

3. The heating and consequent weakening of the structural elements by the fires.
4. The response of the damaged and heated building structure, and the progression of structural component failures leading to the initiation of the collapse of the towers.

For such complex structures and complex thermal and structural processes, each of these steps stretched the state of the technology and tested the limits of software tools and computer hardware. For example, the investigators advanced the state-of-the-art in the measurement of construction material properties and in structural finite element modeling. New modeling capability was developed for the mapping of fire-generated environmental temperatures onto the building structural components.

The output of the four-step simulations was subject to uncertainties in the as-built condition of the towers, the interior layout and furnishings, the aircraft impact, the internal damage to the towers (especially the thermal insulation for fire protection of the structural steel, which is colloquially referred to as *fireproofing*), the redistribution of the combustibles, and the response of the building structural components to the heat from the fires. To increase confidence in the simulation results, NIST used the visual evidence, eyewitness accounts from inside and outside the buildings, laboratory tests involving large fires and the heating of structural components, and formal statistical methods to identify influential parameters and quantify the variability in analysis results.

- Combination of the knowledge gained into probable collapse sequences for each tower,² the identification of factors that contributed to the collapse, and a list of factors that could have improved building performance or otherwise mitigated the loss of life.
- Compilation of a list of findings that respond to the first three objectives and a list of recommendations that responds to the fourth objective.

E.3 SUMMARY OF FINDINGS

Objective 1: Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft.

- The two aircraft hit the towers at high speed and did considerable damage to principal structural components (core columns, floors, and perimeter columns) that were directly impacted by the aircraft or associated debris. However, the towers withstood the impacts and would have remained standing were it not for the dislodged insulation (fireproofing) and the subsequent multi-floor fires. The robustness of the perimeter frame-tube system and the large size of the buildings helped the towers withstand the impact. The structural system redistributed loads from places of aircraft impact, avoiding larger scale damage upon impact. The hat truss, a feature atop each tower which was intended to support a television antenna, prevented earlier collapse of the building core. In each tower, a different combination of impact damage and heat-weakened structural components contributed to the abrupt structural collapse.

² The focus of the Investigation was on the sequence of events from the instant of aircraft impact to the initiation of collapse for each tower. For brevity in this report, this sequence is referred to as the “probable collapse sequence,” although it includes little analysis of the structural behavior of the tower after the conditions for collapse initiation were reached and collapse became inevitable.