

**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 commercial 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 40MegaJoules. 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 2,376,000 Sticks of dynamite. (3 sticks of dynamite is 1 MegaJoule.)

$$\text{Kinetic energy} = 1/2mV^2$$

$$\text{Mass} = 204 \times 10^3 \text{Kg}$$

$$V = 19.7 \text{m/sec}$$

$$\text{KE} = 39.6 \times 10^6 \text{Joules}$$

Energy Content of fuel  
around  $132 \times 10^6 \text{J/gal}$

20,000 gallons =

$$792 \times 10^9 \text{Joules}$$

3 sticks of dynamite is 1Mjoule

So 2,376,000 sticks of dynamite

## Impact Forces

If we assume that the jet liner was Travelling at cruising speed, and Dissipated all of its energy in 1 second, then the impact force is 903,510lbs. This is substantial and generated a moment, for impact at the 70<sup>th</sup> floor if 632,000,000 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=4,018,800N or  
903,510lbs**

**Torque on the  
building=Force x moment**

**=632,000,000ft-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:

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

Drop height

standing

## Estimating the impact forces

The impact force,  $T$ , is related to the failure strain of the steel, 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 equation given on the last overhead becomes as follows:

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

The impact force is roughly 30 times the weight of the tower above! There isn't a building in existence with a factor of safety of 30!

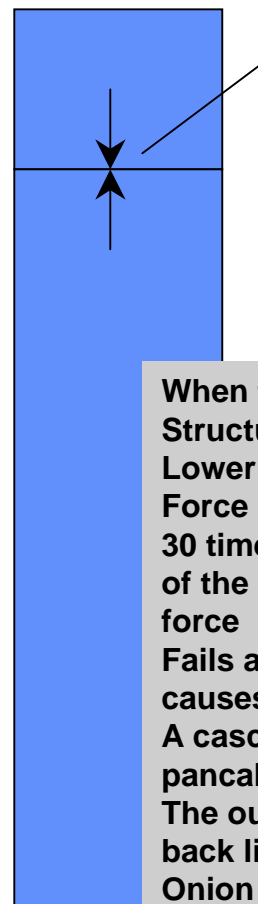
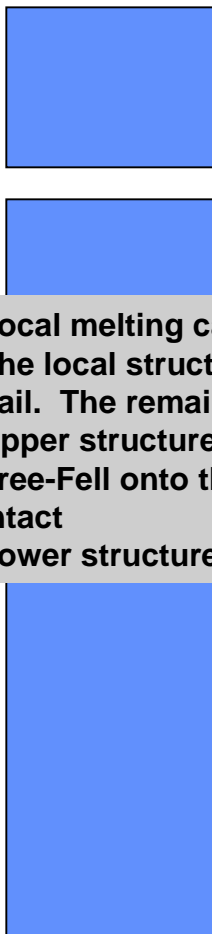


## Failure scenario

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.

