



**U.S. Federal Building and Fire Safety Investigation  
of the  
World Trade Center Disaster**

**4<sup>th</sup> Annual Congress on  
Infrastructure Security for the Built Environment**

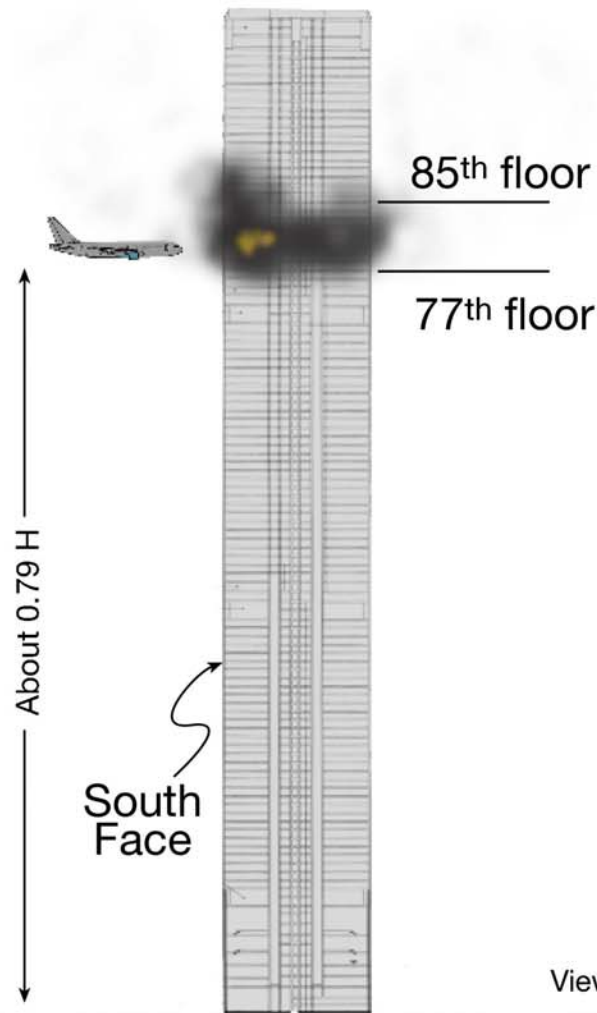
**October 19, 2005**

**Dr. James E. Hill**

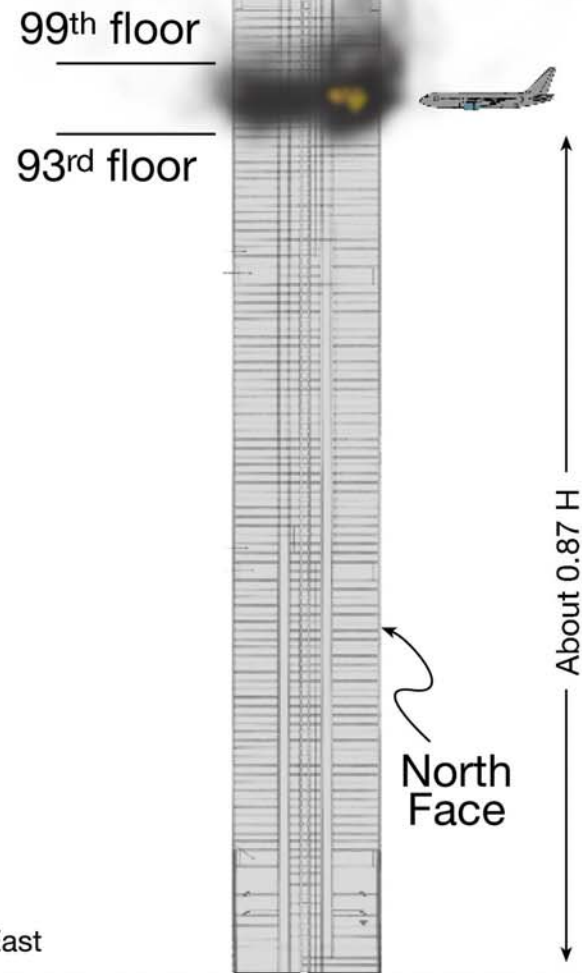
**Director, Building and Fire Research Laboratory  
National Institute of Standards and Technology**

# Investigation Objectives

- Determine **why and how the WTC Towers collapsed**.
- Determine why the numbers of injuries and fatalities were so low or high depending on location.
- Determine the **procedures and practices** that were used in the design, construction, operation, and maintenance of the WTC towers.
- Recommend changes in current **national building and fire model codes, standards, and practices** that warrant revision



**WTC 2:** Hit at 9:02:59 a.m.  
Collapsed after 56 minutes

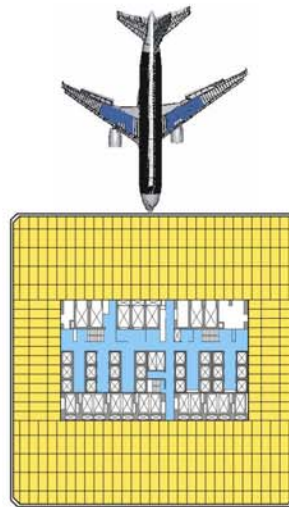


**WTC 1:** Hit at 8:46:30 a.m.  
Collapsed after 102 minutes

View from the East

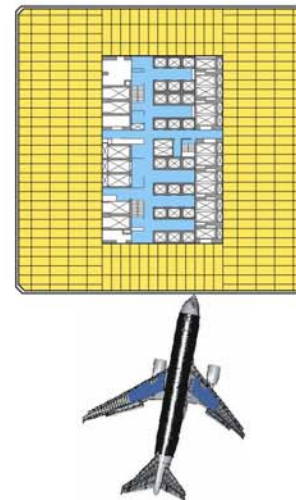
**Point of impact:**  
Close to the center  
and nearly normal  
to the building

WTC 1



WTC 2

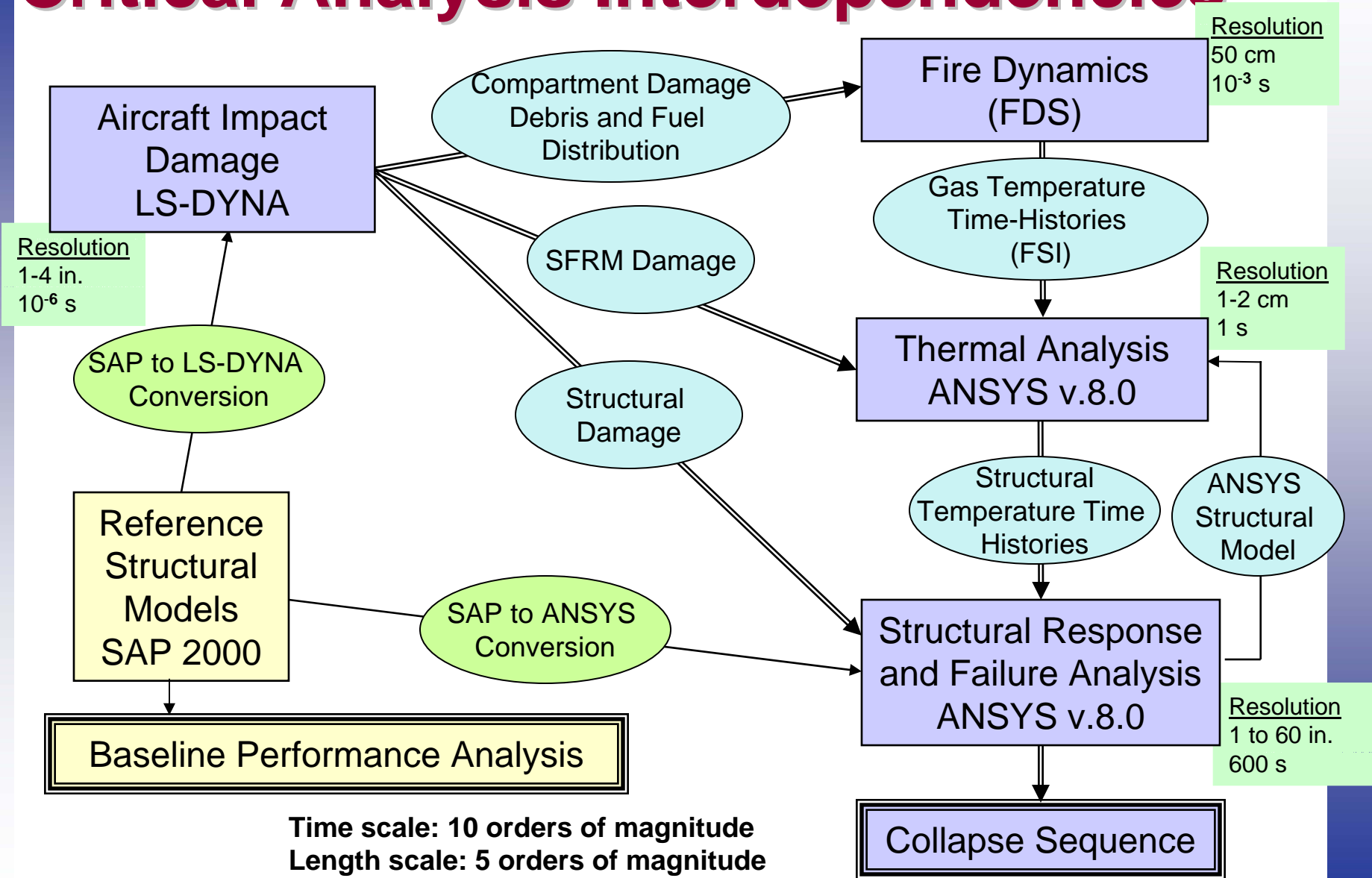
**Point of impact:**  
Close to the corner  
and with an angle



# Analysis of Probable Collapse Sequences

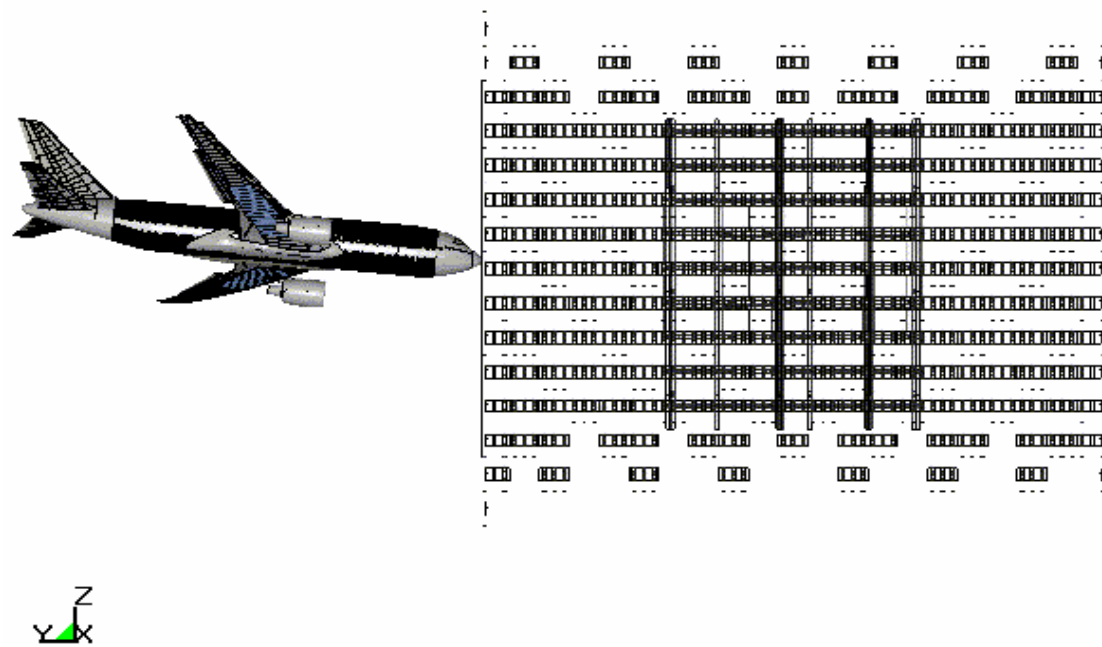
- Analyzed the sequence of events
  - aircraft impact
  - spread of jet-fuel-ignited multi-floor fires,
  - thermal weakening of structural components
  - progression of local structural failures that initiated collapse
- Combined
  - mathematical modeling
  - statistical and probability-based analysis methods
  - laboratory experiments
  - analysis of visual and physical evidence

# Critical Analysis Interdependencies



# WTC 1

Time = 0



# WTC 1 Damage: Composite Summary for Floors 93 to 98

## Severe Floor Damage

Fireproofing and partitions 

Floor system structural damage 

Floor system removed 

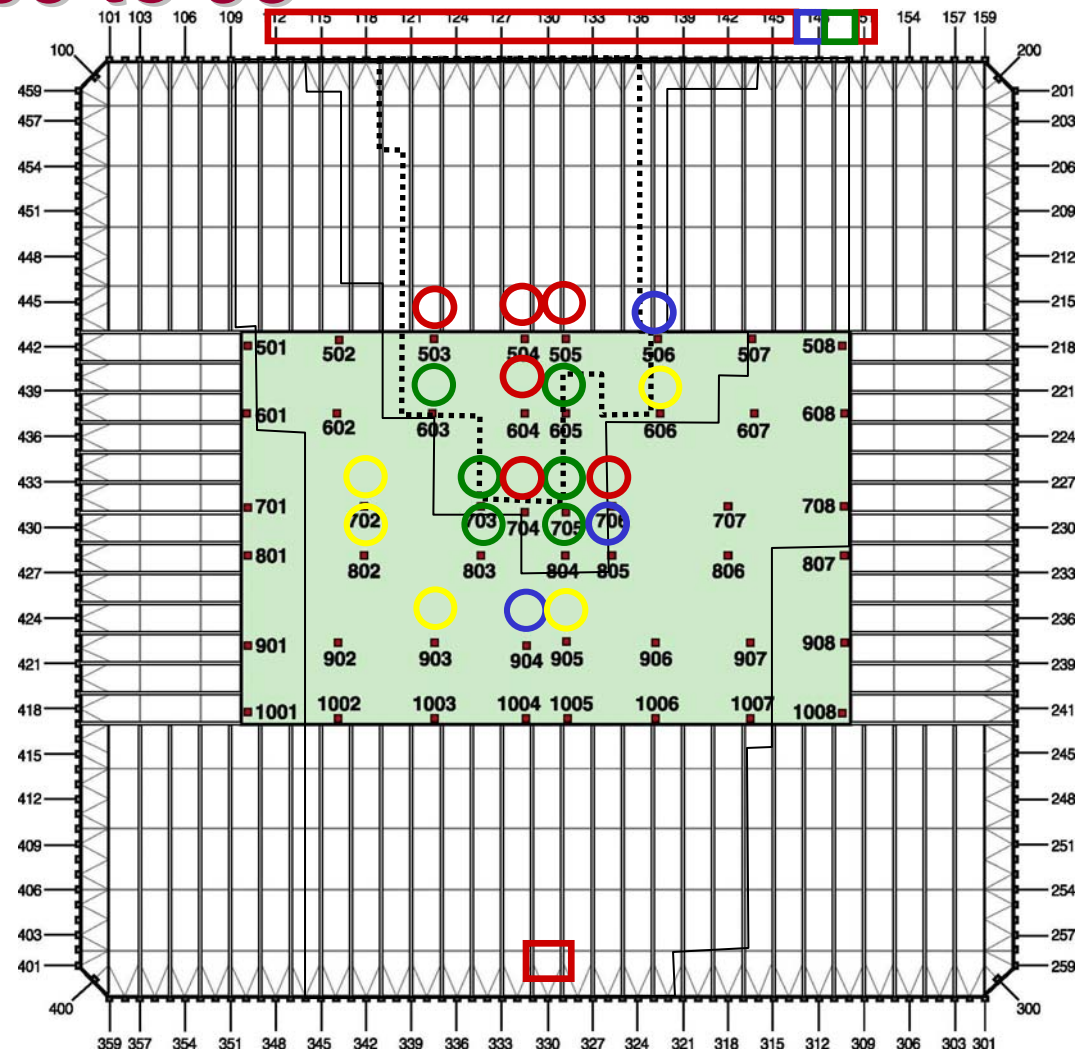
## Column Damage

Severed 

Heavy Damage 

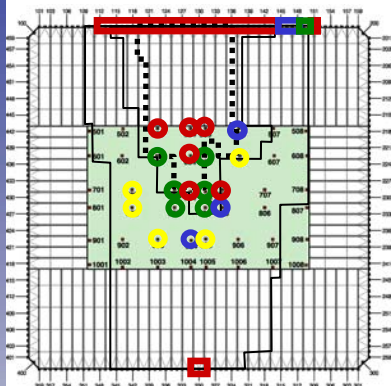
Moderate Damage 

Light Damage 

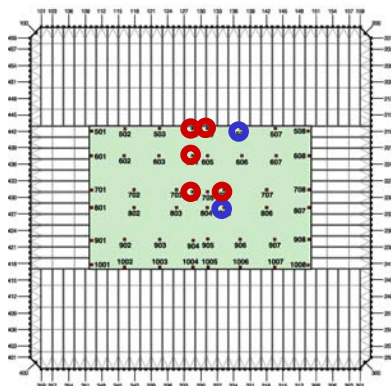




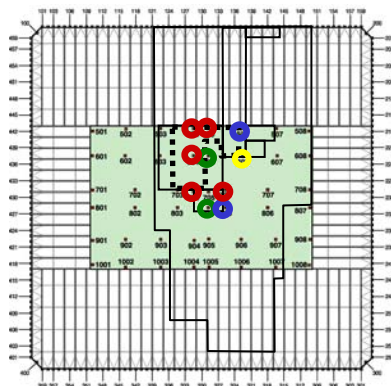
# WTC 1 Damage by Floor



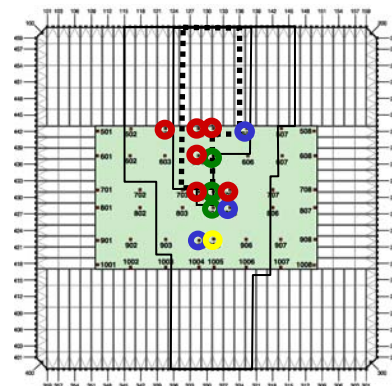
Floors 93 to 98  
Cumulative Damage



Floor 93



Floor 94



Floor 95

## Severe Floor Damage

Fireproofing and partitions

Floor system structural damage

Floor system removed

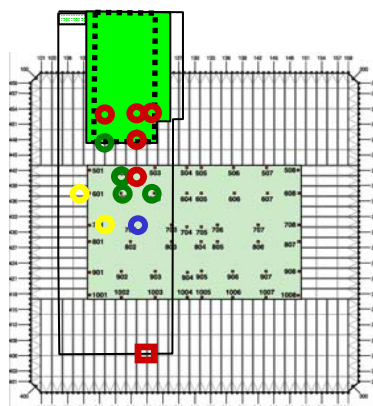
## Column Damage

Severed

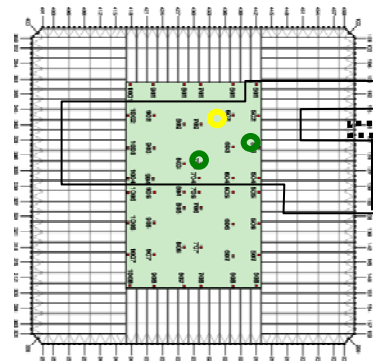
Heavy Damage

Moderate Damage

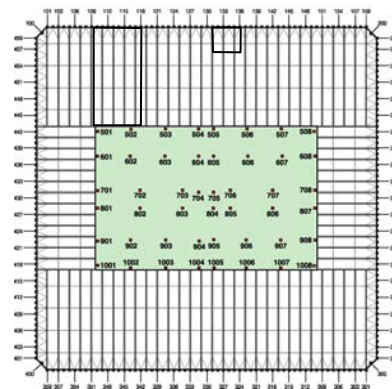
Light Damage



Floor 96



Floor 97



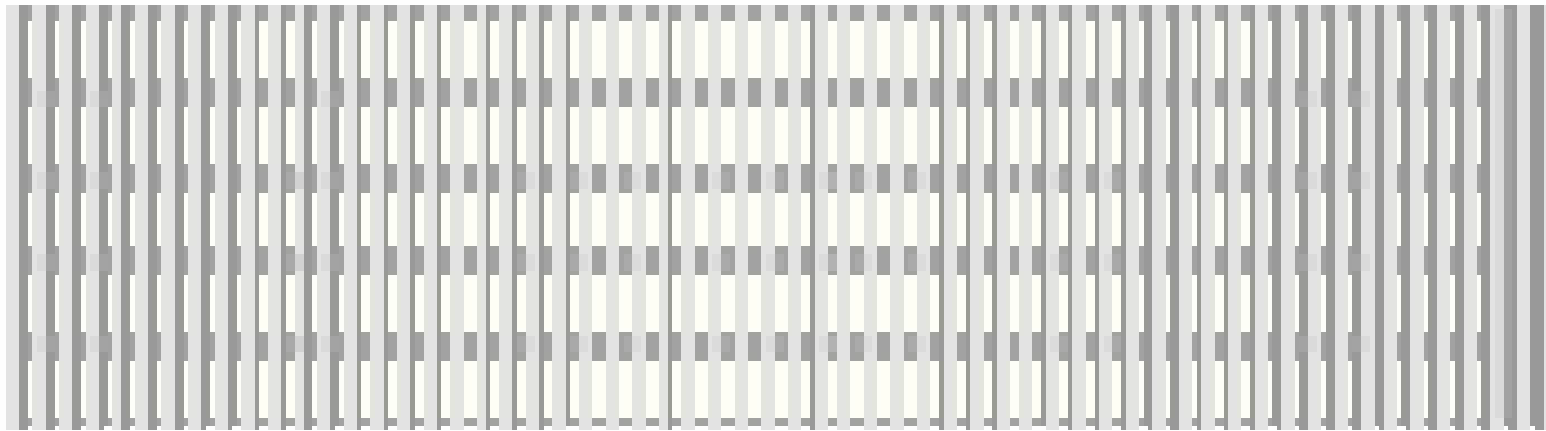
Floor 98

# Role of Aircraft Impact

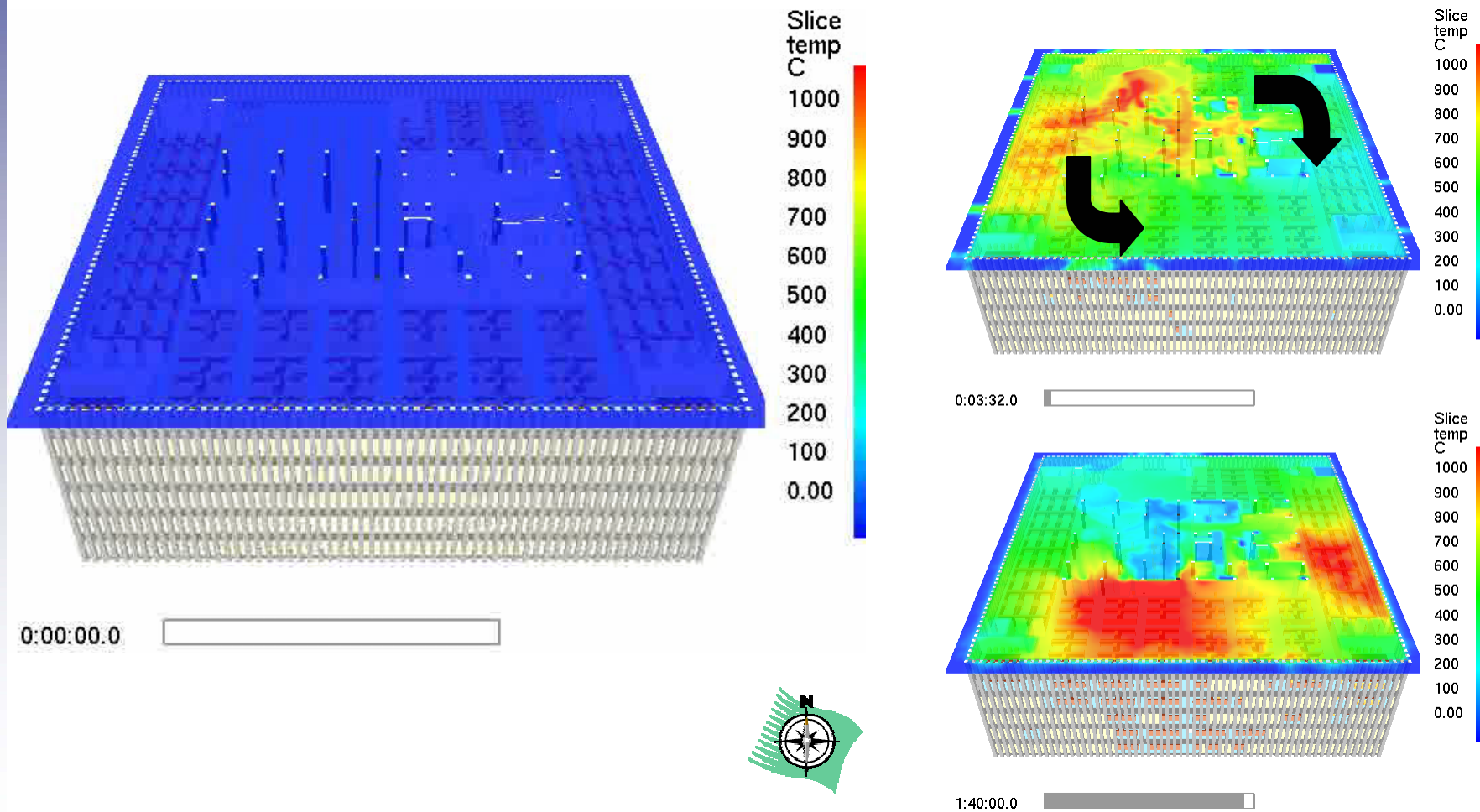
- **Compromised the sprinkler and water supply systems;**
- **Dispersed jet fuel and ignited building contents;**
- **Created large accumulations of combustible matter;**
- **Increased the air supply into the damaged buildings;**
- **Damaged and dislodged fireproofing from structural components; and**
- **Damaged ceilings**

# Reconstruction of the WTC Fires

**NIST**



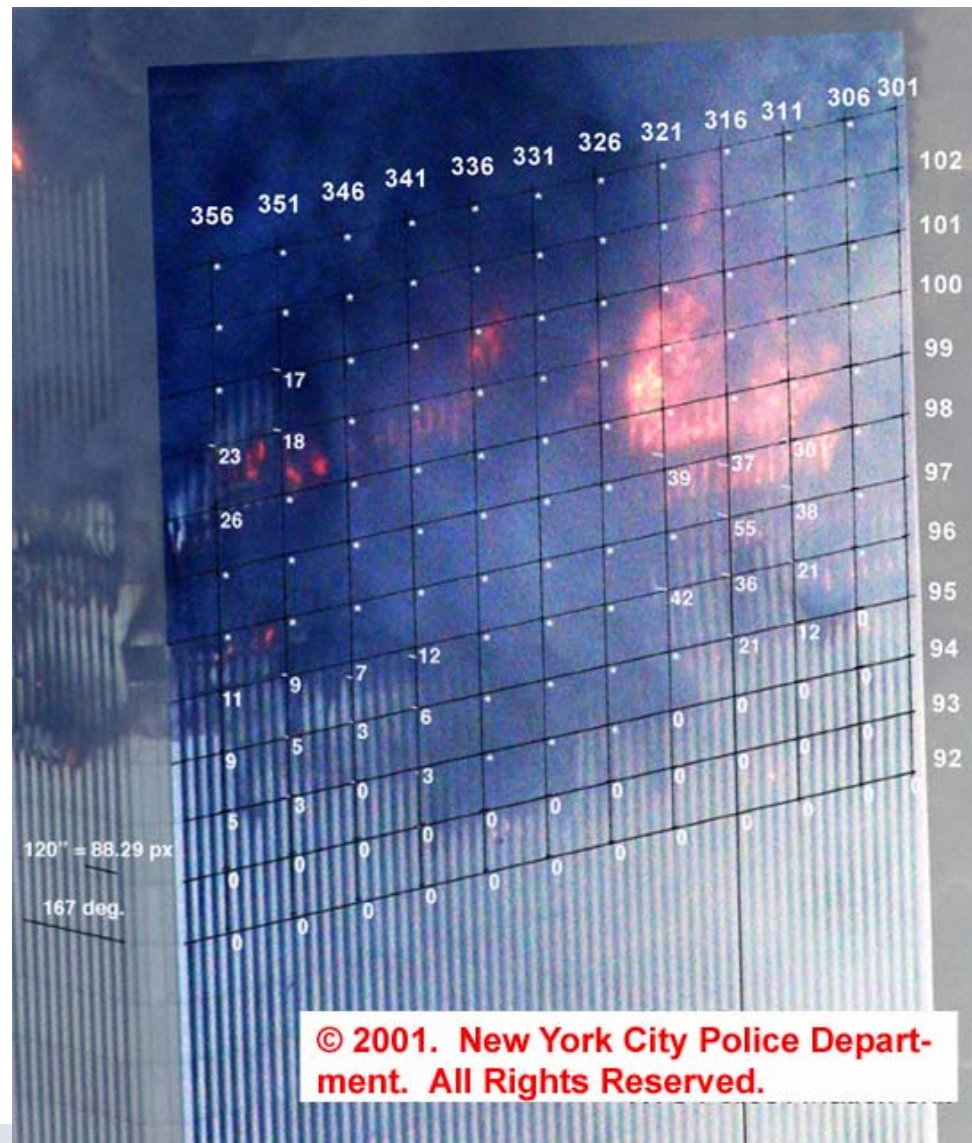
# Upper Layer Temperatures (WTC 1, Floor 97)



# South Face of WTC1

- Time: 10:22 AM
- Measurements of inward bowing (inches)
- **Maximum = 55 inches**  
(uncertainty ~ +/- 6 inches)

- Floor locations approximate
- Blue tinted region digitally enhanced



# Tilting of Building Sections

WTC 1 tilted to the south; WTC 2 tilted to the east and south.

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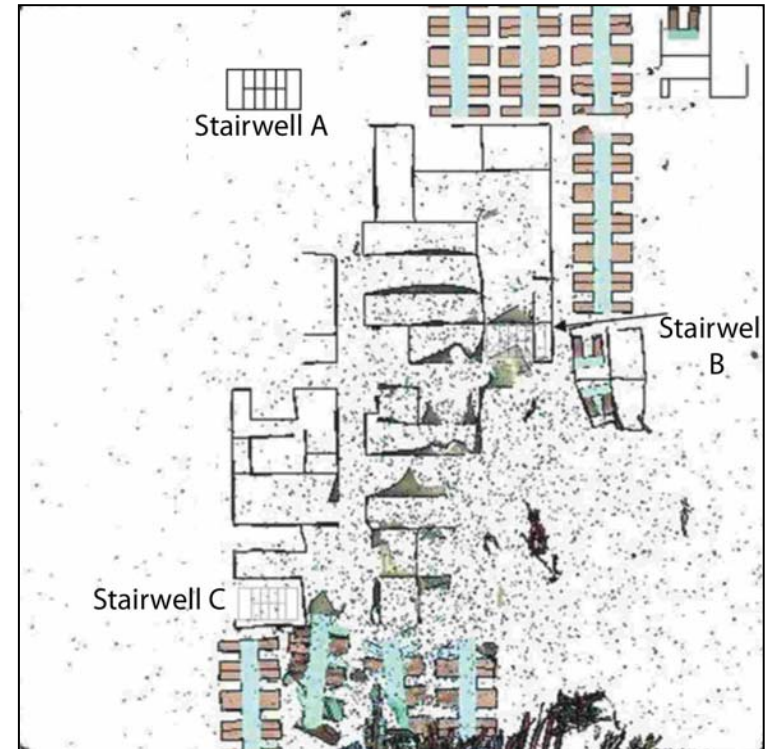
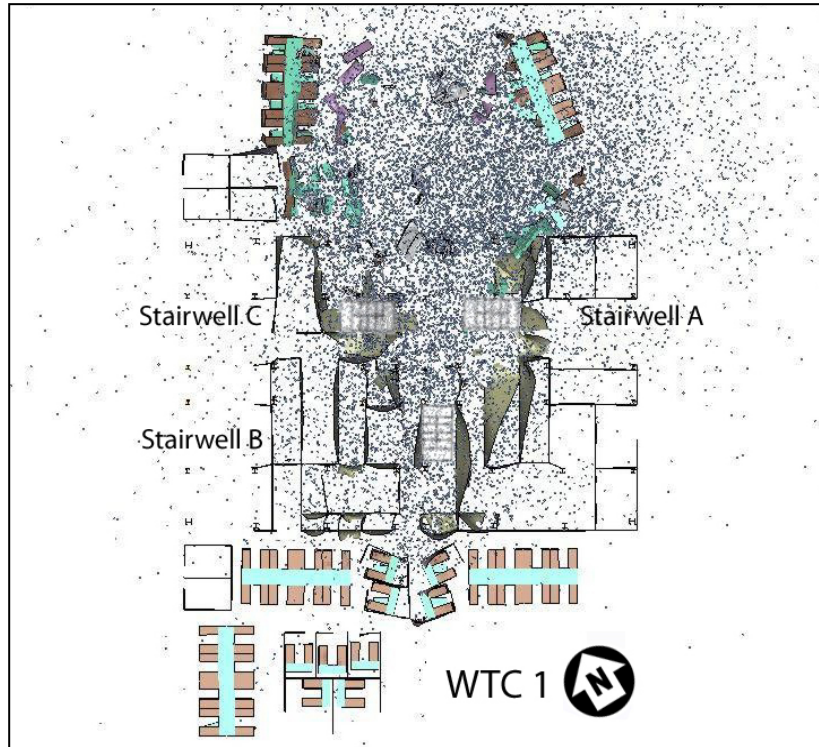
*Initiation of global collapse was first observed by the tilting of building sections above the impact regions of both WTC towers.*

# Evacuation and Emergency Response

Based on 1,056 interviews of surviving WTC occupants and 116 interviews of emergency responders.

- It is estimated that 17,400 occupants ( $\pm 1,200$ ) were present in the WTC towers on the morning of September 11, 2001.
  - About 6 percent of the surviving occupants reported a pre-existing limitation to their mobility.
- Approximately 87 percent of the WTC tower occupants, including more than 99 percent of those below the floors of impact, were able to evacuate successfully.
- 20 percent or more of the 2,567 building occupants and emergency responders who were in the WTC towers and lost their lives may have been alive in the buildings just prior to their collapse.

# Condition of Stairwells



- The stairwells, with partition wall enclosures that provided a 2 h fire-rating but little structural integrity, were damaged in the region of the aircraft impacted floors.
- **One of the stairwells in WTC 2 (Stairwell A on the Northwest side) was passable in the region of aircraft impact for some period of time after WTC 2 was attacked.**
- All three stairwells in WTC 1 and the two other stairwells in WTC 2 were rendered impassable in the region of aircraft impact.



# Key Findings

- **The buildings would likely not have collapsed due to aircraft impact and the subsequent jet-fuel ignited multi-floor fires, if the fireproofing had not been dislodged or had been only minimally dislodged by aircraft impact.**
- **The existing condition of the fireproofing prior to aircraft impact and the fireproofing thickness on the WTC floor system did not play a governing role in initiating collapse on September 11, 2001.**
- **Approximately 87 percent of the WTC tower occupants, including more than 99 percent below the floors of impact, were able to evacuate successfully.**
- **A full capacity evacuation of each WTC tower with 25,000 people would have required about 4 hours and as many as 14,000 people may have lost their lives.**
- **Documents suggest that the WTC towers generally were designed and maintained consistent with the requirements of the 1968 New York City Building Code.**

# 30 Recommendations

- **Increased Structural Integrity**
- **Enhanced Fire Resistance of Structures**
- **New Methods for Fire Resistance Design of Structures**
- **Improved Active Fire Protection**
- **Improved Building Evacuation**
- **Improved Emergency Response Technologies and Procedures**
- **Improved Procedures and Practices**
- **Education and Training**

# Proposals for Changes to Codes

- **The National Institute of Building Sciences (NIBS) is organizing a panel of recognized experts to:**
  - **Prioritize the recommendations**
  - **Develop proposals for changes to building codes**
- **Panel will prepare proposals for ICC and NFPA 5000 and coordinate submission with code update cycles.**