How much Explosives are required to laterally eject multi-ton Steel Sections from the WTC Towers?

Estimating a lower bound

Abstract

Proponents of alternative narratives concerning the collapses of the World Trade Center Twin Towers on September 11, 2001 (“9/11 Truthers”) have claimed that sections of structural steel from the towers were laterally ejected hundreds of feet, or at lateral velocities around 60 to 70 mph, and suggested that this can be explained as the work of charges of explosives that were installed in the buildings to engineer their destruction. Applying the principles of *Conversation of Energy* and *Conversation of Momentum*, we estimate the minimum amount of hypothetical but plausible high explosives per ton of steel necessary to effect such ejections. Several simplifying assumptions are made, generally such that we would tend to underestimate the lower bound.

Introduction

The Twin Towers of the World Trade Center in New York City stood about 415 m tall when they suffered from devastating plane impacts and fires on the morning of September 11, 2001. The North Tower was hit around the 95th floor (~360 m high), the South Tower around the 80th floor (~300 m). After the towers had collapsed, large sections of structural steel assemblies from the perimeter walls, weighing several tons apiece, were found to have hit the faces of buildings outside of the World Trade Center premises, up to approximately 600 feet (~180 m) away from the nearest corner or edge of a tower footprint. No clear video recordings have captured with sufficient clarity how these pieces traveled there. One hypothesis advanced by some members of the so called “9/11 Truth Movement” suggests that explosives were used to intentionally demolish the towers, and that such explosives propelled the steel sections to a lateral velocity sufficient to make them fall ballistically to land where they were found.

Examples for specific claims of this nature are:

- Don Paul and Jim Hoffman[1]: “*[h]eavy pieces of steel were ejected in all directions for distances up to 500 feet, while aluminum cladding was blown up to 700 feet away from the towers*” (cited by D. R. Griffin[2]).
- David Chandler[3]: At 0:06 min: “*Girders from the North Tower of the World Trade Center weighing about 4 tons each were found in the Winter Garden 600 feet away after the towers collapsed*”. At 0:25 min: “*This simulation computes the necessary ejection speed for various girder heights to make the girders land where they did*”. At 1:42 min: “*Forces beside gravity must have been at work on that day. A much more plausible theory, and one that is consistent with many other observed facts, is that the girders were blown out not by air squeezed from between the floors, but by explosive charges that were set in the buildings*

ahead of time.”

- AE911Truth[4]: “*KEY EVIDENCE … 4. Lateral ejection of multi-ton steel framing members distances of 600 feet at more than 60 mph*”. This is backed up by a video[5] with footage of the collapses and opinions spoken by several interviewed persons, such as Richard Gage (0:23 min: “*Videos show multi-ton steel sections of hundreds of individual steel pieces ejecting out of the towers at 60 miles an hour for a distance of 600 feet*”), Jody Gibbs (1:15 min: “*Large, multi-ton beams were hurled hundreds of yards laterally.*”), David Chandler (2:03 min: “*Something happening to throw these things horizontally at those kinds of speed … It really is indicative of some kind of explosion.*”), Leslie Young (2:35 min: “*The floors pancaking upon themselves would create gushes of air out the side, but not the kind of explosive force that we saw, that would throw I-beams across the street into the windows of other buildings*”). At 2:14, a screen caption claims “*Lateral Ejections of Free-Flying Heavy Steel Sections: Up to 70 miles/hr.*”

- John Wyndham and Wayne Coste[6]: “*But NIST never attempted to explain the physical evidence of the building destructions such as what caused four ton perimeter columns and other debris to be ejected horizontally in all directions from the “collapsing” Towers at speeds of up to 70 mph, or why column sections weighing many tons were stuck in buildings hundreds of meters (feet) from the Towers as in Fig.1 [15] [16].*” The latter reference, a “News” item at scientistsfor911truth.org[7], makes specific reference to a wall panel “*[i]mpaled in nearby World Financial Center Building 3 (WFC3), at the 20th floor*” and goes on to “*calculate the minimum horizontal velocity with which the impaled columns were ejected from WTC1, the nearest tower, to hit the 20th floor of WFC3. The velocity is about 43 mph minimum*”, assuming the piece started at the 95th floor of WTC1 and traveled a lateral distance of 468 ft (143 m).

- The boldest claim perhaps was made by Josef Princiotta[8] at a presentation in 2009 in Japan: “*100 Tons of steel ejected in an instant at speeds near 55 MPH*”. The value 54 mph is the result of a calculation assuming a lateral distance of 600 ft and a freefall time of 7.5 s, which would be equivalent to about 900 ft (275 m) vertical drop.

Model and Assumptions

No explanation has been proposed how and why explosives would have been attached to steel sections to propel them horizontally, or what kind of explosives. However, it is possible to construct model scenarios to emulate the situation. Assumptions are geared toward most efficient use of the kinetic energy released by ideally placed explosive charges.

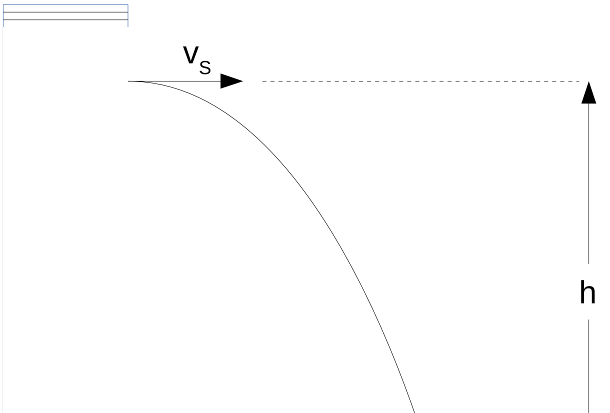

Figure 1: Ballistic curve of steel piece ejected from WTC tower

Ballistic fall

We will assume that a mass of steel m_S starts out at rest from a height h relative to its landing spot and is already detached from the rest of the structure, when an explosive charge of mass m_C attached to it propels it horizontally away from the wall of the tower. The assumption that the direction towards which m_S gets propelled *laterally* is not ideal – an initial momentum vector somewhat upwards in addition to outwards would shoot the steel farther. However, since we are not aware of any claim that steel was shot upwards, and to keep calculations reasonably simple, we disregard that possibility.

It is assumed that the explosive impact accelerates the steel immediately to its final lateral velocity – we will disregard energy losses to deformation of the steel due to the extreme force of the blast. We will also disregard the effect of air resistance.

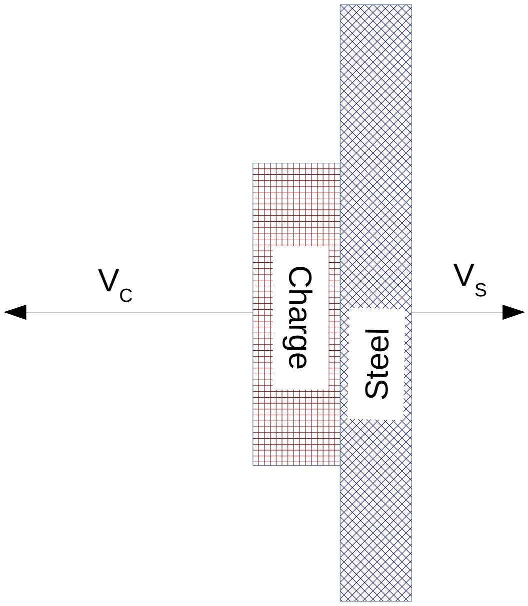

Figure 2: Schematic arrangement of explosive charge on steel

The lateral velocity v_S of the steel that makes it travel the lateral distance d in the time it takes to fall from height h can be thus derived:

Freefall motion is described by

$$h=\frac{1}{2}gt^2 \Leftrightarrow t=\sqrt{2h/g} \qquad (1)$$

Horizontal motion simply by

$$d=v_S t \Leftrightarrow v_S=\frac{d}{t} \qquad (2)$$

Substituting t in the right part of (2) we get

$$v_S=\frac{d}{\sqrt{2h/g}} \qquad (3)$$

For example, for an object falling from a height of 300 m to a position at 200 m lateral distance, we find the necessary lateral ejection velocity to be v_S = 200 m / sqrt(2 * 300 m / (9.805 m s^{-2})) = 25.6 m/s (~57.5 mph). An object falling 415 m down and 180 m far would have to start out at v_S = 19.6 m/s (~44.0 mph).

Explosive propulsion

We will assume that the steel piece has a flat surface directly upon which an amount of explosive material is attached. The centroids of both objects (steel, charge) are adjacent such that the explosion will not impart an angular momentum on either. We will assume that the total mass of the charge gets converted to expanding gas, and that all the gas is propelled parallely and oppositely to the steel. This is unrealistically and in favor of efficiency – some of the gas would, in reality, be propelled at angles oblique to normal such that only a part of its momentum is on the vector opposite to the steel's.

All variables describing the steel will have a subscript "$_S$" and all variables for the charge will be denoted with a subscript “$_C$”.

The properties of the components before the blast are:

m_S	Mass of the steel piece – e.g. 1,000 kg
m_C	Mass of the explosive charge – this is what we will solve for
v_S	Velocity of steel = 0
v_C	Velocity of charge = 0
KE_S	Kinetic energy = 0
KE_C	Kinetic energy = 0
CE_C	Chemical energy = $m_C \cdot SE_C$
SE_C	*Specific energy of the explosive, e.g. for TNT 4.2* $\frac{MJ}{kg}$
p_S	Momentum = 0
p_C	Momentum = 0

After the explosion, momentum must be conserved:

$$p_S = -p_C \tag{4}$$

All the chemical energy shall be transformed to kinetic energy:

$$KE_S + KE_C = CE_C = m_C\, SE_C \tag{5}$$

This assumption is impossible and errs on the side of underestimating the lower bound for charge size, as efficiency would be 100%.

Equation (4) can be expanded using the well-known formula for linear momentum:

$$m_S \cdot v_S = -m_C \cdot v_C \tag{6}$$

Rearranging this equation, we introduce a parameter F – the mass-ratio steel:charge:

$$F = \frac{m_S}{m_C} = \frac{-v_C}{v_S} \tag{7}$$

Equation (5) can be expanded using the well-known formula for kinetic energy:

$$m_C \cdot SE_C = \frac{1}{2} \cdot m_S \cdot v_S^2 + \frac{1}{2} \cdot m_C \cdot v_C^2 \qquad | \quad \div m_C \tag{8a}$$

$$SE_C = \frac{1}{2} \cdot \frac{m_S}{m_C} \cdot v_S^2 + \frac{1}{2} \cdot v_C^2 \qquad | \quad F = \frac{m_S}{m_C} \tag{8b}$$

$$SE_C = \frac{1}{2} \cdot F \cdot v_S^2 + \frac{1}{2} \cdot v_C^2 \qquad | \quad v_C = -\frac{m_S}{m_C} \cdot v_S = -F \cdot v_S \tag{8c}$$

$$SE_C = \frac{1}{2} \cdot F \cdot v_S^2 + \frac{1}{2} \cdot F^2 \cdot v_S^2 = \frac{1}{2}\, v_S^2 \cdot \left(F + F^2\right) \qquad | \quad * \frac{2}{v_S^2} \tag{8d}$$

$$\frac{2 \cdot SE_C}{v_S^2} = F + F^2 \tag{8e}$$

$$F^2 + F - \frac{2 \cdot SE_C}{v_S^2} = 0 \tag{8f}$$

This is a reduced quadratic expression[9] of the form

$$x^2 + p\,x + q = 0 \tag{9a}$$

with $x = F,\, p = 1,\, q = -\frac{2 \cdot SE_C}{v_S^2}$ – the latter is constant when the parameters SE_C and v_S are chosen –, and can be solved with the formula

$$x = \frac{1}{2}\left(-p \pm \sqrt{p^2 - 4q}\right) \tag{9b}$$

So we can solve for the factor F, the ratio between the mass of the steel and the mass of the explosive charge, with the formula

$$F = \frac{1}{2}\left(-1 + \sqrt{1 + 8\frac{SE_C}{v_S^2}}\right) \tag{10}$$

(Note that the second Zero of the function would be negative and thus cannot be applied to a mass)

We can finally apply formula (3) and substitute v_S in (10):

$$F = \frac{1}{2}\left(-1 + \sqrt{1 + \frac{16 \cdot SE_C \cdot h}{d^2 \cdot g}}\right) \tag{11a}$$

The amount of explosives per a given mass of steel would be given by rearranging Equation (7):

$$m_C = \frac{m_S}{F} \tag{11b}$$

For example, substituting the value 1000 kg for m_S in Equation (11b) yields the amount of explosives per ton of steel. The absolute value of the resulting velocity of the explosive gases can be computed by rearranging (7):

$$|v_C| = F * v_S \tag{11c}$$

Discussion

We can now explore the upper bounds of the mass ratio steel:explosives for reasonable applicable intervals of the three parameters SE_C, h and d:

- F increases with increasing specific energy SE_C and drop height h (roughly by the square root of either), and decreases roughly proportional to lateral distance d.
- Conversely, the lower bound for the amount of explosives needed to propel the steel laterally as claimed decreases when SE_C and h increase, or when d decreases.

Common high explosives have specific energies ranging from around 3.6 MJ/kg to a bit above 6 kJ/g[10]. Thermite has a theoretical maximum energy yield of 3.9 MJ/kg, while nano-thermite preparations have been measured to yield only about 1.5 to 2 MJ/kg. We can apply a factor of efficiency to SE_C to account for the inevitable loss of energy, as some of it must be converted to heat, plastic deformation, acoustic waves and expansion of gases to directions not directly opposite to the momentum vector of the steel, or calculate with lower values of SE_C.

No steel from the WTC Tower walls can have fallen from a height greater than 415 m. The North Tower started failing at a height around 360 m – if this was caused by explosives, that would be a reasonable starting height. For the South Tower, that height was approximately 300 m.

Some of the wall panels that were found far away were embedded several stories high above ground in the facades of buildings on the other side of the street:

- The Bankers Trust Building, also known as Deutsche Bank building, at 130 Liberty Street, was hit its north face by heavy debris from the south face of the WTC South Tower[11]. According to the FEMA report, it was located "*about 600 feet due south of the southeast corner of WTC 2*" (page 6-1). It is not clear if this distance is measured from the north face or the center of the building. Gauging Figure 7-1 of the FEMA report[9], it appears that the distance face-to-face was 1.25 times the width of the WTC tower, or approximately only 260 feet (80 m). "*A column section from WTC 2 was embedded in the north edge of the floor slab of the 29th floor*" (page 6-4), that would be a height of approximately 400 feet (122 m). In addition: "*It also appears that one section, or perhaps several sections, of exterior column trees from the south wall of WTC 2 plunged through the north wall of the building just above the 23rd floor*" and cut out a gash all the way down to the ground – this would be approximately 320 feet (98 m) high and represent a far greater mass of steel.
- The American Express Building (WFC3), to the west of West Street across from the North Tower, had a wall panel sticking out of the south-east corner[12], about 19 stories high (estimated: 70 m above ground, or 290 meters below the North Tower collapse initiation zone). The south-east corner of WFC3 appears to be about 465 feet (142 m) from the north-west corner of the WTC North Tower.
- WTC 7[13], which was hit by heavy debris on its south face near its roof, approximately 180 m high and apparently about 370 feet (113 m) from the North Tower's north face. Drop distance from the top of the North Tower would have been about 235 m, and from the collapse initiation zone about 180 m.

For the three peripheral buildings that were hit high, the estimated fall distances shall be assumed as:

- Bankers Trust Building (BTB): d = 80 m, h = 200 – 315 m
- WTC 7: d = 113 m, h = 180 – 235 m
- WFC3: d= 142 m, h = 290 – 345 m

We cannot corroborate lateral distances of 600 feet (183 m), but take this as the maximum anyway, for a piece that fell to the ground:

- Max. distance: d= 183 m, h = 360 m

This results in a maximum lateral velocity of v_S = 21.4 m/2 = 48 mph, using Equation (3). That's less than the higher values of 55 mph, 60 mph or 70 mph given by the various "9/11 Truthers" we quoted in the Introduction.

Table 1 tabulates results for several different combinations of SE_C, h and d. The mass ratio (fifth column) is calculated using Equation (11a), the kg charge (sixth column) uses Equation 11b, v_S uses

Target	SE_C MJ/kg	h m/ft	d m/ft	Mass ratio steel:charge	kg charge per 1000 kg steel	v_S m/s (mph)	v_C m/s
BTB	4.5	315	80	300	3.3	10.0 (22.5)	2995
BTB	4.5	200	80	239	4.2	12.5 (28.2)	2994
WTC 7	4.5	235	113	183	5.5	16.3 (36.7)	2992
WTC 7	4.5	180	113	160	6.2	18.6 (42.0)	2991
WFC3	4.5	345	142	177	5.7	16.9 (38.1)	2992
WFC3	4.5	290	142	162	6.2	18.5 (41.5)	2991
600 ft	4.5	360	183	140	7.1	21.4 (48.0)	2989
BTB	6.0	315	80	347	2.9	10.0 (22.5)	3459
BTB	3.0	315	80	245	4.1	10.0 (22.5)	2445
BTB	1.5	315	80	173	5.8	10.0 (22.5)	1727
600 ft	6.0	360	183	162	6.2	21.4 (48.0)	3453
600 ft	3.0	360	183	114	8.8	21.4 (48.0)	2439
600 ft	1.5	360	183	81	12.4	21.4 (48.0)	1721

Table 1: Calculated mass ratios and velocities for various energy densities, drop heights and distances

Equation (3), and v_C is given by Equation (11c).

For the Specific Energy of the explosive, first a value of 4.5 MJ/kg is assumed (that would be close to TNT, for example. The first seven rows of Table 1 list the results for this value and the seven cases above. The two cases resulting in the lowest and highest amount of explosives needed (BTB with h = 315 m, and 600 ft distance from h = 360 m) were then calculated with Specific Energies of 6.0 MJ/kg, 3 MJ/kg and 1.5 MJ/kg. The first represents the most energetic explosives at almost perfect efficiency – a highly improbable assumption. The last represents realistic explosives and more plausible efficiency.

The best case – most energy-rich explosive, no losses, full height, shortest distance – requires 2.9 kg of explosives per ton of ejected steel. The worst case – low-yield explosive or losses of 50% or more, lowest drop height, farthest distance – requires 12.4 kg explosives per ton of steel. In all cases, the gas velocity depends almost exclusively on the Specific Energy and is very much supersonic (1721 m/s is about 5 times the speed of sound), but well below the range of detonation velocities of common high explosives (urea nitrate has a relatively low 4700 m/s, HMX is near the upper end of the scale with 9400 m/s)[14]. The mass ratio doesn't react very sensitively to varying inputs in the reasonable magnitudes of values used here. Generally, it is found that per ton of steel ejected, at least 8 kg (+/- 50%) of high explosives would be needed for lateral ejection as claimed.

The pieces thus found usually were one or more wall panels. A WTC wall panel consisted of 3 columns with a length equivalent to the height of 3 stories, connected by 3 spandrel plates. The columns were welded box columns, ca. 14 inches (0.36 m) wide, 13.5 inches (0.34 m) deep and approx. 37 feet (11.31 m) high. Spandrels were about 1.30 m high and 10 feet (3.05 m) wide. Of this width, we need to subtract 3 * 0.36 m = 1.08 m to avoid counting the area twice where the spandrel represents one side of the column. In the upper stories, plate thickness was as little as ¼ inch (0.00635 m). Surface area of the columns per panel was thus approximately 3 * 2 * (0.36 m + 0.34 m) * 11.31 m = 47.5 m^2. The three spandrels had an area (outside the columns) of 3 * 1.3 m * (3.05 m – 1.08 m) = 7.68 m^2. The steel volume, assuming the thinnest plates, was thus (47.5 m^2 + 7.68 m^2) * 0.00635 m = 0.35 m^3. At an assumed density of steel of 7.8 tons/m^3, this amounts to about 2.75 tons as the weight of the lightest possible wall panels. Where plate thickness was larger in lower floors, including the impact and fire floors where the collapses initiated, panels weighed easily twice as much – such as 6 or 7 tons.

To eject one such light panel laterally 600 feet using explosives, the minimum charge size can be estimated to be in a range of 10 to 40 kg, requiring gas velocities several times the speed of sound. As we saw earlier, some 9/11 Truthers have claimed 4 tons. Their highest claimed steel velocity was 70 mph = 31.1 m/s. With the most energetic explosives at SE_C = 6.0 MJ/kg, using Equations (10) and (11c), we find that these claims necessitate a theoretical, lossless minimum of 41.7 kg of high explosive. Such an explosion would without fail result in an extremely powerful shockwave. NIST has calculated that exploding a hypothetical 9 pound (4.5 kg) demolition charge in the core of Building 7 of the WTC would result in a shockwave with a sound level of 130 to 140 dB – 1 km away from the building[15]. Blasts from charges ~10 times that size at a height of 300 m or more would have been audible as very distinctive, very loud cracking sounds for many miles around and no doubt would have been heard on almost all sound recordings done within a mile of the WTC. Nothing that comes even close can be heard on any of the existing videos of the collapses today.

Conclusions

We have derived a formula to compute the amount of explosives that would be required at a minimum, in an ideal scenario designed for that purpose, to propel 1 ton of steel laterally such that it lands a given distance d from its origin after falling freely from a height h, given a specific energy of the explosive material used.

Plugging in plausible values for real existing explosives, the height from which WTC wall panels might have originated, and a range of maximum observed distances, we find that roughly 10 kg of explosives are needed to propel 1 ton of steel thusly. Since the steel pieces found at distances from the towers weighed at least 2.75 tons, but may have weighed twice or more, and since any such explosive propulsion would have been less than 100% energy-efficient, it can be estimated that minimum charge sizes of 30 to 100 kg are realistic. The gas velocities of the explosion are found to be several times the speed of sound, which would create shockwaves. Such events, occurring 300 to 400 meters above Ground Zero, would have resulted in extremely loud, highly brisant explosion sounds, created at collapse initiation or early into the collapse (before the top had descended too far down for ejections to fly laterally this far). Nothing even remotely suggesting such blasts was heard or recorded on 9/11/2001.

It is thus extremely unlikely, if not outright impossible, that wall panels found ca. 600 feet away from the tower footprints were thrown there as a result of lateral ejection by explosive charges. This conclusion is independent of the type of explosive material.

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