A Theory for the Collapse of the World Trade Center Towers
by Christian J. Simensen, SINTEF

Abstract
Two airplanes of type Boeing 767 flew into the Twin Towers in the morning of September 11th 2001. The crashes caused fuel to ignite, and the airplanes to be cut to pieces and be buried under building fragments. They were subsequently heated to a high temperature. 30 tonnes of aluminium alloys in the airplanes were melted at 660 °C while the surrounding building was only heated to a much lower temperature due to insulation effects. When the temperature reached 750-800 °C, the huge amount of aluminium melt managed to stream down to the lower floors. There it came in contact with water from the automatic sprinkler devices and possibly other sources. This encounter resulted in a series of fierce explosions due to the generation of hydrogen gas and local heating to high temperatures well above 1200 °C. A complete floor of the buildings was blown apart, and the upper part fell onto the bottom part leading to a complete collapse.

Key words: cutting of materials, material properties, molten aluminium, exothermal reactions, crash

Introduction
Two aircraft of type Boeing 767 hit the Twin Towers WTC 1 and WTC 2 in the morning of 11th September 2001. An hour later, 9:59, WTC 2 collapsed followed by WTC 1 about half an hour later. The surrounding buildings were bombarded with projectiles during the collapse. Building WTC 7, a 47 story skyscraper, caught fire and collapsed later, 17:20, in the afternoon. Why did these buildings collapse? The official report[1] made by a commission from the US government and supported by other publications[2,3] concluded that it was due to overheating of steel bars in the centre of the buildings. A lot of people doubted this solution and claimed that it must have been a conspiracy[4]. One of their basic arguments was that a large number of people had heard explosions immediately before the collapse of the buildings. Therefore they thought that someone had placed dynamite in the buildings. I am going to demonstrate on the basis of physics, thermodynamics and experimental work carried out at Alcoa ltd.[5,6] that both are incorrect. Many of the observations of the buildings on September 11th are used and referred to. The main mistake made by the commission is that they have overlooked the fact that the airplanes contained some 30 tonnes of aluminium. It was the airplane that was close to the fuel tanks and was heated to a high temperature, while the building and the steel bars only increased moderately in temperature. Thus the collapse took place in four stages: the crash, the heating of the airplane, the explosions and finally the collapse itself. I discovered also in 2011 that F. Greening[7] had come to similar conclusion as me already in 2006.

The crash
The scenario, the World Trade Center is shown in figure 1. The Twin Towers are located close to each other, and WTC 7 is only about 50 m away. 08:46 on September 11th WTC 1 was hit by a Boeing 767 (figure 2) between 93 -101st floors at a speed of 710 km/h. A second plane crashed into WTC 2 twenty minutes later at a speed of 820 km/h between 77-85th floor (figure 3). Both aircrafts carried of the order 38 tonnes fuel, and both were descending. Both airplanes came to a stop close to the centre of the buildings, and several construction steel bars must have been cut during the crash. The aircrafts must have gone through several floors before they stopped completely. They must have fragmented severely, and the fuel in the fuel tanks caused a fierce fire.

It is evident that the airplanes went through the outer wall cutting the wall like a Samurai sword and pushing that section of the wall with them (figure 4[8]). This will reduce the speed approximately 50-100 km/hour. Both buildings were a construction of thick steel bars, 3-6 cm in diameter, which made a three dimensional cubic like net of vertical and horizontal rods (illustrated on figure 5). These sets of bars were covered by floors, ceilings and walls. The airplanes went through several series of steel bars, each time the speed was reduced, and more materials were pushed in front and to the sides of the crashing airplanes (figure 5). As the speed fell, the steel bars must have been dragged along, and ceilings must have collapsed. The airplanes must have been cut to pieces by the array of steel bars and probably came to a standstill somewhere in the middle of the building. The airplanes must have taken with them 10-15 series of steel bars and walls which must have piled up in front of them, and sections of the ceilings would probably have fallen on top of the fractures airplanes (figure 6). Thus the airplanes were almost buried in walls and ceilings which were mainly made of gypsum with a low thermal conductivity (see appendix).

What happened to the airplanes? They were probably cut into long, rectangular blocks by the high strength network of rods. These rods probably also sliced the fuel tanks situated in the wings in different heights. The result was that the sectioned tanks were burning with almost constant rate after the crash (figure 6).

Most of the material in the building along the route of the airplane caught fire due to all the sparks and heat generated. Some of these fires were somewhat reduced due to the automatic sprinkler devices in the building. However, all materials with a low ignition point were on fire.

My guess is that the fragmented aircraft ended up in a kind of a bowl on top of 2-3 concrete floors similar to metal in a foundry crucible as shown in figure 7. The fuel was burning in the partly fragmented tanks in this bowl heating the surrounding airplane. Thus near the centre of the buildings were the airplanes buried by building debris, and further away surrounded by well insulated walls made of gypsum and steel bars.

Heating of the airplanes

Near the centre of the building was the fracture airplane with a total net weight of 87 tonnes, people and furniture. All were heated by the fuel (figure 6). This hot zone had almost one common temperature due to the high heat conductivity of the fragmented aluminium parts (see appendix). The weight of the aluminium in each aircraft was of the order 30 tonnes, while the remainder consisted of steel, polymers and carbon fibre materials. The hot zone was surrounded mainly by piled-up walls and floors mostly made of insulating materials which acted as a thermal barrier. Materials along the crash route also burned, but probably at a much lower rate.

During the initial period polymers, furniture and widespread fuel burned, and the temperature of metal in the airplanes increased rapidly. Thereafter the heating rate of the crashed airplane was mainly determined by the heating rate of fuel in the cracked fuel tanks. The aluminium alloys were melted at 660 °C after approximately 45 -60 minutes. This time fits rather well with a 30 tonne aluminium melt that is melted using gas in a foundry (figure 7 and 8). Calculations (see appendix) show that approximately 1900 litres of fuel are required to heat a Boeing 767 from 20 °C to 720 °C. My guess is that a total of 10 tonnes of fuel was used since the surrounding building was also heated.

When aluminium is melted, it is rather viscous, but the viscosity coefficient drops rapidly with increasing temperature. Thus the melt becomes similar to water when the temperature is increased to 750 °C. Aluminium has at that moment a viscosity coefficient of the order 0.04 poise. Aluminium with a a temperature just above it's melting point would solidify when it started to flow down to the floors below. However, when the temperature is increased to 750-800 ºC, the melt has so much surplus heat that it will flow freely in large streams to the floors below as illustrated on figure 9.

The explosions

All water above the heated airplane zone would have evaporated due to the intense heating, while the floors below would be mostly unaffected by the crash. When the hot molten aluminium streamed to the lower floors, it would meet water generated from sprinkler devices (figure 9). These devices were installed in all floors of the Twin Towers. Several tonnes of aluminium would meet a smaller amount of water which supposedly should extinguish fires. The result would be fierce explosions between molten aluminium and water.

Alcoa ltd.[5,6] and other producers[9] have shown that molten aluminium reacts instantly with water (see appendix):

1) $2\ Al\ (melt) + 3\ H_2O \Rightarrow Al_2O_3 + 3\ H_2\ (gas)$

260 kJoules is generated by each mole of water in the reaction[10] resulting in a local increase in temperature of several hundred degrees and an explosion due to the formation of hydrogen gas.

Alcoa ltd. and The Aluminium Association Inc.[5,6,9] have divided these explosions into three categories. The simplest one is where a steam explosion takes place. A more severe one takes place when the steam explosions cause molten metal to be dispersed up to 15 m. The most violent explosion takes place when rust (iron oxides) or contaminants such as fertilizer are present. Then a thermite reaction takes place and causes a local increase in temperature to 1000 – 1500 °C. This reaction is followed by a direct reaction between the melt and water or oxygen. As an example Alcoa ltd. has shown a reaction between 30 kg molten aluminium and 20 litres of water when some rust was present. The result was that a violent explosion took place. The whole laboratory was destroyed, and a crater some 30 meter in diameter was created.

The Aluminium Association[9] reported at a the metallurgical congress in San Francisco in February 2009, that more than 250 aluminium-water explosions have taken place since 1980. Most recently when a Chinese who dropped molten metal on a wet floor, resulting in the deaths of 16 people, 64 injured, and the factory being totally destroyed[11].

Many people in New York reported that they had heard explosions immediately before the collapse of the buildings. Pictures of the Twin Towers immediately before the collapse are shown in figure 10 and 11[12,13]. These pictures are selected from two series taken at 8 frames per second. They show that the explosions take place on the floors below the floors with the fragmented airplanes. Vapour of a different colour came out of the windows indicating that a steam explosion had taken place (figure 10)). The second group of pictures, figure 11, show fast moving spikes of fire leaveing the building. These pictures clearly indicate that explosions must have taken place in the interior. Furthermore, filmstrips taken of WTC 2 immediately before its collapse, show molten metal flowing out of a window down the wall[14]. This metal is aluminium as it is the only metal present in large quantities and has a low melting point. The colour of the melt is bright yellow indicating that the temperature of the melt is above 800 ºC

The collapse

Aluminium-water explosions are rather similar to dynamite explosions in which whole sections of the building are blown apart, and the top of the building falls onto the lower section. The large weight will result in a complete collapse, as for WTC 1 and WTC 2 which were completely demolished.

The destruction of WTC 7

When WTC 1 and WTC 2 collapsed, they took with them a substantial amount of fuel, molten aluminium and fragmented steel. When these parts fell 300-400 m to the ground, they were squeezed between upper and lower sections. The result was a cannonade of hot particles and drops of liquid towards the surrounding buildings. This bombardment has been verified by the observations of small and large lumps in the walls of all neighbouring buildings[15]. It seems to me that WTC 7-building was hit more than the others, and a fierce fire was initiated. This fire obviously came out of control, and the fire brigade heard noise from the building. The firemen were then withdrawn from the building, and it collapsed about an hour later in course of about 32 seconds.

A similar fire took place in Delft on 12th May 2008 where part of a University building collapsed after a fire that lasted for 8 hours[16]. This demonstrates that steel-framed buildings can collapse after several hours in a violent fire. A possible explanation is that the strength of steel bars weakens substantially by increasing the temperature several hundred degrees. When the bars are transformed to austenite, it finally becomes so weak that the local weight of the building becomes too great. The bars crack and bend (and emit noise). Sections of the building will then collapse in less than a minute. This effect is in agreement with the model outlined by NIST NCSTAR 1[1].

Discussion, conclusion and further testing

The observations of the Twin Towers indicate that the following events took place: (1) the crash, (2) heating of the airplanes, (3) molten aluminium flowing down to lower floors, (4) explosions and (5) collapse of buildings. The crash most likely caused an instant heating due to kinetic energy of the airplanes and instant burning of wood and other combustible materials. Then the fractured airplane was heated by the fuel in the open, cracked tanks. The aluminium melted, and later the melt flowed through gaps in the floor and came into direct contact with water from sprinkler devices in the lower floor and a series of explosions took place. If the heating rate (**Q'**) was constant after the initial 2 minutes when the temperature of the airplane is assumed to be increased to 200 °C, then:

1) $Q' \approx \Delta T_1 * \sum_j C_j * W_j / t_1 \approx L_{Al} * W_{Al} / t_2 \approx \Delta T_2 * \sum_j C_j * W_j / t_3$ (joule/sec)

where ΔT_1= 660 °C – 200 °C = 460 °C, ΔT_1= 800 °C – 660 °C = 140 °C, t_1=time from the crash to the aluminium starts melting minus 2 minutes, t_2 = time it took to melt the airplane, t_3=time it took to increase the temperature of the melt from 660 °C to 800 °C, Cj = specific heat of metal **j**, Wj = total weight of material j in the airplane, L_{Al}=aluminiums latent heat of fusion, $\sum_j$ indicates that it is summed over all metals j. The total time between the crash and the collapse is:

2) $t_{total} = t_1 + t_2 + t_3$ + 3 minutes

where the 3 minutes is the initial heating period plus 1 minute from the moment the melt is streaming down to the next floor to the time of explosions. If we assume this simple model, the temperature of the aluminium in the airplane in WTC2 is approximately as outlined in figure 12 where the collapse took place 56 minutes after the crash. The time schedule for the airplane in WTC1 is somewhat slower, 102 minutes between crash and time of collapse, most likely due to the fact that the airplane had a lower impact velocity and did less damage.

The theories that the Twin Towers collapsed by use of dynamite or that the buildings were overheated, were rejected as they can not explain the sequence of event or time schedule. The airplanes were probably heated by the aircraft fuel. Then WTC 1 and WTC 2 most likely collapsed due to explosions between molten aluminium from the airplanes and water.

The outlined theory is in agreement with the observations made in New York on September 11th, and explosions took place as shown in the photo (figure 13[17]) of WTC 2 as the building collapsed. This model can be further verified by finding aluminium particles in the neighbouring buildings of the Twin Towers.

Acknowledgement
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Appendix

Important parameters:

Specific heat of aluminium: 0.96 kJ/kgK
Specific heat of iron: 0.68 kJ/kgK
Heat of fusion (aluminium) 387 kJ/kg
Heating of 87 tonne airplane from 20 to 720 °C: 5.5×10^{10} J
Melting of 30 tonnes of Aluminium: 1.2×10^{10} J
Burning of 1 tonne aviation fuel: 4.38×10^{10} J
1.5 tonnes fuel or 1 900 litres of fuel will heat an empty airplane to 720 °C.

Heat conductivity at 20°C:

Pure aluminium:	245 W/mK	Alumina: approximately 4 W/mK
Aluminium alloys:	230-100 W/mK	Certain Polymers: as low as 0.1 W/mK
Steel: approx.:	40 W/mK	Gypsum: 0.17 W/mK
Carbon: approx:	4 W/mK	

Viscosity coefficient of aluminium at 750 °C: 0.03-0.05 poise

Main reactions[9]

$2Al(melt) + 3\,H_2O \Rightarrow Al_2O_3\,(solid) + 3H_2\,(gas)$; Free Energy: -260 kJ/mol of H_2O

$2Al + Mg(melt) + 4H_2O \Rightarrow Al_2MgO_4(solid) + 4H_2$; Free Energy: -279 kJ/mol of H_2O

The calculations have been made for T=723 °C

Hydrogen may react with oxygen in air:

$2H_2 + O_2 \Rightarrow 2\,H_2O$; Free Energy: -46 kJ/mol of H_2O at 723 °C and -39.5 kJ/mol at 1223 °C

A survey of figures

Figure 1: Photo[3] of the World Trade Center early 2001.

Figure 2: A Boeing 767-300 with a weight of 87 tonnes when empty.

Figure 3: The situation immediately before the airplane hit building WTC2[3].

Figure 4: Picture of WTC 1 immediately after the airplane had cut its way into the building[8]. The contour of the airplane is visible.

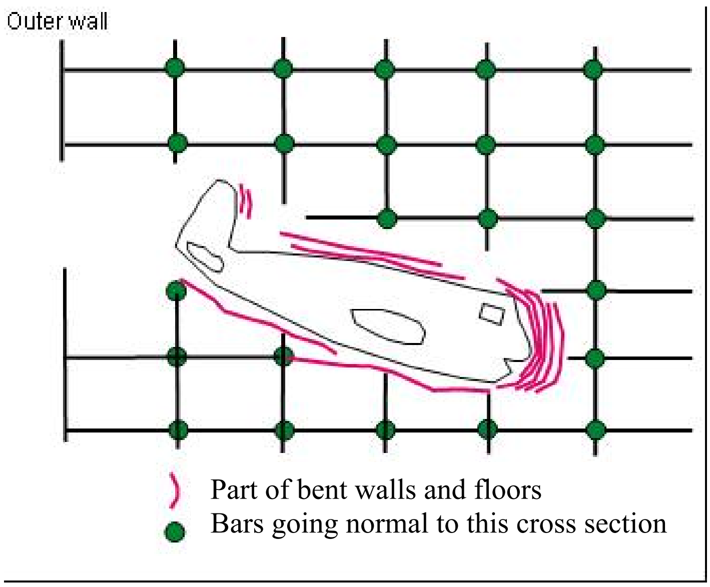

Figure 5: Cross section of the air plane and part of the Twin Tower shortly after the airplane hits the outer wall. Only the array of steel bars is shown. Parts of the floor and walls are dragged along with the airplane.

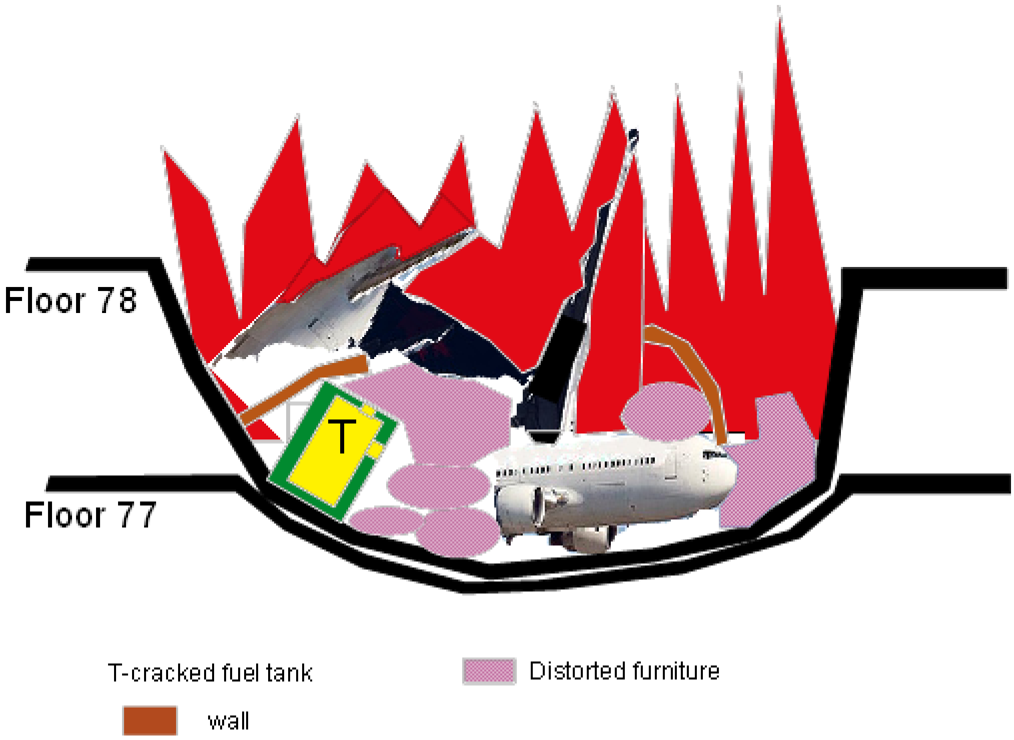

Figure 6: An inner cross section of the Twin Tower around the airplane after the aircraft has come to a stop. A simplified sketch of the fragmented aircraft (grey and black), a fuel tank with petrol (yellow and green, T), walls (brown) and the furniture (violet). The airplane is presumed to have formed a kind of bowl. Everything is on fire immediately after the crash.

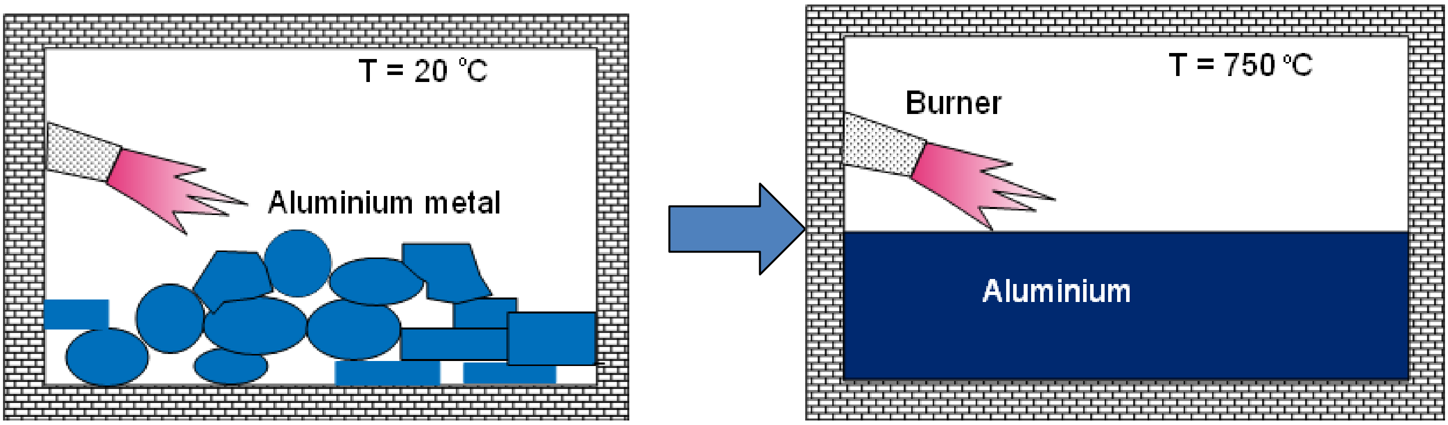

Figure 7
Drawings of a furnace with 30 tonnes of aluminium heated by burners. Aluminium is commonly heated to 750 ºC within an hour in such a furnace.

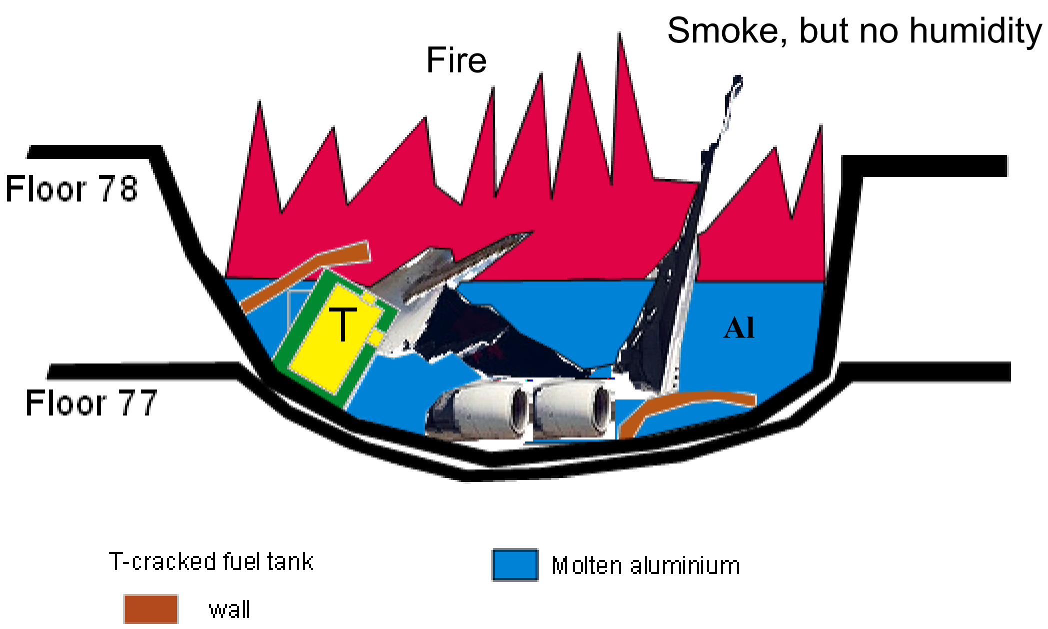

Figure 8
Drawing of the remains of the fragmented airplane after the aluminium has melted. The temperature is approximately 700 °C.

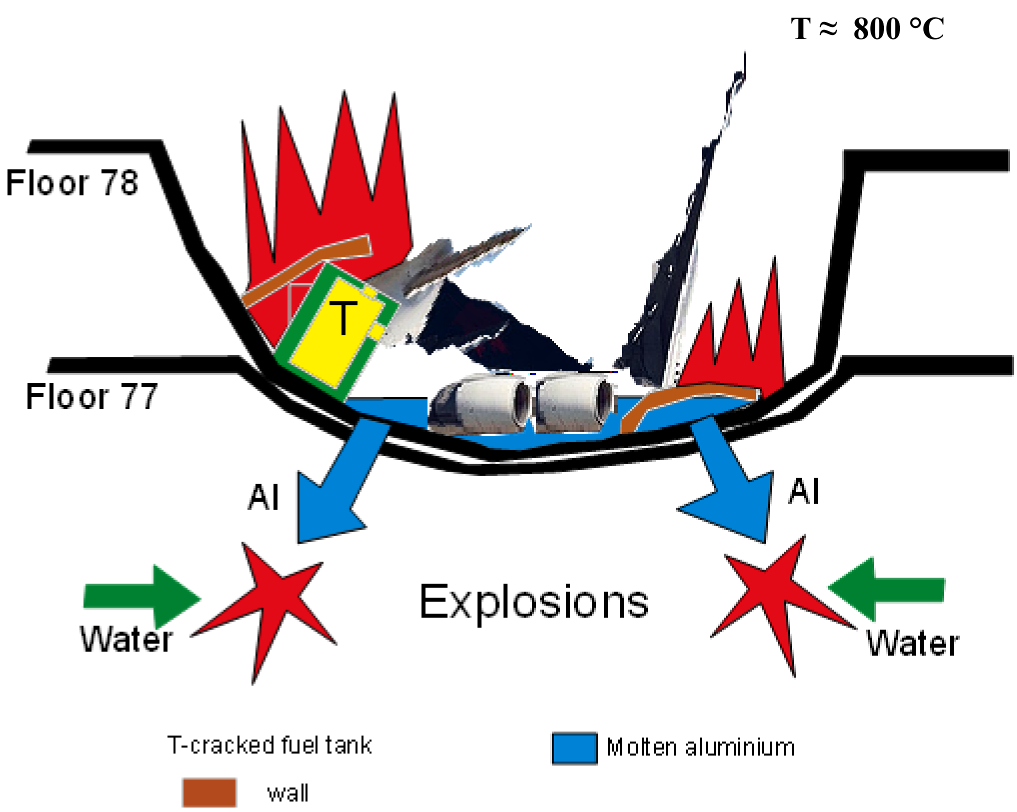

Figure 9
Drawing of the fragmented airplane in the bowl when molten aluminium was flowing through the floor meeting water from the sprinkler devices and causing explosions.

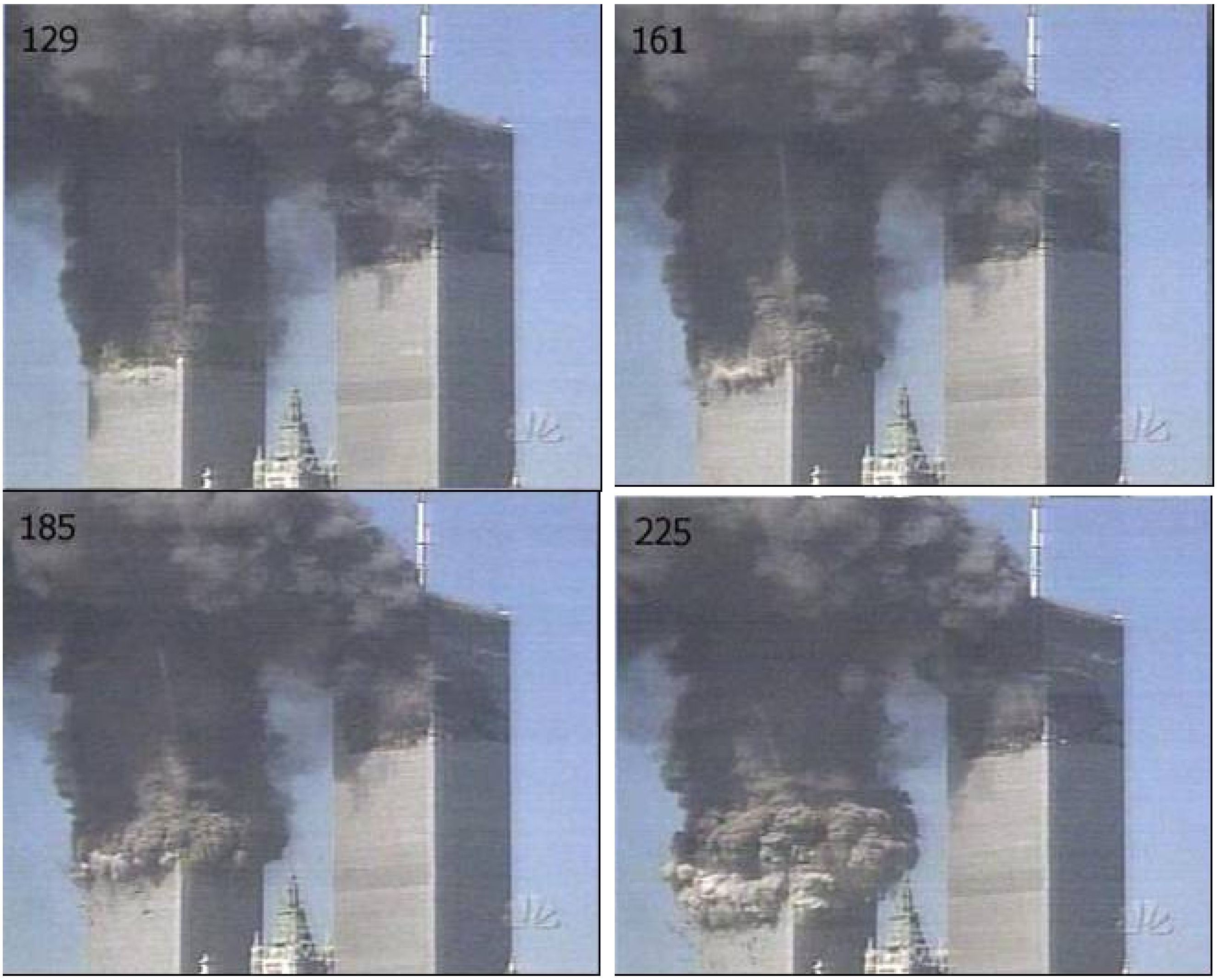

Figure 10: Pictures of WTC 2 at the time of collapse, showing frame numbers taken at 8 frames per second. There are 12 sec from the first to the last picture. Note the grey smoke coming from the floors below the initial fire.

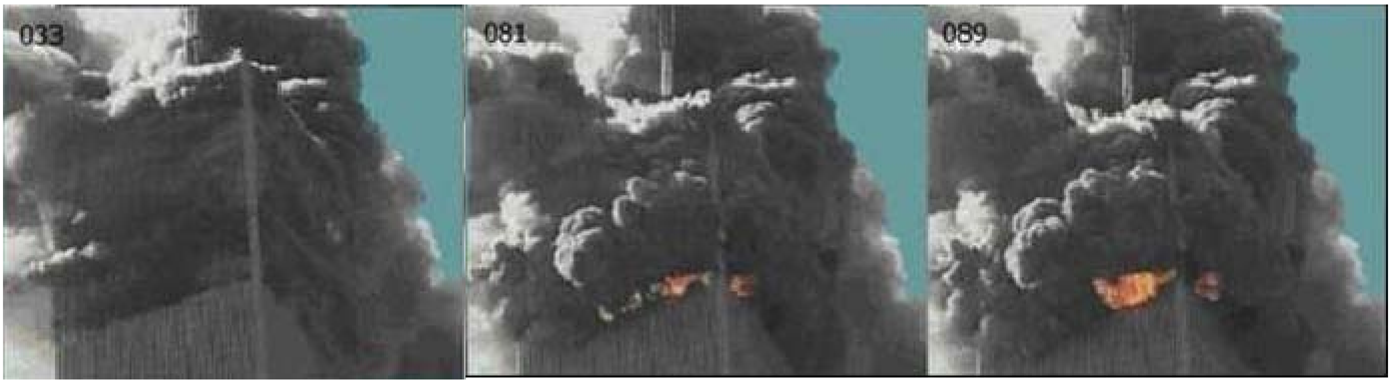

Figure 11
Pictures of WTC 1 at the time of collapse, showing frame numbers taken at 8 frames per second. It is 7 sec from the first to the last picture. Note the red fire spikes coming from the floors below the initial fire.

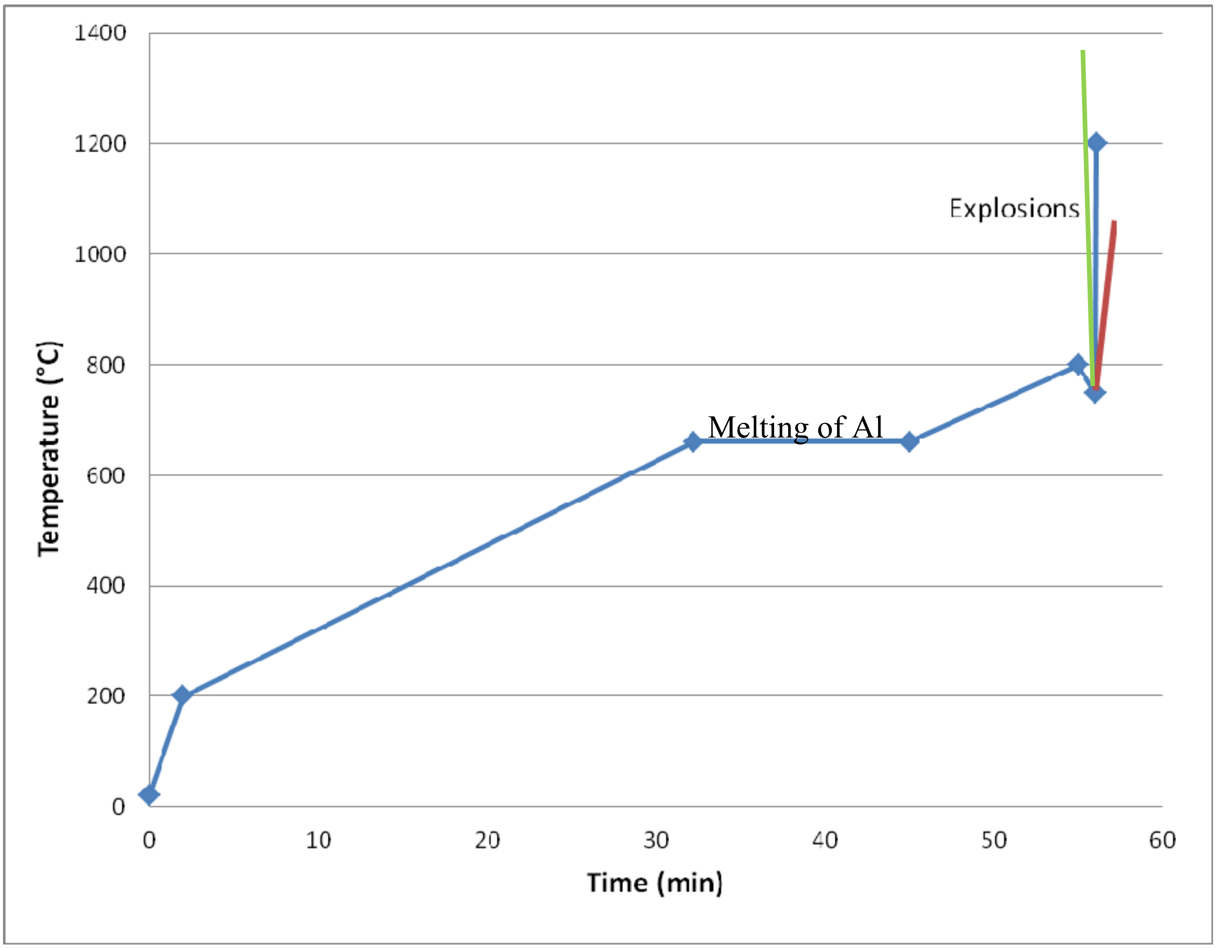

Figure 12: Temperature of aluminium in the airplane in WTC 2 in the period between the crash (t=0) and the collapse of the building (t= 56 minutes).The temperature decreases slightly when the melt leaves the hot zone and flows down to the lower floor (t ≈ 55 minutes).

Figure 13: WTC 2 at the moment it collapses. WTC 7 is the building in front right. It is clearly hit by particles[17].