Federal Building and Fire Safety Investigation
of the World Trade Center Disaster

Reconstruction of the Thermal and Tenability Environment

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Project Objective

Reconstruct, with assessed uncertainty limits, the time-evolving temperature, thermal radiation, and smoke fields in World Trade Center buildings 1, 2, and 7 for use in evaluating the behavior and fate of occupants and responders and the structural performance of the buildings

Project Approach

- Due to lack of physical evidence, we rely almost exclusively on:
  - Computer simulations
  - Experiments
  - Photographic evidence
  - Eyewitness accounts
- Since this type of reconstruction has never been done before, we will be re-defining the state-of-the-art in fire and thermostructural modeling
- Integrated with other Projects, esp. 2 and 6
- Project 5 divided into 8 tasks

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Tasks

1. Visual collection and time line development [Pitts]
2. Characterization of combustibles [Gann]
3. Characterization of partitions [Averill]
4. Characterization of structural insulation [Yang]
5. Fire model (FDS) development [McGrattan]
6. Experiments for model development [Mulholland]
7. Fire reconstruction [McGrattan]
8. Reconstruction validation [Hamins]

Total: 32 people

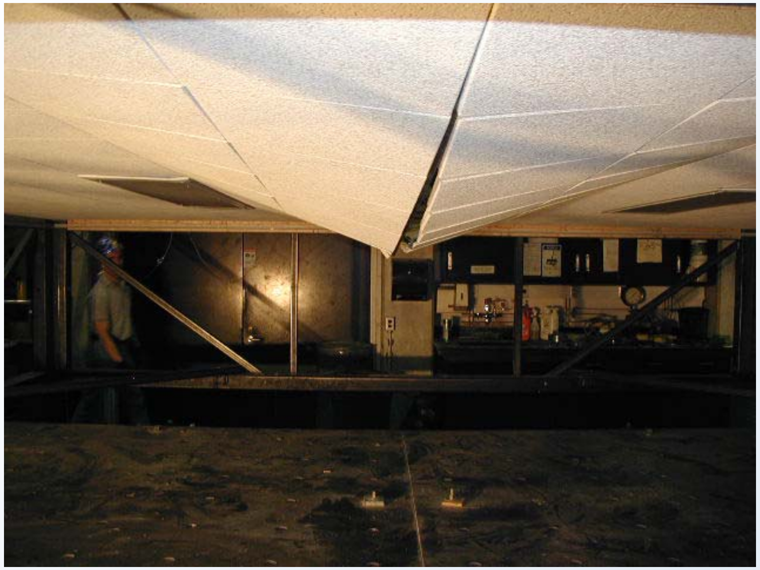
Input Information for Experiments and Modeling [Tasks 2,3]

- Sources of building information
  - Some tenants, Port Authority of New York and New Jersey
- Building combustibles, floor geometry, partition nature
- Aircraft contents (from airlines, Boeing)
  - Jet fuel (mass and location), cabin combustibles, cargo bay contents
- Interim findings
  - Mass of aircraft solid combustibles was significant relative to the mass of the building combustibles in the impact zone
  - View through many windows was blocked by interior walls

Performance of Ceiling Tile Systems [3]

- Premise: Dislodging of ceiling tiles removes a barrier between flames and structural members
- Purpose: Learn about the reaction of the systems to shock (at locations away from the direct aircraft impact)
- Shake table experiments performed at University at Buffalo with collaboration of Armstrong World Industries
  - Tile systems very much like those in tenant and building core spaces
  - Varied intensity and nature of impulse pattern
- Interim finding: Impulses like those estimated from the aircraft caused serious damage to the ceilings, enabling “unabated” heat transport over the walls and to the joists

Performance of Ceiling Tile Systems [3]



1.25 g single pulse

1.25 g complex pattern

Condition of Spray-on Insulation [4]

- Initial Condition
  - Compiled requirements and history
  - Examining buildings for thickness variability
- Measurements of thermal properties
- Measurements of mechanical properties

Thermal Properties of Insulation Materials [4]

- Purpose: Obtain input data for modeling the heat transfer from the fires to the structural members
- Materials
  - Spray-on insulation (3 types) used in all 3 buildings: 25 °C to 1200 °C
  - Gypsum sheet (4 types): 25 °C to 600 °C
- Measurements using adapted ASTM methods
  - Thermal conductivity
  - Density
  - Heat capacity
- Samples currently at test labs

Mechanical Properties of Insulation Materials [4]

- Purpose: Enable estimation of the extent of damage to insulated structural members resulting from impact of aircraft fragments
- Materials
  - Spray-on insulation (2 types) used in WTC 1 & 2
- Measurement using custom and ASTM methods
  - Cohesive properties: sheer strength and tensile strength
  - Bond strength to steel substrates
- Development of simple models to predict dislodgement
- Work currently underway

Modeling of Thermal Transport Through Insulation [4,5]

- Different time and dimension scales for FDS (CFD fire model) and ANSYS (FE thermostructural model)
- Developed novel method for communicating results
- Performed simulations of heat transfer for varying conditions of thermal insulation
  - Reduced thickness
  - Bare spots
- Determined time to weakening temperature of steel
- Accuracy from comparison with data from insulated steel fire tests
- Finding: Small areas of thin or missing insulation can lead to accelerated heating over much larger lengths of steel

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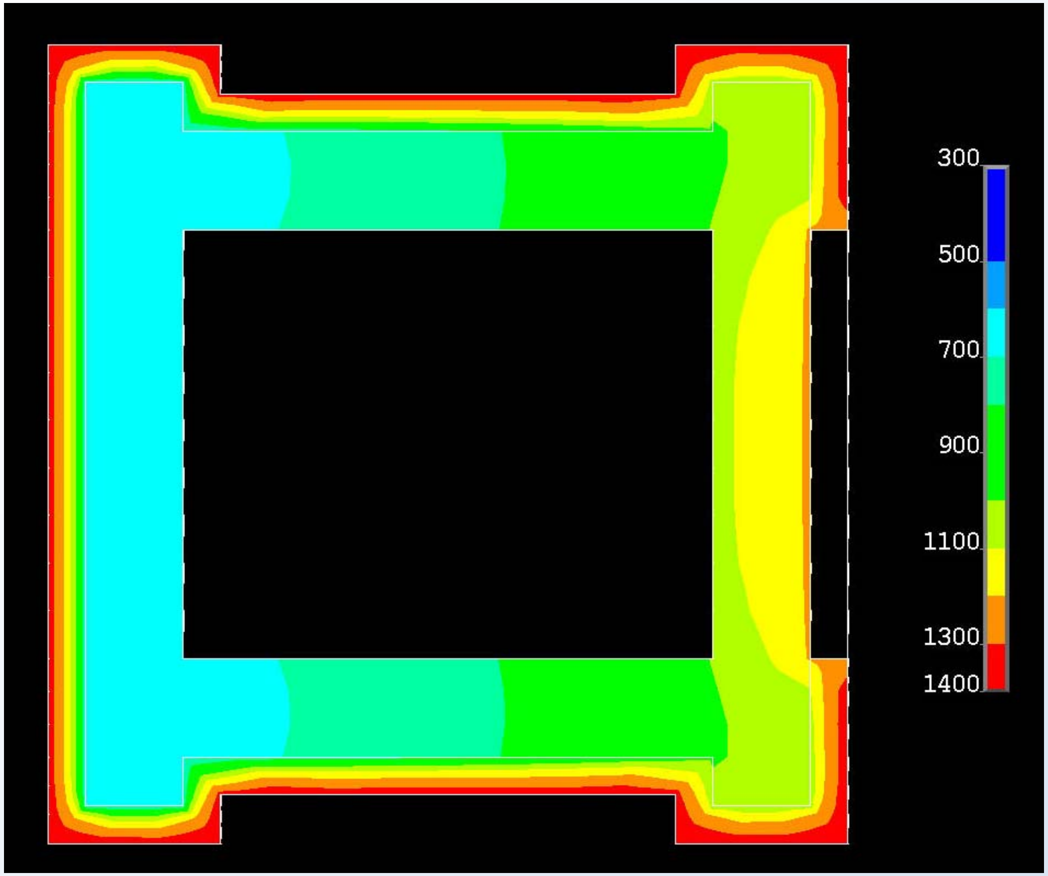
Modeling of Thermal Transport Through Insulation on a Heavy Column [5,7]



1400 K Fire; photo @ 2 h

- Intact 13 mm coating (~BlazeShield): >10 h to raise core column to 900 K (600 °C)
- Random damage (av. 20 %): strength being lost in 6 hours
- Stripped on one face: at that face, 900 K reached in 12 min

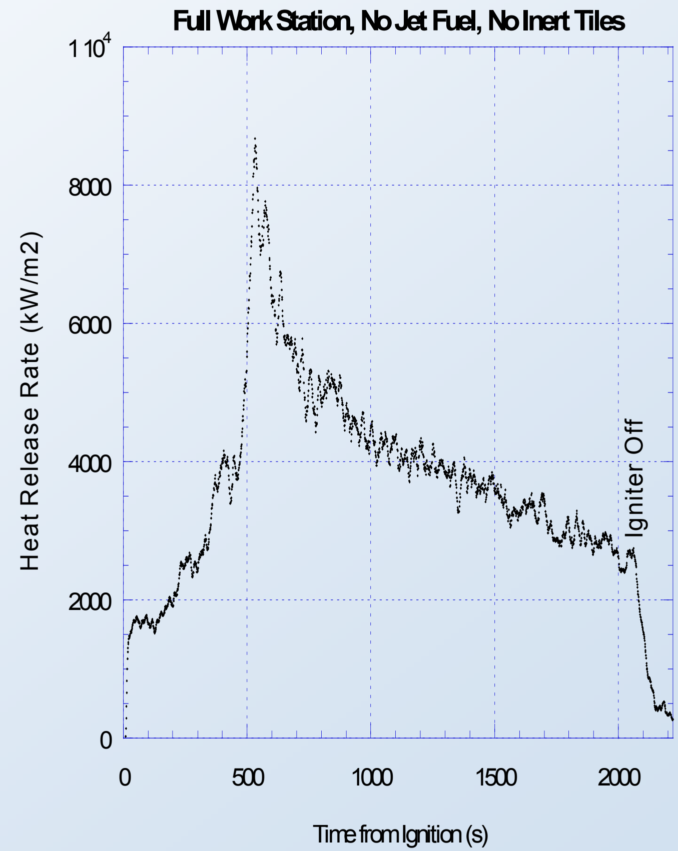
Fire Dynamics Simulator (FDS) [5,7]

- 3-D model
- Fluid dynamics from Navier-Stokes equations
- Combustion and flame spread
  - Radiation-driven gasification of combustible
  - Combustion = stoichiometric mixture fraction
- Resolution: 0.1 m, 0.4 m
- Previously validated for, e.g.,
  - Tunnel fire temperatures
  - Sprinkler activation

Single Workstation Fire Experiments [6]

- Purpose: use results to upgrade FDS
- Combustible: single typical work station
- Conducted under a hood with a confined ceiling
- Variables
  - Presence of jet fuel
  - 30 % coverage by inert material
- Ignition by adjacent 2 MW spray burner
- Measure heat release rate (HRR), sample mass, [CO]
- Film fire progress
- Materials thermophysical data from Cone Calorimeter

Single Workstation Burn [6]



Single Workstation Results [6]

- Modeling at 0.1 m resolution
- Peak heat release rate (HRR) *ca.* 6 MW at *ca.* 9 min
- Jet fuel accelerated peak to *ca*. 3 min, with little change in total HR
- Inert material reduced peak HRR in proportion to surface coverage
- Finding: FDS reproduced the results without adaptation
  - HRR(t) per test
  - Differences among tests
- Little need to tune FDS

Multiple Workstation Experiments [8]

- Purpose: Assess the accuracy of FDS in tests of full complexity
- Three workstations: two contiguous, one separated by an aisle
- Large compartment with one wall mostly open
- Variables:
  - Presence of jet fuel
  - *ca.* 70 % coverage by inert material
  - Location of 2 MW ignition burner (ventilation)
  - Condition of workstation (assembled, rubble)
- Measure HRR, mass of each workstation, [CO], temperatures, heat flux; video
- FDS predictions completed before experiments
  - Resolution reduced to 0.4 m, same as for WTC fire reconstruction

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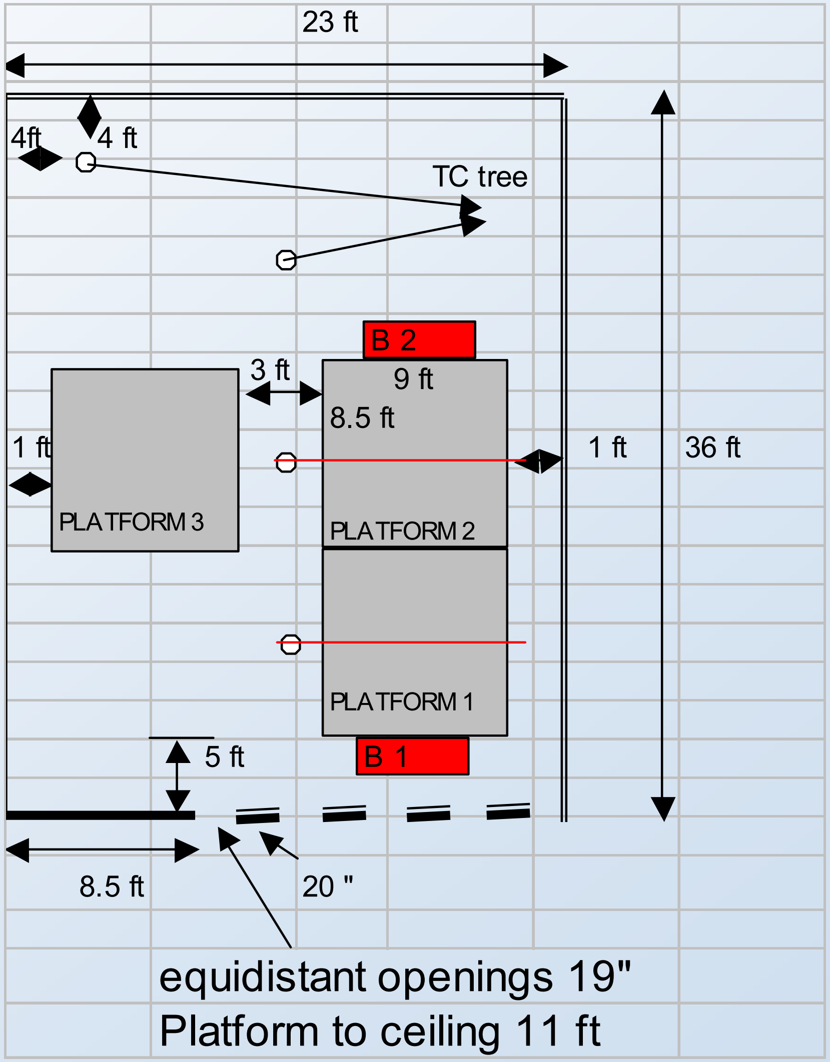
Multiple Workstation Burn [8]



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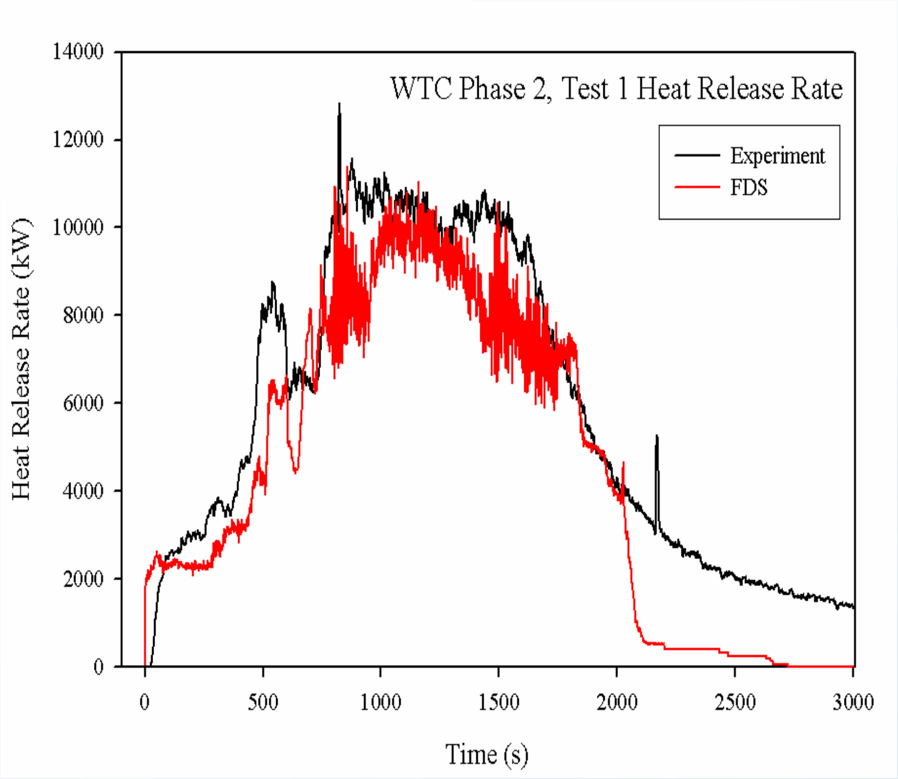
Multiple Workstation Burn Results [8]



- Excellent agreement
- Noise is from turbulence, both in the model and the experiment
- Early HRR falloff in prediction due to small underestimate of combustible mass
- Provisional finding: FDS can be used with confidence to recreate a given WTC fire event

Next Steps

- Parametric variation of building conditions
  - Aircraft damage or none (WTC 1& 2)
  - Ventilation
  - Fuel load and distribution
  - Location and state of partitions
- Comparison of results with visual evidence and verbal accounts
- Identification of most likely fire patterns
- Interaction with thermostructural modeling
  - Potential for building collapse from fires only
  - Identification of most likely collapse processes on 9/11/01

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Thank you

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