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WAS THERE SATAN'S FACE IN THE WORLD TRADE CENTER FIRE? A GEOMETRIC ANALYSIS

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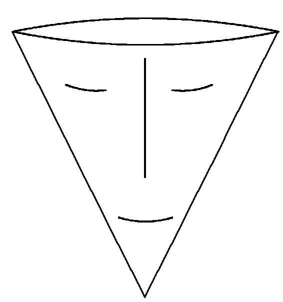
Abstract. *Some photos of the 2001 World Trade Center fire reveal a "face" in the smoke which was interpreted, by some people, as the face of Satan. Most journalists believe, however, that the visible smoke configuration can be explained by natural processes, and that the visible "face" is similar to animal shapes that are sometimes observed in the clouds. In this paper, we present a simple geometric analysis that supports this natural-process explanation.*

Observation. Some photos of the 2001 World Trade Center fire reveal a face-like image which some people interpret as a face of Satan. Actually, there are two unaltered images of this type: a image found in the CNN TV feed, and an image made by a freelance photographer who distributed his photo via Associated Press (AP); see, e.g., [Philadelphia 2001], [Benedetti 2001].

Both images consist of four almost straight line segments on a conic surface. In the CNN image, the "face" is formed by three horizontal lines and one vertical one looking like this:



In the AP image, there are similar four lines (somewhat slanted). It is worth mentioning that neither the TV cameramen nor the photographer observed the image when they were taking pictures, the face-like image was only observed later.

Physical background for geometric analysis. 1. In this paper, we analyze the observed "face" by performing a geometric analysis of possible smoke shapes. To perform such analysis, we will consider the physics of this process, and show that this physics leads to reasonable conclusions about the geometry of smoke shapes.

According to the famous Felix Klein's Erlangen program, geometry is a study of symmetries [Klein 1893]. In view of this idea, to describe the geometric shapes, we do not need to know the exact physical equations, it is sufficient to know what are the symmetries of the corresponding physical processes. This approach has worked perfectly well in many geometric shapes ranging from crystallography (see, e.g., [Yale 1988]) to shapes of celestial bodies ([Finkelstein et al. 1997], [Finkelstein et al. 1997a]), and we will show that it works for smoke shapes as well.

Strictly speaking, since the landscape does not have any exact symmetric, the processes are not exactly symmetric. However, within a reasonable approximation, these processes can be viewed as symmetric.

First, from the large-scale viewpoint, we can view the high vertical building as a vertical *line* ℓ. A vertical line is invariant w.r.t. rotations around this line. This physically reasonable approximation enables us to conclude that the corresponding physical processes should be invariant w.r.t. rotations around this line.

Second, the equations that describe the fire process contain several characteristic lengths. When the fire is huge, it is reasonable to expect that the actual size of this fire is much larger than these lengths. Thus, from the physical viewpoint, we can ignore these lengths and, thus, assume that the process is *scale-invariant*. This assumption is normal in physics. For example, for high-energy particles, for which the energy E is much larger than the rest energy $m_0 \cdot c^2$, it is reasonable to ignore $m_0 \cdot c^2$ and thus, consider such particles as similar to particles with rest mass zero $m_0 = 0$ (like photons). Indeed, high-energy particles possess many properties similar to zero-mass ones like photons: e.g., the high-energy particles travel with a velocity which is very close to the speed of light. Similarly, when we analyze large-scale phenomena that lead to observable geometric shapes of celestial bodies, we can ignore the characteristic lengths and assume that all the involved processes are scale-invariant.

Third, the processes are invariant with respect to "mirror" *reflections*, i.e., reflections across the any plane which contains the central vertical line ℓ (the line that represents the building).

Let us see with what shape we end up by using these symmetries.

Background shape. We have a central point P (where the fire started), and we have physical processes that are invariant w.r.t. rotations around the corresponding central vertical axis, homotheties $\vec{r} \to \lambda \cdot \vec{r}$ with the center at this point P, and mirror reflections. The geometric shape resulting to these processes should therefore be invariant w.r.t. these rotations, homotheties, and reflections.

If we take any point $Q \neq P$ from this shape, then, due to rotation invariance, this shape should contain the entire horizontal circle of points with the same distance $d(P, Q)$, and due to scale-invariance, this shape should contain the homotheties of all such circles – i.e., the vertical cone with the point P as a vertex. Each such cone is invariant w.r.t. reflections.

Thus, the above symmetries explain why the main (background) shape is the shape of the cone.

Comment. It should be mentioned that a cone is an unbounded figure; in reality, of course, we observe only a bounded process, so what we observe is not the entire infinite cone, but its finite *fragment*.

Physical background for geometric analysis. 2. Let us now provide the physical explanations for the lines on the cone.

A cone corresponds to an ideal process which is highly symmetric with respect to homotheties and rotations. A real-life fire is a high-temperature process, and high temperature means strong thermal fluctuations. Fluctuations are, by nature, random, so they violate the original symmetry.

In principle, it is possible to have a fluctuation-based perturbation that changes the initial highly symmetric state into a state with no symmetries at all, but statistical physics teaches us that it is much more probable to have a gradual symmetry violation: first, some of the symmetries are violated, while some still remain; then, some other symmetries are violated, etc. Similarly, a (highly organized) solid body normally goes through a (somewhat organized) liquid phase before it reaches a (completely disorganized) gas phase.

Thus, from the viewpoint of statistical physics, it is more probable to expect perturbations that are invariant w.r.t. some subgroup G' of the initial group G. If a perturbation changes the process at some point a, then, due to invariance, for every transformation $g \in G'$, we will observe a similar change at the point $g(a)$. Therefore, the shape of the resulting change contains, with every point a, the entire *orbit* $G'a = \{g(a) \mid g \in G'\}$ of the group G'. Hence, the resulting *shape consists of* one or several *orbits* of a group G'.

The features on the background: geometric analysis. Let us apply the above general description to our case. In our case, we have a 2-D group G generated by rotations and homotheties. Crudely speaking, a general 1-D subgroup G' can be obtained if we take a single infinitesimal element from G (i.e., strictly speaking, from the Lie algebra of all infinitesimal transformations from G), and take a subgroup generated by G'. An infinitesimal transformation consists of a rotation by an infinitesimally small angle $d\theta$ and a homothety $\vec{r} \to (1 + d\lambda) \cdot \vec{r}$ with an infinitesimally small $d\lambda$. The orbit of the resulting group is a *conic spiral* that is described (in cylindrical coordinates) by the equations $z = k \cdot \rho$ and $\rho = R_0 \cdot \exp(c \cdot \varphi)$, where:

- z is a vertical coordinate;
- ρ is the distance between the given point $\vec{r}$ and the central vertical line ℓ; and
- φ is the angle between the direction $P\pi(\vec{r})$ from P to the horizontal projection $\pi(\vec{r})$ of the point $\vec{r}$ and some fixed direction.

A conic spiral is a general shape. There are two degenerate limit cases of a conic spiral:

- a horizontal circle (corresponding to $c = 0$), and
- a generatrix of a cone, i.e., a straight line on the surface of the cone passing through the cone's vertex (corresponding to $c \to \infty$).

Therefore, in general, we have perturbations which show up as conic spirals, circles, or straight lines on the surface of the cone.

A general conic spiral is unbounded, so, of course, similar to the fact that we observe only a fragment of the cone, we only observe a *fragment* of the conic spiral.

In the above derivation, we did not take into consideration mirror reflections. These reflections affect the resulting shape because the more symmetries are preserved, the more probable the shape. A general conic spiral is not invariant under any reflection. The only two cases of a conic spiral which are invariant under some reflections are the two above degenerate cases:

- a horizontal circle is invariant under an arbitrary mirror reflection (to be more precise, under a reflection across an arbitrary plane containing the central vertical line ℓ);
- a straight line passing through the cone's vertex is only invariant under one specific mirror reflection: reflection across the plane formed by this generatrix and the central vertical line ℓ.

Thus, we arrive at the following conclusion:

The features on the background: conclusion and comparison with observations. The conclusion from the above analysis is that:

- the most probable shape is a horizontal circle;
- a somewhat less probable shape is a straight line passing through the cone's vertex; and
- the least probable shape is a general conic spiral.

This conclusion is in good accordance with the fact that in the observed picture, we have:

- three fragments of horizontal circles,
- a single fragment of a straight line passing through the vertex, and
- no fragments resembling generic conic spirals.

General conclusion. In this text, we showed that both the background shape (the cone) and the features on this background (horizontal and vertical lines) can be explained by our geometric analysis.

Thus, the observed face-like shape can be naturally explained by the physics and geometry of fire.

Open problem. In the above text, we provided a geometric explanation of the shapes, and a *qualitative* explanation of the relative frequency of different shapes. It would be great to have a geometry-based *quantitative* explanation of such relative frequencies.

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