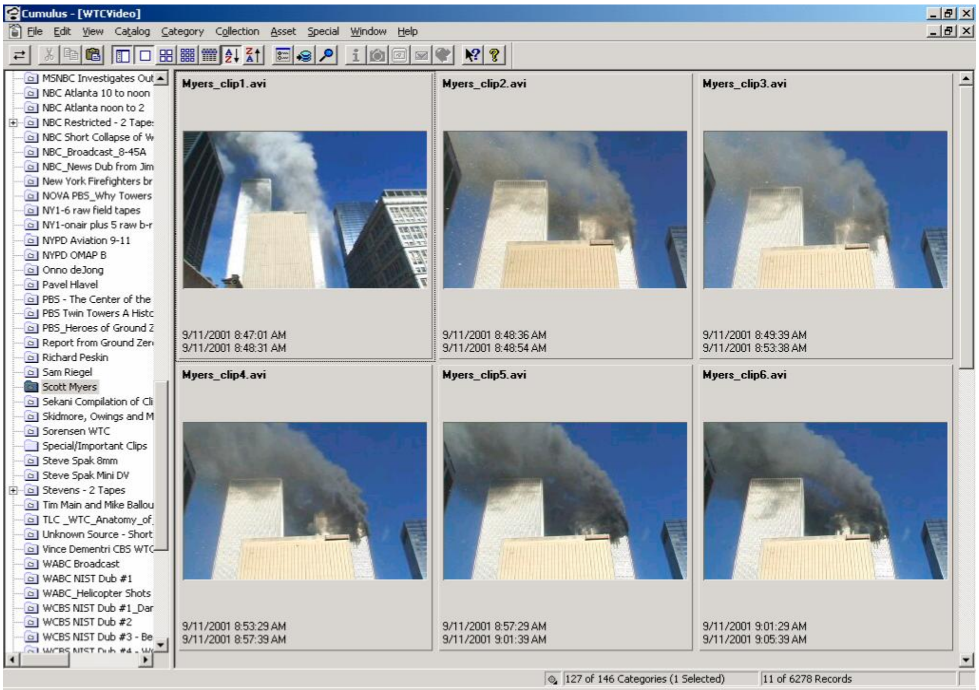


Source: Thumbnail © 2001 Mark Stetler.

Figure 2-2. An example of the first page of the Cumulus data entry sheet for photographic assets.

Cumulus allows thumbnails of entire catalogs or selected subsets to be displayed. This made it possible to review large numbers of photographs and video clips quickly and to decide which were most likely to be useful for a particular purpose. A variety of asset characteristics could also be shown simultaneously. Typically, the asset name and the time the asset was recorded were displayed. Figure 2 3 shows an example of thumbnails taken from the video database.

Not all collected visual material was incorporated into the two catalogs. Photographs and videos judged not to contain information directly relevant to the Investigation were not included. Even so, the number of photographs and video clips added to the catalogs was large. The photographic catalog includes 7,118 assets, and the video catalog includes 6,982 assets representing over 76 hr of material.



Source: Thumbnails © 2001 Scott Meyers.

Figure 2-3. An example of a Cumulus asset screen display for the video database. Thumbnails are shown along with the time and dates when the recording started and ended.

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Chapter 3
TIMING OF PHOTOGRAPHS AND VIDEO CLIPS

Since one of the major goals of this task was the development of time lines for fire growth and spread in World Trade Center (WTC) 1 and WTC 2, it was important to assign times of known accuracy to assets included in the two image catalogs. This task was greatly complicated by the absence of accurate times for the majority of visual material collected.

The visual material assembled during the Investigation can be classified into two broad categories with regard to time information—material that incorporates some indication of relative time and that for which no time information is provided.

3.1 VISUAL MATERIAL INCORPORATING TIMESTAMPS

Modern photographic and video digital cameras often record camera clock times as part of their output. For photographs, this information is usually stored as an integral part of the image in a header known as an EXIF file. Similarly, digital video cameras often embed a variety of information, including the camera clock time, as part of what is known as meta data. Software is available for reading these clock times from EXIF and other meta data media file formats. While a great help, these times usually still required some adjustment because people do not generally set their camera clocks accurately. In some cases, clocks were found to be off by days or even years. Even so, the relative times over the short time period of the events of September 11, 2001, were quite accurate.

Occasionally, analog photographic and video cameras imprint a time stamp on their outputs that can provide relative times similar to EXIF or meta data.

The following subsections describe approaches and tools that were developed to partially automate the assignment of accurate times to series of photographs and videos containing integrated time information.

3.1.1 Photograph Tools

In order to make the best use of the information embedded in digital photographs, software was required to retrieve the EXIF file information and to adjust the recorded clock times. The commercial software package CatDV is able to retrieve meta data embedded in a variety of media formats, including digital photographs and mini-DVs. The Access database PhotoTiming was written for the purpose of determining the actual times for a set of photographs given the relative EXIF time for each and a single accurate time reference. For a set of photographs sharing a common clock from the same digital camera, an accurate time for a single photograph was sufficient to set the relative times for the entire set.

Figure 3 1 shows a PhotoTiming data sheet for a selected set of photographs. A file generated by CatDV containing the EXIF data for each photograph, if available, was read into PhotoTiming. The equivalent EXIF and known relative times were entered into the appropriate fields at the upper right of the data sheet. Selection of the Calculate Photo Times button filled the Actual Time column with the appropriate values for each EXIF time. In this example, the EXIF times were found to be off by 102 s.

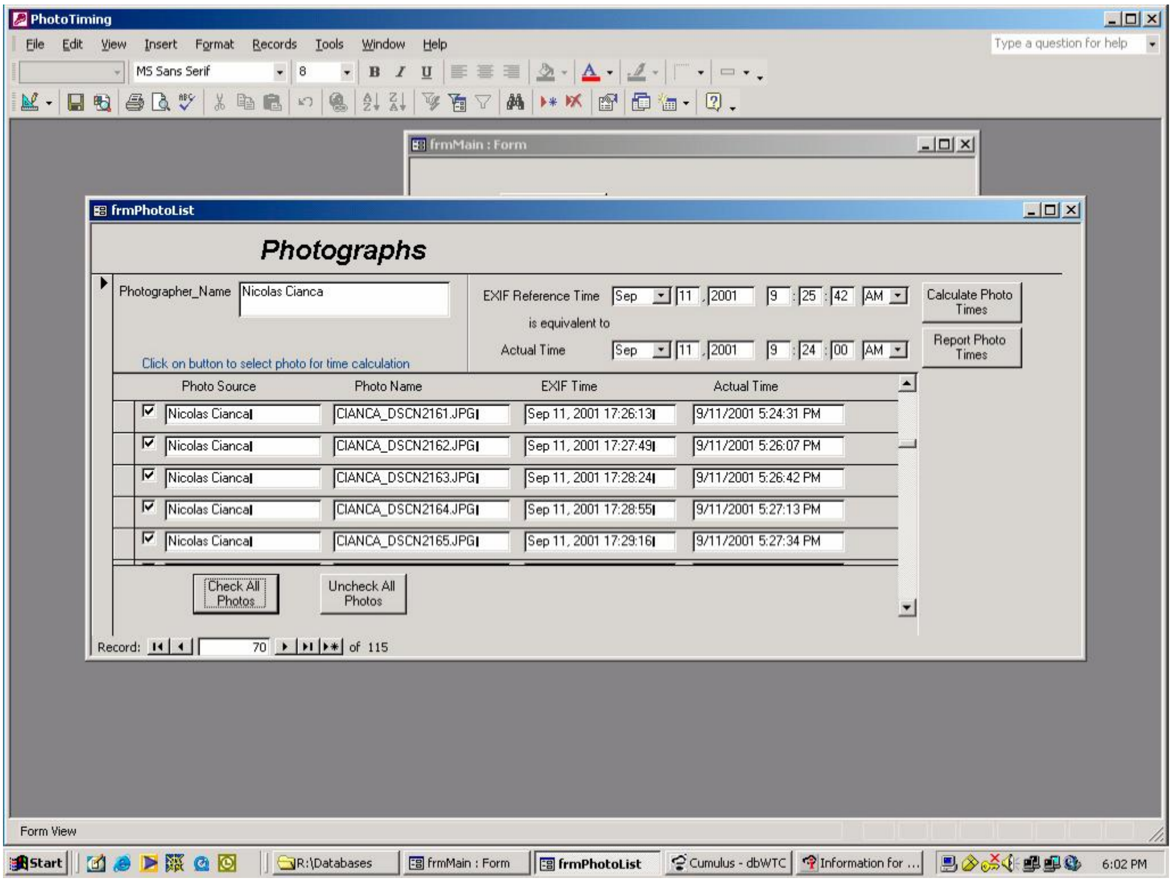

Figure 3-1. An example of the PhotoTiming sheet for calculating times for photographs containing EXIF meta data is shown.

3.1.2 Video Tools

In addition to containing the video database described in Section 2.5.2, VideoList also assisted with timing the clips taken from a videotape. This function was similar to that in the PhotoTiming tool. For a broadcast video that was filmed in real time, the timing of every clip in the video, except for replays, could be set from knowing the time at a single point. An example of this use of VideoList is shown in Figure 3 2. A clip file generated in Adobe Premiere for a specified video was read into VideoList. The mini-DV time of an event in the video whose timing was known, such as the moment of the second aircraft impact on WTC 2, was identified. Both times were entered into the appropriate fields at the upper right of the data sheet. Clips to be timed (excluding replays) were identified by a check mark, and the requested calculation resulted in the actual times in and out for each clip as shown in Figure 3 2. This tool was also useful in calculating start times for continuous video segments broken into multiple clips.

For each mini-DV video that contained meta data, CatDV was used to extract the clock times for the In and Out points for each clip. These values enabled the timing of every clip in the video from a single reference time.

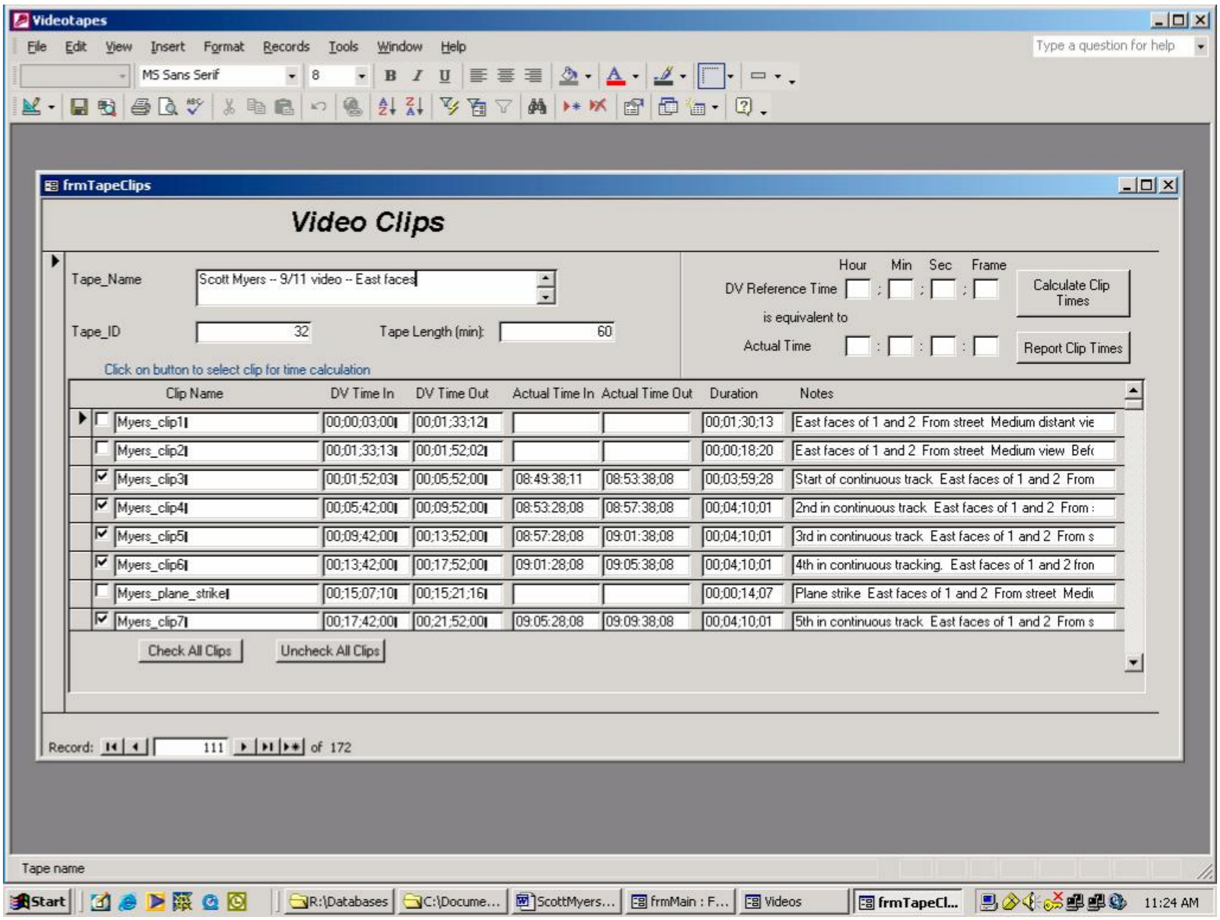

Figure 3-2. An example of the VideoList sheet for calculating clip times for video assets.

3.2 VISUAL MATERIAL WITHOUT TIME STAMPS

Most analog visual devices, such as film-based photographic and video cameras and analog video recorders that record on tape, do not provide a clock output that is recorded. For these cases it was necessary to assign times using approaches such as those described below. In the case of photographs, this required assigning a time to each individual photograph. The situation is similar for video recordings, but with a major difference. Video can be thought of being comprised of a series of closely spaced images, known as frames, having very well defined and known time spacing. As long as the camera records continuously, the times for the entire video could be assigned by simply determining the absolute time for a single frame.

3.3 REFERENCE TIME

Recognizing that the majority of timing information available from the visual material itself was of high relative accuracy, but of unknown and variable absolute accuracy, a timing scheme was adopted in which all of the times for items in the databases were placed on a common relative time scale tied to a single well-defined event. Due to the large number of different views available, the moment when the nose of the second aircraft struck the south face of WTC 2 was chosen to be this time. This event was defined to have occurred at 9:02:54 a.m. based on times for major events included in the earlier Federal Emergency Management Agency (FEMA) report (McAllister 2002) describing the events of September 11, 2001.

3.4 TIMING TECHNIQUES

Once the reference time was chosen, it was possible to place times on videos that showed the second aircraft impact. By matching other photographs and videos to these initially assigned videos, the assignments were extended to visual materials that did not include the primary event. Using this process, it was possible to place photographs and videos extending over the entire period of the event on a single time line. Sets of photographs containing EXIF times and video clips that either contained meta data or were continuous over relatively long periods were particularly useful for this purpose, because a single time assignment would allow the entire series to be timed. Sets of photographs recorded on film or analog videos that were frequently turned on and off were the most difficult items to time since individual matches were required for each photo or video clip.

Matching visual images and assigning times turned out to be a demanding task, requiring unique approaches. A variety of characteristics were employed to match times in different photographs and videos. These include distinct shadows cast on the buildings by the smoke plumes, the appearance and locations of smoke and fire plumes, the occurrence of well-defined events such as a falling object or the sudden appearance of smoke, and a variety of other unlikely clues such as a clock being recorded in an image.

3.5 TIMES FOR THE FIVE MAJOR EVENTS OF SEPTEMBER 11, 2001

To assist in the timing process, relative times for the five major events of September 11, 2001--first aircraft impact, second aircraft impact, collapse of WTC 2, collapse of WTC 1, and collapse of WTC 7--were determined with 1 s accuracies. These times are summarized in Table 3-1. Note that the building collapse times are defined to be when the entire building was first observed to start to collapse. In the case of WTC 7, a penthouse on the roof sank into the building before the main collapse started.

Table 3-1. Times for major events of September 11, 2001.

Event	Relative Time from Visual Analysis	Adjusted Time from Television Broadcasts	Time Reported in the FEMA Study	Time Based on LDEO Recent Analysis
First aircraft impact	8:46:25 a.m.	8:46:30 a.m.	8:46:26 a.m.	8:46:29 a.m.
Second aircraft impact	9:02:54 a.m.	9:02:59 a.m.	9:02:54 a.m.	9:02:57 a.m.
Collapse of WTC 2	9:58:54 a.m.	9:58:59 a.m.	9:59:04 a.m.	9:59:07 a.m.
Collapse of WTC 1	10:28:17 a.m.	10:28:22 a.m.	10:28:31 a.m.	10:28:34 a.m.
Collapse of WTC 7	5:20:47 p.m.	5:20:52 p.m.	5:20:33 p.m.	5:20:42 a.m.

It is not only important to assign relative times for photographs and videos, but also to provide an indication for how accurately they are known. For this reason, timing uncertainties were estimated for each time determination and included in the databases.

The timing process was initially difficult. However, Task staff timing skills improved with practice while more visual material became available, and the number of timed assets increased. Ultimately, 3,357 of the 7,118 catalogued photographs and 2,789 of the 6,982 video clips in the databases were timed with assigned relative uncertainties of 3 s or better.

3.6 ABSOLUTE TIME ACCURACY

Many of the news broadcasts on September 11, 2001, had the current time imprinted on the screen. These imprints are known in the industry as "bugs." As these broadcasts were timed, it became apparent that there were small differences between times for the second aircraft impact based on these bugs and the time used as the basis for the database. Checks with several broadcasters indicated that the bugs should be quite close to the actual time because the clocks used as sources for the bugs are regularly updated from highly accurate sources, such as geopositioning satellites or the precise atomic-clock-based timing signals provided by NIST as a public service. Careful checks showed small time differences between different video recordings, but these were generally less than 1 s. These small discrepancies were likely due to variations in transmission times resulting from the different pathways that the video signals took to the sites where they were recorded. Based on four independent video recordings, the actual time of the second aircraft impact was determined to be 9:02:59 a.m., or 5 s later than the time assigned in developing the database. The estimated uncertainty is 1 s. Table 3-1 compares times for the major events taken from the database, adjusted to television time, and reported in the FEMA report (McAllister 2002).

The times listed for the major events in the FEMA report (McAllister 2002) were based on seismic signals (and analysis) recorded by the Lamont-Doherty Earth Observatory (LDEO) of Columbia University at a location 21 miles from the WTC site in Palisades, New York. These signals have subsequently been reanalyzed by LDEO, working under a contract from the NIST WTC Investigation. (Kim, 2005) A reinterpretation of the types of seismic signals received resulted in slightly revised times for the major events. The results of this recent analysis are also included in Table 3-1. The uncertainty for the first aircraft impact on WTC 1, the collapse of WTC 2, and the collapse of WTC 1 were reported by LDEO to be 1 s, while that for the aircraft impact on WTC 2 is 2 s. Recalling that uncertainties for times of the major events based on the television broadcasts are estimated to be 1 s, it can be seen from Table 3-1 that the two aircraft impact times derived by NIST and LDEO now agree within the combined uncertainties.

Times listed in Table 3-1 for the collapses of the two towers based on the television records and the revised LDEO analysis appear to differ significantly. These differences are likely due to different definitions used for the collapse times. The times based on visual analysis refer to the time when the collapse of a tower first became evident, while the times based on seismic records likely indicate the time when the falling debris first struck the ground. The differences between the two times were estimated to be approximately 9 s for WTC 2 and approximately 11 s for WTC 1 based on videos of the collapses. When the times required for falling debris to reach the ground are subtracted from the LEDO times, the collapse times also agree within the reported uncertainties.

Since the times derived from television broadcasts (i.e., those in column 3 of Table 3-1) are believed to be accurate and also agree with the most recent analysis of seismic signals, 5 s were added to times included in the NIST WTC databases when precise times were reported for the Investigation.

3.7 REFERENCES

Kim, W.X., 2005 "Analysis of Seismogram Data Recorded on September 11, 2001 during the World Trade Center, New York City Disaster, Final Technical Report to the Building and Fire Research Laboratory," Lamont-Doherty Earth Observatory of Columbia University, Palisades, New York, January 31.

McAllister, T., ed. 2002. World Trade Center Building Performance Study: Data Collection, Preliminary Observations, and Recommendations. FEMA 403. Federal Emergency Management Agency. Washington, DC, May.