Introduction to science of fire and explosion

11TH NOVEMBER 2020

The Chemistry of Fire

- **Fire** : a transformation process during which oxygen is united with some other substance to produce noticeable quantities of heat and light (flame).
- **Oxidation**, the fundamental chemical reaction of fire, is the process of the combination of oxygen with other substances to produce new substances.

Example : an equation of oxidation process for burning of methane gas,

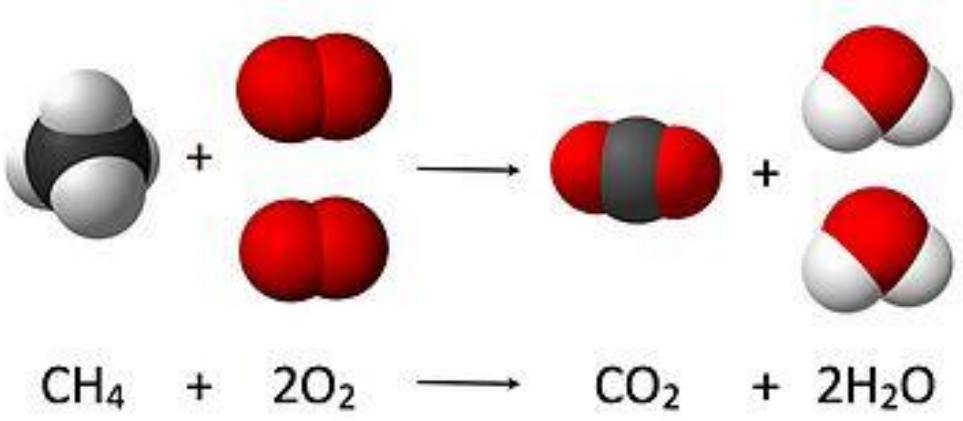
$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

an equation of oxidation process for rust forming,

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

Heat

- Molecules must absorb energy to break apart their chemical bonds, and that they will liberate energy when their bonds are reformed.



- Heat energy is required to initiate the combustion of methane.
- The excess energy is liberated as heat and light and is known as **heat of combustion**.

Such combustions are said to be **exothermic**.

https://en.wikipedia.org/wiki/Combustion

Ignition temperature

- To start the oxidation process of methane, the temperature of reactants (methane and oxygen) must be raised to a temperature known as **ignition temperature**.
- The fire becomes a chain reaction, absorbing a portion of its own liberated heat in order to generate even more heat.
- The fire will continue to burn until either the supply of oxygen or the fuel is exhausted.

Table : Ignition Temperature of Some Common Fuels

Fuels or chemicals	Ignition Temparature (°C)
Acetone	465
Ethyl Alcohol	365
Methyl Alcohol	470
Gasoline (petrol)	246-280
Glycerol	370
Isopropyl Alcohol	399
Paper	218-246
Wood	300

http://www.engineeringtoolbox.com/fuels-ignition-temperatures-d_171.html

Note : The minimum temperature required to ignite a gas or vapor in air without a spark or flame being present is known as **AUTOIGNITION TEMPERATURE**.

Flash point

- To produce a flame, the oxidation has to proceed at rapid rate.
- A fuel will achieve a rapid reaction rate with oxygen when it is in the **gaseous state**.
- This physical state increases the rate or speed at which the oxidation takes place.
- This remains true whether the fuel that may be feeding the flame is a solid such as wood, paper, cloth, or plastic, or a liquid such as gasoline or kerosene.
- In case of liquid fuel, a minimum temperature known as **flash point** is needed to allow a liquid to give off sufficient vapor to form a mixture with air that will support combustion.
- **The ignition temperature is always considerably higher than the flash point**.

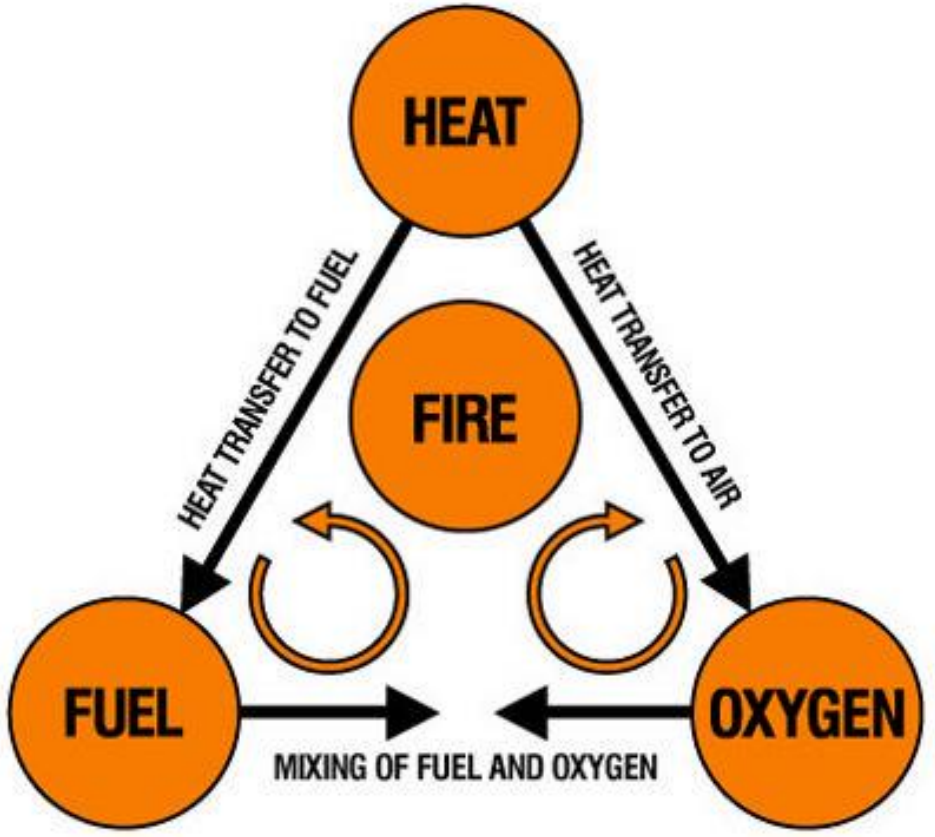
Pyrolysis

- The solid fuel will burn only when it is exposed to heat that is hot enough to decompose the solid into gaseous products.
- This chemical breakdown of solid material is known as **pyrolysis**.
- A match of other source of heat initiates the pyrolysis of the solid fuel, the gaseous products react with oxygen in the air to produce heat and light, and this heat in turn is used to pyrolyze more solid fuel into volatile gases.
- In the absence of heat sufficiently high enough to pyrolyze the fuel, **glowing combustion** or combustion taking place on the surface of a solid fuel without presence of a flame occurs.

Spontaneous combustion

- **Spontaneous combustion** or **spontaneous ignition** is a type of combustion which occurs by self-heating.
- The natural heat-producing process can cause fire in the presence of sufficient air and fuel.
- For example, hay stored in barns provides an excellent growing medium for bacterial whose activities will generate heat. The heat can build up and eventually, the ignition temperature of hay is reached, spontaneously setting off a fire.

The Fire Triangle



- The basic components contributing to a fire are **fuel**, **heat** and **oxygen**.
- A fuel must be present.
- Oxygen must be available in sufficient quantity to combine with the fuel.
- Heat must be applied to initiate the combustion, and sufficient heat must generate to sustain the reaction.

http://dpm.nida.ac.th/main/index.php/articles/fire/

Spontaneous Human Combustion (SHC)

- SHC describes reported cases of the burning of a living (or very recently deceased) human body without an apparent external source of ignition.
- One of the common markers of a case of SHC is that the body – or part of it – suffered and extraordinarily large degree of burning while the surroundings or the lower limbs remained comparatively undamaged.

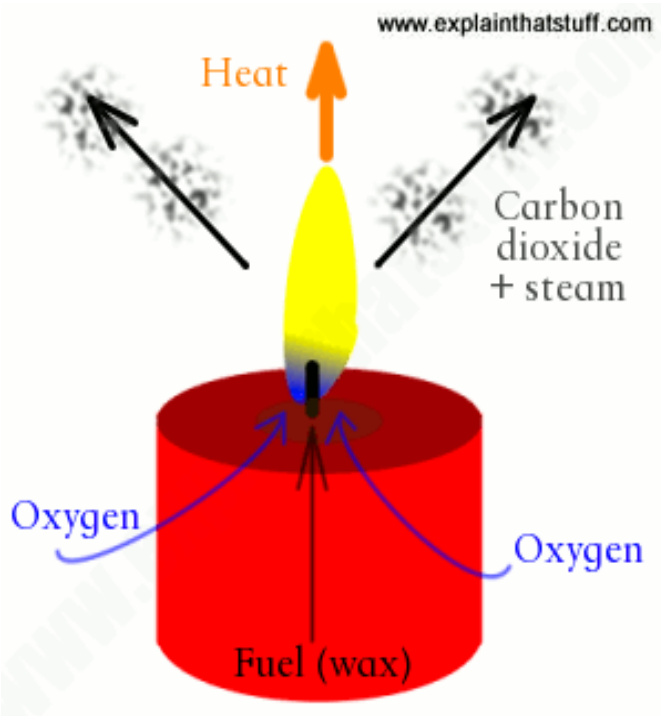
Forensic science international 188 (2009) e 17 – e 19

Wick effect

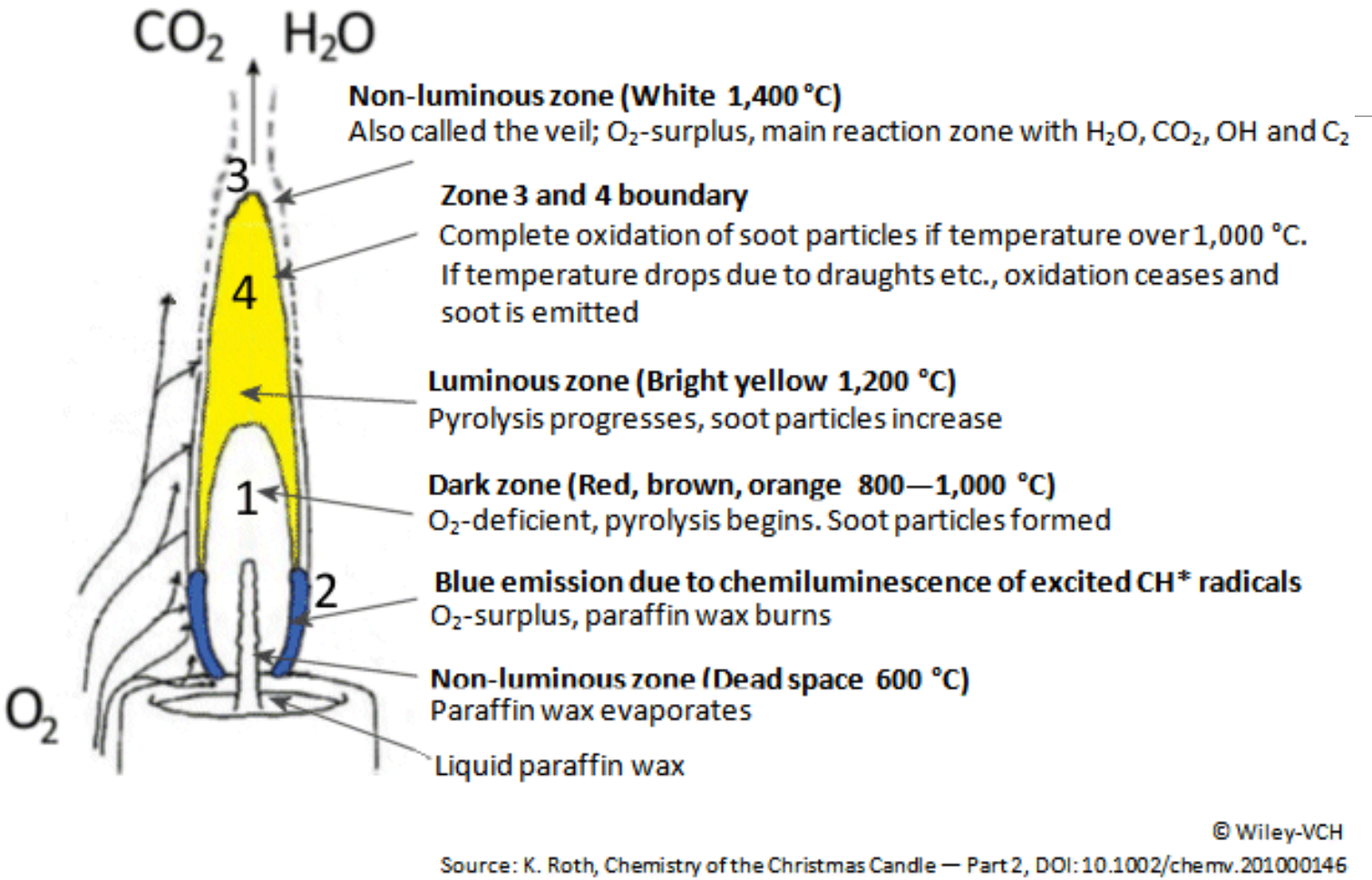
- The composition of the human body is not homogeneous.
- Three main combustible constituents exist within a body and are not evenly distributed throughout : (i) soft tissues, (ii) bone and (iii) fat.
- After clothing ignited, body fat could melt and fuel the nearly complete combustion of body.
- The clothing of a subject can soak up human fat and act like the wick of a candle.
- The fat catches fire and leads to the slow combustion of the fat over the course of an hour, with no visible flame.
- The slow and passive phenomenon is described as **wick effect** or **candle effect.**

How candles use combustion

- A candle is composed of a wick on the inside surrounded by a wax made of flammable fatty acids (hydrocarbon substance).
- The wax has a low melting point so it instantly turns into a hot liquid and vaporizes, funneling straight up around the wick as though it's rushing up an invisible smokestack (chimney).
- The wax vapor catches light and burns, sending a flame high above the wick.
- The wax ignites the wick and keeps it burning.



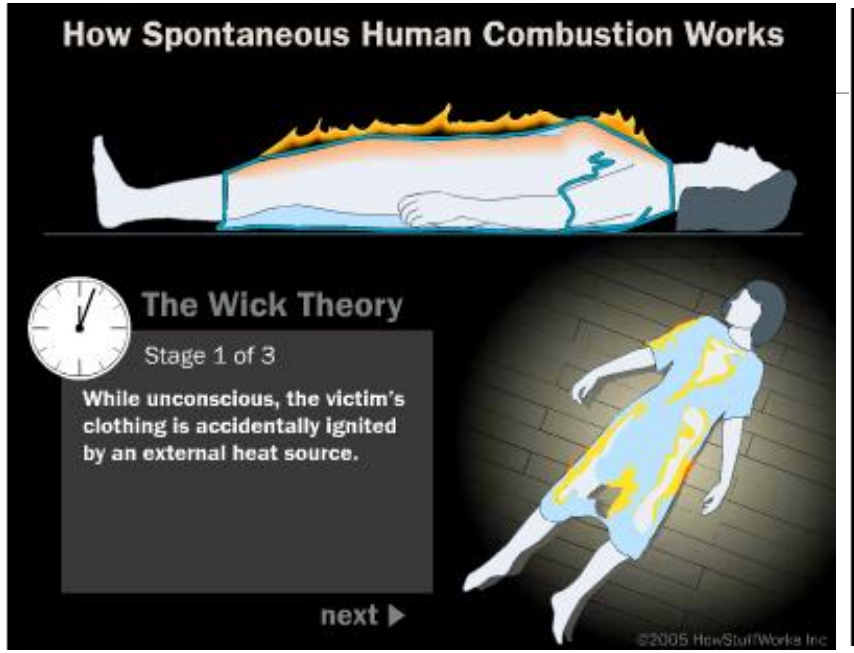
What makes a candle flame?

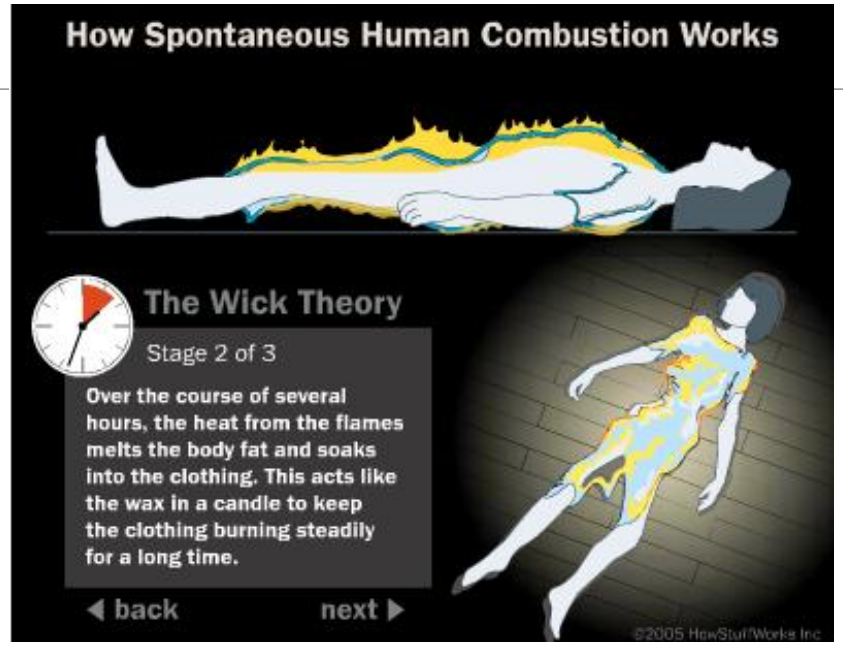


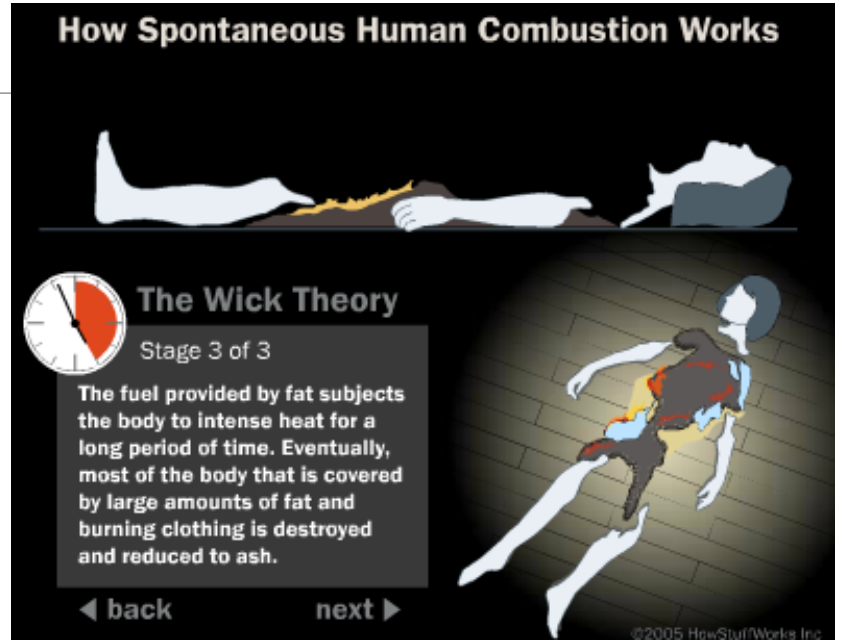
Source: K. Roth, Chemistry of the Christmas Candle — Part 2, DOI: 10.1002/chemv.201000146

http://www.chemistryviews.org/details/ezine/1393243/What_Makes_a_Candle_Flame.html

How spontaneous human combustion works
Wick effect







In the human body, the body fat acts as the flammable substance, and the victim's clothing or hair acts as the wick. As the fat melts from the heat, it soaks into the clothing and acts as a wax-like substance to keep the wick burning slowly.

http://science.howstuffworks.com/science-vs-myth/unexplained-phenomena/shc1.htm

Explosives and oxidizing agents

- Explosives are substances that undergo **a rapid exothermic oxidation reaction**, with the production of large quantities of gases.
- The sudden buildup of gas pressure that constitutes the nature of an explosion.
- Detonation occurs so rapidly that oxygen in the air cannot participate in the reaction; thus many explosives must have their own source of oxygen.
- Chemicals that supply oxygen are known as **oxidizing agents**.
- Examples of oxidizing agents include **potassium nitrate** and **nitroglycerin**

Explosives

- An explosion is the product of combustion, like fire, accompanied by the creation of gases and heat.
- A distinguishing characteristic of an explosion is the **rapid rate** at which the reaction proceeds.
- The speed at which explosives **decompose or burn** varies greatly from one to another and permits their classification as high and low explosives.
- **Low explosives**, such as black and smokeless powder, have slow burning rates (less than 1,000 m/s).
- **High explosives**, such as TNT, PETN and RDX, detonate almost instantaneously at rates from 1,000 to 8,500 m/s.

The search: The TWA plane crash

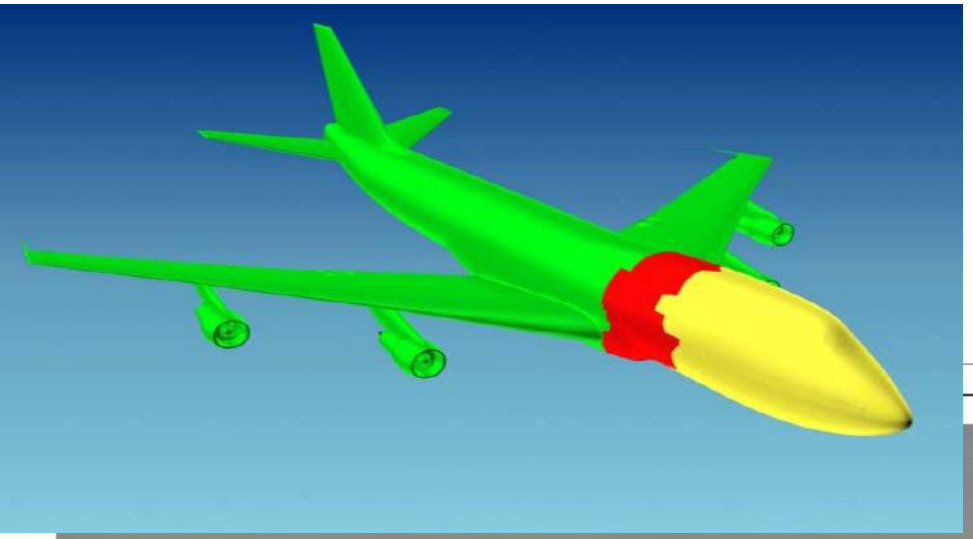
- **Trans World Airlines Flight 800** (**TWA 800**), was a Boeing 747-100 which exploded and crashed into the Atlantic Ocean near East Moriches, New York, on July 17, 1996, 12 minutes after take off from John F. Kennedy International Airport on a scheduled international passenger flight to
- All 230 people on board were killed in the third-deadliest aviation accident in U.S. territory

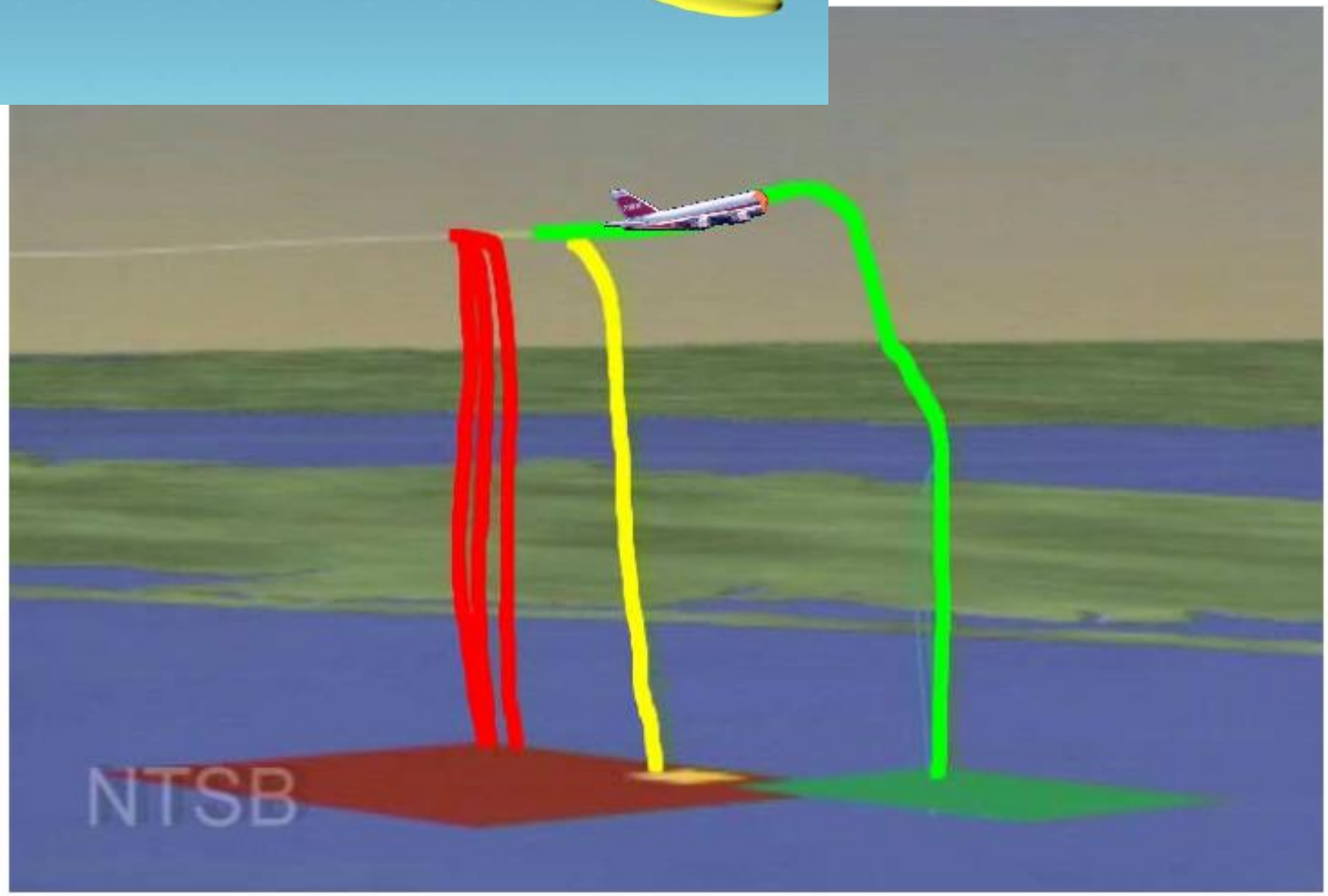
https://www.rt.com/usa/twa-800-crash-probe-632/

Possible causes of plane crash

- structural failure and decompression
- detonation of a high-energy explosive device, such as a missile warhead exploding either upon impact with the airplane, or just before impact
- a bomb exploding inside the airplane
- a fuel/air explosion in the center wing fuel tank.

Breakup pattern of TWA 800



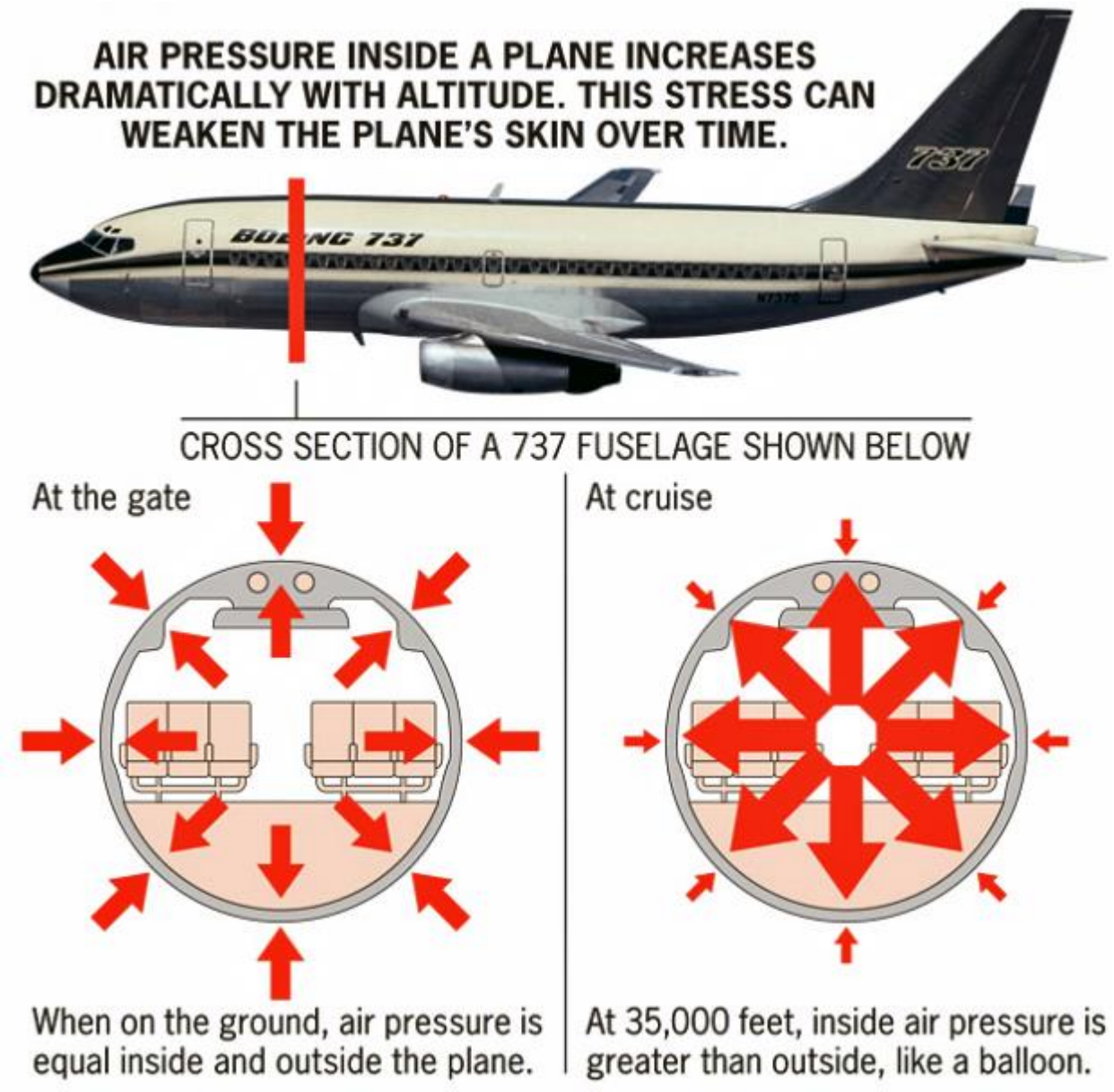


- Wreckage found in each zone corresponded to specific areas of the aircraft.
- Three debris fields were identified based on distribution of wreckage on the ocean floor.

1st Possible cause

Structural failure and decompression

An unplanned drop in the pressure of a sealed system, such as an aircraft cabin, and typically results from human error, material fatigue, engineering failure, or impact, causing a pressure vessel to vent into its lower-pressure surroundings or fail to pressurize at all.



http://cosmo-code.blogspot.com/2014/03/helios-airways-flight-522-disaster.html

The damage on fuselage considered to a probable source of the accident causes cracks extending on both sides of the rivet holes along the upper rivet row.

http://www.disastercity.info/ghost/sequence/

Fuselage of Aloha Airlines Flight 243 after the explosive decompression in 1988

https://g4svenezuela.wordpress.com/tag/aviation-safety/

The cargo door tore off in flight and caused an explosive decompression resulting in nine deaths

https://twitter.com/spiegeltv/status/5415166355224780 81

2nd Possible cause

Detonation of high energy explosive

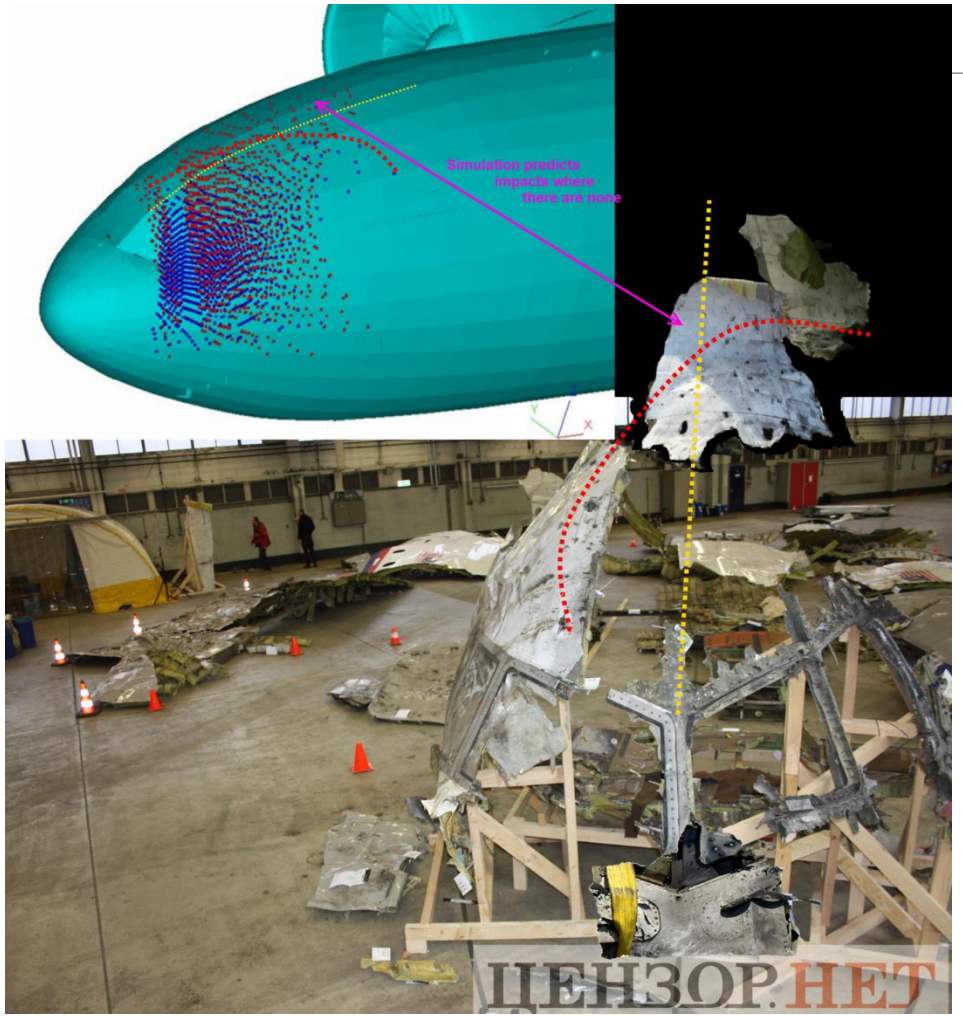
- **Malaysia Airlines Flight 17** crashed on 17 July 2014 after being shot down, killing all 283 passengers and 15 crew on board.
- The "impact pattern made by high-energy objects is clearly visible."
- The reconstruction shows the exact point of impact where the cockpit was torn from the rest of the plane.

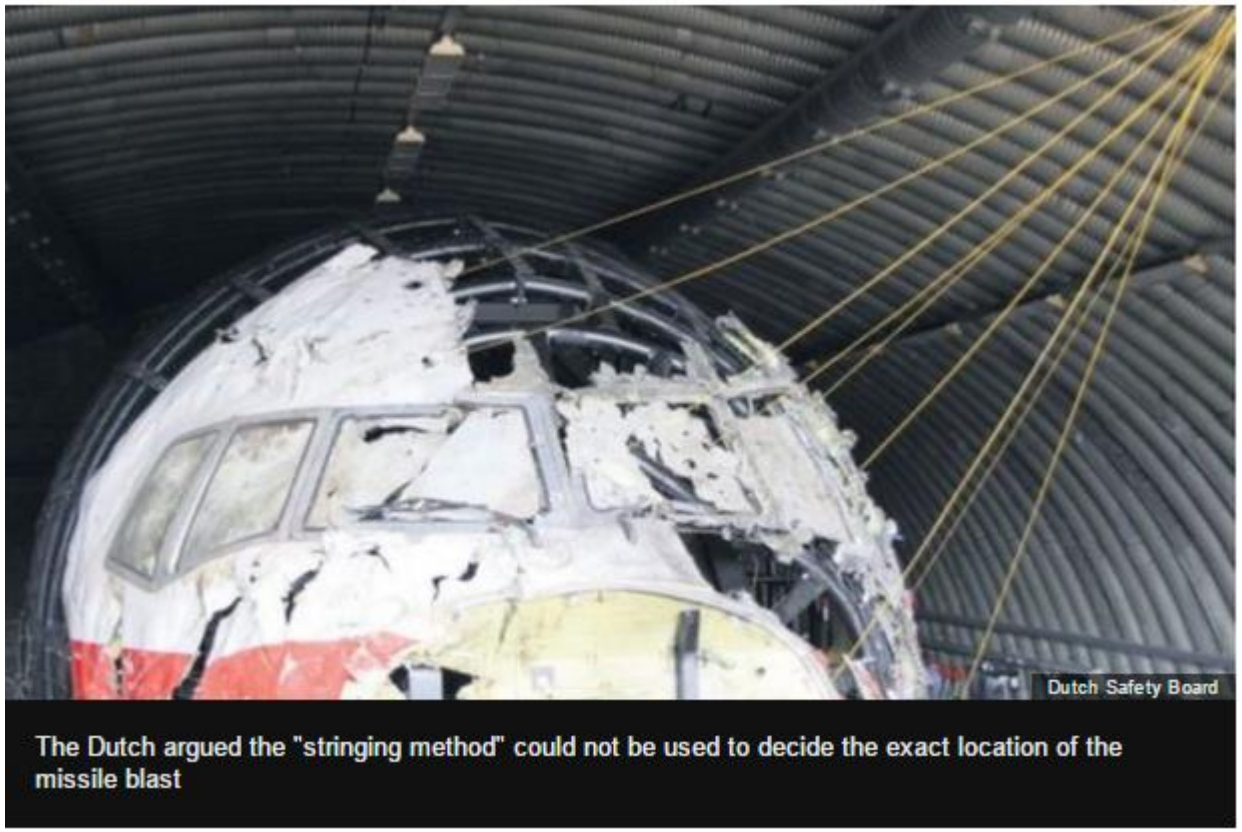
https://www.inverse.com/article/6979-dutch-investigators-reconstructed-mh17-to-find-true-cause-of-flight-crash

MH17 reconstruction and comparison

https://twitter.com/maxvanderwerff/status/655271814093012992

Determination of the fragment trajectories





The Dutch argued the "stringing method" could not be used to decide the exact location of the missile blast

http://www.whathappenedtoflightmh17.com/simulation-versus-facts-of-mh17-missile-damage/

3rd Possible cause

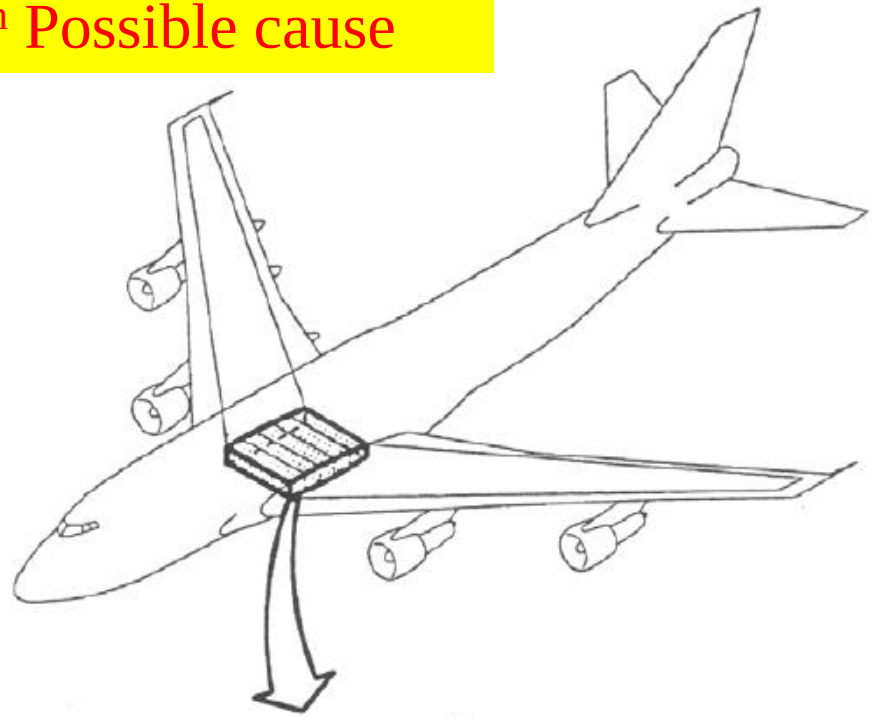
A bomb exploding inside the airplane

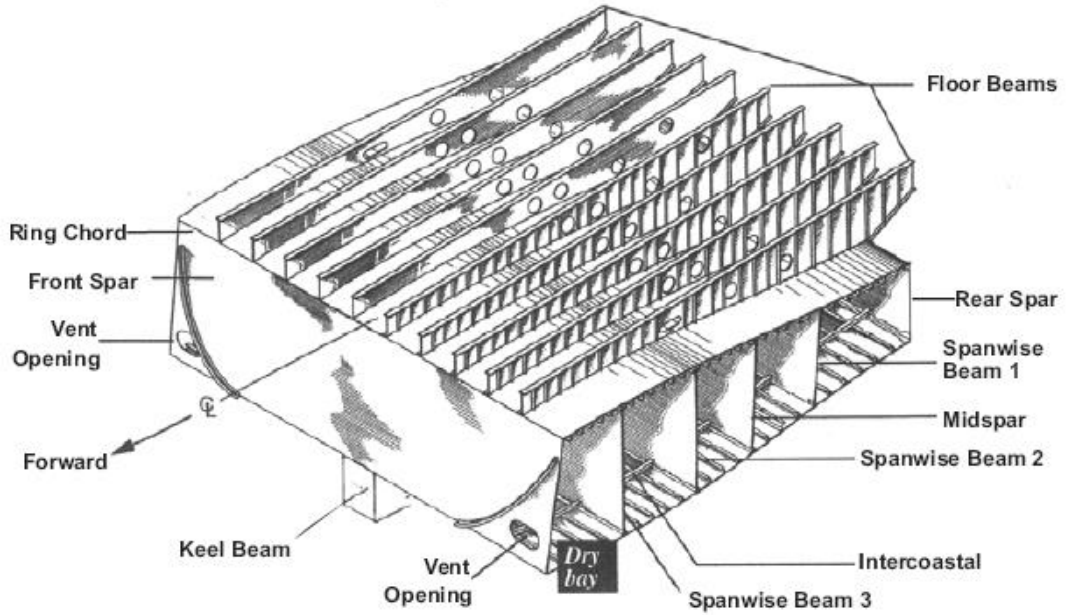
http://www.express.co.uk/news/uk/612324/Lockerbie-bombing-two-Libyans-identified-suspects-1988-attack

- On 21 December 1988, **Pan Am Flight 103** operating the transatlantic leg of the route, was destroyed by a terrorist bomb, killing all 243 passengers and 16 crew, in what became known as the **Lockerbie bombing**.
- Large sections of the aircraft crashed onto residential areas of Lockerbie, Scotland, killing 11 more people on the ground.

https://en.wikipedia.org/wiki/Pan_Am_Flight_103

4th Possible cause





Fuel/air explosion in the center wing fuel tank

- The investigators concluded that the first event in the breakup sequence was a fracture in the wing center section of the aircraft, caused by an "overpressure event" in the center wing fuel tank.
- An explosion of the center wing fuel tank, resulting from ignition of flammable fuel/air mixture in the tank.
- The most likely source of ignition energy for the explosion could be from an electrical arc within the fuel tank.