ALMA, in the young supernova remnant SN1987A has confirmed these predictions. The production of dust occurs in various zones of the ejected material a few months after the supernova explosion and the dust mass gradually increases over a period of five years from small values (10^{-4} solar masses) to large values (0.1 solar masses). This gradual growth provides a possible explanation for the discrepancy between the small amounts of dust formed at early post-explosion times and the high dust masses derived from recent observations of supernova remnants like SN1987A, Cassiopeia A and the Crab nebula;

- Sputtering of dust by shocks in the remnant phase is highly dependent on the clumpiness of the gas in the remnant. Large dust grains (> 0.1 microns; see Figure 3) survive shocks and can be injected in the interstellar medium. These grains will finish their life in proto-stellar nebula and be incorporated in meteorites in the solar nebula. Observation time on the space telescope Herschel was obtained to study dense gas clumps rich in molecules and dust in the supernova remnant Cassiopeia A. These observations confirmed the existence of molecules formed in the supernova that are later shocked in the remnant, with the detection of warm CO emission lines;
- A sample of a deep-sea manganese crust that showed the ^{60}Fe "supernova- signal" was searched for live ^{244}Pu, and revealed unexpected low fluxes. This finding indicates that no significant actinide nucleosynthesis happened within the last few hundred million years. This is incompatible with normal actinide production in supernovae and suggests that a rare event rate, *i.e.*, a small subset of supernovae or neutron-star mergers, has seeded the solar nebula.

4. Physics of compact objects: explosive nucleosynthesis and evolution

Many stars form binary or multiple systems, with a fraction hosting one or two degenerate objects (white dwarfs and/or neutron stars) in short-period orbits, such that mass transfer episodes onto the degenerate component ensue. This scenario is the framework for a suite of violent stellar events, such as type Ia supernovae, classical novae, X-ray bursts, or stellar mergers (involving white dwarfs, neutron stars and black holes). The expected nucleosynthesis accompanying these cataclysmic events is very rich: classical novae are driven by proton-capture reactions in competition with β-decays, proceeding close to the valley of stability, up to Ca. Type I X-ray bursts are powered by a suite of nuclear processes, including the rp-process (rapid p-captures and β-decays), the 3α-reaction, and the αp-process (a sequence of (α,p) and (p,γ) reactions); here, the nuclear flow proceeds far away from the valley of stability, merging with the proton drip-line beyond A = 38, and reaching eventually the SnSbTe-mass region, or beyond. In type Ia supernovae, the detailed abundances of the freshly synthesized elements depend on the peak temperature reached and on the excess of neutrons and protons (which depend in turn on the metallicity of the white dwarf progenitor as well as on the density at which the thermonuclear runaway occurs); they constitute the major factory of Fe-peak elements in the Galaxy, and roughly speaking, the abundance pattern of their ejecta is the result of four different burning regimes: nuclear statistical equilibrium (NSE) and incomplete Si-, O-, and C-Ne-burning. A suite of different nuclear processes are expected to occur during stellar mergers (indeed, neutron star mergers have been suggested as a possible site for the r-process).

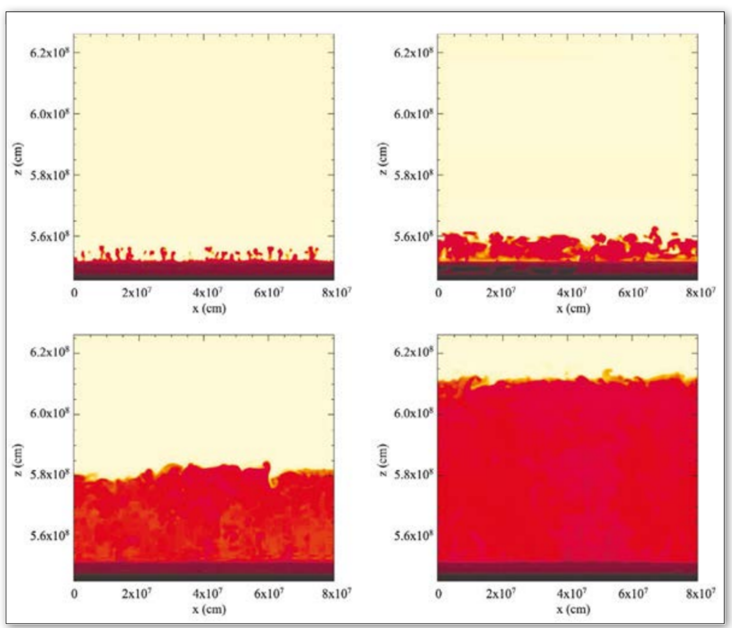
"The experience achieved in the multi-national, multi-institute EuroGENESIS project has built and organized a European Community in the wide field of nuclear astrophysics."

This collaboration consisted of groups with expertise in experimental and theoretical nuclear physics, computational hydrodynamics (with emphasis in multidimensional simulations of stellar explosions and on their associated high-energy emission in X- and gamma-rays), and cosmochemistry (through laboratory analysis of presolar grains), from 11 institutions.

Among the most relevant results achieved in this area by the different components of the Collaboration, one could mention:

- 3-D simulations of nucleosynthesis accompanying double white dwarf mergers, with emphasis on

▾ FIG. 4: Two-dimensional snapshots of the development of hydrodynamic instabilities, in a 3-D simulation of mixing at the core-envelope interface during a nova explosion, calculated with the hydrodynamic code FLASH (adapted from Casanova *et al.* 2011, Nature, 478, 490).



▲FIG. 5: DRAGON, an example of recoil mass separator for the study of nuclear reactions of astrophysical interest, located in the ISAC facility at TRIUMF (Vancouver). Image courtesy of Steven Oates.

Li production and on the origin of R Cor Bor stars (a variety of hydrogen-deficient stars with high carbon abundances);

- New nuclear reaction-rate compilation based on Monte Carlo method. Improvements on a suite of reaction rates of interest for nova nucleosynthesis;
- First 3-D simulation of mixing at the core-envelope interface during nova outbursts (Figure 4);
- Identification of a number of oxide grains of a putative nova origin;
- Identification of the most relevant nuclear uncertainties affecting type Ia supernova and type I X-ray burst nucleosynthesis predictions.

Conclusion

The experience achieved in the multi-national, multi-institute EuroGENESIS project has built and organized a European Community in the wide field of nuclear astrophysics. It led to new and effective interactions and information flow across the scattered and widely-spread and individually-small research groups of nuclear physics experimentalists (Figure 5), theorists, modellers and astrophysical observers. This permitted joint rather than isolated actions. It probably laid the ground work for future joint explorations at a trans-national level, necessary to make break-through advances in such a complex and inter-related field that spans from the microcosmos of nuclear forces to the macroscopic cosmic objects and the chemical evolution across the entire universe. ■

About the authors

Jordi José (Technical Univ. Catalonia) works at the crossroads between computational astrophysics, nuclear physics and cosmochemistry. His research has focused in the modelling of stellar explosions, mostly in classical novae and X-ray bursts.

Martin Asplund (Australian National University) has broad research interests, ranging from the Sun and the origin of the Solar System, over stellar physics and extrasolar planets, to the history of the Milky Way and the origin of the elements across cosmic time.

Corinne Charbonnel (Univ. Geneva and CNRS) is a specialist in stellar evolution and nucleosynthesis, chemical and dynamical evolution of massive stellar clusters and galaxies, and planet habitability.

Isabelle Cherchneff (Univ. Basel) investigates the formation of cosmic dust in evolved stellar environments (AGB stars, massive stars and supernovae). She models the production of molecules, dust clusters and grains through an interdisciplinary approach that involves hydrodynamics, chemistry, nanoscience and astronomy.

Roland Diehl (Max-Planck-Institute for Extraterrestrial Physics and TU München) is a gamma-ray astronomer working with space telescopes for cosmic nuclear line spectroscopy. His main research interests are massive stars and supernova explosions, and their impact on the surroundings.

Andreas Korn (Uppsala Univ.) uses stellar spectroscopy to trace the chemical evolution of the cosmos. He has worked on hot, short-lived stars as well as cool, old stars in the Milky Way and its neighbors.

Friedrich-Karl Thielemann (Univ. Basel) makes use of properties of stable and unstable nuclei in order to employ them in predictions for nucleosynthesis ejecta, originating from stellar evolution and explosions (*e.g.*, X-ray bursts, supernovae, hypernovae, compact object mergers, gamma-ray bursts).

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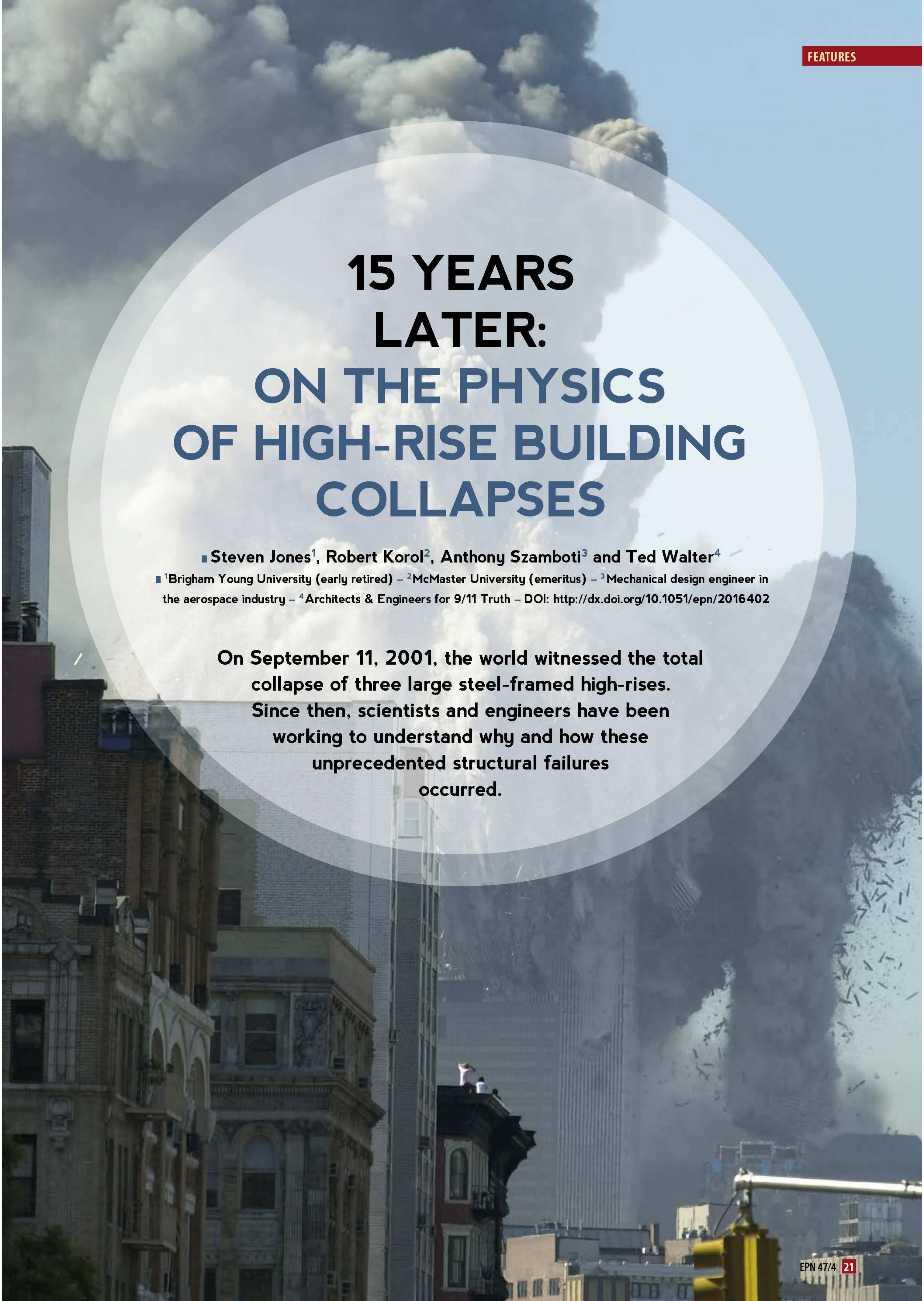


15 YEARS LATER: ON THE PHYSICS OF HIGH-RISE BUILDING COLLAPSES

Steven Jones[1], Robert Korol[2], Anthony Szamboti[3] and Ted Walter[4]

[1]Brigham Young University (early retired) – [2]McMaster University (emeritus) – [3]Mechanical design engineer in the aerospace industry – [4]Architects & Engineers for 9/11 Truth – DOI: http://dx.doi.org/10.1051/epn/2016402

On September 11, 2001, the world witnessed the total collapse of three large steel-framed high-rises. Since then, scientists and engineers have been working to understand why and how these unprecedented structural failures occurred.

NOTE FROM THE EDITORS

This feature is somewhat different from our usual purely scientific articles, in that it contains some speculation. However, given the timing and the importance of the issue, we consider that this feature is sufficiently technical and interesting to merit publication for our readers. Obviously, the content of this article is the responsibility of the authors.

In August 2002, the U.S. National Institute of Standards and Technology (NIST) launched what would become a six-year investigation of the three building failures that occurred on September 11, 2001 (9/11): the well-known collapses of the World Trade Center (WTC) Twin Towers that morning and the lesser-known collapse late that afternoon of the 47-story World Trade Center Building 7, which was not struck by an airplane. NIST conducted its investigation based on the stated premise that the "WTC Towers and WTC 7 [were] the only known cases of total structural collapse in high-rise buildings where fires played a significant role."

Indeed, neither before nor since 9/11 have fires caused the total collapse of a steel-framed high-rise—nor has any other natural event, with the exception of the 1985 Mexico City earthquake, which toppled a 21-story office building. Otherwise, the only phenomenon capable of collapsing such buildings completely has been by way of a procedure known as controlled demolition, whereby explosives or other devices are used to bring down a structure intentionally. Although NIST finally concluded after several years of investigation that all three collapses on 9/11 were due primarily to fires, fifteen years after the event a growing number of architects, engineers, and scientists are unconvinced by that explanation.

Preventing high-rise failures

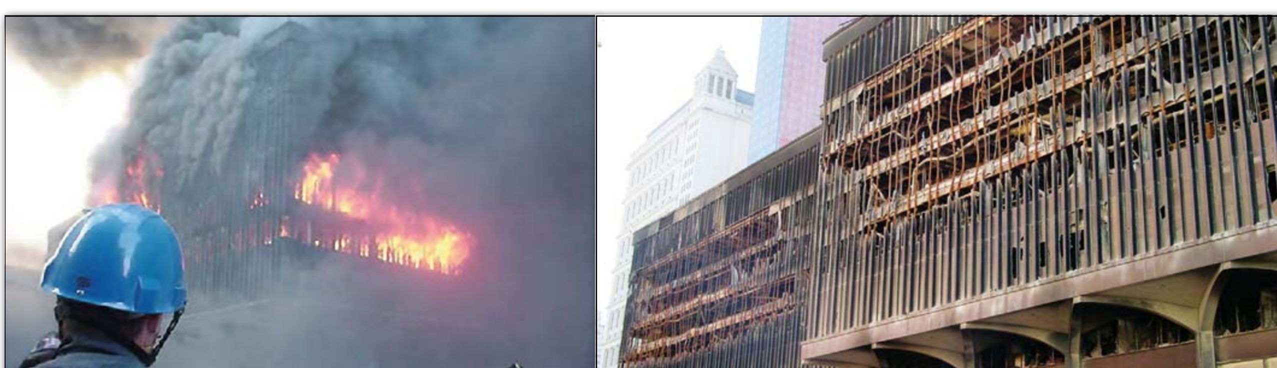
Steel-framed high-rises have endured large fires without suffering total collapse for four main reasons:
1) Fires typically are not hot enough and do not last long enough in any single area to generate enough energy to heat the large structural members to the point where they fail (the temperature at which structural steel loses enough strength to fail is dependent on the factor of safety used in the design. In the case of WTC 7, for example, the factor of safety was generally 3 or higher. Here, 67% of the strength would need to be lost for failure to ensue, which would require the steel to be heated to about 660°C);
2) Most high-rises have fire suppression systems (water sprinklers), which further prevent a fire from releasing sufficient energy to heat the steel to a critical failure state;
3) Structural members are protected by fireproofing materials, which are designed to prevent them from reaching failure temperatures within specified time periods; and
4) Steel-framed high-rises are designed to be highly redundant structural systems. Thus, if a localized failure occurs, it does not result in a disproportionate collapse of the entire structure.

Throughout history, three steel-framed high-rises are known to have suffered partial collapses due to fires; none of those led to a total collapse. Countless other steel-framed high-rises have experienced large, long-lasting fires without suffering either partial or total collapse (see, for example, Fig. 1a and 1b) [1].

In addition to resisting ever-present gravity loads and occasional fires, high-rises must be designed to resist loads generated during other extreme events—in particular, high winds and earthquakes. Designing for high-wind and seismic events mainly requires the ability of the structure to resist lateral loads, which generate both tensile and compressive stresses in the columns due to bending, the latter stresses then being combined with gravity-induced compressive stresses due to vertical loads. It was not until steel became widely manufactured that the ability to resist large lateral loads was achieved and the construction of high-rises became possible. Steel is both very strong and ductile, which allows it to withstand the tensile stresses generated by lateral loads, unlike brittle materials, such as concrete, that are weak in tension. Although concrete is used in some high-rises today, steel reinforcement is needed in virtually all cases.

To allow for the resistance of lateral loads, high-rises are often designed such that the percentage of their columns' load capacity used for gravity loads is relatively

▾**FIG. 1:** WTC 5 is an example of how steel-framed high-rises typically perform in large fires. It burned for over eight hours on September 11, 2001, and did not suffer a total collapse (Source: FEMA).



▲ **FIG. 2:** WTC 7 fell symmetrically and at free-fall acceleration for a period of 2.25 seconds of its collapse (Source: NIST).

low. The exterior columns of the Twin Towers, for example, used only about 20% of their capacity to withstand gravity loads, leaving a large margin for the additional lateral loads that occur during high-wind and seismic events [2].

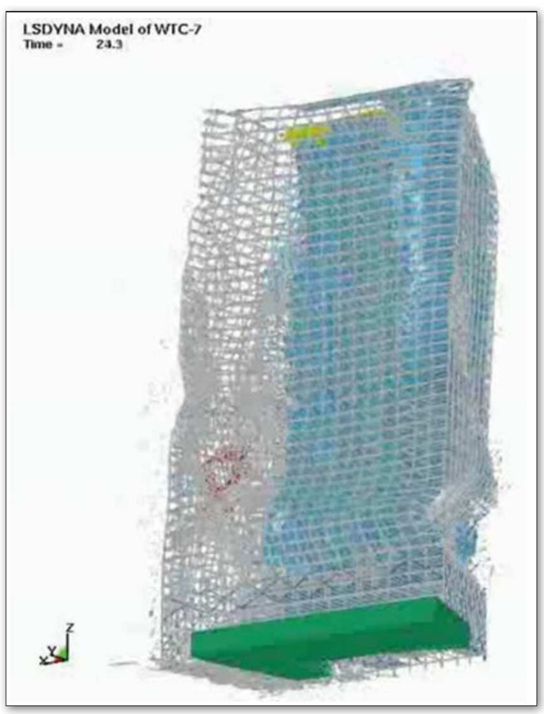
Because the only loads present on 9/11 after the impact of the airplanes were gravity and fire (there were no high winds that day), many engineers were surprised that the Twin Towers completely collapsed. The towers, in fact, had been designed specifically to withstand the impact of a jetliner, as the head structural engineer, John Skilling, explained in an interview with the *Seattle Times* following the 1993 World Trade Center bombing: "Our analysis indicated the biggest problem would be the fact that all the fuel (from the airplane) would dump into the building. There would be a horrendous fire. A lot of people would be killed," he said. "The building structure would still be there." Skilling went on to say he didn't think a single 200-pound [90-kg] car bomb would topple or do major structural damage to either of the Twin Towers. "However," he added, "I'm not saying that properly applied explosives—shaped explosives—of that magnitude could not do a tremendous amount of damage.... I would imagine that if you took the top expert in that type of work and gave him the assignment of bringing these buildings down with explosives, I would bet that he could do it."

In other words, Skilling believed the only mechanism that could bring down the Twin Towers was controlled demolition.

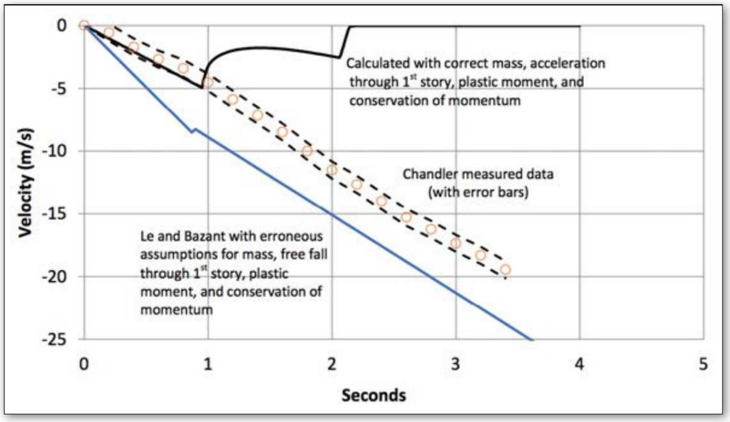
Techniques of controlled demolition

Controlled demolition is not a new practice. For years it was predominantly done with cranes swinging heavy iron balls to simply break buildings into small pieces. Occasionally, there were structures that could not be brought down this way. In 1935, the two 191-m-tall Sky Ride towers of the 1933 World's Fair in Chicago were demolished with 680 kg of thermite and 58 kg of dynamite. Thermite is an incendiary containing a metal powder fuel (most commonly aluminum) and a metal oxide (most commonly iron(III) oxide or "rust"). Eventually, when there were enough large steel-framed buildings that needed to be brought down more efficiently and inexpensively, the use of shaped cutter charges became the norm. Because shaped charges have the ability to focus explosive energy, they can be placed so as to diagonally cut through steel columns quickly and reliably.

In general, the technique used to demolish large buildings involves cutting the columns in a large enough area of the building to cause the intact portion above that area to fall and crush itself as well as crush whatever remains below it. This technique can be done in an even more sophisticated way, by timing the charges to go off in a sequence so that the columns closest to the center are destroyed first. The failure of the interior columns creates an inward pull on the exterior and causes the majority of the building to be pulled inward and downward while materials are being crushed, thus keeping the crushed materials in a somewhat confined area—often within the building's "footprint." This method is often referred to as "implosion."



◂ **FIG. 3:** The final frame of NIST's WTC 7 computer model shows large deformations to the exterior not observed in the videos (Source: NIST).



▲ **FIG. 4: The above graph [10] compares David Chandler's measurement [9] of the velocity of the roofline of WTC 1 with Bažant's erroneous calculation [11] and with Szamboti and Johns' calculation using corrected input values for mass, acceleration through the first story, conservation of momentum, and plastic moment (the maximum bending moment a structural section can withstand). The calculations show that—in the absence of explosives—the upper section of WTC 1 would have arrested after falling for two stories (Source: Ref. [10]).**

The case of WTC 7

The total collapse of WTC 7 at 5:20 PM on 9/11, shown in Fig. 2, is remarkable because it exemplified all the signature features of an implosion: The building dropped in absolute free fall for the first 2.25 seconds of its descent over a distance of 32 meters or eight stories [3]. Its transition from stasis to free fall was sudden, occurring in approximately one-half second. It fell symmetrically straight down. Its steel frame was almost entirely dismembered and deposited mostly inside the building's footprint, while most of its concrete was pulverized into tiny particles. Finally, the collapse was rapid, occurring in less than seven seconds.

Given the nature of the collapse, any investigation adhering to the scientific method should have seriously considered the controlled demolition hypothesis, if not started with it. Instead, NIST (as well as the Federal Emergency Management Agency (FEMA), which conducted a preliminary study prior to the NIST investigation) began with the predetermined conclusion that the collapse was caused by fires.

Trying to prove this predetermined conclusion was apparently difficult. FEMA's nine-month study concluded by saying, "The specifics of the fires in WTC 7 and how they caused the building to collapse remain unknown at this time. Although the total diesel fuel on the premises contained massive potential energy, the best hypothesis has only a low probability of occurrence." NIST, meanwhile, had to postpone the release of its WTC 7 report from mid-2005 to November 2008. As late as March 2006, NIST's lead investigator, Dr. Shyam Sunder, was quoted as saying, "Truthfully, I don't really know. We've had trouble getting a handle on building No. 7."

All the while, NIST was steadfast in ignoring evidence that conflicted with its predetermined conclusion. The most notable example was its attempt to deny that WTC 7 underwent free fall. When pressed about that matter during a technical briefing, Dr. Sunder dismissed it by saying, "[A] free-fall time would be an object that has no structural components below it." But in the case of WTC 7, he claimed, "there was structural resistance that was provided." Only after being challenged by high school physics teacher David Chandler and by physics professor Steven Jones (one of the authors of this article), who had measured the fall on video, did NIST acknowledge a 2.25-second period of free fall in its final report. Yet NIST's computer model shows no such period of free fall, nor did NIST attempt to explain how WTC 7 could have had "no structural components below it" for eight stories.

Instead, NIST's final report provides an elaborate scenario involving an unprecedented failure mechanism: the thermal expansion of floor beams pushing an adjoining girder off its seat. The alleged walk-off of this girder then supposedly caused an eight-floor cascade of floor failures, which, combined with the failure of two other girder connections—also due to thermal expansion—left a key column unsupported over nine stories, causing it to buckle. This single column failure allegedly precipitated the collapse of the entire interior structure, leaving the exterior unsupported as a hollow shell. The exterior columns then allegedly buckled over a two-second period and the entire exterior fell simultaneously as a unit [3].

NIST was able to arrive at this scenario only by omitting or misrepresenting critical structural features in its computer modelling.[4] Correcting just one of these errors renders NIST's collapse initiation indisputably impossible. Yet even with errors that were favorable to its predetermined conclusion, NIST's computer model (see Fig. 3) fails to replicate the observed collapse, instead showing large deformations to the exterior that are not observed in the videos and showing no period of free fall. Also, the model terminates, without explanation, less than two seconds into the seven-second collapse. Unfortunately, NIST's computer modelling cannot be independently verified because NIST has refused to release a large portion of its modelling data on the basis that doing so "might jeopardize public safety."

The case of the Twin Towers

Whereas NIST did attempt to analyze and model the collapse of WTC 7, it did not do so in the case of the Twin Towers. In NIST's own words, "The focus of the investigation was on the sequence of events from the instant of aircraft impact to the initiation of collapse for each tower.…this sequence is referred to as the 'probable collapse sequence,' although it includes little analysis of the structural behaviour of the tower after the conditions for collapse initiation were reached and collapse became inevitable."[5]

Thus, the definitive report on the collapse of the Twin Towers contains no analysis of why the lower sections failed to arrest or even slow the descent of the upper