The NIST WTC Investigation--
How Real Was The Simulation?

A review of NIST NCSTAR 1

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nistreview.org

December 2006

Abstract

The NIST investigation of the WTC building failures was extensive, but NIST did not substantiate its conclusions experimentally. On the contrary, many of NIST's tests contradicted its conclusions. Furthermore, there are several examples in which NIST chose to manipulate input data, and then certify its findings based upon the inevitable conclusions that derive from the manipulated input. One finds little acknowledgement on the part of NIST that uncertainties in its simulations translate into uncertainties in its findings.

NIST's physical tests were inadequate. Their ASTM E119 tests and their workstation burn tests were improperly modeled. Further, the former produced results that contradicted NIST's conclusions and the latter fell far short of testing the performance of realistic steel members in the actual fire conditions. The workstation burn tests showed that the temperatures were generally too low, especially in the ventilation-controlled WTC environments. The ASTM E119 tests showed that the WTC floor trusses should have easily withstood the fires they experienced on 9/11.

There were also flaws in NIST's computer simulations, including its impact simulation, its fire loading simulation, its temperature mapping simulation, its thermal/structural component simulations, and its global simulation. The LS-DYNA simulation showed that the aircraft would have done much less damage than NIST assumes, and NIST's subsequent "scenario pruning" was confused and unsubstantiated. The decision to exclude the hat truss from the structural/thermal response simulations was a significant omission. The sequence of failed truss seats leading to pull-in forces on the exterior columns is central to NIST's theory but not explained or supported by simulation.

This paper will conclude that the findings of the NIST investigation, although not necessarily incorrect, are not inherently linked to the reality of the failure mechanisms that took place in WTC buildings 1 and 2. The author calls on NIST to explain the discrepancies in its reports, admit the level of uncertainty in its findings, broaden the scope of its investigation, and make its raw data available to other researchers.

Keywords: Buildings, collapse, fire, large deflections, stability, structural analysis, structural damage, structural response to fire, World Trade Center.

1.0 Introduction

The destruction, on September 11, 2001, of the seven buildings that comprised the World Trade Center (WTC) complex in New York City was arguably the most significant series of structural failures in the history of modern construction. As members of the building community, we are keenly interested in understanding the cause of these failures and the lessons to be learned from them.

The first official response to the WTC collapses, a report from FEMA (the Federal Emergency Management Agency), did little to explain the failures of WTC buildings. It was followed by several interim reports, and then a final series of reports from the National Institute of Standards and Technology (NIST) that expanded the discussion of WTC 1 & 2, dealt with WTC 7 briefly, and ignored the other buildings. (NIST has promised a full report on WTC7 by early 2007.) NIST did not entirely accept FEMA's conclusions, but, as this report will argue, did an unsatisfactory job of validating its own.

An important question in reviewing any scientific study is Do the findings follow from objective testing, or are the data and tests manipulated to fit a desired outcome? This paper will show that NIST followed a pattern of favoring data that supported its theories and rejecting valid data that did not.

It will also discuss how realistic and conclusive the tests were that NIST performed. As we shall see, NIST did very little physical testing, and, of that, much was irrelevant or inconclusive. In fact, almost the entirety of NIST's testing was actually computer simulation. In itself, this is not necessarily problematic. What is disconcerting is that NIST seems to attribute a level of certainty to its computer-generated findings that may be grossly out of scale. Since building codes, safety standards, and building design will be influenced by the conclusions and recommendations of the NIST WTC reports, it is important that a realistic assessment be made of the foundation upon which they rest.

This paper will attempt to comment on all testing that NIST performed in its WTC investigation and follow the "order" of the tests as one informed the next. It takes no interest in the non-building discussions. Only WTC 1 and WTC 2 will be addressed as these are the only buildings discussed in NCSTAR 1 (the series of reports considered herein).

It should be noted that the intent of this paper is to evaluate the validity of NIST's conclusions, not the merit of the suggestions that derive there from. This report takes no position at all regarding whether NIST's recommendation for improving building safety should be implemented, and is not intended as an effort to resist the improvement of building safety standards. NIST should be recognized and applauded both for the massive effort put forth to investigate these extraordinary building failures and for its efforts to advocate improved building safety. Unfortunately, despite its intensive research, some internal conflicts remain unresolved. These conflicts will be the focus of this paper and its intent is to encourage their resolution. Furthermore, the author, lacking resources, makes no attempt to provide parallel testing data or simulations, but only attempts to suggest ways in which the stated procedures could have been more rigorous.

(Note: Referenced materials are available online at www.wtc.nist.gov and www.nistreview.org)

2.0 Physical Tests

The NIST WTC investigation suffered from a paucity of physical testing. Effectively, all of NIST's conclusions are derived from computer simulation. The reasons for this are not entirely clear. NIST should have performed destructive tests on mockups of key components of the WTC structural systems. This was especially important since many of the WTC building's structural features were very innovative for their time. As section 3 will argue, complex structural systems involving several materials, components, and connections can be much more accurately tested with physical models. As we review the few physical tests that NIST performed, we see that they left many questions unanswered.

2.1 Single Workstation Burn

NCSTAR 1-5, section 3.2 describes the first of only two series of physical tests conducted by NIST designed to predict the temperatures and heat release rate (HRR) profiles that the WTC buildings (1 and 2) might have experienced due to building combustibles. (A second series was conducted for the purpose of validating a computer simulation.) Unfortunately, NIST lists only the heat release rates and mass loss profiles--it does not list the temperatures attained during the tests. This is significant in that it is critical to establish whether common office furnishings and equipment, such as the WTC buildings contained, could have reached temperatures sufficient to cause the structural systems to fail. The issue becomes more relevant in light of several considerations, such as:

- Modern office furniture is required to meet strict flame-resistant standards. It is unlikely that any items in the typical office spaces contained any unusually combustible materials. As NIST noted, "visits to showrooms indicated that, while there was a broad range of prices and appearances, the cubicles were fundamentally similar." (NCSTAR 1-5 p50, para4)
- NIST dismisses the possibility that jet fuel played a sustained role in the fires. "While much of the public attention has been focused on the jet fuel, most of this was combusted in only a few minutes." (NCSTAR 1-5 p50, para3)
- Even significant workstation fires would fail to support the theory that fire significantly weakened the critical core columns, since "fuel loading in the core areas of the focus floors was negligible." (NCSTAR 1-5 p51para2)
- As shown in Figures 3-5, 3-6, and 3-8 (NCSTAR 1-5 p53 & 56), the tests were conducted with no limit to ventilation. However, NIST's FDS computer simulation found that the WTC fires, at least in WTC 1, "were generally ventilation limited." (NCSTAR 1-5 p183) On an airtight floor, NIST calculates that "only about 2 percent of the combustibles would have burned" (NCSTAR 1-5 p49, para3) and, if instantaneously ignited, would have burned out "in about 2 min." (NCSTAR 1-5 p49, para4) "Since the fires burned longer than this and since they thus consumed far more of the combustibles, the rate at which fresh air became available played a major role in determining the duration of the fires." (NCSTAR 1-5 p49, para5) Although the airplane impacts caused large apertures on one side of the buildings, this alone would not allow for moving ventilation. How much ventilation was allowed by broken windows in other locations? How far above the 2%/2min. burn-out threshold did the increased ventilation and office-furniture fires take the "ventilation-limited" fires? Based upon this series of tests, it is very difficult to tell.

2.2 Multiple Workstation Burn

NIST does not explain why the single and multiple workstation burn tests were conducted separately and with no reference to each other. However, this latter series of tests gives us the only empirical (physical) data on the actual temperatures that may have occurred in the WTC 1 and WTC 2 buildings. Although six tests were conducted and six profiles were given for the heat release rates (HRR) of these tests, the temperature profile was given for only <u>one</u> of the tests. This means that out of 12 physical tests (single and multiple workstation burn test series) NIST provided the temperature profile for only one of them. As it turns out, the profile that NIST chose agrees reasonably well with the settings they selected for their computer simulations. It is regrettable that the other results are not available for comparison.

The computer simulation that NIST was interested in validating with this series of tests was their computational fluid dynamics (CFD) program. Their reason for doing so was sensible:

The predictions of the fire behavior in the building interior were potentially subject to significant uncertainty. To estimate this uncertainty, the National Institute of Standards and Technology (NIST) conducted compartment fire tests at large scale (but still smaller than the acre-size fires that burned in the towers on September 11, 2001) and compared the results with the output from FDS simulations." (NCSTAR 1-5 p69)

A fundamental problem with these tests, however, is that, as NIST's Figure 4-6 (NCSTAR 1-5 p77 and below) shows, the tests were not ventilation limited. The fires in the WTC buildings were.

Source: NIST.

Figure 4–6. Multiple workstation fire experiment.

Two other things that are important to keep in mind regarding the temperatures of these tests are the length of time to peak temperature and the heat transfer rate to the structural steel. NIST's tests found that peak temperatures were reached in 20-30 minutes, and that temperatures were below 600C shortly thereafter. (NCSTAR 1-5 p78 Figure 4-8). Later, in NCSTAR 1-6, NIST states that "results of both the multi-workstation experiments and the simulations of the WTC fires showed that the combustibles in a given location, if undisturbed by the aircraft impact, would have been almost fully burned out in about 20 min." (p280, para1) Therefore, based upon these tests, the fires had only about 20 minutes to affect the temperature of any exposed steel structure (these tests measured ambient air temperature, not the temperature of the steel). Since NIST states repeatedly that insulated steel would not have failed, we are left to consider whether the rubblized debris left in the wake of the aircraft trajectory, with its arguably greatly reduced surface area, would have burned longer than the workstation tests, and whether this time would have been sufficient to transfer enough heat to insulation-compromised steel members. The most critical fires would have started first. (The critical area was where insulation might have been compromised by aircraft impact. This is also where the fires would have originated.) Therefore, if they were at all similar to fires in the multiple workstation tests, they should have done their damage within the first half hour—long before either tower 1 or 2 fell.

2.3 Floor Assembly Fire Resistance

The NIST's ASTM E119 fire tests of the floor assemblies were generally irrelevant to the investigation because they did not simulate the existing conditions of the "all-important SFRM" (Sprayed-on Fire Resistive Material) (NCSTAR 1-6 p6 para1). Although they were used to "validate and provide guidance to the development of the floor models and to the interpretation of analyses results," (NCSTAR 1-6 p5, para3) the greatest relevance the tests provided was to establish that the trusses were likely more robust than those modeled in computer simulation. Even with minimal or no insulation, instead of the 2+ inches of insulation documented to have been on the WTC trusses on 9/11/01, the trusses did not fail the fire tests.

NIST tests intended "to establish the baseline performance of the floor system of the WTC towers under thermal loading as they were originally designed." (NCSTAR 1-6 p37, para4) But this was not the existing condition. For example, "the standard 17 ft test…had no SFRM on the bridging trusses nor on the underside of the metal deck." (NCSTAR 1-6 page lxxiii, para1) The trusses should have been modeled as much more fire resistive, since "the upgraded insulation was thermally equivalent to a uniform thickness of 2.2 in." (NCSTAR 1-6 page lxxi, para3)

This upgrade of the SFRM is noted repeatedly.

…"thermal protection was upgraded…in WTC 1, floors 92-100, and 102…and WTC 2, floors 77, 78, 88, 89, 92, 96 and 97." (NCSTAR 1-6 p20, para1)

"The entire impact zone for Tower 1 (92-99) was upgraded with 1-1/2" spray-on fireproofing." (NCSTAR 1-6 p25, para1)

"The overall average thickness determined from the 256 individual measurements was found to be 2.5 in. with a standard deviation of 0.6 in. Thus, the average SFRM thickness on the upgraded upper floors appears to be greater than that estimated from photographs taken on the upgraded lower floor." (NCSTAR 1-6 p25, para3)

…"the average of the adhesive and cohesive strengths was found to be 409 psf for the ¾ in. SFRM, and the average is 622 psf for the 1-1/2 in. SFRM. These values are considerably greater than the manufacturer's published strength of 295 psf, obtained using the ASTM E 736 method under laboratory conditions." (NCSTAR 1-6 p35, para7)

With the upgrading of insulation so well documented, why did NIST choose to do all of its physical testing of floor assemblies with no or insufficient insulation? Was it because in computer simulation, "with the thermally equivalent 2.2 in. of fireproofing intact on the south trusses, these trusses did not heat appreciably, and the floors did not sag"? (NCSTAR 1-6 p215, para2) Even if the reason was that NIST wanted to simulate damaged SFRM—a justification NIST does not make—surely they could have simply done that. They could have modeled the proper thickness of SFRM and removed some of it at random. Instead, they performed tests that bore little relationship to the existing WTC buildings and therefore had questionable validity.

Another highly significant factor, generally ignored, is that "at the time of design and construction, the towers were not sprinklered." (NCSTAR 1-6 p14, para3) Thus the floors were designed to endure fires even without sprinklers. Even where the sprinkler system failed on 9/11/01, the trusses, with or without the upgraded SFRM, should have handled the office fires without failure, as they did in 1975 with only ½" of SFRM. (NCSTAR 1-6 p282, para12) Furthermore,

"In 2000, a property assessment report stated that the WTC towers were classified as 'Class 1B – noncombustible, fire-protected, retrofitted with sprinklers in accordance with New York City Local Law 5/1973.'" (NCSTAR 1-6 p16, para4)

Therefore, any of these retrofitted sprinklers still functioning on 9/11/01 would have made the existing truss assemblies even more fire-resistive than those in the tests.

Of course, the most significant aspect of the tests is that, even though they were modeled improperly, the trusses performed well and did not fail:

"The tests showed that the floors were capable of considerable sagging without collapse." (NCSTAR 1-6 page xliv, para3)

"Finding 7: All four tests demonstrated that the floor assemblies were capable of sagging without failure. The unrestrained test, which had two 0.875 in. bolts fastening the main truss to the truss seats, did not sag sufficiently to bear on the bolts." (NCSTAR 1-6 page lxxii, para4)

"Finding 8: All four test assemblies supported their full design load under standard fire conditions for two hours without collapse." (NCSTAR 1-6 page lxxii, para5)

In fact, NIST's Table 3-1 (NCSTAR 1-6 p49) shows that no trusses tested failed, and NIST's Figure 3-15 (NCSTAR 1-6 p52) shows that the maximum deflection in tested trusses was only 15".

As a parting thought for this section, it is telling that

> *"The restrained 35 ft floor system obtained a fire resistance rating of 1-1/2 h while the unrestrained 35 ft floor system achieved a 2 h rating. Past experience with the ASTM E 119 test method would lead investigators to expect that the unrestrained floor assembly would not perform as well as the restrained assembly, and therefore, would receive a lower fire rating." (NCSTAR 1-6 p54, para4)*

It is notable that the results of this physical test were just opposite of what was expected and, therefore, what would have been modeled in computer simulation if the tests were not conducted. Thus, even though the tests were generally uninformative for this investigation, they did have the value of demonstrating the danger of trusting computer simulations without validation of the infinitely more complex real-world physical models.

In reviewing the relatively few physical tests performed (or sponsored) by NIST, we see that they were either lacking in critical information, or unsuitable to inform the computer simulations that they were intended to validate. This put the simulations on a poor foundation. In the next section, we shall see that these computer simulations had problems as well.

3.0 Computer Simulations

As we turn our attention from the physical to the digital, we see that NIST's investigation truly begins and ends in the realm of simulation. NIST never tackles the Herculean task of fully modeling the structures. Instead, they patch together a composite of various specific studies in hope of recreating a likeness of the collapses. Unfortunately, a fundamental problem with using computer simulation is the overwhelming temptation to manipulate the input data until one achieves the desired results. Thus, what appears to be a conclusion is actually a premise. We see NIST succumb to this temptation throughout its investigation. Hence, it is unsurprising that, NIST's theories are supported by its simulations. Fortunately, we are allowed to see enough of the simulation to question whether these theories are robust.

For example, we read

> *As the structural analysis approached the time to collapse, the ability of the analyses to match the time to failure depended upon the variance in the analysis results. When considering the sequence of structural events and time to failure, it was more important to match the sequence of events as the time to collapse initiation was influenced by adjustments in influential parameters and imposition or matching of observables. …The times to failure for the collapse sequences, however, are subject to considerable variability, particularly since they are sensitive to small changes in the magnitude of the pull-in forces. (NCSTAR 1-6 p295 para1)*

While it is understandable that NIST desired to have its computer simulation match the observed condition, one wonders why manipulation was required to effect this. One also wonders how extensive this manipulation was. Obviously, if this were a physical test, little or no manipulation would be possible. The results would simply be compared and contrasted to the observed condition and rated for viability.

NIST claims that

> *To determine the probable collapse sequence for each tower, NIST adopted an approach that combined mathematical modeling, statistical and probability based analysis methods, laboratory experiments, and analysis of photographs and videos. (NCSTAR 1-6 p lxiv para3)*

Yet, when one reads the reports, one realizes that they are almost exclusively focused on the computer models. If any other calculations were performed, they certainly were not listed.

The following excerpt exemplifies NIST's disconcerting tendency to blur the distinction between known reality and imagined simulation:

> *The floors supported the occupants and furnishings and transferred these loads to the columns, acted as diaphragms to transfer loads between exterior faces when under wind loads, and provided lateral stability for columns. With damage to the SFRM on the floor trusses, fires caused thermal expansion and sagging of the floors in the impact damage areas. (NCSTAR 1-6 p xlvi para1)*

The first sentence explains the known mechanisms of the building's structural system, the second sentence describes NIST's unconfirmed theory. Yet, both read as points of fact. This dichotomy is further illustrated in the following passage:

> *First, the aircraft impact resulted in significant damage not only to the exterior of the buildings, but also to the floors and core structures inside the buildings and as a consequence, weakened the structures to some degree. Second, the jet fuel dispersed inside the towers ignited the building contents and furnishings, and the damage to the buildings' facades as well as damage to the interiors influenced the amount of oxygen reaching the fires and, therefore, the speed at which the fires grew and moved throughout the affected floors. Third, the impacts of the jet aircraft were of sufficient force to dislodge significant portions of the all-important SFRM in the impact and fire-affected regions. (NCSTAR 1-6 p6 para1)*

Although stated categorically, everything after the second comma is, ultimately, speculation. It may be an excellent theory, it may be true, but it is not known. The casual reader would not be aware of this and perhaps is not intended to be.

In view of this schizophrenia, it is all the more unsettling to read

> *The sequences are supported by extensive computer modeling and the evidence held by NIST. (NCSTAR 1-6 p lxvi para5)*

Computer modeling, extensive or otherwise, is, at best, only as good as the input it receives, and we shall see NIST's willingness to manipulate the input. As far as the "evidence held by NIST" is concerned, until such evidence is held by the public domain, it will be impossible for outsiders to know exactly what it supports.

Adding to the lack of clarity, NIST often refers to its simulations as if they were physical models.

> *The response of the structural components and their connections for the tenant floors and exterior walls was examined with detailed structural models. (NCSTAR 1-6 p lxxiii para4)*

> *Temperatures of the steel structural components and concrete floor slabs were predicted using accurate models of the structures. (NCSTAR 1-6 p6 para3)*

Even if these models were detailed and accurate, it is difficult to tell from the passages that they are only computer simulations.

It is tempting to downplay the significance of the use of computer simulation over physical testing. Certainly, both have great potential for inaccuracy and one might assume that there is no meaningful difference between the two. Yet, we have already seen that there can be fundamental differences between very basic assumptions, such as the relative performance of restrained versus unrestrained trusses under fire load. Such conditions will be, of necessity, modeled according to the laws of physics as a physical model, whereas a corresponding computer simulation will be, at best, an amalgam of physical assumptions.

NIST admits

> *The mapping of the output from the fire dynamics simulations to the thermal models, and the mapping of the temperatures derived from the thermal analyses to the structural models, were complex and challenging tasks due to the vastly different dimensional scales, time increments, element types, and software used in the various analyses. (NCSTAR 1-6 p9 para7)*

and

> *This investigation required…software tools not typically employed in structural analysis or design. This study necessitated the use of sophisticated analysis methodologies at the limits of structural engineering experience and training. (NCSTAR 1-6 p9 para6)*

Thus, NIST acknowledges that its simulations were "at the limits of structural engineering experience and training." On which side of this limit did NIST find itself? We shall see in the following examples.

3.1 Aircraft Impact

(Citations in this section are from NCSTAR 1-2B, unless otherwise noted)
In the regrettable dearth of any photographic or testimonial evidence regarding the condition of the core columns after aircraft impact, NIST relied upon advanced computer simulation to estimate the damage caused. (p195 para1)

> *"The global impact analyses were the primary method by which the damage to the towers was estimated. The global analyses included, for each tower, a "base case" based on a best estimate of all input parameters. They also provided more and less severe damage estimates based on variations of the most*

influential parameters. These more and less severe damage scenarios provided a range of damage estimates for the towers due to aircraft impact." (p385 para4)

However, in this simulation, as in all simulations that NIST conducted, the worst possible damage is assumed to have occurred. But there are some problems with the logic of making this assumption. First, the 'base' case better matched the observed data. Second, even the base case seems to overestimate the damage.

<u>Matching Observed Data</u>

All three levels of assumed severity that NIST modeled matched the observed data reasonably well, but the base case, by definition, came closest. Although, in the end, NIST chose to accept the more severe case and reject the other two, they could have just as well chosen the less severe case instead.

> *"The overall agreement with the observed damage was good for all three analyses, with the base case global impact analysis providing the best match to the observed damage." (p389 para1)*

> *"'base case' based on a best estimate of all input parameters (based on photographic and video evidence, material testing, and data in the open literature)" (p197 para3)*

> *"The calculated and observed damage in the impact damage zone were in good agreement." (p386 para2) (WTC 1 base case)*

> *"The calculated and observed geometry and magnitude of impact damage were in good agreement. That served to partially validate the geometry of the aircraft model, including the aircraft orientation, trajectory, and flight distortions of the wings. Agreement of both the mode and magnitude of the impact damage partially validated the constitutive and damage modeling of the aircraft and exterior wall of the tower." (p387 para5) (WTC 2 base case)*

> *"The magnitude and mode of impact damage on the exterior wall were still in good agreement with the observed damage for this less severe impact scenario." (p276 para1) (WTC 1)*

> *"The mode and magnitude of the calculated and observed impact damage on the exterior wall are still in good agreement in this less severe impact analysis." (p312 para1) (WTC 2)*

Thus, based upon the observable data, there was no basis for rejecting the less severe cases as NIST did.

<u>Damage Overestimated</u>

Depending on the assumed severity, the number of severed core columns produced in simulation of the aircraft impacts ranged from one to six in WTC 1 (p389 para3) and from three to ten in WTC 2 (p390 para2). "The calculated damage to the core of WTC 1 consisted of three severed columns and four heavily damaged columns." (p386 para4) (base case) But are these numbers realistic? The following passage suggests that they are not.

> *"The residual velocity and mass of the engine after penetration of the exterior wall was sufficient to fail a core column in a direct impact condition. Interaction with additional interior building contents prior to impact or a misaligned impact against the core column could change this result." (p382 para10)*

From this simulation we learn that an impact by the most dense and massive component of the aircraft, the engine, could cause, at most, only one column to fail—and only if it were aligned perfectly and struck the column directly. In WTC 2, one of the engines (and a landing gear) exited the building without significant obstruction. (p390 para5) So, if the engines could fail, at most, one column in WTC 2 and two columns in WTC1, what could have failed all of the other columns? Was it the fuselage? This is not likely, based upon the description of the simulation.

> *"The forward fuselage structures were severely damaged both from the penetration through the exterior columns and the penetration of the 96^{th} floor slab that sliced the fuselage structures in half." (p201 para3) (WTC 1)*

"At 0.3 s after impact…the airframe was mostly broken up" (p206 para2) (WTC 1)

"The fuselage structures were severely damaged both from the penetration through the exterior columns and the penetration of the 96th floor slab that sliced the fuselage structures in half. The downward trajectory of the aircraft structures caused the airframe to collapse against the floor." (p385 para6) (WTC 1)

"The forward fuselage structures were severely damaged both from the penetration through the exterior columns and the penetration of the 81st floor slab that sliced the fuselage structures in half. The downward trajectory of the aircraft structures caused the airframe to collapse against the floor…" (p234 para2) (WTC 2)

"At 0.2 s after impact…the airframe was mostly broken up." (p234 para2) (WTC 2)

So there seems to be some discrepancy between what the LS-DYNA simulation (that NIST used for the aircraft impact analysis) describes and shows in figures and what it concludes in terms of failed columns. It is also interesting to compare LS-DYNA to other simulations, such as those conducted by MIT and WAI.

"In general, the MIT and WAI studies appeared to predict more damage to the core columns compared to the NIST estimates." (p391 para2) "The NIST aircraft model also contained an order of magnitude more elements and explicit modeling of the fuel." (p391 para1)

One might conclude from the above that NIST's simulation is conservative. Conversely, one might conclude that by simulating the aircraft impact with a ten-fold increase in accuracy, fewer columns are shown to have failed. Would an even more finely modeled simulation show even fewer failed columns?

Although NIST claimed, as above, that the base cases best matched the observables, they later claimed that, instead, the more severe cases (B and D) did.

"WTC 1 and WTC 2 global models were subjected to Case B and Case D aircraft damage and fires, respectively. The results of the isolated wall, core, and full floor analyses indicated that structural responses to Case B and Case D more closely matched observed structural behavior in photographs and videos than did Case A or Case C, respectively. Thus, Case B and case D were chosen for the global analysis of WTC 1 and WTC 2, respectively." (NCSTAR 1-6 p235 para3)

Yet, even the more severe cases did not seem to put undue stress on the surrounding, non-failed columns, causing only two columns to load beyond the nominal maximum. "Figure 8-10 shows that only two columns had a demand-to-capacity ratio greater than 1.0." (NCSTAR 1-6 p240 para2)

Although it may be true that "inaccuracy associated with mathematical or numerical models…did not necessarily have a significant effect on the estimated impact damage to the WTC towers," (p384 para3) it may be that an over-eagerness to inflate this estimated damage did.

3.2 Fire Dynamics Simulator

Pruning the Simulations

It was difficult to determine when NIST discarded various fire scenarios from its initial range of possibilities. Trying to understand why they did so is even more difficult. NCSTAR 1-5 chapter 6 section 6.2 tells us that the simulations "denoted as Cases A and B for WTC 1 and Cases C and D for WTC 2, used initial conditions provided by the impact analysis (NIST NCSTAR 1-2)." (p103 para7) From this we might assume that there were four conditions tested in the impact analysis--A, B, C & D. To verify, NIST refers us to NCSTAR 1-2.

We find our first clue in NCSTAR 1-2 chapter 7 section 7.1, which discusses the results of the computer-simulated aircraft impact damage results:

> *The global impact simulations provided, for each tower, a range of damage estimates. This included the base case, based on reasonable initial estimates of all input parameters, along with a less severe and a more severe damage scenario. The less severe damage case did not meet two key observables: (1) no aircraft debris was calculated to exit the side opposite to impact and most of the debris was stopped prior to reaching that side, in contradiction to what was observed in photographs and videos of the impact event (see Section 7.10), and (2) the fire-structural and collapse initiation analyses of the damaged towers (NIST NCSTAR 1-6) indicated that the towers would not have collapsed had the less severe damage results been used. As a result, this chapter provides detailed description of the results of the analyses pertaining to the base case and the more severe case, which were used as the initial conditions for the fire dynamics simulations (NIST NCSTAR 1-5F), thermal analyses (NIST NCSTAR 1-5G), and fire-structural response and collapse initiation analyses (NIST NCSTAR 1-6). Only a brief description is provided for the less severe damage results for comparison purposes. The details of the less severe damage estimates can be found in National Institute of Standards and Technology (NIST) NCSTAR 1-2B." (p167 para1)*

We learn several things from going to this reference. First of all, we learn that there were not only four conditions tested in the simulation, there were actually six. But two of these conditions, the less severe cases, were dropped because they "did not meet two key observables," namely, 'no aircraft debris exited the building,' and "the towers would not have collapsed."

Let's address the first assertion. To do this, we turn to NCSTAR 1-2B, which describes the observables in more detail. Does this report confirm that the base and severe cases matched the observables of exiting debris, meriting their inclusion, while the less severe cases did not, thus meriting their dismissal?

Of the several pages that discuss the computer simulated damages caused by the less severe cases, the only sentence that comes close to addressing the issue of exiting debris says this (referring to WTC 1): "Little or no debris penetration of the south wall of the tower was expected for the less severe impact condition." (NCSTAR 1-2B p285 para1) Not what we would call a smoking gun, but suggestive of NIST's assertion. Fortunately, if we read on, we come to section 9.11, "COMPARISON WITH OBSERVABLES." On page 340, we are reassured that "In the less severe damage analysis, as shown in Figure 9-120, none of the aircraft debris that passed through the core was calculated to exit the building." (para1) This is all very well. But in the next paragraph (p344 para1) we read:

> *Because of model size constraints, the panels on the south face of WTC 1 were modeled with a very coarse resolution. Neither the spandrel splice joints nor exterior column butt joints were modeled. Column ends and spandrel edges were merged together. The model, therefore, underestimates the damage to the tower on this face.*

This certainly evidences the reason why "there is significant uncertainty in this estimate associated with the exit trajectory." (NCSTAR 1-2B p344 para2) In other words, the justification for disallowing the less severe condition based upon exit trajectory is missing. So, do the base and severe cases match the exiting observables? Well, in the same paragraph quoted above we read of a piece of landing gear that was observed (in video) to exit the south side of WTC 1 at "about 105 mph." How fast did it exit from the base and severe cases?

> *"No portion of the landing gear was observed to exit the tower in the simulations, but rather was stopped inside, or just outside, of the core." (NCSTAR 1-2B p345 para1)*

Since no material exited the buildings in <u>any</u> of the simulations, then obviously, this disqualifies them <u>all</u>. How could NIST explain such a discrepancy? Like this:

> *In order to simulate the trajectory of specific pieces of aircraft debris, a fairly precise knowledge of the internal configuration of the building would be needed. This is especially true with components passing through the core of the building, where some of the most massive building contents and partition walls were present. Uncertainties regarding the internal layout of each floor, such as the location of hallways or walls, can make the difference between debris from a specific component passing through or being stopped*

inside the structure. Modeling uncertainties may also have contributed to the inability to predict the trajectory of specific aircraft components. (NCSTAR 1-2B p345 para1)

There was significant uncertainty as to the actual layout of the workstations and other building contents on the impacted floors of the towers. …Uncertainties regarding this layout, such as missing partition walls and workstations, can make the difference between debris from a specific component passing through or being stopped inside the structure." (NCSTAR 1-2B p349 para2)

So the point NIST seems to be making is that they should not have relied upon exit trajectories to decide that a simulation is invalid. Yet, this is precisely what they did. Was the situation similar for WTC 2? Did *this* simulation justify omitting the less severe case?

No landing gear debris exited the building in either the base case or the less severe simulations. (NCSTAR 1-2B p353 para1)

In all three simulations…it was estimated that the building contents would likely stop the engine fragments prior to impacting the northeast corner of the exterior wall. (NCSTAR 1-2B p353 para3)

None of the three WTC 2 global impact simulations resulted in a large engine fragment exiting the tower. (NCSTAR 1-2B p353 para4)

Since, in real life, a landing gear and an engine <u>did</u> exit WTC 2, there was absolutely no basis for selecting the base and more severe cases while eliminating the less severe cases for either building simulation. They were all invalid by NIST's own standard and all of them should have been either rejected or accepted equally.

The fact that all three cases matched observables well for the point of impact and poorly or not at all for the point of exit shows that NIST's decision to exclude the less severe case (and not the others) was unfounded. As NIST notes in its summary:

The most valuable observable was the damage to the impacted exterior wall of each tower. The impact damage to the exterior walls was well documented and the response did not depend as much on unknown parameters, such as the detailed office layout on each floor. (NCSTAR 1-2B p363 para1)

Observed trajectories of specific aircraft components, such as the landing gear and engines, were considered to be of lower importance in validating the simulated damage to the tower. A fairly precise knowledge of the internal configuration of the building would be needed in order to simulate the trajectory of specific aircraft debris. Damage to the opposite side of each tower from the point of impact was also of lower importance. These parts of the tower were modeled with lower resolution and as a result, the models were not sufficient to capture the detailed damage. (NCSTAR 1-2B p363 para2)

Since we have established, by NIST's own argument, that its first justification for dismissing the less severe cases was arbitrary, we are left with only the second one. It is a circular reason that we will encounter many times: "The towers would not have collapsed."

<u>More Simulations Pruned</u>

Looking at NIST's Figure 9-2 in NCSTAR 1-6 page 291, one gets the idea that NIST ran three variants each (less severe, base, and more severe) of four tests, for a total of 81 scenarios. Thus, we are puzzled when we go searching for the "less severe" case for the second and third tests. The second test is the Fire Dynamics Simulator (FDS). NIST has this to say about why a less severe case for the FDS can not be found:

Hundreds of preliminary calculations were performed to study the fire behavior. …After this development phase, two final multi-floor simulations included variation of the influential parameters over plausible ranges. These two simulations, denoted as Cases A and B for WTC 1 and Cases C and D for WTC 2, used initial conditions provided by the impact analysis (NIST NCSTAR 1-2). (NCSTAR 1-5 p103 para7)

Evidently, the less severe cases got lost in the "development phase." When NIST refers to "Cases A and B" and "Cases C and D," they mean the two base cases (A and C) and the two more severe cases (B and D). We are left to assume that the less severe cases have been disposed of in some appropriate manner. NIST makes no mention at all of a less severe case for the third test, the Fire Structure Interface (FSI). It seems that after dismissing the less severe case from the impact test (LS-DYNA, discussed above), no 'less severe cases' were considered for any of the other tests. NIST gives no explanation for this decision, but it becomes apparent that this decision was indeed made when we look at the next figure (9-3) on the following page (292), which shows the less severe and base cases being jettisoned as the investigation progressed. (The FDS program generated the time- and space-varying gas temperatures and radiation fields and the FSI used these values to map the temperature distribution to the exposed structural elements. (NCSTAR 1-5 p83))

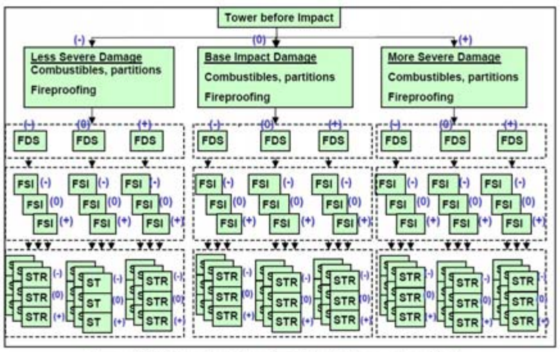

Figure 9–2. Full analysis tree for influential parameter effects.

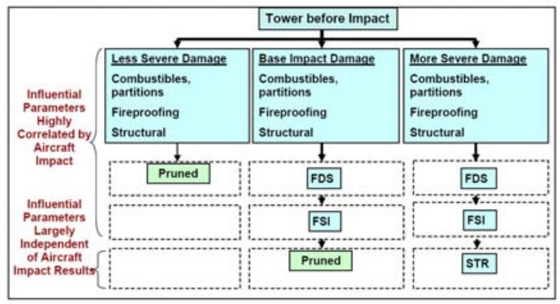

Figure 9–3. Pruned analysis tree for influential parameter effects.

As coy as NIST is about why they abandoned the less severe cases in the impact tests (and, evidently, in all the other tests along with it), they are more succinct, if not straightforward, in their explanation of why they abandoned the base case(s):

> *Structural models of the two aircraft-damaged buildings indicated that, in the absence of weakening by fires or other substantial insult, the buildings would have continued to stand indefinitely (NIST NCSTAR 1-6D). The application of the fire scenarios in Cases B and D to the aircraft-damaged towers resulted in collapse. (NCSTAR 1-5 p180 para1)*

Thus, NIST selected cases B and D, the more severe cases, which represented fires and conditions that NIST believed were more severe than the evidence would suggest. But, they don't specifically tell us that the *reason* they dropped the base cases (A and C) was that these base cases (and, obviously the less severe cases, had there been any) would not have led to collapse. NIST selected the more severe cases because, and only because, they were the only ones that produced the desired outcome. Such arbitrary selection undermines our ability to rely upon the results of the simulation.

Accuracy of the Fire and Heat Transfer Models

NIST was adept at using the FDS, having developed it since 1978 (NCSTAR 1-5 page69 para5&7). But this was an extraordinary investigation; in scope, in scale, in complexity, and in lack of explicit evidence. "The predictions of the fire behavior in the building interior were potentially subject to significant uncertainty. To estimate this uncertainty, the National Institute of Standards and Technology (NIST) conducted compartment fire tests at large scale and compared the results with the output from FDS simulations." (NCSTAR 1-5 p69 para6) So, while NIST admits that their predictions would involve "significant uncertainty," the impression one comes away with is that their computer simulations would be validated by conducting physical tests and comparing the results of the two.

In principle, this was an excellent idea. The limitation was that the physical tests were conducted in highly controlled conditions and, as NIST acknowledges, on a grossly smaller scale. It takes substantial digging, and some reasoning, to grasp how much of NIST's investigation was digital guesswork.

Although NIST has had several years to practice for this ultimate test of their FDS software, the shear scale of the models led to difficulties running the program. “To overcome these difficulties, the National Institute of Standards and Technology (NIST) developed the Fire Structure Interface (FSI).” (NCSTAR 1-5 p83, para3) So, this was FSI 1.0. Or, rather, we could call it the “Beta” version. Did it work? It’s hard to tell. They did test it, but they used a 5’ steel bar to do so. Evidently, the FSI program and the heated steel bar compared favorably. Did that qualify FSI to test multiple complex components in a multi-floor fire? One wonders.

If we have reason to question the reliability of the tests, we have even more reason to be concerned about the boundary conditions and parameters under which they were conducted. NCSTAR 1-5 page 180 describes the characteristics of an intense fire that might have led to the collapse of a WTC tower:

- *Ignition on a single floor by a small bomb or other explosion. If arson were involved, there might have been multiple small fires ignited on a few floors.*
- *Air supply initially determined by the building ventilation system.*
- *Moderate fire growth rate. In the case of arson, several gallons of an accelerant might have been applied to the building combustibles, igniting the equivalent of several workstations.*
- *Water supply to the sprinklers and standpipes maliciously compromised.*
- *Intact structural insulation and interior walls.*

Except for the air supply and insulation, this fairly well describes the actual WTC fires. But NIST then tells us “The four cases described in this report represented fires that were far more severe than this.” (NCSTAR 1-5 p180 para8) Far more severe? How so? NIST lists four points.

> *#1 “The incident jet fuel created large and widespread early fires on several floors.” (NCSTAR 1-5 p180 para9)*

But this would have only caused the fires to start--and end--earlier. It did not make them burn any hotter. The physical tests showed that most contents reached peak heat release rate within a half hour. The towers failed after a far longer period of time. Also, most of the jet fuel ignited and burned up immediately.

> *#2 “The aircraft and subsequent fireballs created large open areas in the building exterior, through which air could flow to support the fires.” (NCSTAR 1-5 p180 para10)*

But WTC 1 was, as NIST acknowledges, ventilation limited. Arguably, they both were, since a hole in only one side of a building does not create airflow. A hole in two sides of a building creates airflow, and only as much as the smaller hole. That’s why the fires burned so smoky. They were starving for air.

> *#3 “About 10,000 gal of jet fuel were sprayed into multiple stories, simultaneously igniting hundreds of workstations.” (NCSTAR 1-5 p180 para11)*

(See #1 above.)

> *#4 “The impact and debris removed the insulation from a large number of structural elements that were then subjected to the heat from the fires.” (NCSTAR 1-5 p180 para12)*

NIST invests most of its stock in this last idea. However, if the impact and debris had so much force that they were able to remove the insulation adhered to the structural members, if they could knock the gypsum wallboard clean off of the core columns, wouldn’t they also have cleared out any combustible matter in their path? How did the aircraft strip off all of the insulation and leave the workstations in place? Even if this could be accomplished, just how many columns could have had the insulation stripped from them? It would have had to be enough to fail the entire building, since all of the simulations showed that “none of the columns with intact insulation reached temperatures over 300C.” Even in the more severe cases, “the temperature of the insulated exterior and core columns would not have increased to the point where they would have experienced significant loss of strength or stiffness.” (NCSTAR 1-5 page 181 para2)

In fact, even the simulations showed that "In WTC 1, if the fires had been allowed to continue past the time of building collapse, complete burnout would likely have occurred within a short time since the fires had already traversed around the entire floor and most of the combustibles would already have been consumed." (NCSTAR 1-5 page 181 para1) Thus, even using experimental technology and exaggerated input parameters, NIST came very close to having buildings that just wouldn't fall down.

3.3 Structural/Thermal Response

Having estimated the effects of the airplane impacts and ensuing fires, NIST then examined the three major subsystems, namely, the core, the floor trusses, and the exterior wall. These analyses were used to inform a highly stylized and minimally modeled global simulation of each building.

Core Subsystem Models

NIST's premise related to the core was that

> *In both WTC 1 and WTC 2, significant weakening of the core due to aircraft impact damage and thermal effects was also necessary to initiate building collapse. (NCSTAR 1-6 p322 para2)*

So, it was critical to NIST's theory to show a significantly weakened core. Unfortunately, they take questionable liberties in order to do this.

At the outset of the model, NIST had a problem.

> *The isolated core models did not converge for WTC 1 case B and WTC 2 case D structural impact damage, which had more severed columns than Cases A and C. The core needed to redistribute loads to other areas in the global system for a stable solution with Cases B and D structural damage. (NCSTAR 1-6 p lviii para2)*
>
> *Case B and D impact damage could not be used for the isolated core models as no stable solution was obtained. Instead, for WTC 1, Case A impact damage was used for both Case A and Case B temperature histories and, for WTC 2, Case C impact damage was used for both Case C and Case D temperature histories. (NCSTAR 1-6 p187 para1)*

This means that the severe case impact results could not be used to perform the temperature evaluation because the buildings fell down too soon. So, NIST used the base case impact damage to evaluate the base case and severe case temperature histories. The conflict here is that NIST's final conclusion is that the buildings only would have failed if the most severe cases were used at every step. In fact, NIST concludes that it has accurately modeled the actual event at the end of its report, whereas, when we look closely at their procedure, we see that this is not the case. This use of the base case for the impact damage proves that Figure 9-3, shown previously, is not correct.

Another oddity related to the difference between the base cases (A and C) and the severe cases (B and D) is that when the temperature histories were applied (to all four), the columns in the base case of WTC 1 buckled and the columns in the severe case of WTC 2 did not.

> *Case A resulted in column buckling. Case B resulted in column buckling. (NCSTAR 1-6 p188 para1)*
> *No columns buckled in either Case C or Case D. (NCSTAR 1-6 p192 para1)*

This means that Figure 9-3 is now wrong on two counts, since the severe case must be rejected once again. NIST fails to point this out in its summary conclusion.

Another concern regarding the core analysis is that NIST chose to model it without the hat truss.

> *By not including the hat truss, the primary load path for core column load redistribution was removed, leaving the core floors, which typically provided a secondary load path. (NCSTAR 1-6 p lviii para2)*

And, although NIST claims "the core was effective in redistributing loads from damaged core columns to adjacent core columns when load path through the hat truss could not be developed due to either severed columns or column splices," (NCSTAR 1-6 p231 para3) still, this was a major deviation from the actual construction. Considering how much emphasis NIST places on the hat truss elsewhere in its reports, it is misleading to downplay the effects it would have had in supporting the damaged core.

A last consideration of the core evaluation involves two important factors: (1) The columns were insulated with gypsum board, not SFRM, and (2) there were no combustibles contained therein. Central to NIST's theory is that "both temperatures and stresses were high in the core area." (NCSTAR 1-6 p lxvix para2) Yet, elsewhere we find that

> *The core space contained relatively little combustible mass. (NCSTAR 1-5 p49 para7)*

> *The fuel loading in the core areas of the focus floors was negligible. (NCSTAR 1-5 p51 para2)*

So, exactly what caused the high temperatures? Certainly not the jet fuel, which burned off quickly. Furthermore, NIST has made much of the impact damage to the SFRM fire insulation. But, as mentioned, the core columns were protected by gypsum board, not SFRM.

> *The gypsum panels were used to form fire resistant enclosures around steel core columns, stairwells, mechanical shafts, and the core area in the towers. The core column thermal insulation varied according to the column location and exposure to occupied spaces. Column surfaces in public access areas were protected with gypsum enclosures, while the remaining surfaces were protected with SFRM. (NCSTAR 1-6 p xlii para9)*

Considering the lack of combustibles and the use of the more durable gypsum board, why did NIST believe that the "temperatures and stresses were high in the core area"? We are not given a reason.

<u>Full Floor Subsystem Models</u>

NIST admits that

> *The structural response analyses were subject to uncertainties in the input parameters, such as the extent of impact damage to the structure, the temperature histories of structural components (based upon the post-impact insulation condition and the fire growth and spread), and material properties at elevated temperatures. … The uncertainty in the temperature-dependent material properties increased with increasing temperature. (NCSTAR 1-6 p10 para1)*

Since the simulated responses were subject to increasing uncertainty as they approached the critical temperatures under consideration, the input and interpretation of the results became increasingly important. NIST assures us that "mechanical and chemical properties were determined for steel specimens recovered from the WTC site to assure that the materials used were in conformance with those specified in the original design." (NCSTAR 1-6 p5 para1) But this was done only by computer simulation. No results of physical testing of any material from the WTC buildings were integrated into the models. So, we are back to trusting the uncertainties of the computer simulation and the objectivity of the input parameters and output interpretation.

Is such objectivity in question in this simulation? As a point of reference, we note that,

> *If the floors of the towers were airtight,…since there was only enough oxygen to generate 2.5 x 10^4 MJ, only about 2 percent of the combustibles would have burned. …Assuming the fires were almost instantaneously ignited by the jet fuel, at that burning rate, 2.5 x 10^4 MJ would have been generated in about 2 min. Since the fires burned longer than this and since they thus consumed far more of the combustibles, the rate at which fresh air became available played a major role in determining the duration of the fires. (NCSTAR 1-5 p49 para1-5)*

This is especially troubling because “the major fires in WTC 1…were generally ventilation limited.” (NCSTAR 1-5 pl para9) So, the actual fires should have been very near the two-minute burnout. Were they? It is difficult to tell the exact condition of the fires from the visual evidence, but NIST modeled them as being much longer and more intense than the above reference should allow. This also may be why the simulations required incorrect modeling:

> *The straps and studs at the exterior wall had been removed from the floor models, which provided additional resistance to horizontal loads. (NCSTAR 1-6 p225 para7)*

NIST claims to have modeled the floor systems to closely match observed phenomena. Predictably,

> *The less severe case was not used in the subsequent fire dynamics, thermal, and structural analyses as it did not reasonably match key observables. (NCSTAR 1-6 p121 para2)*

Again, we are left to wonder what ‘key observables’ NIST is seeing. They mention “hanging objects” in WTC 2.

> *Following the aircraft impact and fireballs, hanging objects were observed through the windows of the east and north faces. The hanging objects suggest that there was structural damage to WTC 2 Floor 83 along the east face and to Floors 81 to 83 of the north face near the northeast corner. (NCSTAR 1-6 p liv para7)*

> *On the east face and north face of WTC 2, draped objects were observed through the windows of Floor 82 on the east face and Floors 81 to 83 on the north face near the northeast corner. The draped objects appeared to be hanging floors. The drape of these objects was observed to increase with time. (NCSTAR 1-6 p lxxv para4)*

However, NIST’s Figure 9-16 (NCSTAR 1-6 p312) shows the hanging objects just after impact and again just before collapse. They look the same. Also, this phenomenon was not observed anywhere else in WTC 2 or in WTC 1, suggesting it was anomalous. With so little external verification, it is difficult to substantiate the accuracy of this simulation.

<u>Exterior Wall Subsystem Models</u>

The primary issue with respect to the exterior wall subsystem was whether the floor trusses sagged sufficiently to pull on the exterior columns enough to induce buckling and then collapse.

> *Inward bowing of an exterior wall was a necessary but not sufficient condition to initiate collapse. (NCSTAR 1-6 p322 para2)*

> *The primary role of the floors in the collapse of the towers was to provide inward pull forces that induced inward bowing of exterior columns (south face of WTC 1; east face of WTC 2). (NCSTAR 1-6 p lxxix para1)*

> *Sagging floors continued to support floor loads as they pulled inward on the exterior columns. There would have been no inward pull forces if many of the floor truss seats had failed and disconnected. (NCSTAR 1-6 p lxxix para2)*

> *As the exterior wall buckled (south face for WTC 1 and east face for WTC 2), the column instability propagated to adjacent faces and caused the initiation of the building collapse. (NCSTAR 1-6 p lxxix para3)*

> *Floor sagging induced inward pull forces on the south wall columns. (NCSTAR 1-6 p lxvii para12)*

It is critical to understand that essentially no floor sagging and little wall bowing was actually observed. So when NIST discusses sagging and bowing, they are usually discussing simulated, not observed, phenomena. The few exceptions to this rule are not completely reassuring.

Inward bowing was observed only on the south face. The north face had extensive aircraft impact damage, and the damaged floors were not capable of imposing inward pull forces on the north face. (WTC 1) (NCSTAR 1-6 p333 para5)

Inward bowing was observed only on the east face. The south face had extensive aircraft impact damage, and the damaged floors were not capable of imposing inward pull forces on the south face. There was no impact damage or fire on the west floors to cause pull-in forces on the west face. (NCSTAR 1-6 p334 para3)

So, the observed bowing was highly asymmetric and the reasons for this are more dismissive than explanatory. Further, NIST claims a dubious level of accuracy in estimating the extent of this bowing:

Inward bowing of the east wall was first observed at 9:21 a.m. The inward bowing was approximately 10 in. +/- 1 in.at Floor 80. (NCSTAR 1-6 p334 para3)

Also, NIST refers to an odd dichotomy related to the pull-in forces exerted on the exterior columns:

The WTC 1 collapse sequence consisted of five main events: aircraft impact, core weakening, floor sagging and disconnection, inward bowing of the south wall, and collapse initiation. (NCSTAR 1-6 p298 para1)

But, how could inward bowing follow floor disconnection, since obviously "there were no inward pull forces where the floors were disconnected"? (NCSTAR 1-6 p 321 para4) Even if we accept the computer simulation finding that

Floor sagging induced inward pull forces on the east wall columns.
About an additional 1/3 of the connections to the east exterior wall on floor 83 failed due to thermal weakening of the vertical supports. (NCSTAR 1-6 p307 para13,14)

still, we are only seeing that some connections fail and others pull. Pulling connections might later fail, but failed connections can never pull.

With this in mind, we turn our attention to the actual point of connection between the floor trusses and the exterior columns, the truss seats. NIST accurately notes that "floor sagging between supports may cause tensile failure of the truss seats, or development of tensile forces that pull columns inward." (NCSTAR 1-6 p89 para11) Obviously, as noted, it can not simultaneously cause both. We should, therefore, take a very close look at the truss seat connections to see what horizontal tensile forces they were capable of translating.

NIST's Figure 4-8 shows interior seats horizontally restrained by only one (1) 5/8" ASTM A325 bolt. (NCSTAR 1-6 p68) The exterior seats were slightly more restrained in that they also had welded gusset plates.

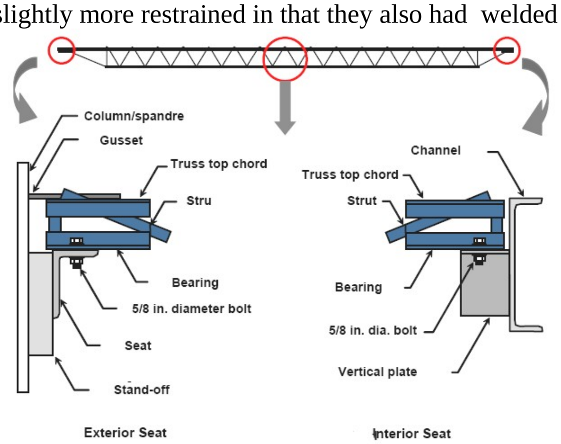

Figure 4-8

The weak link in the system, then, would have been the ASTM A325 bolt at the interior seat.

The shear strength of the bolts controlled the truss seat horizontal tension capacity. (NCSTAR 1-6 p79 para1)

Once these interior bolts failed, a truss would no longer translate lateral forces from a core column to an exterior column. The lateral forces then acting on the exterior column from the weight of the hanging floor slab would still have been significant, but no longer a product of "floor sagging between supports." Since this is the mechanism NIST proposes, let us focus on the failure point of the interior seat.

Assuming that intense fires were acting at the boundary of the core/truss systems, and thus assuming that the truss seats were exposed to at least 600C, NIST's table 4-4 (NCSTAR 1-6 p75) shows that the interior seat capacity against horizontal tensile force is only 9 kips. (So does figure 4-16 NCSTAR 1-6 p78) How does this number relate to the forces that were expected to have been acting on the exterior columns?

Column buckling was found to occur when an inward lateral load (pull-in) of approximately 12 kips was applied to three adjacent floor levels. (NCSTAR 1-6 p xlix para1)

Column instability (buckling) was reached with a transverse load of 12.6 kips per column. (NCSTAR 1-6 p115 para2)

Thus, we are 3 kips away from a working mode of failure. In support of this conclusion we note that in simulation

The interior truss seat bolts sheared off at 566C.
The gusset plate fractured and the exterior truss seat bolts sheared off at around 680C.
The truss walked off the exterior truss seat at 730C. (NCSTAR 1-6 p87 para6-8)

We are also left to reconcile the effects of thermal expansion of the truss systems.

At lower elevated temperatures (approximately 100C to 400C), the floor thermally expanded and displaced the exterior columns outward by a few inches. (NCSTAR 1-6 p225 para2)

However, since, "the exterior seat angles and interior stiffened seat had 1-3/4 in. slotted holes," (NCSTAR 1-6 p69 para1) this expansion likely would have sheared the exterior bolts (if not the interior bolts) long before sagging occurred.

We have already questioned the amount of bowing observed in visual evidence. How accurate was the bowing induced in simulation?

The inward deflection of the exterior wall when it could no longer support the gravity load (i.e., at the buckling load) was approximately 10 in. (NCSTAR 1-6 p xlix para1)

However, NIST claims there were observed deflections of up to 5 feet. A later citation comes closer, but still falls short:

WTC 1 exterior wall analysis found that an inward pull force of 6 kips at each column at Floors 95 to 99, starting at 80 min after the aircraft impact, caused a maximum inward bowing of 31 in., shown in Fig E-9. This inward deflection was smaller than the observed maximum bowing of 55 in. +/-6 in., and the wall was stable at 100 min. (NCSTAR 1-6 p lix para3)

Finally, in order to have a working failure mode, NIST suggested that

Instability of an exterior wall subsystem could occur when at least three floors were disconnected (i.e. the floor does not restrain the exterior wall subsystem) and the exterior wall subsystem was subjected to additional vertical or lateral loads. (NCSTAR 1-6 p119 para9)

But this is an extension of our previous problem. If the vertical loads were constant and the floors were disconnected, where did the "additional vertical or lateral loads" come from? Evidently, they came directly from NIST:

> *Since the full floor models did not accurately estimate the pull-in forces at floor/wall connections, the fire-induced damage obtained from the full floor model analyses were modified by observations obtained from the examination of photographs and videos performed by NIST (NIST NCSTAR 1-5A). (NCSTAR 1-6 p231 para5)*

Thus, throughout the simulations, NIST tweaked the input until the buildings fell down.

Global Model

We are given little to review by the time we reach the global simulation. NIST's global analysis mostly consisted of estimated column loads. Still, we get a glimpse of some issues.

> *Initial trials with Case A and case B damage and temperatures limited pull-in forces to areas with floor sagging sufficient in the full floor models to cause pull-in forces. However, such limited areas of pull-in forces did not produce results that were consistent with the observed inward bowing. This was primarily due to the lack of fireproofing damage to the south exterior wall and floor truss on the south side in Case A impact estimates. With the thermally equivalent 2.2 in. of fireproofing intact on the south trusses, these trusses did not heat appreciably, and the floors did not sag. (NCSTAR 1-6 p215 para2)*
>
> *In one trial, the magnitude of the pull-in force was increased over time until the the (sic) wall became unstable at 90 min. When the magnitude of the pull-in force reached 9.37 kip per column, the analysis stopped due to non-convergence. At the end of analysis, the maximum inward bowing was 24.7 in. (NCSTAR 1-6 p215 para4)*
>
> *The maximum inward bowing of 31 in. was smaller than the observed maximum bowing of 55 in. and the bowed wall was still stable in the analysis at 100 min. The magnitude of pull-in forces was expected to be less than 6 kip in the global analysis with the addition of gravity loads from the core subsystem as it also weakened; therefore, pull-in forces of 4 kip to 5 kip were used in the global model analyses.*
> *Two additional trials were analyzed. In the first trial, the magnitude of the pull-in forces was set to 1.0 kip and 4.0 kip for the south and north halves of the east wall, respectively. (NCSTAR 1-6 p219 para4)*
>
> *Thermal expansion of the floors was not included in the global models. (NCSTAR 1-6 p236 para3)*
>
> *Several factors cause convergence problems in floor trusses in the global analysis. (NCSTAR 1-6 p234 para2,3)*

So, when the global model finally comes together, we get a picture of a marginally stable system, stripped of several important factors and highly dependent upon input in key areas. Ultimately, NIST has crafted an interesting but fragile theory dependent upon several critical conditions that may or may not have existed as they were modeled.

4.0 Summary and Practical Applications

The author acknowledges the scope and complexity of the task with which NIST was challenged, as well as the excellent qualifications of, and hard work performed by, those involved. However, the purpose of this paper was to be critical in nature, highlighting areas in which the author believes NIST should have been more rigorous in its procedures. We have seen several such areas.

We have seen that NIST's physical tests were inadequate. Their ASTM E119 tests and their workstation burn tests were improperly modeled. Further, the former produced results that contradicted NIST's conclusions and the latter fell far short of testing the performance of realistic steel members in the actual fire conditions. The workstation burn tests showed that the temperatures were generally too low, especially in the ventilation-controlled WTC environments. The ASTM E119 tests showed that the WTC floor trusses should have easily withstood the fires they experienced on 9/11.

We have also seen inadequacies, some minor, some significant, at every stage of NIST's computer simulations, including its impact simulation, its fire loading simulation, its temperature mapping simulation, its thermal/structural component simulations, and its global simulation. The LS-DYNA simulation showed that the aircraft would have done much less damage than NIST assumes, and NIST's subsequent "scenario pruning" was confused and unsubstantiated. The decision to exclude the hat truss from the structural/thermal response simulations was a significant omission. The sequence of failed truss seats leading to pull-in forces on the exterior columns is central to NIST's theory but not explained or supported by simulation. But, most of all, it is NIST's repeated willingness to manipulate input data in order to support its hypotheses that casts doubt on the validity of its conclusions.

As noted at the outset, since building codes, safety standards, and building design will be influenced by the conclusions and recommendations of the NIST WTC reports, it is important that these inadequacies be addressed, not dismissed. NIST should explain the discrepancies in its reports, admit the level of uncertainty in its findings, broaden the scope of its investigation, and make its raw data available to other researchers. Although NIST has produced an impressive body of work in its attempt to solve a very difficult problem, they have also shown that there are problems associated with relying too heavily on computer simulation. We have learned several lessons from the NIST investigation that should be applied to future investigations of building failures.

First, we have learned that the complexity of building behavior, especially under thermal loading, is difficult to model accurately and may yield surprising results, as did the restrained/unrestrained behavior of the floor truss burn test. This argues for the erection of actual, physical mockups of critical component assemblies, such as the truss seats, in order to understand the true value of their properties. Also, physical samples of strained and weathered materials from failed structures should be collected and rigorously tested instead of simply being assumed to be identical to FEA simulations of comparable materials. Where large-scale testing is viable, physical tests should come as close as possible to the actual conditions experienced by the structure. In light of these lessons, the author calls upon NIST to review its findings related to the failures of WTC 1 & 2, and to implement these suggestions in its investigation of other building failures, such as that of WTC 7.

Computerized testing is at an exciting stage of development. Analysis programs can create excellent simulations of simple material stresses and are extraordinarily useful in modeling structural load paths. Someday soon they may be able to perform complex evaluations such as the ones attempted by NIST. Until that time, it is important for the industry to recognize their limitations.

Appendix: Related Observable Data

Since the purpose of this paper is to examine the information contained within the NIST reports, and not the information excluded, this appendix serves only to argue that a significant body of evidence was not addressed by NIST. (Although many of the citations suggest the presence of explosives, this section is not meant to be comprehensive in any way, nor to formulate alternative theories, nor to draw conclusions. More extensive and detailed examples of observable data not discussed by NIST as well as accompanying theories, both weak and strong, can be found from several other sources.) Had it taken a broader scope of inquiry, NIST might have been interested in evidence such as the following.

<u>Reports of Explosions</u>

(Unless otherwise noted, all quotes under this heading are from FDNY transcripts (emphasis added) made available through a New York Times FOIA request and are available on the NYT website)
There were several reports of explosions. This in itself may not be significant, as collapsing or falling matter can sound like an explosion and simple flashovers can look like them. The most likely scenario indicating building collapse as a direct result of explosive detonation would be to see/hear such explosion(s) immediately prior to collapse, as in the following experiences reported by firemen on the scene:

> You **see three explosions** and **then** the whole thing coming down. (F. CAMPAGNA file #9110224 p8)
>
> Then the south tower—we heard an **explosion, looked up**, and the building started to **collapse**. (E. SHEEHEY file #9110226 p3)
>
> …**we heard the explosion and the building started to come down**…2 World Trade Center started to collapse. (J. RAE file #9110294 p3)
>
> You could hear explosions. We didn't know what it was. We thought it was just a small collapse. As I looked straight ahead of me, I saw total darkness. Everything was coming our way like a wave. (F. CAMACHO file #9110318 p4)
>
> As we walked through those revolving doors, that's when we felt the rumble. I felt the rumbling, and then I felt the force coming at me. I was like, what the hell is that? In my mind it was a bomb going off.
> The pressure got so great, I stepped back behind the columns separating the revolving doors. Then **the force** just blew past me.   It **blew past me it seemed for a long time**. In my mind I was saying what the hell is this and when is it going to stop?
> **Then it** finally **stopped**, that pressure which I thought was a concussion of an explosion. It turns out it was the down pressure wind of the floors collapsing on top of each other. At that point everything went black, and **then the collapse came**. It just rained down on top of us.
> **There were secondary explosions**, I don't know, aerosol cans or whatever. But we're in the darkness. We see basically the glow of a flashlight and still things coming down. The noise, the explosions, whatever it was. (J. MALLEY file #9110319 p5,6)
>
> …we were taking a break on 30, and that's when we heard a rumble, outside explosion, and I think that was the other building coming down…
> I heard an explosion and turned around and the building was coming down. (J. IPPOLITO file #9110342 p5,8)
>
> …as I was looking at him **I heard the explosions**, looked up, **and saw** like **three floors explode**, saw the antenna coming down, and turned around and ran north. (K. GORMAN file #9110434 p6)
>
> …we heard this huge explosion, and that's when the tower started coming down. (R. CHELSEN file #9110475 p9)
>
> …**there was a tremendous boom, explosion**, we both turned around, and the top of the **building was coming down** at us. (E. KENNEDY 9110502 p7)

> I guess about three minutes later you just heard explosions coming from building two, the south tower. It seemed like it took forever, but **there were about ten explosions**.
> We then realized the building started to come down.
> Q. When the north tower was coming down, did you have any indication? Did you hear the explosions again? Did anybody warn you like they heard on the radio of anything like that?
> A. You did hear the explosions. The second one coming down, you knew the explosions. Now you're very familiar with it. (C. CARLSEN file #9110505 p6-10)

> First I thought it was an explosion. I thought maybe there was a bomb on the plane, but delayed type of thing, you know, secondary device.
> Q. (Chief Art Lakiotes) I was convinced for a week it was secondary devices.
> A. You know, and **I** just **heard** like **an explosion** and a then a cracking type of noise, and **then it sounded like a freight train**. (T. JULIAN file #9110386 p10)

> I don't know what time later a loud rumble—it **sounded like an explosion**. We thought it was a bomb. **We ran under the bridge**, me, Joe Cassaliggi and two police officers; I think one police officer and one Secret Service. We ran under the bridge. There's a column there, over here, right on the sidewalk, a big six foot round masonry column.
> We get behind that, **and number two tower comes down** and debris comes right around us. (T. SPINARD file #9110445 p9)

Also telling are the many reports of explosions and fires taking place lower in the buildings than the impact zones:

> For whatever reason, I just happened to look up and saw the whole thing coming down, pancaking down, and the **explosion**, blowing out about **halfway up**. (H. SCOTT file #9110365 p6)

> Then the **building popped, lower than the fire**…it seemed like…there is a secondary device because the way the building popped I thought it was an explosion. (T. BURKE file #9110488 p8)

> Q. Bill, just one question. The fire that you saw, where was **the fire**? Like up at the upper levels where it started collapsing?
> A. It **appeared** somewhere below that. Maybe **twenty floors below the impact** area of the plane. I saw it as fire and when I looked at it on television afterwards, it doesn't appear to show the fire. It shows a rush of smoke coming out below the area of the plane impact.
> The reason why I think the cameras didn't get that image is because they were a far distance away and maybe I saw the bottom side where the plane was and the smoke was up above it. (W. REYNOLDS file #9110288 p4)

Further confirmation of the damage on lower floors can be found in the following reports from the NIST review of radio dispatches. Notice that there was not only fire, but "a lot of debris" reported on floor 22 almost immediately after impact. Also we note the fire on floor 51 of (presumably) WTC 2. Although it is reasonable to believe this was burning jet fuel, this would only have been the assumption of the observer on the scene.

> 8:47 am—WTC Security reports that there is a fire on floor 22 of WTC 1 (PA/WTC Security Radio Channel X) (NCSTAR 1-8 p36 para4)
> 8:49 am—WTC Security reports that there is damage and a lot of debris on floor 22 of WTC 1 (PA/WTC Security Radio Channel X) (NCSTAR 1-8 p36 para5)
> 9:10 am—PAPD police desk receives a report that there is burning jet fuel on floor 51 of one of the towers. (Note: Communications suggest this is WTC 2.) (PAPD Radio Cannel W) (NCSTAR 1-8 p36 para9)

Buildings other than WTC 1, 2, and 7 were completely ignored by NIST. This brief glimpse into the developments of the Marriott Hotel is, therefore, compelling. Note the timing involved and the number of explosions reported:

> As the **second plane hit** the second tower, we were **called**.
> We were told go to the second tower, report to the lobby.

> We were there about **ten minutes** before the chief told us go to the Marriott Hotel, go from the 14th floor up, search and evacuate all the floors.
> So we walk all the way up, no problem. **Then** we hear the **explosion** and debris falling. We were looking out of the windows and see body parts all over the place. It was scary. It was very sad.
> We searched 14, 15, **went in one lobby, we came out the other way**, we went in one stairway, came up—when we hit the 19th floor, something horrendous happened. It was like a **bomb went off**. We thought we were dead.
> The whole building shook. The brick coming out of – the door to the hallway into the hotel blew off like somebody had thrown it all over the place. It shook all over the place. We were thrown on the floor.
> We looked inside the lobby after **everything calmed down**, and everything was collapsed. The building was still shaking and we're **still hearing explosions going on everywhere**, so we decided let's get out of here.
> Mike Mullen walked one flight up, and **then** the most horrendous thing happened. That's when hell came down. It was like a huge, **enormous explosion**. I still can hear it. Everything shook. Everything went black. The wind rushed, very slowly [sound], all the dust, all the – and everything went dark.
> We were rolling all over the floor, banging against the walls. We separated from each other. I thought I was alone. I thought I was buried alive. (A. RIVERA file #9110489 p3-7)

In the above account, there were two major events and several minor events. The two major events are too close together to be the collapse of each tower, since they decided to leave after the first major event. So, even if one of the major events was the collapse of one of the towers, what explains all of the other explosions?

<u>Fire Damage in Lobby/Basement</u>

NIST mentions damage to the lobby areas in passing but gives the issue short shrift. (NCSTAR 1-5 p10 para1) NIST contents itself with the explanation that jet fuel traveled down one or more elevator shafts, stopped at the lobby (there were several cellar levels), and let itself out of the elevator doors before combusting. However, notice the amount of overpressure described below, including damage to the marble and elevator:

> I didn't go into the lobby, but I could see into the lobby. It seemed like there were people burnt. Guys were saying there were people burnt on the elevator, people burnt in the lobby. I heard them say **there was marble blown off the walls**. I imagine the concussion came down the elevator shaft or something and blew everything out. (FDNY transcripts T. SPINARD file #9110445 p11)

> I said to him, "There was a bomb in the basement. It's not going to go down."
> **When we got down to the lobby, it was like a bomb hit it**. I looked around and said, oh, my God, **every window is busted**. I was shaky. (FDNY transcripts A. RICCIO file #9110277 p5,6)

> We entered in through the front doors of the lobby. The lobby was screwed. **All the windows were already broken. Marble walls** that surrounded the elevator shaft, they **were cracked and broken**…. I'm still thinking a bomb went off….
> We headed for the B staircase. It was pretty much in the center of the core. We had to go through these turnstiles. I remember there was a lot of rubble on the floor there. There was elevator doors (sic) ajar. **There were elevator doors missing. I could see an elevator car twisted in the shaft.**
> I remember I looked up at the ceiling because I thought maybe the ceiling got charred because there was a bunch of rubble on the floor. It was about three feet high in the middle. The ceiling wasn't charred. So I had thought the floor blew up.
> I was telling guys afterwards the floor must have blown up. Maybe there was a bomb downstairs or something. But I came to learn that that was bodies. We had to climb over and around this pile.
> Q. A pile of bodies, in the lobby?
> A. I didn't recognize it as bodies. I don't know if my mind didn't see it.
> Q. Burned?
> A. Burned.
> Q. Near the elevators?
> A. It looked like rubble to me.
> Q. Right.

A. Right outside the elevators, in the core. We had to climb up and around it—it was like three feet high in the middle—to enter the B staircase.
(FDNY transcripts W. GREEN file #9110392 p4-7, 15, 28, 29)

How could all of the windows in the lobby be blown out due to jet fuel that had just traveled 80 floors, intact and unburned, when the jet fuel didn't even blow out many windows on the floors of impact? What caused the elevator doors to be blown completely away?

These accounts of damage to the lobby are strengthened by the following accounts from the NIST report. Notice that the officer at the police desk blames the damage on an explosion on an upper floor but the officer on the scene describes the explosion as having occurred in the basement. This comports with the report of broken water pipes deep underground (level B4).

8:51 am—PAPD police desk receives a call that an explosion was observed in the basement of the B1 level of WTC 1. The police desk informs the officer on the B1 level that what he saw resulted from an explosion on the upper floors of the building. (PAPD Radio Channel W) (NCSTAR 1-8 p36 para6)

8:57 am—PAPD police desk receives report that water pipes are broken on the B4 level of WTC 1. (PAPD Radio Channel W) (NCSTAR 1-8 p36 para7)

Horizontal Expulsion of Debris/Steel

There were accounts of horizontal forces that were inconsistent with a collapse driven only by gravity forces:

…I was distracted by a large explosion from the south tower and it seemed like **fire was shooting out a couple of hundred feet in each direction**, then all of a sudden the top of the tower started coming down in a pancake.
(FDNY transcripts W. REYNOLDS file #9110288 p3)

There was an explosion at the top of the Trade Center and **a piece of Trade Center flew across the West Side Highway and hit the Financial Center**… (FDNY transcripts C. FENYO file #9110295 p3)

These accounts are fully supported by the FEMA report (FEMA 403/September 2002). Although the collapses of WTC 1 & 2 are generally considered to have been vertical in nature, massive debris was found over 500 feet away from the buildings. (FEMA 403 p1-9 Figure 1-7; p1-13 Figure 1-9B, chapters 5-7) What caused the debris to travel so far?

Pressure Pulses, Smoke Puffs, Quick Burns, Molten Metal

Regarding WTC 1:

Pressure pulses of smoke were pushed out the west face at its north edge and center {two seconds prior to collapse} (NCSTAR 1-6 p156 Table 6-1)

At 9:06:27 a.m., a short-lived, but intense, burst of flame appeared near the top of a window near the southern edge of the floor. (NCSTAR 1-5 p13 para1)

Very shortly after 9:18 a.m. intense fires with external flames appeared within the rooms on the northeast corners of the 96th and 97th floors. A similar fire was observed in the northeast corner room on the 94th floor around 9:25 a.m. Very shortly after these fires appeared, streamers began falling from the area. The intense flames in these windows only lasted a few minutes, having died down by 9:35 a.m. (NCSTAR 1-5 p14 para2)

By the start of this period, extremely intense fires present on the west side of the south face on the 95th, 96th, and 97th floors. (NCSTAR 1-5 p14 para4)

At around 9:38 a.m. a jet of flame appeared from a window midway between the north edge and the center of the face. (NCSTAR 1-5 p14 para5)

Around 9:40 a.m. a flame suddenly erupted from the south side of the 98th floor. (NCSTAR 1-5 p14 para6)

An event took place within the tower at 10:18:48 a.m. that generated a pressure pulse with sufficient magnitude to force a large amount of smoke from the open windows on the 92nd floor, along with smaller amounts from open windows on other floors on the north face and on the other faces of the tower. While it seemed likely that the pressure pulse was generated by some sort of collapse within the tower, e.g., a portion of the core settling or a partial floor collapse, it has not been possible to determine the nature of the event or even its general location based on the visual record. Shortly after the pressure pulse, an intense fire appeared at the western edge of the 95th floor. (NCSTAR 1-5 p17 para1)

Around 10:21:15 a.m. there was an intense burst of flame from the 98th floor (NCSTAR 1-5 p17 para2)

Roughly 3s prior to collapse initiation, this line of fire brightened noticeably. During the collapse, bright flames were expelled from the southern side of the 98th floor (NCSTAR 1-5 p17 para2)

Regarding WTC 2:

A fireball on the east face was observed coming from Floor 82. Fireballs on the north face were observed coming from Floors 79 o 82. The deflagration prior to the fireballs may have caused a pressure pulse to act on floors above and below. (NCSTAR 1-6 p167 para8)

Molten material pouring from the northeast corner indicated that Floor 81 on the east side of the north face may be shifting. If the substance was molten aluminum, that would have required temperatures on the order of 500C or higher. (NCSTAR 1-6 p168 para2)

Numerous puffs of smoke may indicate internal changes in architectural or structural features. (NCSTAR 1-6 p168 para3)

Shortly after 9:29 a.m., an intense flame suddenly erupted on the north face from a window on the 83rd floor. (NCSTAR 1-5, page 32, para2)

The unusual short-lived smoke puffs from windows on the face described earlier continued, apparently randomly, throughout the period. Some of these released sufficient smoke to briefly obscure the face. In some instances smoke was also pushed simultaneously from windows on the north and south faces….Unlike observed for the smoke puffs, (sic) intense flames were also visible coming from many of the these (sic) windows and, instead of lasting only a few seconds, the heavy smoke and flames were present for just over a minute before they abated as quickly, seemingly, as they appeared….This unusual event was not unique. Two similar releases of smoke and fire, each lasting roughly one minute, were observed during periods starting just before 9:40 a.m. and after 9:42 a.m. (NCSTAR 1-5, page 32, para3)

It should be remembered that a significant fraction of the observed fire on these floors was associated with the three roughly one-minute-long periods of heavy smoke flow from these floors. (NCSTAR 1-5, page 34, para1)

Just before 9:52 a.m., puffs of smoke and/or dust were expelled from multiple locations on the north face near the east edge. Almost immediately a bright spot appeared at the top of a window on the 80th floor four windows removed from the east edge, and a glowing liquid began to pour from this location. This flow lasted approximately 4 s before subsiding. Many such liquid flows were observed from near this location prior to the collapse of the tower. Several were accompanied by puffs of dust and smoke that were now occurring frequently. (NCSTAR 1-5, page 34, para2)

A fourth short-lived (again roughly a minute) release of heavy smoke and flame from windows on the 79th and 80th floors of the east face occurred around 9:45 a.m. Three additional, somewhat less intense, releases

> lasting similar lengths of time occurred around 9:47 a.m., around 9:52 a.m., and just before 9:56 a.m. Smoke puffs, similar to those seen earlier, occurred multiple times during the period. (NCSTAR 1-5, page 34, para3)
>
> At least 65 occurrences of smoke puffs were documented along with seven times when the one-minute long smoke releases took place. (NCSTAR 1-5, page 37, para1)
>
> The evidence suggests that these smoke puffs resulted from pressure pulses generated within the tower and transmitted to other locations. (NCSTAR 1-5, page 38, para1)
>
> The short-term release of large amounts of smoke along with external flaming over large areas of a building facade is not a typical building-fire behavior. (NCSTAR 1-5, page 38, para2)

As NIST notes, there were many reports that were not "typical building behavior." Based upon these and other reports of anomalous conditions, several researchers have called upon NIST to explain what many consider to be evidence of pre-placed explosive devices. In response, NIST claims that it has found

> no corroborating evidence for alternative hypotheses suggesting that the WTC towers were brought down by controlled demolition using explosives planted prior to September 11, 2001. (NCSTAR 1-6 p lxxx para1)

However, we might ask how hard they looked for such evidence. To answer this, we should consider NIST's objective, namely,

> to determine why and how the two towers (WTC 1 and WTC 2) collapsed following the initial impacts of the aircraft. (NCSTAR 1-6 p xxxvii para1)

Any other consideration was beyond its scope of interest. Obviously, NIST would not find something it was not looking for.

Although no comprehensive theories for the use of controlled demolition have been proven, NIST should consider all evidence within its scope of work and make every reasonable effort to explain anomalous phenomena. This is especially important with respect to the pending investigation of WTC 7.