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Possible options in identifying an explosion on board an aircraft based on the characteristics of scattered remains

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Abstract

This article attempts to determine the possibility of identifying an explosion on board an aircraft based on the scattered remains. To reach this goal, a detailed analysis of reports on aviation accidents was performed in the context of the scattering of remains at various crash sites.
Moreover, explosions cause an emission of large amounts of hot gases at supersonic speeds, which is the main source of destruction. The destruction is quite characteristic and depends on the material subjected to damage. It allows for the unequivocal identification of an explosion.
The performed analysis and conclusions confirmed the thesis set forth in the article that, by means of analyzing the scattered remains after a plane crash, it is possible to determine, with high probability, whether an explosion occurred on board during the flight, which could be the cause of the event. This way of initially determining the causes of accidents would allow for targeting further accident investigation methodology and improving the workflows for teams investigating plane crashes.

Keywords: explosion, plane crash investigations, safety

1. Introduction

The problem of air transport safety is one of the most important issues for every organization involved in broadly understood aerial navigation. Over the last few years, significant advances have been seen in aviation, especially in terms of safety. However, there are still potential hazards for any aviation operation, such as a plane crash, including an explosion on board an aircraft. It must be highlighted that the main sources of explosions include irregularities in the functioning of an aircraft (malfunctions) or purposeful activity of a defined group of people in order to intentionally cause a plane crash (Lasek, et al., 2010). The source of explosions include explosive charges, fuel, dangerous loads or faulty construction. Regardless of the source, the effects of an explosion are similar.

The last reported case of an explosion on board a plane occurred in February 2016 on board Airbus A321 from Daallo Airlines. The explosion caused a hole in the aircraft's skin. Due to the low altitude, a sudden decompression in the cabin did not occur, which could have caused further damage. Finally, the aircraft landed safely. This event shows that the hazard is still real and must be taken into account.

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Identifying explosions and their sources while investigating the cause of an accident is a significant and complex problem. One of the crucial initial methods to determine the cause of an accident related to an onboard explosion may be using the characteristics of the scattered remains. At the same time, it allows ruling out other causes of the accident at the beginning of the investigation, which significantly shortens the examination process (Konieczka, et al., 2017).

This work attempts to determine whether it is possible to identify an explosion on board an aircraft based on the scatter of the remains. It involves a thorough analysis of the characteristics of the scattered aircraft remains in order to confirm or rule out the occurrence of an explosion on board during the flight, regardless of the potential source. This way of determining the causes of accidents would allow for a more focused accident investigation methodology and improve the workflows of the teams investigating plane crashes. When the initial identification of the event points to an explosion, a further investigation of the possible explosion, and hence determining its location and causes, would be justified (Żyluk, et al., 2006).

At the same time, we attempted to define the existing regularities in remains scatter after accidents of a defined source. The main source documents for analysis would include final reports prepared by appropriate committees for aviation accident investigations concerning different plane crashes. For the analysis, the same number of reports with and without explosions were chosen. Those reports had to include sufficient documentation of remains scattering. Hence, three well-documented examples for both types of accidents were chosen. Upon examining the details of accidents, we tried to find repeating schemes and regularities that would allow us to confirm the question set forth in this work. We focused on photographs and descriptions included in the reports. We also used all descriptions and explanations provided by the experts (Ewertowski, et al., 2015). For the purpose of the analysis, only large aircraft were chosen, i.e., according to valid regulations, only planes with a MTOW mass of more than 5700 kg.

2. The main features of explosions on board an aircraft

An explosion is a phenomenon of rapid emission of a large amount of energy, with a sudden increase in pressure, temperature, emission of radiation and acoustic waves. Another definition states that explosion is “a phenomenon of a sudden change in the system condition, with the release of potential energy contained in the system and change of this energy into mechanic energy”. These definitions are consistent and fully describe the explosion specificity. A fast exothermic chemical reaction may cause an explosion, e.g. burning; however, it may also be the result of a sudden physical phenomenon (Urbański, et al., 1981).

Explosives (e.g. TNT, hexogen, octogen, dynamite) are chemical compounds or mixtures. Under an external energetic impulse of proper intensity, a fast chemical reaction with the emission of large amounts of very hot gases develops. The energetic pulse can be mechanical (impact, friction, puncturing), thermal (flame, hot sparkle, white-hot item), explosive (detonation of a different explosive, strong shock wave) or electrical (electric sparkle). Apart from the emission of radiation in the form of light and acoustic waves in the form of noise, an explosion of explosive charge results in the propagation of significant amounts of gases at supersonic speed, which is the primary source of destruction. The damages are quite characteristic and they depend on the material subjected to destruction.

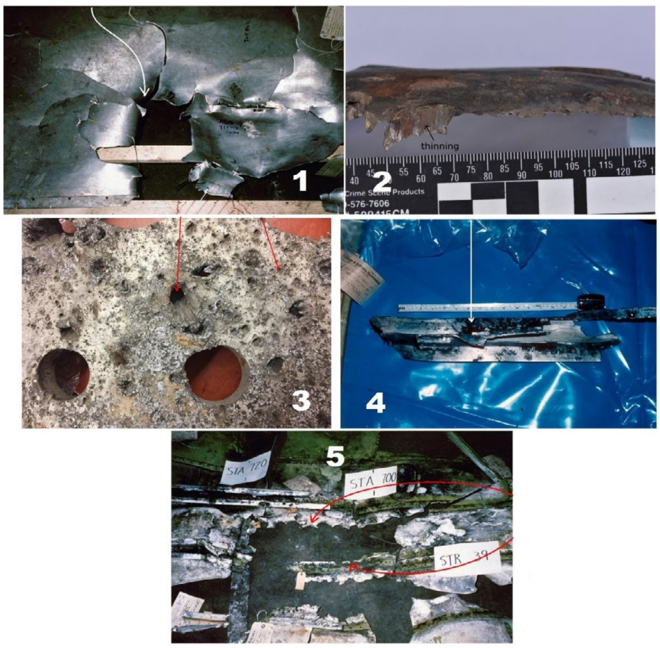

Figure 1. Examples of characteristic damages to materials resulting from an explosion:
1 – Bending and rolling the material inside or onto itself,
2 – Flattening at the edges,
3 – Small craters and micropitting on the surface,
4 – Blackening of the surface,
5 – Shredding around the edge
(Yeh, et al, 2019).

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The most important and most frequent damages to materials indicative of an explosion are as follows (Yeh, et al., 2019):

- Small craters and micropitting on the surface due to the close contact of hot gas.
- Material fragments bent in the direction of the gases; in extreme cases, these fragments may even be rolled one on the other.
- Characteristic shredding of the material along the edges.
- Flattening at the edges of the material due to excessive forces expanding the given fragment.
- Blacking of the surface due to gas burning during the explosion.

The characteristic features of damages resulting from an explosion in a plane's construction are presented in Fig. 1.

Apart from material damage near the explosion of the charge, the force of gas propagation during the explosion is so considerable that it results in the rupture of the aircraft skin and forming a hole in the airplane construction.

In the case of a hole in the aircraft's skin at high altitudes, a sudden decompression of the cabin occurs. This phenomenon results from the fact that inside the plane cabin, there is atmospheric pressure appropriate for the proper functioning of the human body, and outside, the pressure is much lower. When the barrier between these two zones, such as the body of the plane, is ruptured, sudden equilibration of pressure begins. Fast-moving masses of air carry energy large enough to break the already weakened elements of the plane construction, leading to further destruction. Hence, an explosion on board an aircraft is especially dangerous at the high altitudes (10–12 km) because, apart from damage to construction elements and the plane's weakened body strength, differences in pressure cause more unfavorable activity in terms of force. This phenomenon will not occur at low heights; if so, the results will be less destructive.

3. The object of the analysis

The analysis was performed based on the following plane crashes resulting from a cause other than an explosion:

- a Concorde plane in 2000 in Gonesse (France).
- a Boeing 737 plane in 2007 near Douala (Camerun).
- McDonnell Douglas DC-9-83 plane in 2014, near Gossi (Mali).

The analysis was performed for the following plane crashes resulting from an explosion:

- a Boeing 747 plane in 1988 near Lockerbie (Scotland).
- a Boeing 747 plane in 1996 near New York (the United States of America).
- DC-10 plane in 1989 (Repport, et al.,1991) at the Ténéré desert (Niger).

4. Analysis of characteristics of the remains scattering

The characteristics of the scattered remains in accidents without an explosion are presented in Table 1. The sites of such incidents have a relatively small area covered with remains of the plane, usually not greater than 1 km^2. In the three analyzed cases, these were areas of the size of 0.017 km^2, 0.025 km^2 and 0.071 km^2, respectively. Of course, the size of the area is closely related to the altitude and speed of the flight, as well as the plane construction. In all of the cases, the concentration of the wreckage elements in one place can be seen. The remains are not scattered and are usually placed close to each other. At the same time, we observe local mixing of the construction elements from different places on the plane. In the three analyzed cases, there are elements from different places of the plane in the whole site area, sometimes located very far apart. For accidents where an explosion did not occur, the above-mentioned damages characteristic for an explosion cannot be seen. In all of these cases, the plane crashed on the ground and did not leave any parts on the flight path. The damages occurred after the plane crashed on the ground and include plane elements catching fire.

Table 1. The characteristics of the remains field for aviation accidents without an explosion (Zastawny, et al., 2021).

Accident	Cause	Area of the crash site	Characteristics of the area	Characteristic damages
Concorde, in 2000 (Accident, et al., 2002)	Tyre rupture / damage to the fuel tank	0.017 km²	Crash of the whole plane, large concentration of the wreckage fragments, mixing of elements from different sites of the construction	Burning down, damage to the fuel tank by a piece of metal lying on the runway
Boeing 737, in 2007 (Technical, et al., 2019)	CFIT (Controlled flight into terrain). This acronym denotes an event when the pilot makes a fully functional machine crash against the ground)	0.025 km²	Crash of the whole plane, large concentration of the wreckage fragments, mixing of elements from different sites of the construction	Burning down, severe destruction of the wreckage
McDonnell Douglas Dc-9-83, in 2013 (Final, et al., 2016)	CFIT	0.071 km²	Crash of the whole plane, large concentration of the wreckage fragments, mixing of elements from different sites of the construction	Burning down, severe destruction of the wreckage

An important feature of this group of events is the presence of intensive fire in the massed wreckage fragments. This results in fire initiation due to the heavy impact of the large mass of the plane against the ground and the continued functioning of the drive system until the moment of the crash, which usually results in fire.

The characteristics of the scattered remains for accidents with explosions are presented in Table 2. In the case of such events, the surface of the area where the wreckage is scattered is relatively large and comparably larger than in the case of an event not related to an explosion. In the three analyzed cases, the size of this area is between 36 km² and 250 km².

In all analyzed cases, a large scatter of the wreckage fragments along the flight direction was found, accounting for deviation as per the wind direction. Additionally, a lack of concentration of the wreckage elements in one place is observed. At the same time, there is a visible sectoral division of the scatter of the wreckage fragments, consistent with the manner of destruction of the aircraft construction during the flight. Elements scattered over a large area may be divided into a few groups, where the parts may be generally matched to a given location in the aircraft construction. This means that in all the cases, the plane construction disintegrated entirely in the air, and the separate parts of the plane hit the ground. Additionally, in the three analyzed cases, the collected fragments located in the area of the explosion site presented damages characteristic of an explosion (mentioned at the beginning of this work).

Table 2. The characteristics of the remains field for aviation accidents with an explosion (Zastawny, et al, 2021). .

Accident	Cause	Area of the crash site	Characteristics of the area	Characteristic damages
Boeing 747, in 1988 (Report, et al., 1990)	Explosion of explosives in the cargo hold	250 km²	Scattering of the fragments along the path, no concentration of the parts, sectoral division of scattering	Small craters, pitting, flat surfaces on the edges, rolling of metal, shredding
Boeing 747, in 1996	Explosion of the central fuel tank	36 km²	Scattering of the fragments along the path, no concentration of the parts, sectoral division of scattering	Small craters, pitting
DC-10, in 1989	Explosion of an explosive in the cargo hold	128 km²	No part concentration, sectoral division of scattering	Small craters, pitting, rolling of metal, blackening of the surface

5. A comparison of the characteristics of the scattered aircraft remains

An analysis of the course and details of the presented aviation accidents and the obtained results allow us to conclude that accidents with and without an explosion on board the aircraft present specific characteristics of the wreckage remains distribution. Based on this, one may notice repeating schemes, scenarios, phenomena and relationships. The basic characteristics of the scattered aircraft remains in cases related to an explosion include a sudden decompression of the cabin and the whole construction is divided into fragments during the flight. This fact results in a greater scattering of the remains than in the case when the whole plane crashes

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against the ground. Additionally, this allows for making paths of fragments scattering as the result of being carried by the wind in a given direction. This is especially visible in the case of an explosion at a large altitude.

Moreover, due to the separation of parts during the flight, the event site contains sectors with parts from only one area on the plane. Based on sector analysis, one may reconstruct the sequence of the division of the whole construction into fragments. This is due to the fact that they will be placed on the ground according to the path of remains scattered and in the sequence of hitting the ground. The lack of mixing fragments from different locations on the plane is a characteristic feature.

In the case of an accident without an explosion, the wreckage site contains parts from different locations on the plane. The remains of an aircraft flying in a nosedive, flying flat with a slight lowering or according to the corkscrew phenomenon, will have certain features that would allow for identifying the last phase of the flight. An aircraft that goes into a corkscrew in the last phase of the flight usually hits the ground at a small angle. The location of the remains on a large area along the part formed by the wreckage on the ground is indicative of this. The wreck on the ground also makes a characteristic arch. Its width depends on the corkscrew phase (the earlier the phase, the broader the arch). An aircraft flying flat with a slight lowering will form a long path when crashing against the ground due to the small crashing angle, and the remains will be scattered over a large area. A marked arch made by the wreck on the ground will be visible. The characteristic low speed is supported by the presence of large wreckage elements or even the whole aircraft with visible external damages. The nosedive can be identified through observing the small scatter of the remains at the crash site, which indicates a large crashing angle. Another feature will be a large cavity in the ground formed by the wreck because of the high speed and crash angle (Konieczka, et al., 2019). The characteristic image of the scattered remains for both cases is presented in Fig. 2.

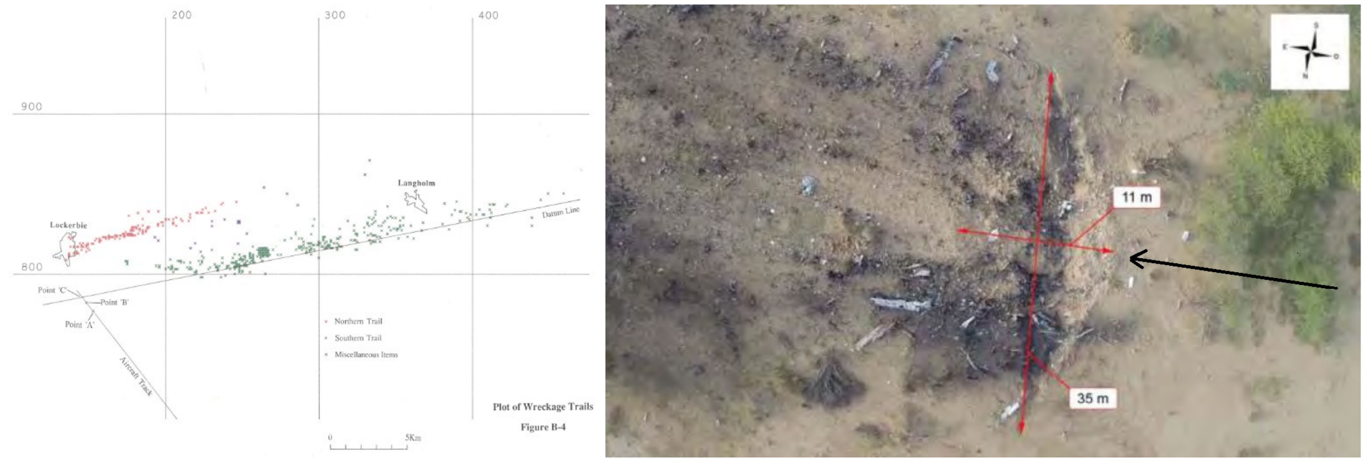

Figure 2. A comparison of aircraft remains scattering without an explosion and after an explosion.

At the top, there is a photo of a crater formed as a result of a crash near Gossi (Final, et al., 2016) without an explosion, with an indicated flight direction (black arrow).
At the bottom, there is a scheme of the crash site at Lockerbie made using the axis method and sector method (Report, et al, 1990). Red indicates the northern path of the scatter of the remains due to wind, green indicates the south path, and purple indicates the other parts. The flight direction is marked as “aircraft track”, and “datum line” is the approximate direction of remains scattering along the south path.

6. Summary

The article presents a detailed analysis of reports on selected aviation accidents, mostly in terms of the scattering of the remains at the crash site. The analysis and conclusions allowed us to confirm the thesis that it is possible to determine whether there was an explosion on board during the flight based on analyzing the remains scatter after a plane crash. Such an explosion could be the cause of the accident. Differences in the wreckage site presentation seem quite unequivocal for reaching these conclusions. The method of determining an explosion during a flight as the cause of an aviation accident involving a large aircraft might prove to be an alternative, quite fast and effective solution for those investigating the accident.

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Despite the variety and multiple aspects of the analyzed aviation events, the study performed for appropriate schemes of the remains area for accidents related and non-related to an explosion on board revealed a set of characteristic regularities and phenomena that allow and facilitate determining whether an explosion occurred during the flight.

Moreover, the work defines the typical characteristics of the scattered aircraft remains when no explosion occurred and the typical characteristics of scattered aircraft remains in case of an explosion. Using a slight simplification, the characteristics of the scattered aircraft remains in the case of no explosion feature:

- a small area of the crash site on the ground,
- a large concentration of the wreckage elements,
- mixing of elements from various locations in the aircraft construction.

The characteristics of the aircraft remains scatter in case of explosion feature:

- a large area of falling of aircraft elements,
- scattering of fragments along the paths (wind influence),
- a lack of element concentration,
- sector-like division of the scattered elements.

At the same time, based on the references, we determined and presented examples of characteristic damage to the aircraft in the case of an on board explosion. These are:

- small craters,
- micropitting,
- flattening on the edges,
- rolling of metal,
- shredding.

These allow for making an additional confirmation of the hypothesis obtained while analyzing the aircraft remain scatter.

At the same time, it should be noted that the conclusions made based on the characteristics of the scatter field of aircraft remains are only slightly influenced by such factors as speed, profile, the flight's altitude, the strength and direction of the wind and ground characteristics at the crash site. However, these factors must be considered, and, in some configurations, they may prove helpful in the analysis.

It seems justified to perform further studies on this topic. Further research will allow for reaching more precise conclusions. Hence, it will be possible to determine the sequence of damages in a more detailed way.

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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