NIST Response to the World Trade Center Disaster

World Trade Center Investigation Plan

April 29, 2003

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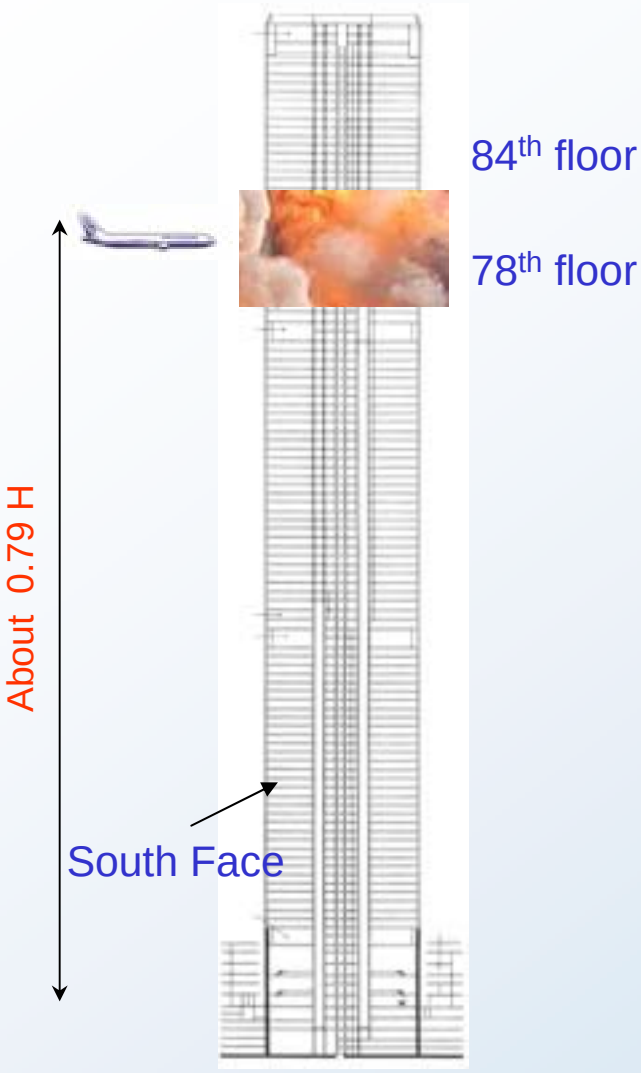
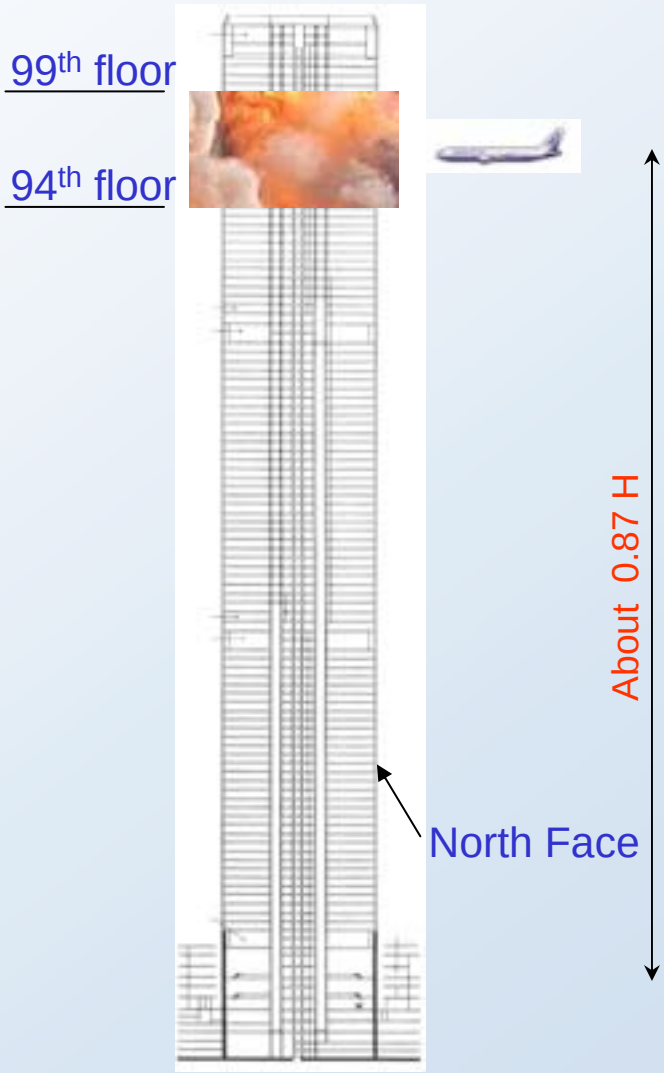


South tower: Hit at 9:03 AM
Collapsed after 56 minutes



North tower: Hit at 8:46 AM
Collapsed after 1 hour, 43 minutes

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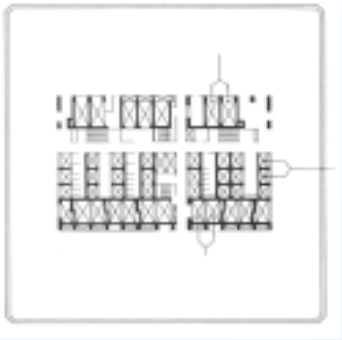
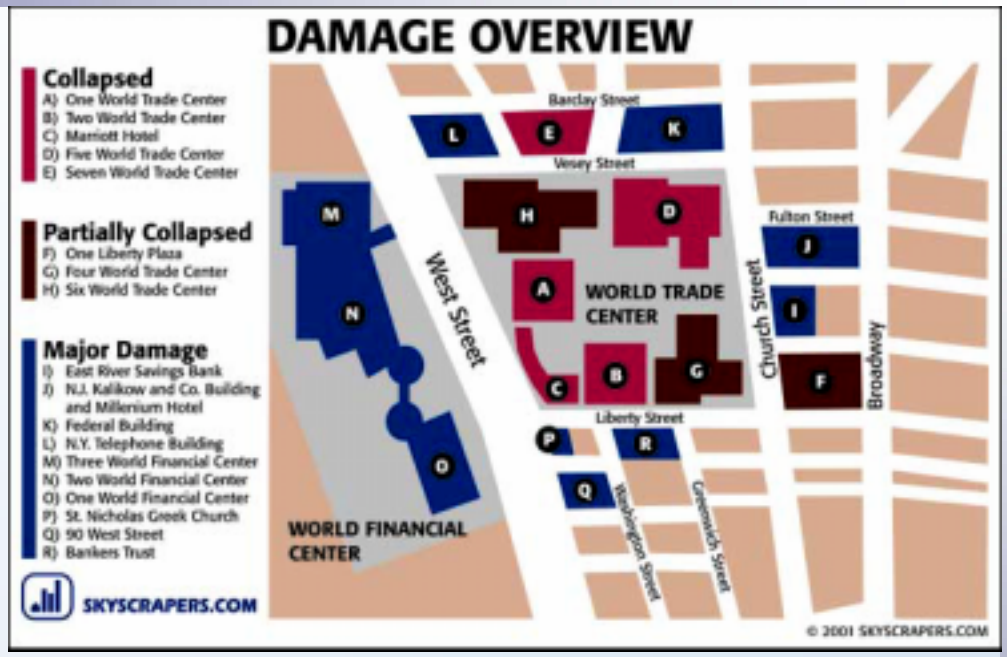
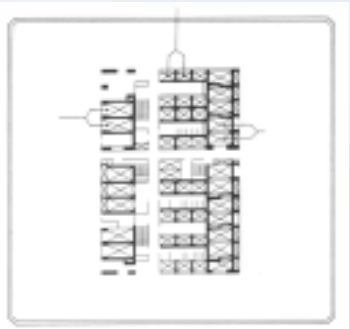
Point of impact: close to the center and nearly normal to the building



North tower



South tower



Point of impact: close to the corner and with an angle

Anecdotal Observations:

15-20 million sq. ft. lost on 9/11

17 million sq. ft. of vacant office space in downtown Manhattan

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Barclay St.
West Broadway St.
Verizon Building
Washington St.
7 WTC (47 Stories)
Old Post Office Building
Vesey St.
6 WTC (9 Stories)
5 WTC (9 Stories)
American Express Building
Fulton St.
Millenium Hotel
1 WTC (110 Stories)
West St.
Austin J. Tobin Plaza
Church St.
Dey St.
Merrill Lynch Building
3 WTC (22 Stories)
2 WTC (110 Stories)
4 WTC (9 Stories)
Cortlandt St.
1 Liberty Plaza Building
Liberty St.
Washington St.
Greenwich St.
90 West Building
Bankers Trust Building

Plan Development Process

June 10, 2002:	• Proposed plan with project details available for public comment
June 24, 2002:	• Public meeting in New York City to receive comments on scope of proposed plan
June 30, 2002:	• Due date for public comments on proposed plan
August 21, 2002:	• Refined plan published and adopted for implementation
September 9, 2002:	• Funds transferred to NIST from FY 2002 emergency appropriation via FEMA

Goals

- **To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the World Trade Center disaster**

- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, maintained, and used
  - Improved tools, guidance for industry and safety officials
  - Revisions to codes, standards, and practices
  - Improved public safety, and business and insurance stability

- **Estimated Time-to-Completion:**
  - Final report in 24 months
  - Interim progress reports and key project reports along the way

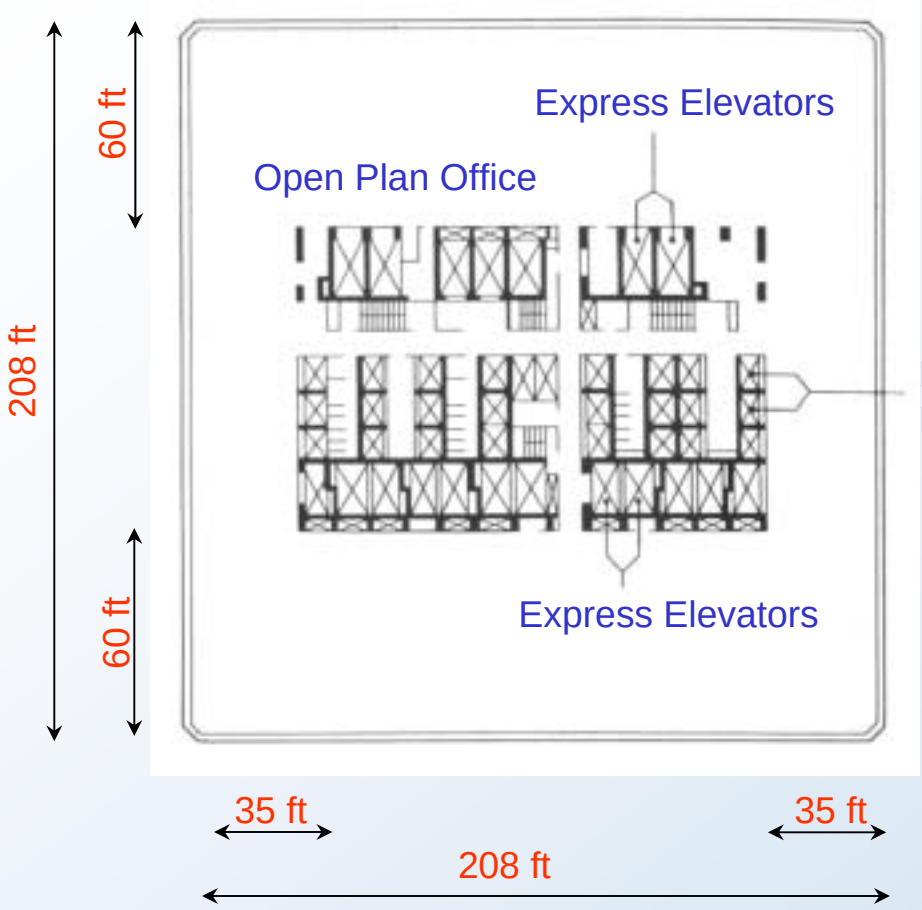
Objectives

- Determine technically, why and how the buildings WTC 1, 2, and 7 collapsed following the initial impact of the aircraft
- Determine why the injuries and fatalities were so low or high 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 the WTC buildings
- Identify, as specifically as possible, building and fire codes, standards, and practices that warrant revision

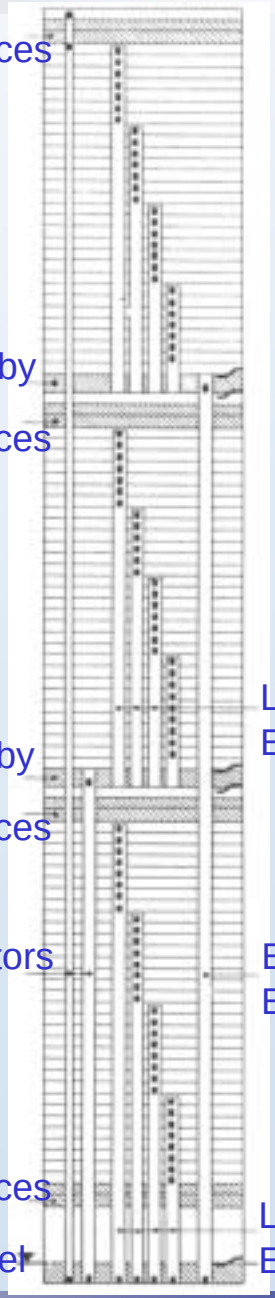
Guiding Principles

- Active, comprehensive, thorough, independent, and objective
- Fully informed of concerns and issues of all parties and within limits of available resources
- Open and inclusive process in planning and conducting investigation and in publishing and disseminating findings and recommendations
- Improve practice, standards, and codes and reduce future risks by focusing on:
  - Fact-finding and analysis of the facts
  - Validating and verifying existing knowledge
  - Creating new technical and/or scientific knowledge
- Non-technical issues outside scope: no findings of fault or negligence of any individual or organization
- Maintain ongoing liaison with professional community, public, and local authorities
- Project teams of NIST and external world-class technical experts

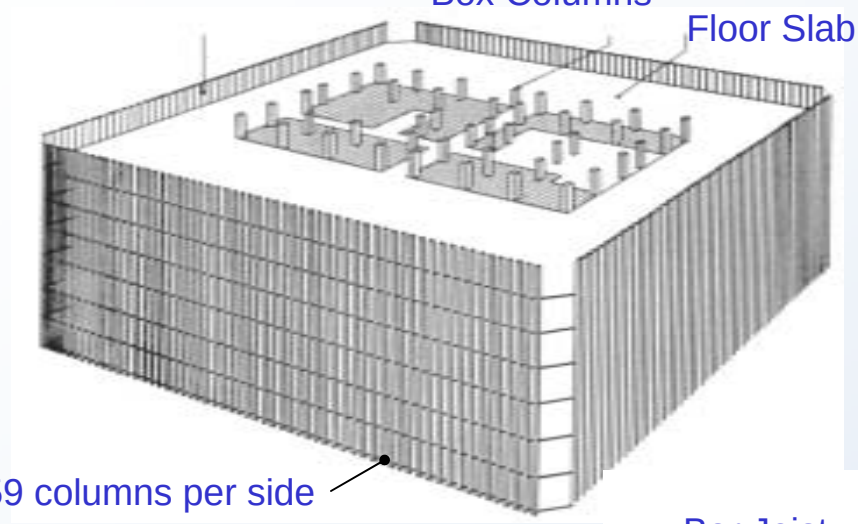
System Design Concept

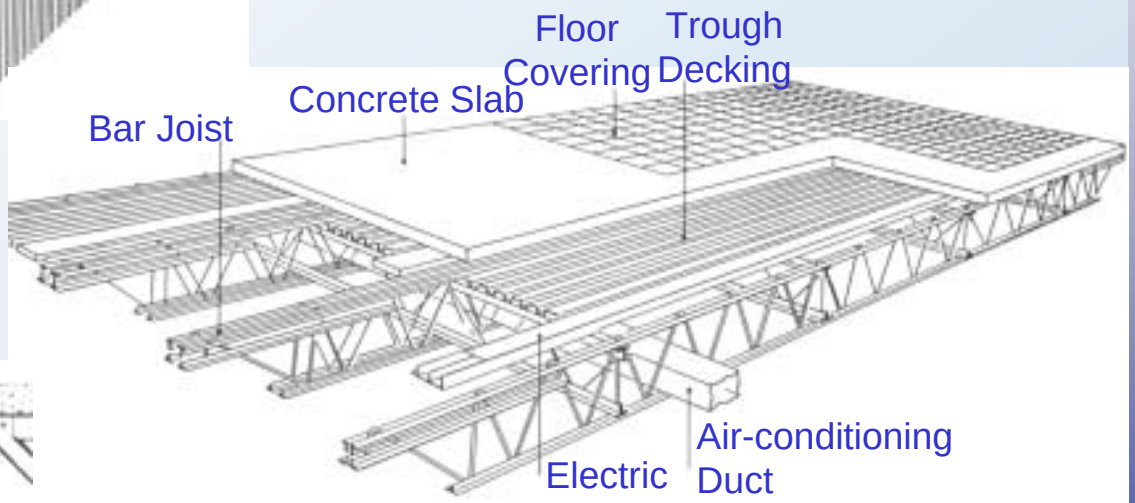


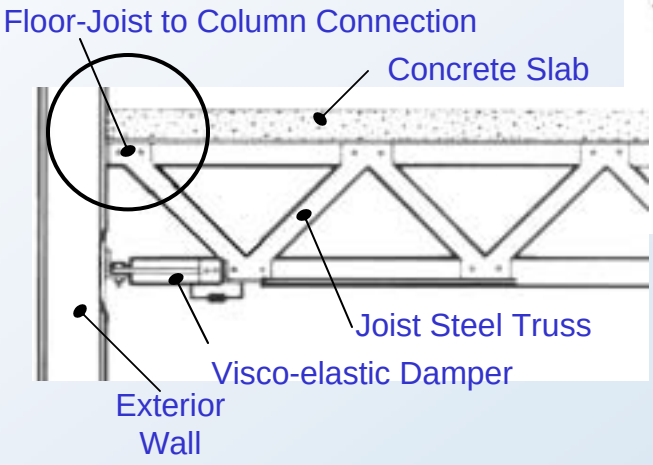
Underground
Car Park
(total capacity 2000)

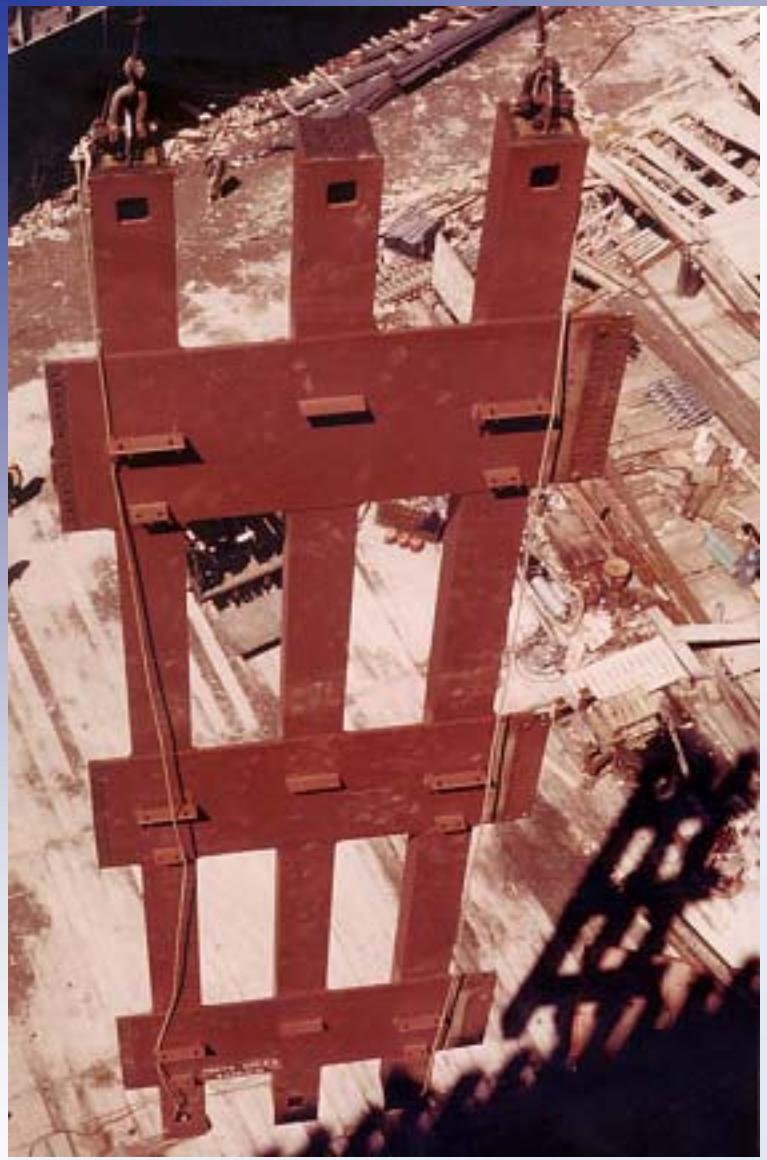


System Design Concept









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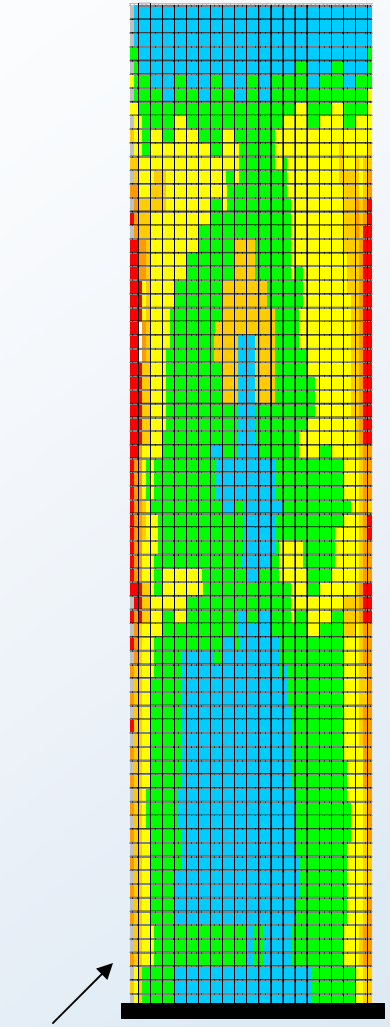
Structural Steel: WTC 1 North Face



Simulated distribution of column yield strengths

- **Gravity loads primary factor in <u>core</u> column design.**
- 4 grades of steel
  (99% are 36 and 42 ksi yield strength)
- Conventional (albeit massive!) column & beam construction

- **Wind loads primary factor in <u>perimeter</u> column design.**
- 14 different grades of steel
  (36 to 100 ksi yield strength)
- Arrangement of steel neither symmetric nor the same for the two towers

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NIST WTC Investigation Projects

BPAT Recommendations

Government, Industry, Professional, Academic Inputs

Public Inputs

Public Inputs

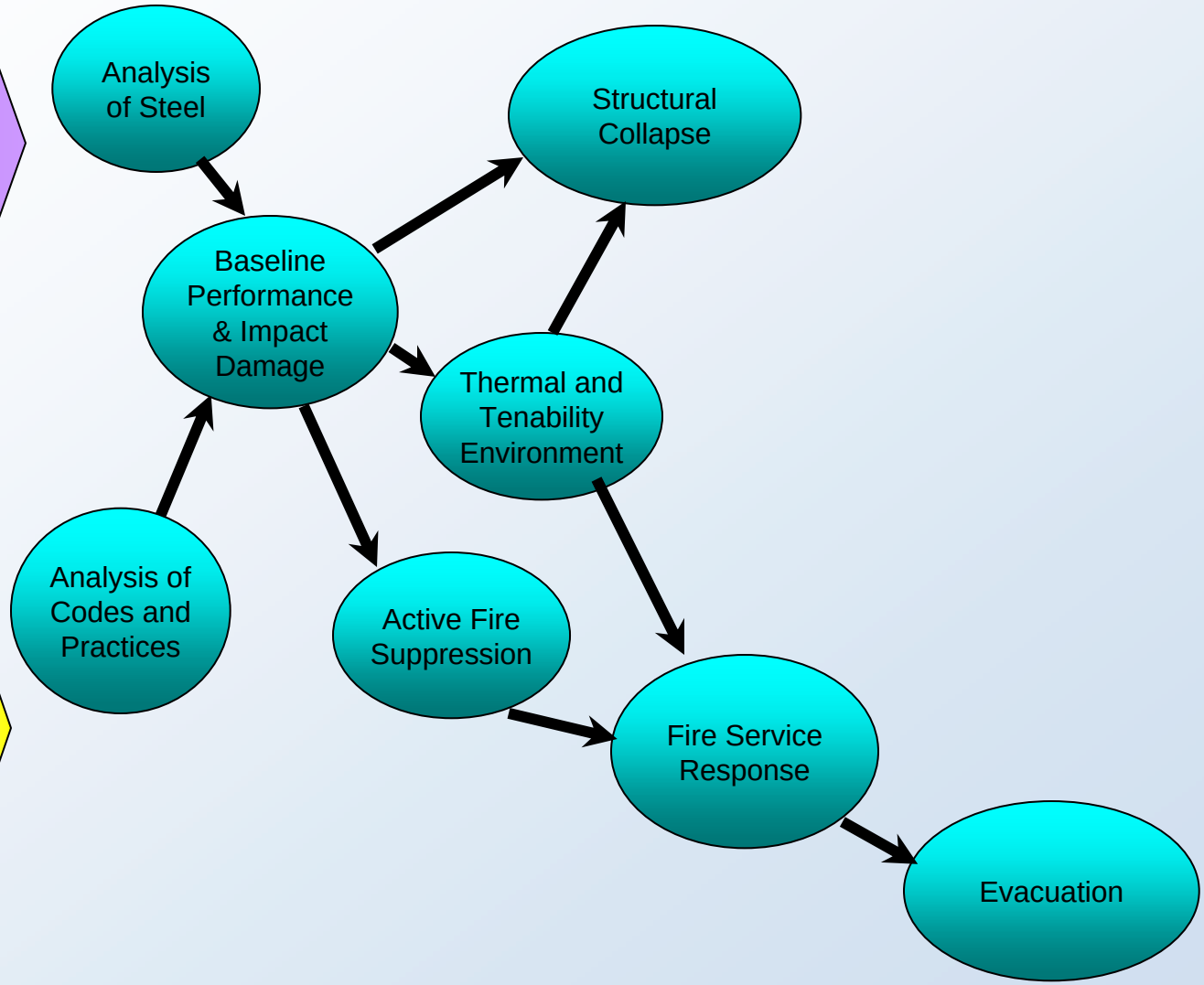
Documents

Video/ Photographic Records

Oral History Data

Emergency Response Records

Recovered Structural Steel



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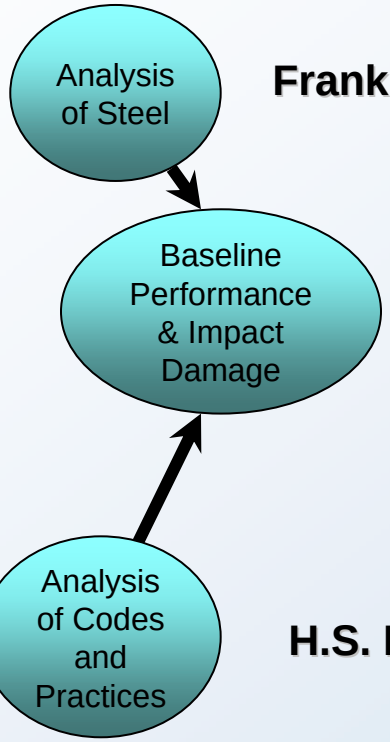
NIST WTC Investigation Plan

Public, Industry, and Technical Inputs



Frank Gayle

Fahim Sadek

H.S. Lew, Dick Bukowski

Public Inputs, Documentary and Material Evidence, Oral History

Scope of Project #1

Analysis of Building and Fire Codes and Practices

- Review **design calculations and project documents**; **project specifications and as-built drawings**; establish design loads and methods used to proportion structural components; approval process for systems not covered by governing code and anticipated abnormal loads
- Review **building construction** (construction logs, change orders, test and inspection reports); document significant events during construction and over the life of the buildings
- Review **active and passive fire protection** features during construction and occupancy (fireproofing, egress, fire stops, compartmentation, enclosure shafts, sprinkler system, fire alarm)
- Review design, operation, maintenance, and inspection of **emergency access and evacuation systems**; U.S. versus international standards; standards, practices, and policies for firefighter lifts
- **Compare design requirements versus code provisions** (NYC, NYS, and national model codes) during design and now; comparison with provisions of selected other major U.S. city codes
- Review **structural systems maintenance and modifications** from initial occupancy to September 11, 2001; review modifications made following the 1993 bombing; focus on portions of building affected by aircraft impact
- Review **fire protection systems maintenance and modifications** from initial occupancy to September 11, 2001; focus on portions of building affected by aircraft impact

Scope of Project #2

Baseline Structural Performance and Aircraft Impact Damage Analysis

- **Develop reference structural models** of WTC 1 and WTC 2; capture intended behavior of structural system, including prefabricated column-spandrel panels, composite floor diaphragm, hat-truss, and connection details; major modifications during bid, construction, and occupancy
- **Analyze baseline performance** of WTC towers under design gravity and wind loads to estimate safety margins; compare original design wind loads with estimates of design wind loads from recent wind tunnel tests
- **Analyze damage to structural system due to aircraft impact** with WTC 1 and WTC 2; **estimate collateral damage** to fireproofing, fire protection system, and fire compartments; analyze component, subsystem, and system level structural damage; assess most probable damage states and influence of knowledge and random uncertainties
- Determine **role of floor diaphragms and hat truss** on structural integrity of WTC towers; analyze stability of undamaged towers with missing or damaged floor systems and/or without hat truss
- Determine **safety margin of WTC 1 and WTC 2**, immediately after aircraft impact and under service loads

Scope of Project #3

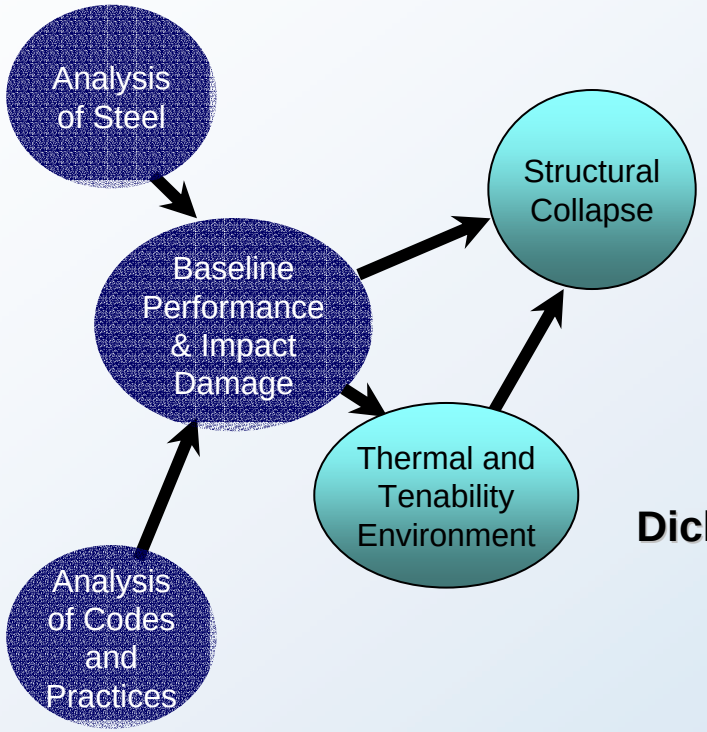
Metallurgical and Mechanical Analysis of Structural Steel

- **Collect and catalog available structural steel**; identify location of steel pieces within the WTC buildings; document relevant steel specifications and specified properties for the WTC towers and WTC 7; obtain proprietary data from suppliers as needed
- **Document failure mechanisms and damage** based on visual observations of recovered steel, especially for available columns, connectors, and floor trusses
- **Determine the metallurgical and mechanical properties** of steel, weldments, and connections
  - Identify grades of steel used for different structural components
  - Room temperature properties to analyze baseline performance
  - High strain rate properties for aircraft impact analysis studies
  - Creep and high temperature properties to evaluate structural fire response
- Analyze the steel and primer paint metallographically to **estimate maximum temperatures reached by available steel**
- **Compare steel properties obtained with applicable material specifications**
  - Perimeter column-spandrel panels;
  - Composite floor truss system
  - Core columns

NIST WTC Investigation Plan

Public, Industry, and Technical Inputs

Public Inputs, Documentary, and Material Evidence, Oral History



John Gross, Terri McAllister

Dick Gann

Scope of Project #5

Reconstruction of Thermal and Tenability Environment

- **Collect and analyze photographic and video images** to guide initial conditions for modeling fires, rates of fire spread through buildings, and floors on which structural collapse may have begun; review **eyewitness accounts of damage to buildings**

- Gather data on internal construction materials/systems, furnishings/contents, and other fuel sources (oil storage tanks, aviation fuel); **characterize types of combustibles and estimates of mass loading**; compare data with prior surveys of similar occupancies

- **Identify pathways for fire ventilation and compartment-to-compartment fire spread** by compiling existing data on fire performance of floor, wall, and ceiling systems, and on the nature of openings (ducts, shafts, etc); conduct complementary experiments as needed

- Determine **thermal properties of structural insulation (fireproofing) systems** as a function of temperature, and effects of vibration, impact, and shock on thermal performance; estimate extent to which fireproofing was in place on September 11, 2001; assess whether chemical interaction between insulation and steel at elevated temperatures could degrade performance

- **Extend capabilities of NIST's Fire Dynamics Simulator (FDS)** to reconstruct temperature, thermal, and smoke fields (including floor spaces, stairwells); use reduced-scale experiments to validate FDS sub-models

- **Reconstruct fully involved fires, with and without initial damage from aircraft or incident debris**; assess probable fire paths and timeline of fire spread, influence of knowledge and random uncertainties; parameters include ignition mode/location, jet fuel and building contents, ventilation system, compartment damage, core pressurization, fire protection system, rate and extent of fire spread, extent of hot smoky and toxic conditions

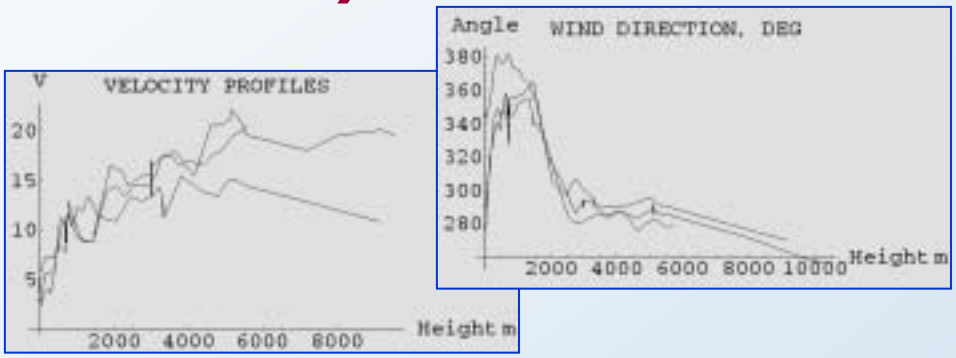
Scope of Project #6

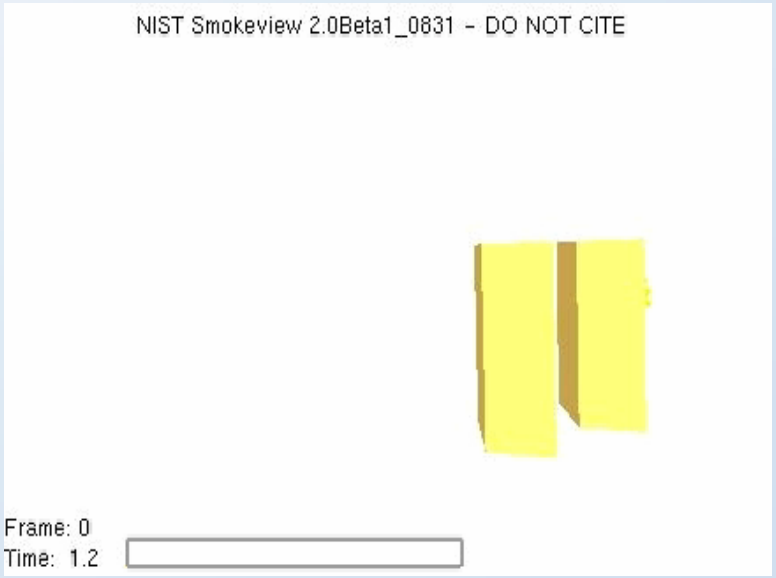
Structural Fire Response and Collapse Analysis

- Evaluate **thermal-structural response of floor and column subsystems under service loads**; model typical composite floor system, prefabricated column-spandrel panels, and core column systems; model typical connection supports; standard (ASTM E-119, ASTM E-1529) fires, and real fires based on fire dynamics simulations; unprotected steel, and steel with different fireproofing thicknesses; assess local failure of components and sub-systems using strength, serviceability, and stability criteria
- Evaluate **thermal-structural response of WTC towers under service loads, without and with aircraft impact damage**; model structural system to include fire-affected and impact damage regions; standard (ASTM E-119, ASTM E-1529) fires, and real fires based on fire dynamics simulations; unprotected steel, and steel with different fireproofing thicknesses; assess failure of subsystems and system using strength, serviceability, and stability criteria; determine safety margin of components and subsystems critical to system collapse initiation
- Conduct **tests of structural components and systems under fire conditions**; use tests to validate analysis models and provide response data otherwise unavailable
- Evaluate failure hypotheses for the WTC towers; identify candidate sequence of events for collapse initiation; assess probable collapse initiation sequences, and influence of knowledge and random uncertainties; evaluate role of floor diaphragms, connections, hat truss, and other key elements; **identify most probable structural collapse sequence**
- Document **past fire performance of open-web steel bar joist systems**; review available fire incident and insurance investigation reports; review available test reports (ASTM E-119) or others; domestic and international data; compare past performance with performance of bar joist floor system in WTC towers
- Analyze **thermal-structural response of WTC 7 through collapse initiation**; model structural system with refinement in fire-affected region; standard (ASTM E-119, ASTM E-1529) fires, and real fires based on fire dynamics simulations; determine safety margin of components and subsystems critical to system stability; assess failure of subsystems and system using strength, serviceability, and stability criteria; assess probable collapse initiation sequences, and influence of knowledge and random uncertainties; evaluate role of transfer trusses and other pivotal elements; identify most probable structural collapse sequence

Simulation Tool for Re-creation of Fire and Smoke Movement (Rehm et al.)

Three commercial flights reported data using the Addressing and Reporting System (ACARS)

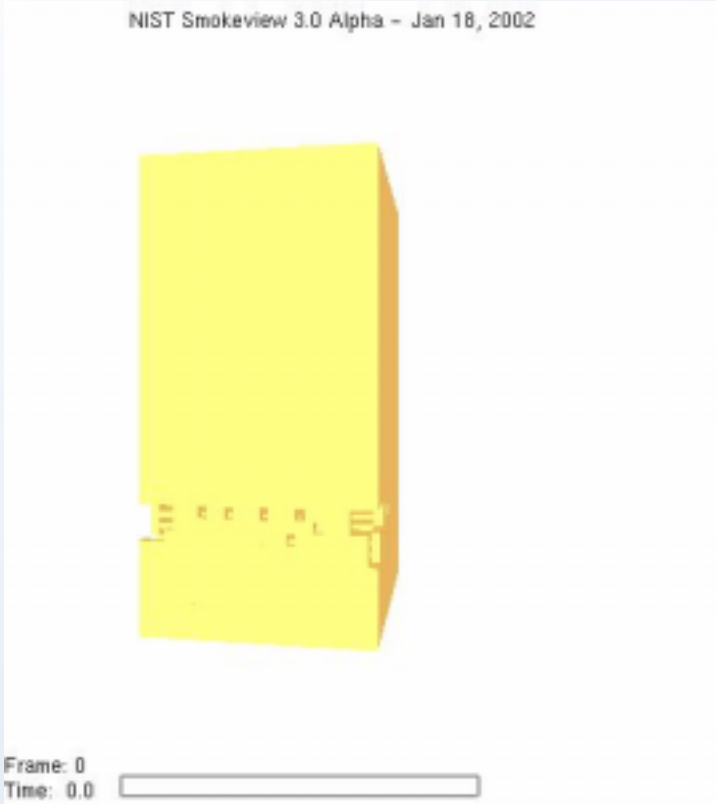




FDS 1

Wind 5 m/s to south

South Tower Fireball



Seconds after impact.
About 3000 kg fuel consumed.

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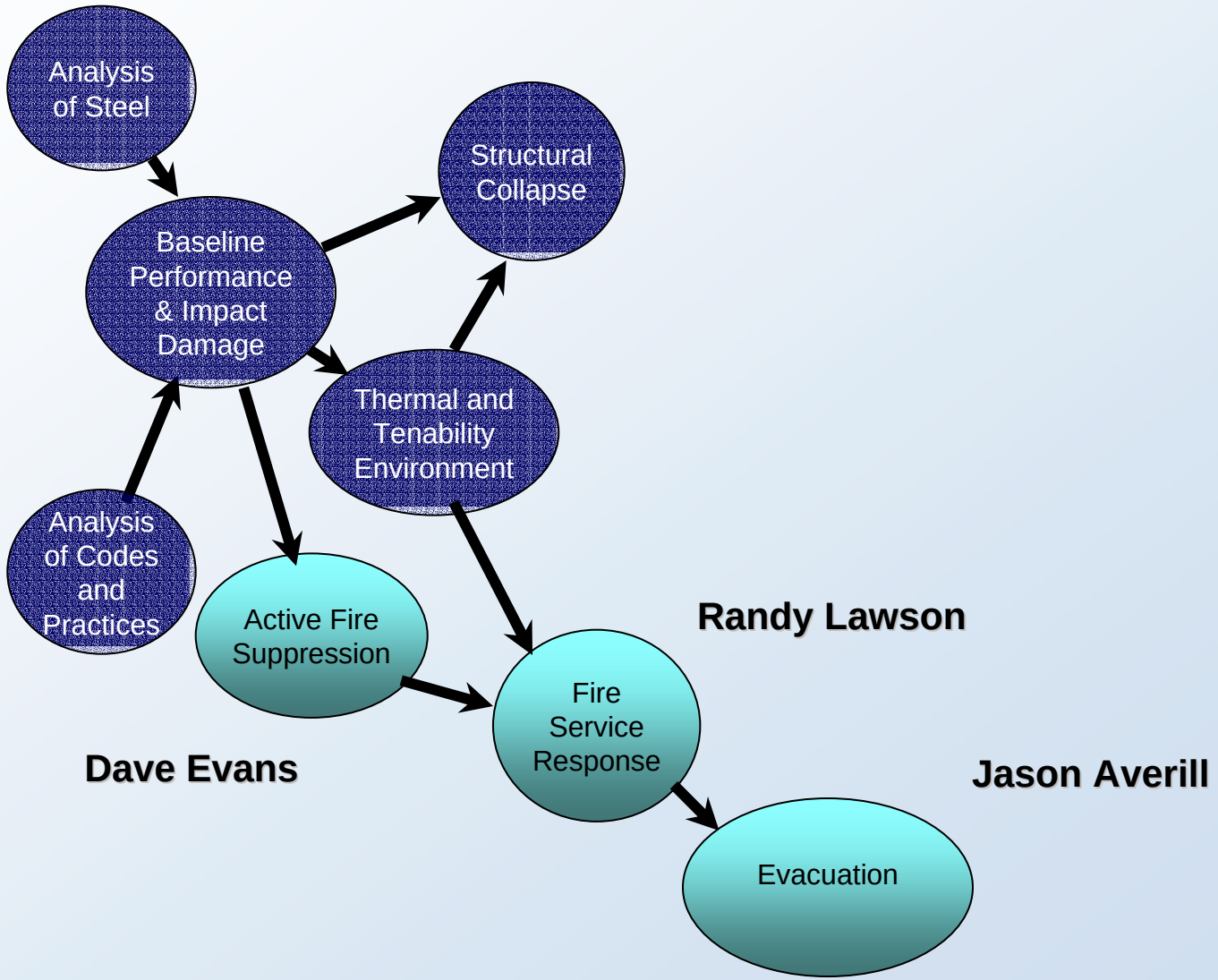
Simulation Tool for Recreation of Fire and Smoke Movement

NIST WTC Investigation Plan

Public, Industry, and Technical Inputs

Public Inputs, Documentary, and Material Evidence, Oral History



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Scope of Project #4

Investigation of Active Fire Protection Systems

- Document the **design, installation, and normal operation of active fire protection systems** (sprinkler system, fire water supply, power supply, pre-connected hoses, fire alarm, emergency communication systems, smoke management systems); review available fire inspection reports; review capacities, redundancies, and defense-in-depth
- Document the **past performance of active fire protection systems during significant fires**
- Estimate **limits of performance for fully functional sprinkler systems** as installed
- Review **inspection records** for active fire protection systems; document **modifications** made to the fire alarm system after the 1993 bombing incident
- Document **performance of active fire protection system on September 11, 2001**; assess system performance under similar fires without aircraft damage to the system

Scope of Project #7

Occupant Behavior, Egress, and Emergency Communications

- **Collect new first-person data** from occupants and those with safety responsibilities, first responders, and families of victims affected by the WTC disaster via interviews and statistical surveys; focus on occupant behavior, human factors, egress, and emergency communication
- **Compile and analyze first-person media accounts** from survivors and families in coordination with other data collection efforts
- **Collect archival records from prior WTC evacuation incidents and practice evacuations**, including changes made to evacuation procedures, augmented with oral history data from fire safety directors
- Document **pre-event data on egress components** (stairs, lighting, back-up power, elevators), active fire protection systems, occupancy level and distribution on September 11, 2001, emergency communication systems, and emergency plans and drills
- **Analyze data to study movement of people during evacuation**, including decision-making and situation awareness, time-constrained evacuation strategies, emergency communications, fire protection and firefighting, role of fire wardens and fire safety directors, and issues concerning people with disabilities; develop evacuation timeline
- **Evaluate evacuation designs and protocols**; compare with code requirements and practices; compare observed evacuation data with predictions of alternate egress models and experience with prior evacuations; review occupant protection practices for tall buildings, considering different (e.g., phased, full) evacuation strategies

Scope of Project #8

Fire Service Technologies and Guidelines

- Document **emergency response data** on first responder fatalities, command and control procedures, equipment performance, radio and 911 communications, dispatch logs, and positioning of emergency apparatus

- Document **operations and functioning** of communication systems, on-site emergency information systems, fire alarm panels, elevator control panels, standpipes and fire hoses, and other pre-positioned emergency equipment

- **Collect oral history data** from surviving first responders, those in control of emergency operations, and witnesses to the extent data has not been documented fully

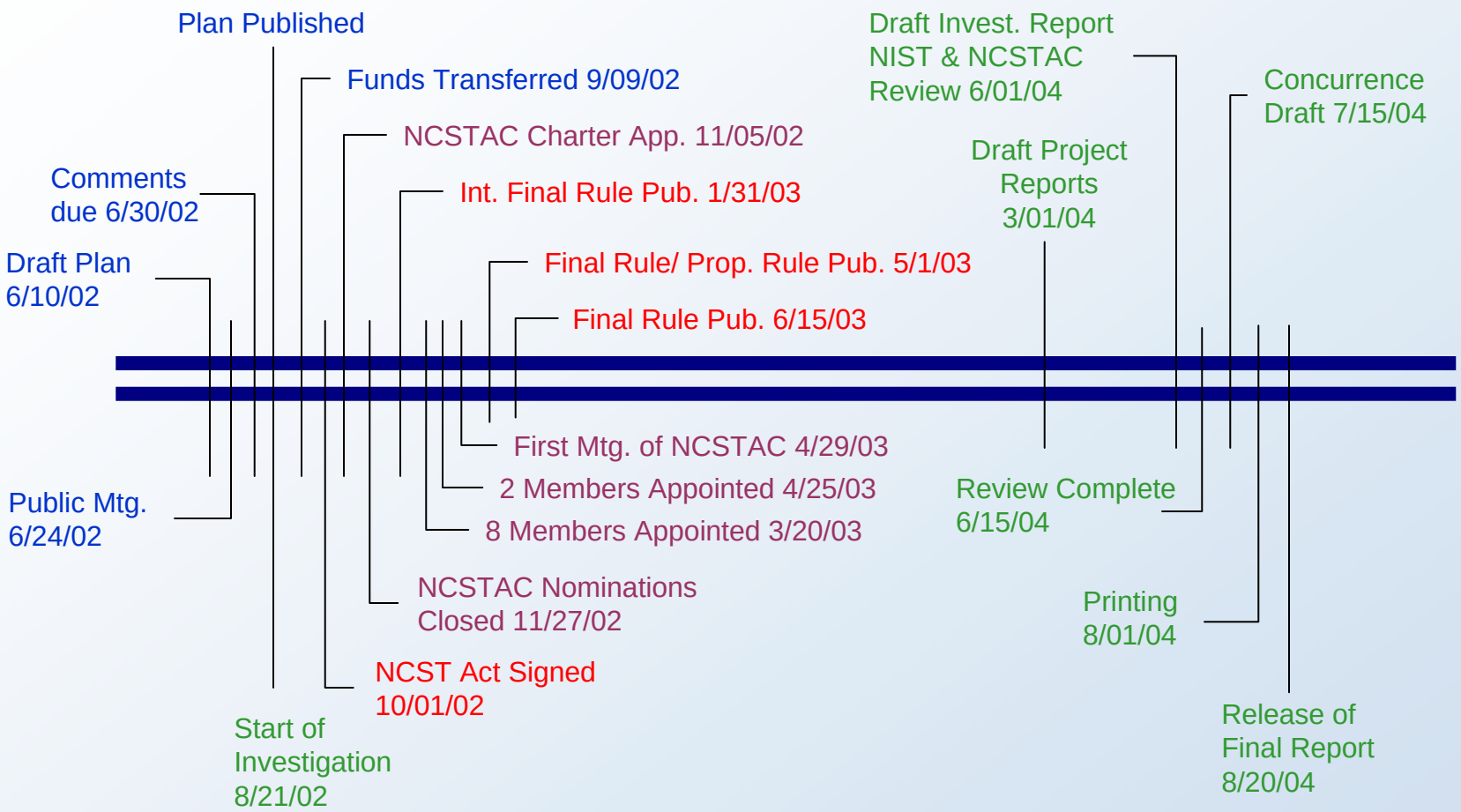
- Analyze data to **determine effects of key factors on responder success**: influence of building design, influence of aircraft impact damage and fuel run-off; occupant egress as related to fire service operations; ability to fight large fires on upper floors of tall buildings; change in fire service practices due to 1993 bombing; pre-planning, training, and standard operating procedures during incident; firefighter accountability, location and tracking; fire and emergency response protocols for tall buildings; resources available for initial situation assessment and incident management, including possibility of structural collapse; communications and coordination with other authorities

- Identify **alternative emergency response practices and technologies and R&D needs** that could advance safety and effectiveness of first responders during massive fires in tall buildings: knowledge/information systems for command and control; elevator use by firefighters; firefighter tracking systems; interoperability of communication systems; fire growth and smoke hazard prediction; structural safety monitoring, assessment, and prediction; simulation tools for training

Lessons to be Derived

- **Lessons for Structural Fire Protection**
  - Dynamics of building fires and collapse vulnerability of buildings to fires
  - General methodologies for fire safety design and retrofit of structures
  - Behavior of fireproofing materials and connections used in steel structures
  - Behavior of open-web steel trussed joists in fires
  - Collapse mechanisms and role of pivotal components such as transfer girders and floor diaphragms
- **Lessons for Life Safety**
  - Firefighting technologies and practices for tall buildings
  - Occupant behavior and evacuation technologies and practices for tall buildings
  - Control of fire spread in buildings with potentially large open floor plans
  - Command, control, and communication systems for fire service response
- **Lessons for Engineering Practice**
  - Evaluation process for innovative systems
  - Margin of safety and redundancy to accommodate abnormal loads

WTC Investigation Timeline



Color Key: **Investigation Plan Development** **NCST Act Implementation** **Investigation** **NCST Advisory Committee**

Desired Outcomes

Make buildings safer

Enhance safety of fire and emergency responders

Better protect occupants and property in future

Better emergency response capabilities and procedures in future

Contact Information

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Thank You