ME 346

Engineering Analysis of Tragedy at WTC

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Consider the details of a 767

Passengers- up to 375
Fuel Capacity –23,980 gallons
Engines – PW 4062 63,300lb thrust
GECF6-80C2B8F 63,500lb
Cruise Speed at 35,000ft – 530mph
Take-off Weight 450,000lbs

Aircraft have the equivalent power of a small scale commerical power plant

A simple calculation shows that the Amount of energy required to get the 767 to 35,000 ft in ten minutes requires The output of a small commercial power Plant.

Potential energy = mgh
$=21 \times 10^9$ Joules

Reaches altitude in 10 minutes

35.6 Megawatts

Energetics

The kinetic energy of a 767 at impact is on the order of 4000MegaJoules. Though this energy is considerable, it is clear that the tower withstood this impact. Though damaged, TWC managed to remain standing for approximately 1 hour.

As such, it was not the impact, but the energy in the fuel that compromised the structural integrity of the building. The calculation to the right shows that the energy content of gasoline is roughly 132MegaJoules per gallon. Jet fuel has an even greater energy content. If 20,000 gallons of fuel detonated at once, this would amount to the equivalent of 7,920,000 Sticks of dynamite. One can see that the impact energy of the jet is negligible compared to the energy content of the fuel (3 sticks of dynamite is roughly 1 MegaJoule.)

Kinetic energy = $1/2mV^2$

Mass=204×10^3Kg
V=197m/sec

KE=39.6×10^8Joules

Energy Content of fuel
around 132×10^6J/gal
20,000gallons =
2.64×10^{12}Joules
3 sticks of dynamite is 1Mjoule
So 7,920,000 sticks of dynamite energy content of the fuel!

Impact Forces

If we assume that the jet liner was Travelling at roughly 440 mph, and Dissipated all of its energy in 1 second, then the impact force is 9,000,000 lbs. This is substantial and generated a moment, for impact at the 70th floor of 6,320,000,000 ft-lbs. Even so, the building withstood the impact, so these forces are not responsible for bringing the building down. Though they did weaken the building, the impact of the jet did not bring the building down.

Momentum=mv
F=mv/sec=40,188,000N or 9,000,000lbs

Torque on the building=Force x moment

=6,320,000,000ft-lbs at the base

What brought the buildings down?

- Impact was clearly not the cause…no analysis needed.
- Did the fuel melt/or weaken the structural metal?
  - Adiabatic flame temperature of Kerosene = 1727C
  - Melting temperature of steel = 1570C
  - Clearly, at the flame front the Kerosene can melt the steel
  - Flames billowed out the windows…the tower uses a structural steel skin…the flame was licking that skin, so the steel melted.
  - Even if T was half the flame temp, the metal would creep rapidly, kink a column and buckling failure occurs.

Why did the building pancake?

- Structural collapse at impact site, leads to drop of upper structure onto lower structure.
- Impact is, at least, 2 times the static load for infinitesimal drop.
  - More like:

$$T = 2g \cdot M \cdot \left\{ \frac{1}{\varepsilon_f} \left(\frac{d}{L} \right) + 1 \right\}$$

Drop height

Standing height
Of the building

Estimating the impact forces

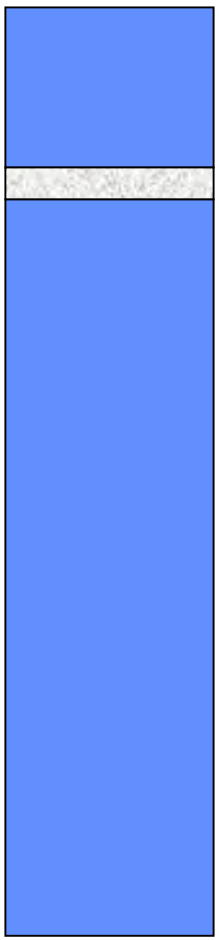
The impact force, T, is related to the failure strain of the steel, ε_f the weight above the failed floor , Mg, the drop height, d, and the intact building height, L. If we presume one floor collapsed, and the remaining height is 70 stories, then the drop height, d is 1 story, and the equation given on the last overhead becomes as follows:

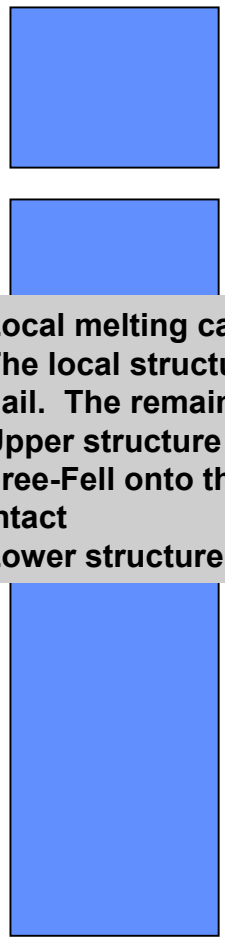
$$T = 2g \cdot M \cdot \left\{ \frac{1}{0.001}\left(\frac{1}{70}\right) + 1 \right\} = 30.5Mg$$

Here I assume that a reasonable estimate of the failure strain is 0.001. This strain is usually associated with the strain at which materials either yield or fracture. Since the system is both steel and concrete, and the temperature is so high, this value of the failure strain is reasonable. The impact force is roughly 30 times the weight of the tower above!

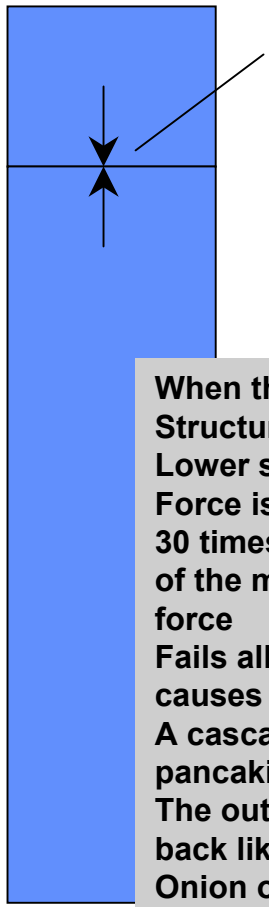
Failure scenario

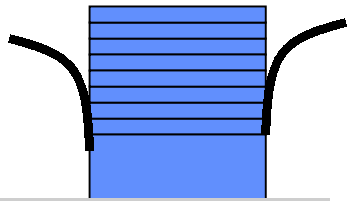
Fire confined
To the impact
Site raised the
Temperature
Of the steel to
At or near
melting
Point.





Local melting caused
The local structure to
Fail. The remaining
Upper structure then
Free-Fell onto the
intact
Lower structure





When the upper
Structure hits the intact
Lower structure, the impact
Force is on the order of
30 times the weight
of the mass above! This
force
Fails all the attachments and
causes
A cascade of floors
pancaking downward.
The outer steel skin peels
back like an
Onion once detached from
the floor slabs.